ISSN 0250-5231

Indian Journal of AIR POLLUTION CONTROL

VOL XVII NO.2, VOL XVIII, NO 1&2 AND VOL XIX, NO. 1&2, SEPTEMBER 2017,
MARCH & SEPTEMBER 2018, AND MARCH & SEPTEMBER 2019

Modeling of Air Emissions from an Open Dumpsite in Chennai City

Published by:
INDIAN ASSOCIATION FOR AIR POLLUTION CONTROL
(Delhi Chapter)
c/o Envirotech Instruments Pvt. Ltd.
A-271, Okhla Industrial Area, Phase-I, New Delhi - 110020
E-mail: iaapcdelhi@gmail.com ; Web site: www.iaapc.in

ISSN 0250-5231

Indian Journal of Air Pollution Control, Vol XVII, No.2, Vol XVIII, No 1-2 & Vol XIX, No. 1-2, September 2017, March & September 2018, and March & September 2019

Indian Association for Air Pollution Control

(Delhi Chapter)

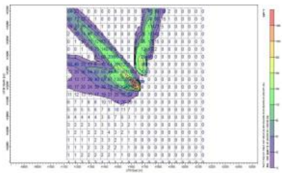
C/o Envirotech Instruments Pvt. Ltd., A – 271, Okhla Industrial Area, Phase- 1, New Delhi- 110020

ISSN 0250-5231

Indian Journal of Air Pollution Control, Vol XVII, No.2, Vol XVIII, No 1-2 & Vol XIX, No. 1-2, September 2017, March & September 2018, and March & September 2019

Indian Journal of AIR POLLUTION CONTROL

VOL XVII NO.2, VOL XVIII, NO 1&2 AND VOL XIX, NO. 1&2, SEPTEMBER 2017, MARCH & SEPTEMBER 2018, AND MARCH & SEPTEMBER 2019



Modeling of Air Emissions from an Open Dumpsite in Chennai city

Published by:

INDIAN ASSOCIATION FOR AIR POLLUTION CONTROL

(Delhi Chapter)

c/o Envirotech Instruments Pvt. Ltd.

Indian Journal of Air Pollution Control

(Vol XVII, No.2, Vol XVIII, No 1-2 & Vol XIX, No. 1-2, September 2017, March & September 2018, and March & September 2019)

CONTENTS

From the Editor-in-Chief

Hon'ble Supreme Court of India terms Delhi a gas chamber

Every winter northern part of the country especially NCR-Delhi region suffers from severe air pollution because of burning of stubbles (parali) in the states of Punjab and Haryana. Large amounts of toxic pollutants cause severe air pollution due to harmful respirable particulate matter and gases such as carbon monoxide, volatile organic compounds, and carcinogenic polycyclic aromatic hydrocarbons. These pollutants also undergo physical and chemical transformation in the atmosphere. Thick blanket of smog thus formed travels long distances and reaches NCR-Delhi region where it stays because of limited dispersion. This converts Delhi into a gas chamber as termed by Hon'ble Supreme Court of India. This has become a regular phenomenon with minor variations and results in air pollution emergency when people are advised to stay in their homes or wear masks when going out. Hon'ble Supreme Court of India had to order the Centre to prepare, in consultation with the states, a national comprehensive plan for this problem. The Supreme Court even ordered to install smog towers to clean the polluted air.

Public anger erupts every year against central and state governments for not being able to control this menace year after year despite annoyance expressed by the Supreme Court and the National Green Tribunal (NGT). About 23 million tonnes of stubbles are burnt in the months of October-November. Due to stubble burning around October the concentration of particulate matter in the atmosphere rises to 1000 micrograms per cubic meter, far more than the safe limits of 50 micrograms. Polluted air affects all persons especially people suffering from pulmonary and cardiovascular diseases. Patients suffering from asthma, bronchitis, and chronic obstructive pulmonary disease (COPD) are at higher risk.

The situation arises due to many reasons. Now superior varieties, which mature in shorter time than the normal ones, are available. This encourages farmers to raise two crops wheat - rice in rotational cycle. To supply wheat and rice through public distribution system to ensure food security, government gives free power and provides for assured procurement of wheat and rice with good minimum support price. This results in excess production every year, more than the relevant stocking norms. Excess produce rots in the open or is even spoiled in the rain. All this comes at economic, and environmental cost. Although Punjab has extensive canal network, but to ensure water availability to irrigate the fields in a large area of the state, more infrastructure with additional cost is required. Rains are not sufficient to provide the amount of water required for the inundated conditions of paddy. The farmers, therefore, extract ground water. As per records, for producing one kilogram of rice in Punjab over 5000 liters of water is required. For an annual paddy production of 12 million tons about 45 trillion liters of water is needed. To prevent ground water exploitation, Punjab and Haryana enacted a "Preservation of subsoil Water Act, 2009" and banned paddy transplantation till 15 June, the onset of rainy season. The problem started with this.

Late transplantation pushed harvesting to October-November. In order to quickly prepare the fields for the next rabi crop in November, harvesting was done by using combine harvesters which leave paddy stalks standing in the fields instead of cutting the stalks from the roots and ploughing the roots back into the soil to improve soil fertility. Since cutting of standing stalks from roots by engaging labour is not economical, farmers dispose paddy stubble by burning these in the field itself. This deprives the soil of carbon, nitrogen, potassium, and phosphorus and destroys useful microbes in the upper layers of soil. Thick smoke travels with wind currents to NCR-Delhi and adjoining areas causing extreme air pollution affecting man, animals, plants, and different components of the environment.

Prof. C.P. Kaushik

SECRETARY'S REPORT

On Completion of his term in September 2017, Dr. B. Sengupta stepped down as President, however, due to delay in holding GBM and Elections of the new team, Dr A. L. Agarwal took over as interim President. The elections were subsequently held on 12th May 2018 and elected Dr. J. S. Sharma, an eminent Scientist & Head of Environment at ONGC, as President, along with following office bearers for a term of two years.

1	**Patron**	**Dr. B. Sengupta, Former MS, CPCB and outgoing President**
2	**President**	**Dr. J. S. Sharma, Head Environment, ONGC**
3	**National Vice President**	**Dr. S. D. Attri, DDG, IMD**
4	**Vice Presidents (4)**	**Dr. J. K. Moitra, EMRTC** **Dr. Mukesh Sharma, Prof IIT-K** **Dr. Prashant Gargava, CPCB** **Dr. Arun Sharma, GTB Hospital**
5	**General Secretary**	**Shri S. K. Gupta, Envirotech**
6	**Treasurer**	**Dr. Rajendra Prasad, Ecotech**
7	**Joint Secretaries (2)**	**Dr. S. K. Goyal, ZO, NEERI, Delhi** **Dr. Shankar Agarwal, NPL**
8	**Chief Editor**	**Dr. Malti Goel, Ex-DST**
9	**Editors (2)**	**Dr. Anubha Mondal -DTU** **Dr. S.K. Tyagi, Ex-CPCB**
10	**Executive members (6)**	**Dr. P. B. Rastogi, Ex-MoEF & CC** **Dr. Abhijit Pathak, CPCB** **Dr. Suresh Tiwari, IITM** **Dr. Prateek Sharma, TERI** **Dr. Sumit Sharma, TERI** **6th nomination to be decided by the Executive committee**
11	**Invited Representatives**	**Vacant** **All the nominations from different Regions (6) to be finalized by the Executive Council after finalizing regions**

The newly elected team at its first meeting held on 6th June, 2018 at ONGC office reiterated the importance of Air Quality and its impacts on Human Health, Plants and Vegetation, Agriculture and on materials and resolved to continue the good work done by the association. The team recalled the significant contributions made by it on many issues like National Ambient Air Quality Standards, Indoor Air Quality, Impact of fine dust, Noise and VOC's on Human Health and burning of Agricultural residues.

Team extended an invitation to all professionals working in this area to join the Association and work together for the welfare of the society. The EC also inducted Shri Deeraj Singh, Dr Ravinder Khairwal, Dr Gopal Pradhan, Dr Tanu Jindal, Dr Dipankar Saha , Dr Shiva Nagendra & Shri S C Tyagi to fill up the Vacant posts in the Executive Committee.

The new team organized a conference on 28th July 2018 at Hotel Surya, New Delhi to deliberate and recommend appropriate actions to maintain status of National Heritage for River Ganga. This conference was also to express solidarity with Prof GD Agrawal with his mission to ensure uninterrupted natural flow in the Ganges throughout the year. A few members from IAAPC-DC also visited him at Haridwar where he was on fast unto death for this demand.

Historical monuments are our National Heritages. A National workshop was organized on 3rd November, 2018 at hotel Le-Meridian, New Delhi on the impacts of Air Pollution on Monuments. Association organized another National workshop on "Air Pollution & Health Linkage" at PHD Chamber of Commerce, New Delhi on 1st June 2019.

All the above conferences and workshops were very well attended, and highly useful information was shared.

On 11th October 2018, the country lost Prof GD Agrawal, a true Environmental Scientist, Former Member Secretary of CPCB and one of the founders of IAAPC. Association was extremely sad on his demise and decided to organise an annual lecture in his Honour.

Dr. Prashant Gargava, one of our Vice Presidents took over as Member Secretary of CPCB and due to his increasing commitments there, he stepped down from the IAAPC as V.P.

Prof C.P Kaushik, former Professor GJUS&T, Hisar and Dr. Archana Yadav from ONGC were inducted in the Executive Committee on 23rd July 2019 to strengthen the Editorial Team.

IAAPC-DC also took up the issue of shifting National HQ to Delhi and to merge with Delhi chapter. Sincere Efforts were made by President. He visited Vadodara also for this purpose but could get assurances only. No success has been achieved so far.

Twenty new Members joined the Association during the period under report and it is hoped that this number would go up gradually.

In spite of the best intentions, no issue of the JOURNAL could be published. However, with renewed efforts during the last few months, it has been possible to publish this present issue. It is a combined issue covering the backlog of previous unpublished issues till September 2019.

S. K. Gupta

Modeling of Air Emissions from an Open Dumpsite in Chennai City

Harikrishnan Sasidharan, Anju Elizbath Peter and S. M. Shiva Nagendra*

Department of Civil Engineering, Indian Institute of Technology, Chennai, India- 600 036
(*Corresponding author: S.M. Shiva Nagendra, E-mail addresses: snagendra@iitm.ac.in, shivanagendra@yahoo.com)

Abstract

This paper presents the characteristics of criteria air pollutants such as coarse particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), oxides of nitrogen (NO_x) and sulfur dioxide (SO_2) measured near a major open dumpsite in Chennai city, India. Result indicated that winter and post-monsoon seasons showed highest concentrations due to poor dispersion conditions in Chennai. Further, AERMOD, a regulatory model, was used to study the spatial distribution of the air pollutants emitted from open dumpsite during critical winter period. The simulation results (1% dumpsite solid waste catches fire) indicated PM_{10} concentrations were as high as 250 μg/m^3 at 1 Km from the dumpsite. In another scenario where 2% dumpsite solid waste catches fire showed PM_{10} concentrations over 200 μg/m^3 at 3 kilometers from the dumpsite. This study shows that dumpsite fires of high magnitude can cause severe air quality problems in the surrounding environment.

Keywords: Open dumpsite, Solid waste dumpsite, Air quality, Air pollutant characterization, Modeling, Simulation, Area source emission, Air pollutant dispersion.

1. Introduction

With limited land availability and infrastructure for municipal solid waste (MSW) management, MSW disposal through open dumping and burning is still being practiced in lower-middle-income countries (LMICs). The various activities in open MSW dumpsites, specifically movement of waste loaded heavy-duty vehicles, unloading and compaction of waste and MSW burning release the ground level-plume of toxic compounds and causes adverse health impacts to community population living close to dump sites (Peter et al.,2018). While the leachate problem has been addressed frequently in the literature, air pollution due to the dumpsites is less understudied. The understanding of atmospheric dispersion of air pollutants such as particulate matter (PM), oxides of nitrogen (NO_x) and sulfur dioxide (SO_2) from open dumpsites is important for assessing the environmental impact of the dumpsites on the surrounding environment.

There have been limited efforts to model air pollution from solid waste landfills. Various air pollutant dispersion models, namely box model, gaussian dispersion model, eulerian model, lagrangian model, CFD Model and dense gas model can be used to predict pollutant concentrations in the neighborhood of the dumpsite. The open dumpsite is considered as an area source for modelling air emissions. AERMOD is a Gaussian dispersion-based model developed by the American Meteorological Society (AMS) and the United States Environmental Protection Agency (EPA). It is widely used for modelling of emissions from area sources (Macleod et al., 2005; Kesarkar et al., 2006). Previous studies reported that AERMOD gives good predictions for the modelling of area source emissions. In the present study, we have used AERMOD to model air pollutants dispersion from Perungudi solid waste dumpsite in Chennai city.

2. Methodology

2.1 Study area

Chennai city is located close to the Bay of Bengal on the southeastern coast of India in the state of Tamil Nadu. The average elevation of the city is around 6.7 meters, and the highest point is 60 m. The weather in Chennai is typically hot and humid. The city has four major seasons; winter (January and February), summer (March-May), and the southwest monsoon (June-September) and post-monsoon or northeast monsoon (October-December). The average annual rainfall is about 140 cm (55 in). The prevailing winds in the city are usually southwesterly between April and October and northeasterly during the rest of the year.

Perungudi dumpsite is one of the two municipal solid waste dumpsites in Chennai city. It is located at coordinates 12°57'13.5" North and 80°14'5.8" East, geographically inside the Pallikaranai marshland, which is an ecologically sensitive area. The present generation of municipal solid waste in the city is about 4500 Metric tons per day, out of which is 2100 to 2300 Metric tons of solid waste is being dumped at Perungudi dumpsite every day. The total area of the dumpsite is about 400 acres in the marshland. Perungudi dumpsite lies south of Velachery, one of the biggest residential areas in Chennai city. Perungudi dumpsite was well outside the southern end of the Chennai Corporation when it started the operation 30 years ago. The city further expanded towards the south over the years and residential zones were developed near the dumpsite. On the east side of the dumpsite, residential areas are very close (less than 100 m). On the west side of the dumpsite, residential zones are around 1 kilometer away. Established commercial areas and IT parks also exist there on the west side of the dumpsite.

Figure 1: Monitoring location and Perungudi solid waste dumpsite.

2.2 AERMOD dispersion modelling

In India, the Gaussian based dispersion models are used for regulatory compliances of ambient air quality. Air emissions from the open dumpsite situated at Perungudi, Chennai was modeled using AERMOD. The steady state Gaussian Regulatory Model, AERMOD, developed by the American Meteorological Society (AMS) and the U.S. Environment Protection Agency (EPA) (EPA, 2004). AERMOD requires input data of meteorology and terrain which are obtained by a meteorological data preprocessor (AERMET) and terrain preprocessor (AERMAP) AERMET data was obtained for the year 2012 of the present study domain from M/s Lakes Environmental, Ontario, Canada. The meteorological data contains surface air and upper air met data. The terrain pre-processor

AERMAP uses gridded terrain data for the modeling area to calculate a representative terrain-influence height associated with each receptor location. The gridded data is supplied to AERMAP in the format of the Digital Elevation Model (DEM) data (USGS, 1994).

Further, DEM at 90 m resolution of Perungudi dumpsite was generated from Shuttle Radar Topography Mission Global Coverage (available at http://www.webgis.com/srtm3.html). A domain of 10 km x 10 km was taken with the dumpsite at the center for modeling the PM_{10}, SO_2 and NO_x emissions. The domain was divided into fine resolution grids of 500 m x 500 m (0.25 Km^2) and pollutant concentrations were simulated in each of these grids. Emission rate, which is one of the critical input parameters for air pollution modeling, was calculated from the emission factors provided by US EPA. Emission factors for particulate matter, Sulfur oxides and Nitrogen oxides are 8 Kg/MT, 0.5 Kg/MT and 3 Kg/MT respectively. The AERMOD simulations for the Perungudi dumpsite were made for critical period of the year 2012. The 24-hr averaged PM_{10}, SO_2 and NO_x concentrations were simulated for three different hypothetical conditions are, (i) 50 m X 50 m (2500 m^2) area in a day for 1 m depth in fire (1% of the receptor grids); (ii) 65 m X 100 m (6500 m^2) area in a day for 1 m depth in fire (1% of entire dumpsite) and (iii) 100 m X 130 m (13000 m^2) area in a day for 1 m depth in fire (2% of entire dumpsite), for four critical days of the year 2012 having poor meteorological conditions.

Since the objective present study is to find the impact of open dumpsite emissions on residential areas, 24-hour average concentrations were simulated. Since the receptor population (children and women) in the residential regions could be staying in the houses throughout the day, finding 24 hours averaged concentrations of PM_{10}, SO_2 and NO_x were more meaningful.

2.3 Monitoring campaign near the dumpsite

Further air pollutant monitoring campaigns were conducted near Perungudi dumpsite at a monitoring station set up about 500 m away from the dumpsite on its west side to understand the impact of air pollution from dump site on surrounding environment. PM_{10}, $PM_{2.5}$, SO_2 and NO_x samples were collected from April to July in 2015 (14 days) and $PM_{2.5}$ samples from February to March in 2016 (11 days). The monitoring instruments was kept on the rooftop of the building (10 m height above the ground level) located at coordinates 12°57'22.44" North and 80°12'57.99" East.

PM_{10} and $PM_{2.5}$ concentrations were monitored using high volume sampler (APM 460 NL, Envirotech; APM 550, Envirotech). Glass fiber filter paper with a size of 20.3 x 25.4 cm was used for PM_{10} sample collection and Polytetra Fluoro Ethylene (PTFE) filter paper of 47 mm diameter and 0.2 µm pore size was used for $PM_{2.5}$ sampling. Filter papers were conditioned by keeping in a desiccator for 24 hours before sampling to remove any moisture content. Ambient air laden with the particulates were passed through an inlet pipe with a flow rate of 0.9-1.1 m^3/min for PM_{10} and 16.67 l/min for $PM_{2.5}$ into a cyclone separator where the coarser particles gets settled down due to the centrifugal force and the fine particulate matter (<10 µm and <2.5 µm) gets deposited on the glass fiber filter and PTFE filter papers respectively. The difference in the weight of the filter paper after and before sampling gives the total mass of the particles deposited and the concentrations of PM_{10} and $PM_{2.5}$ are measured gravimetrically by weighing the particulate mass deposited on the filter dividing by the air flow rate. Filter papers were desiccated for 24 hours prior and after the sampling. SO_2 and NO_2 concentrations were monitored using the gaseous sampling attachment (APM 411, Envirotech) at an air flow rate of 0.3-0.4 l/min. Modified West & Gaeke Method and Jacobs & Hochheiser modified method were used for analysis of SO_2 and NO_2 concentrations, respectively (CPCB, 2011c). SO_2 and NO_x particles were sampled with the use of impingers. Absorbing solution used for SO_2 was Potassium Tetrachloro Mercurate (TCM) and Sodium Hydroxide (NaOH) for NO_x. During sampling, a complex, dichlorosulphitomercurate was formed by the absorption of SO_2 in absorbing solution and nitrite ions were produced in NO_x absorbing solution. Later the pollutant concentrations were indirectly determined by finding absorbance of solutions using the UV spectrometer.

2.4 Physical characteristics of municipal solid waste (MSW) at the dumpsite

100 kg of waste sample was collected manually after coning and quartering method for compositional analysis. All separable physical components of the bulk waste were segregated manually. Fig. 3 illustrates the composition of fresh MSW being disposed at the dumpsite. The MSW consists of food waste, plastics, yard waste, textile and construction and debris (C&D), which share about 62% of total MSW. Other components such as tissue paper, glass bottle, rubber, leather, plastic cups, plastic bottles, paper, cardboard, foam, metals, electric wire and cans constitute 38% of total MSW. In the dumpsite, it observed that biodegradable wastes were mixed with recyclable items such as metals, paper, plastics and glass (Peter et al., 2019). The metal scrap burning by the informal sector (rag pickers and waste pickers) is frequently observed in the dumpsite, releasing THMs into the atmosphere. The waste pile compaction processes and use of soil, construction and demolition waste as cover on dumped wastes are still practiced at the dumpsite.

3. Results and discussion

3.1 Seasonal wind rose profile of Chennai city for the year 2015

Wind speed and wind direction data of Chennai city from the monitoring station located at Chennai International Airport was collected for the year 2015. Using this data, the wind rose diagrams for four seasons in Chennai city, according to Indian Meteorological Department was constructed using the software OriginPro.

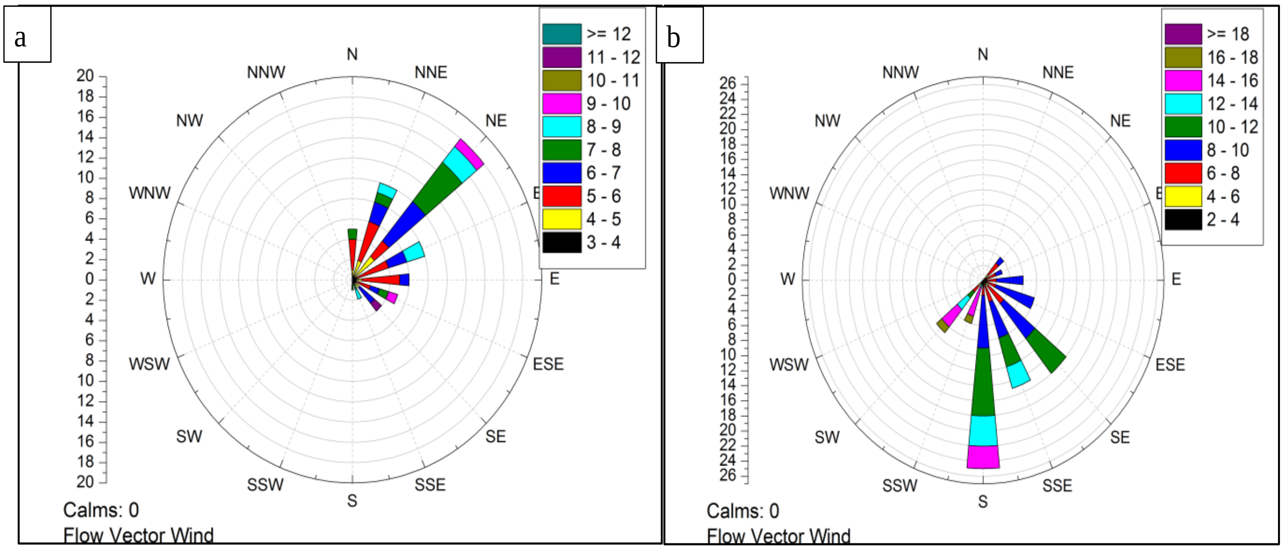


Figure 2: Windrose diagrams of Chennai in the winter season (a) and summer season (b) of the year 2015 (Wind speeds are in the unit Kilometers per hour).

The Winter season in Chennai is from January to February. It is the calmest season in Chennai (Figure 2). Most days in winter, the average wind speed was varied between 5 Km/h to 8 Km/h. The highest recorded wind speed of the season was 11 Km/h and the lowest was 3 Km/h. The predominant wind direction of the season was northeast with 18 days wind blew from that direction, followed by north-northeast and east-northeast directions with 10 and 8 days, respectively. Since the wind speeds are low, high pollutant concentrations can be expected in the winter season near the dumpsite.

The summer season in Chennai is from March to May. Wind speed is comparatively high in summer at Chennai, with most days wind speed varied between 8 Km/h to 16 Km/h (Figure 4). The highest recorded wind speed was 17 Km/h and the lowest was 3 Km/h in summer. The wind blew from a south direction on most days in summer with 25 days; followed southeast and south-southeast directions with 16 and 15 days, respectively. The pollution dispersion is often associated with land-sea breezes in coastal regions (Miller et al.,2003). The high-temperature difference between sea and land during summer presents high potential for a strong land-sea breeze, thus resulting in the higher potential for dispersion. High wind speeds indicate that pollutant concentrations will be low in the summer season near the dumpsite.

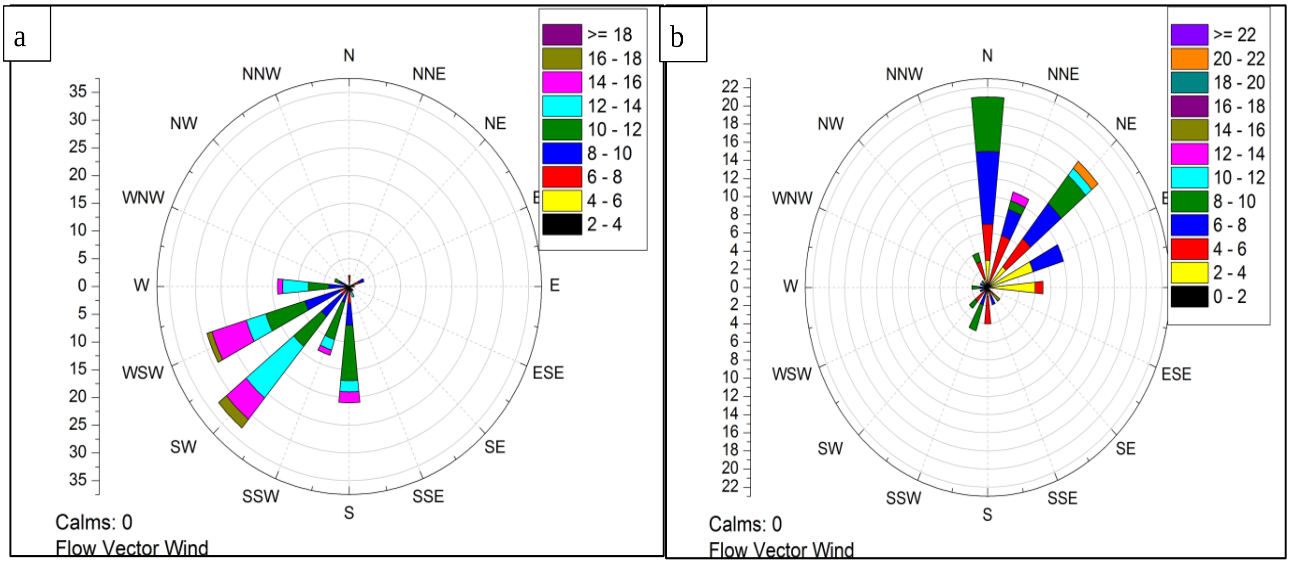


Figure 3: Windrose diagrams of Chennai in southwest monsoon season (a) and post-monsoon season (b) of the year 2015 (Wind speeds are in the unit Kilometers per hour).

Southwest monsoon is the most extended season in Chennai, spans from June to September. Southwest monsoon has the strongest wind speeds. On most days of the season, average daily wind speed varied between 10 Km/h and 18 Km/h (Figure 3). The highest recorded wind speed was 16 Km/h and the lowest was 4 Km/h. The wind blew from a southwest direction on most days in summer with 33 days; followed west-southwest and south directions with 29 and 26 days wind blew from those directions, respectively. Very high wind speeds indicate that pollutant concentrations will be the lowest in this season near the dumpsite.

Post-monsoon or northeast monsoon season in Chennai is from October to December. On most days in this season, wind speed was in the range of 2 Km/h to 10 Km/h. The highest recorded wind speed of the season was 21 Km/h, which is accounted for by a cyclone. The lowest wind speed recorded was 2 Km/h. The predominant wind direction of the season was north with 21 days wind blew from that direction, followed by northeast and north-northeast directions with 18 and 11 days, respectively. The low wind speeds indicate that high pollutant concentrations are likely near the dumpsite in the post-monsoon season.

3.2 Characteristics of air quality near the dumpsite

Both monitoring campaigns in 2015 summer and 2016 winter seasons near Perungudi dumpsite showed air pollutant concentrations within ambient air quality standards. In the summer of 2015, PM_{10} concentrations varied from 40 µg/m^3 to 50 µg/m^3 on most days. $PM_{2.5}$ concentrations varied from 10 µg/m^3 to 46 µg/m^3. $PM_{2.5}$ levels were closer to the standard limit than that of PM_{10}. SO_2 concentrations varied between 3.8 µg/m^3 to 12.5 µg/m^3 and NO_x concentrations varied between 3.4 µg/m^3 to 5 µg/m^3 in this period. In the winter of 2016, $PM_{2.5}$ concentrations varied from 5 µg/m^3 to 55 µg/m^3.

The monitoring station was set up on the west side of the dumpsite, and hence on the days in which wind direction was blowing from the East, pollutant concentrations were found to be higher. Wind from any other direction, especially from the west, chances of pollutant reaching the monitoring station is very low. Hence when the wind was flowing from other than east direction, the concentrations were found to be less.

For example, on the three days of the monitoring campaign in February, the wind was blowing from east. On these days recoded the $PM_{2.5}$ concentrations were 47.8 µg/m^3, 51.1 µg/m^3 and 54.6 µg/m^3, closer to the ambient air standard of 60 µg/m^3 than any other days. On 19/05/2015, the wind direction was blowing from the Southwest. $PM_{2.5}$ concentration on this day at the monitoring station was 24.6 µg/m^3, one of the lowest recorded concentrations during the summer monitoring campaign. This illustrates that wind direction dictates the directional movement of air pollutants.

The wind blew from the east direction on both 09/02/2016 and 26/02/2016, but the average wind speeds on these days were 3 Km/h and 11 Km/h, respectively. The recorded $PM_{2.5}$ concentration on 09/02/2016 was 47.79 µg/m^3 and 26/02/2016 was 6.29 µg/m^3. This illustrates that high wind speed will reduce the pollutant concentration near the dumpsite. The recent study at Perungudi dumpsite identified six major sources as contributors to $PM_{2.5}$ including metal scrap and plastic burning, resuspension of leachate contaminated soil, vehicular movements, mixed garbage burning, sea spray and crustal sources (Peter et al.,2018).

Ratio between $PM_{2.5}$ and PM_{10} in the summer of 2015 is depicted in Figure 4. $PM_{2.5}$ is much dangerous to humans than PM_{10} since they can go deep inside the lungs. Hence the days which have high $PM_{2.5}$ to PM_{10} ratio exist are more dangerous to the receptor population. The $PM_{2.5}/PM_{10}$ ratio were above 0.9 in the five days of the summer and these days can be considered of having worse air quality in terms of particulate matter.

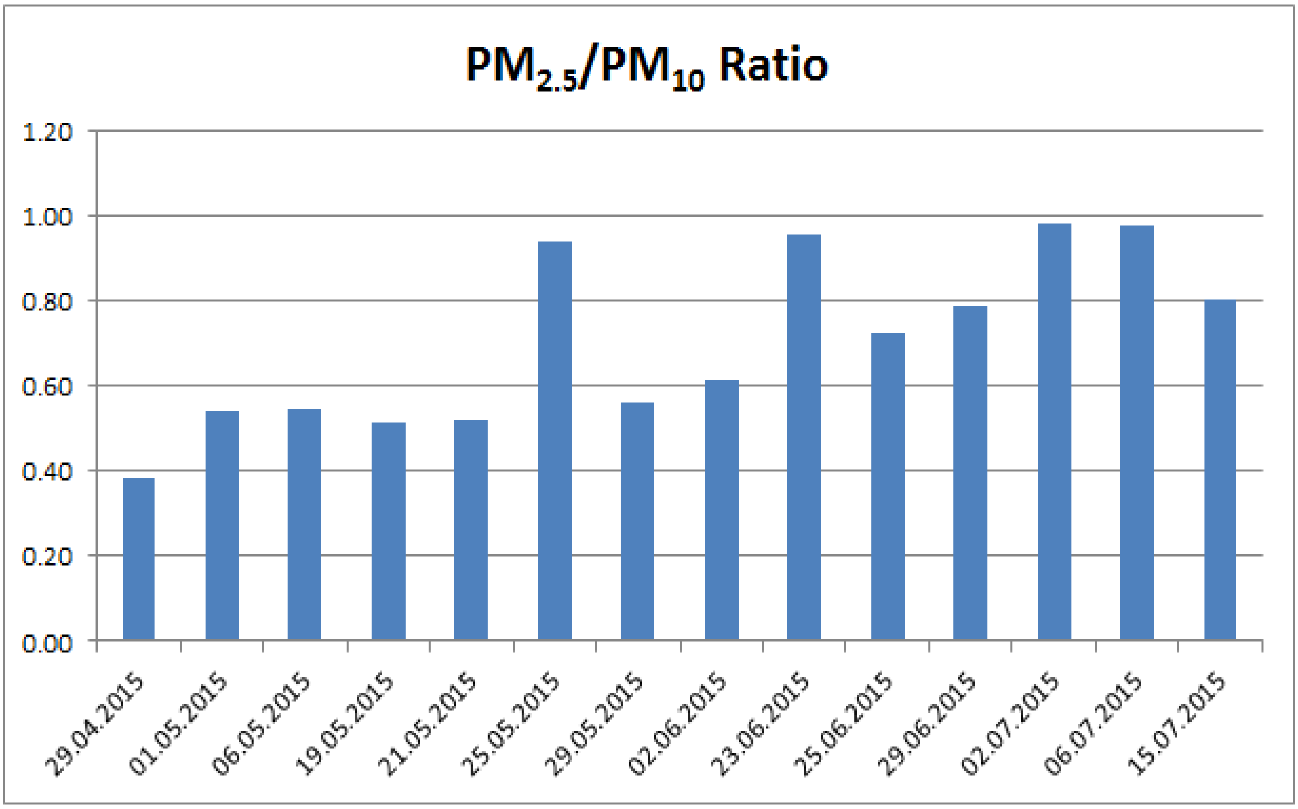


Figure 4: Ratio between $PM_{2.5}$ and PM_{10} at the monitoring station.

3.3 Simulation of air quality near the dumpsite

Table 1 shows the receptor area in which simulated pollutant concentrations are expected to be higher than the national ambient air quality standard for PM_{10}, NO_x and SO_2 in the meteorologically critical days of the year 2012. Each receptor grid is in the size of 0.25 Km^2. Receptor area with high pollutant concentration has an increasing trend with an increase in the emission source area.

Table 1: Area near the dumpsite with over ambient air quality standard concentration in different simulations.

Area of source →		50 m X 50 m (1% of Receptor grid)		65 m X 100 m (1% of Dumpsite Area)		100 m X 130 m (2% of Dumpsite Area)	
Date	Pollutant	No. of Grids	Area (Km^2)	No. of Grids	Area (Km^2)	No. of Grids	Area (Km^2)
09.01.12	PM_{10}	1	0.25	4	1	13	3.25
	NO_x	1	0.25	2	0.5	5	1.25
	SO_2	-	-	-	-	1	0.25
26.02.12	PM_{10}	1	0.25	6	1.5	12	3
	NO_x	-	-	3	0.75	6	1.5
	SO_2	-	-	-	-	1	0.25
25.10.12	PM_{10}	3	0.75	13	3.25	22	5.5
	NO_x	2	0.5	4	1	9	2.25
	SO_2	-	-	-	-	-	-
02.12.12	PM_{10}	1	0.25	2	0.5	3	0.75
	NO_x	1	0.25	1	0.25	2	0.5
	SO_2	-	-	-	-	-	-

In the simulations, the post-monsoon day 25/10/2012 was the worst case pollution scenario where 5.5 Km^2 area around the dumpsite is expected to have above standard PM_{10} concentration if solid waste from 2% dumpsite area catches fire in a day. It was followed by the winter day 09/01/2012, where 3.25 Km^2 area to have above standard PM_{10} concentration in the same source emission condition. The winter day 26/02/2012 and the post-monsoon day 02/12/2012 were simulated to have above standard PM_{10} concentration for 3 Km^2 and 0.75 Km^2 area respectively for the same emission condition. Many of these receptor grids fall under residential regions near the dumpsite.

On all four days, air pollutant characteristics were simulated, the only varying parameter is meteorological conditions. Low wind speed enables the pollutants to accumulate in the ambient air. Average wind speed for 09/01/2012, 26/02/2012, 25/10/2012 and 02/12/2012 are 2.9 Km/h, 2.2 Km/h, 2.68 Km/h and 4.2 Km/h respectively. All four days had comparatively low wind speeds than usual. Higher average wind speed on 02/12/2012 explains why that day had the smallest air pollutant concentrations in the group.

NO_x and SO_2 simulations showed dispersion patterns similar to corresponding PM_{10} simulations on all four days. But the receptor area with above standard concentration for these pollutants was significantly lower than in PM_{10} simulations. This is because of the higher emission rate of PM_{10} compared to NO_x and SO_2.

Table 2 shows the location of the farthest receptor grid, which showed above standard pollutant concentration with respect to the open dumpsite in each simulation. The direction and distance of the receptor grid showed in table 4 are measured from the center of the dumpsite. The open dumpsite is spread over four receptor grids in the simulations. The distance of the farthest receptor grid with above standard pollutant concentration from the center of the dumpsite has an increasing trend with an increase in the emission source area.

The direction in which air pollutants were dispersed to is controlled by wind direction in that given day. Predominant wind directions for 09/01/2012, 26/02/2012, 25/10/2012 and 02/12/2012 are west-southwest, northeast, south and northwest, respectively. Because of this wind direction, the direction of the receptor grids with above standard pollution concentrations from the center of the dumpsite for 09/01/2012, 26/02/2012, 25/10/2012 and 02/12/2012 were east-northeast, Southwest, north and southeast respectively.

Table 2. Location of the farthest receptor grids with over ambient air quality standard concentration in different simulations (Distance and direction are measured from the center of dumpsite).

Area of source →		50 m X 50 m (1% of Receptor grid)		65 m X 100 m (1% of Dumpsite Area)		100 m X 130 m (2% of Dumpsite Area)	
Date	Pollutant	Direction	Distance (Km)	Direction	Distance (Km)	Direction	Distance (Km)
09.01.12	PM_{10}	ENE	0.56	ENE	2.24	ENE	4.72
	NO_x	ENE	0.56	ENE	1.12	ENE	2.24
	SO_2	-	-	-	-	ENE	0.56
26.02.12	PM_{10}	Inside	0	SW	2.12	SW	5.32
	NO_x	-	-	SW	1.41	SW	2.12
	SO_2	-	-	-	-	Inside	0
25.10.12	PM_{10}	Inside	0	N	2.06	N	3.64
	NO_x	Inside	0	N	0.56	N	1.58
	SO_2	-	-	-	-	-	-
02.12.12	PM_{10}	Inside	0	SE	0.71	SE	1.41
	NO_x	Inside	0	Inside	0	SE	0.71
	SO_2	-	-	-	-	-	-

All receptor grids between the farthest grids mentioned in table 4 and the dumpsite have above standard pollutant concentrations in the simulations. In the case of solid waste catches fire at 2% of the dumpsite area in a day, the simulations of 09/01/2012 show grids till 4.72 Kilometers away from the dumpsite have above standard concentration for PM_{10} and grids till 2.24 kilometers away has above standard concentration for NO_x in east-northeast direction. All these grids fall under residential areas in the east side of the dumpsite.

For the same source emission scenario, simulations of 26/02/2012 show grids till 5.32 Kilometers away from the dumpsite have above standard concentration for PM_{10} and grids till 2.12 kilometers away has above standard concentration for NO_x in a southwest direction. Much of these grids after 1.2 kilometers from the dumpsite fall under residential regions as well. Similarly, simulations of 25/10/2012 and 02/12/2012 also showed receptor grids fall under residential zones having above-standard concentrations for PM_{10}. Figure 5 and figure 6 shows simulations of PM_{10} dispersion from 2% of dumpsite catches fire for the four meteorologically critical days near the dumpsite. Figure 7 shows simulations of NO_x dispersion on two critical days for the same source emission condition. SO_2 dispersion characteristics for the critical days also showed similar dispersion patterns with significantly low concentration.

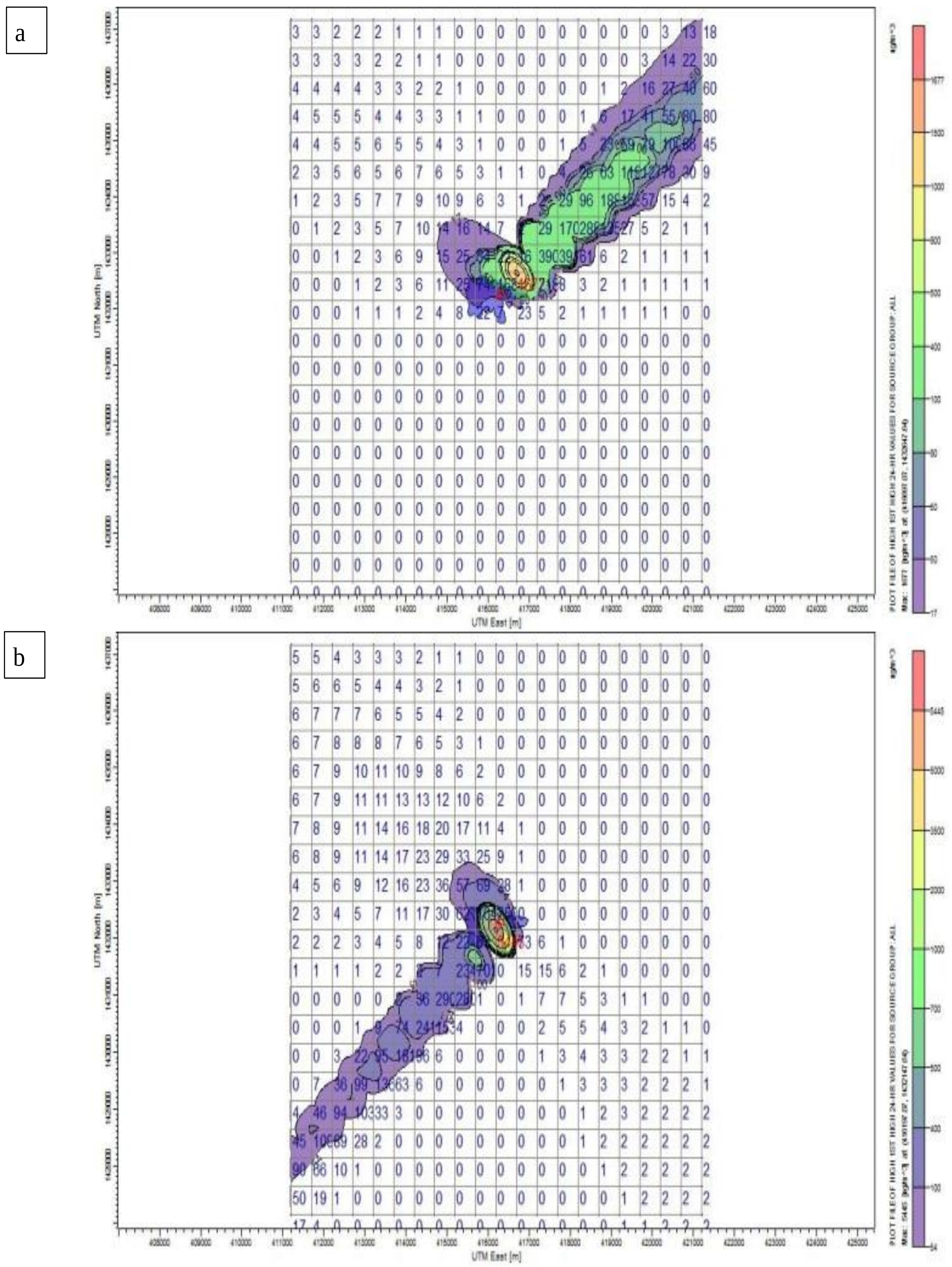


Figure 5: Dispersion of 24-hr average PM10 concentrations for 09/01/2012 (a) and 26/02/2012 (b) with solid waste catches fire on 100 m X 130 m area at dumpsite.

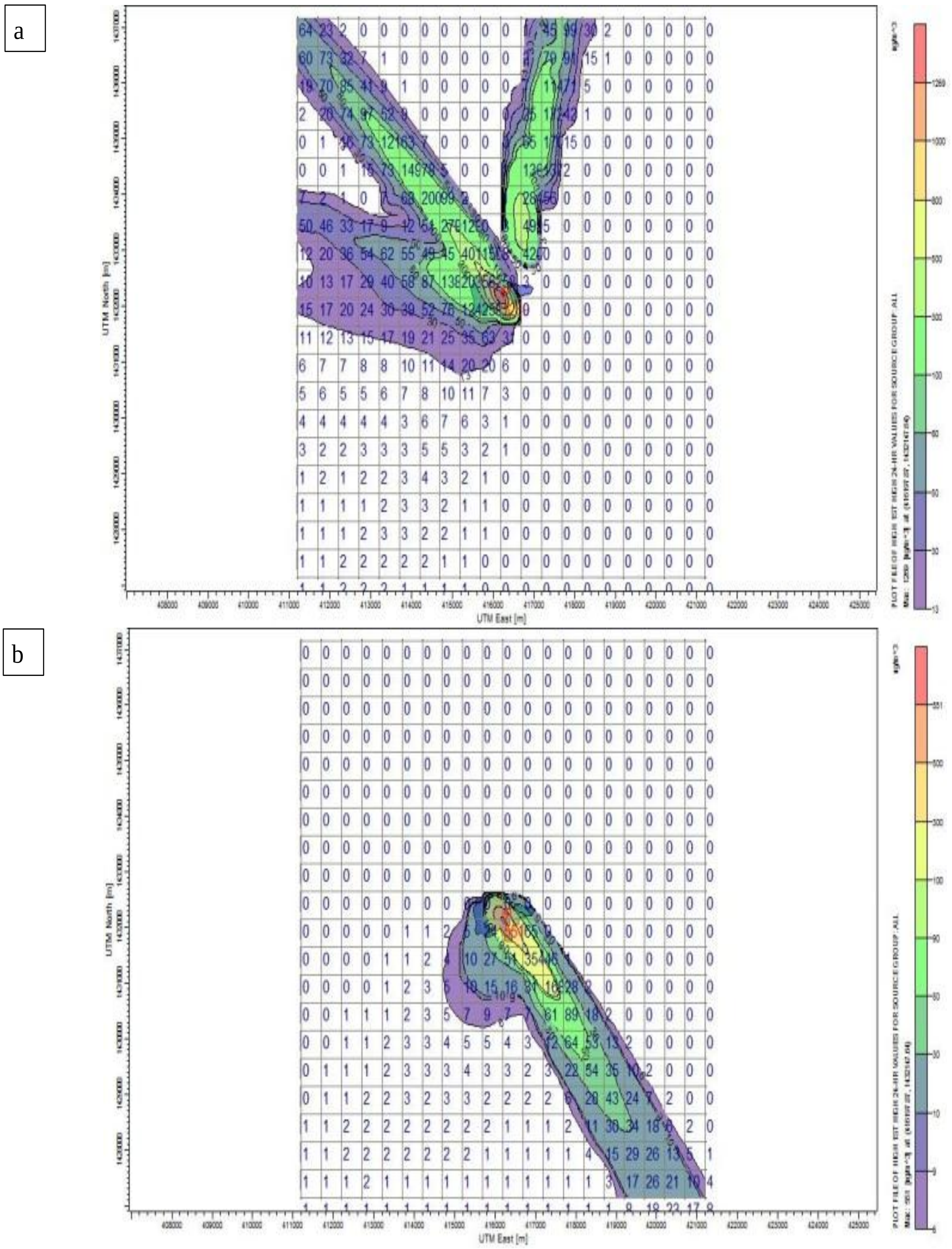


Figure 6: Dispersion of 24-hr average PM10 concentrations for 25/10/2012 (a) and 02/12/2012 (b) with solid waste catches fire on 100 m X 130 m area at dumpsite.

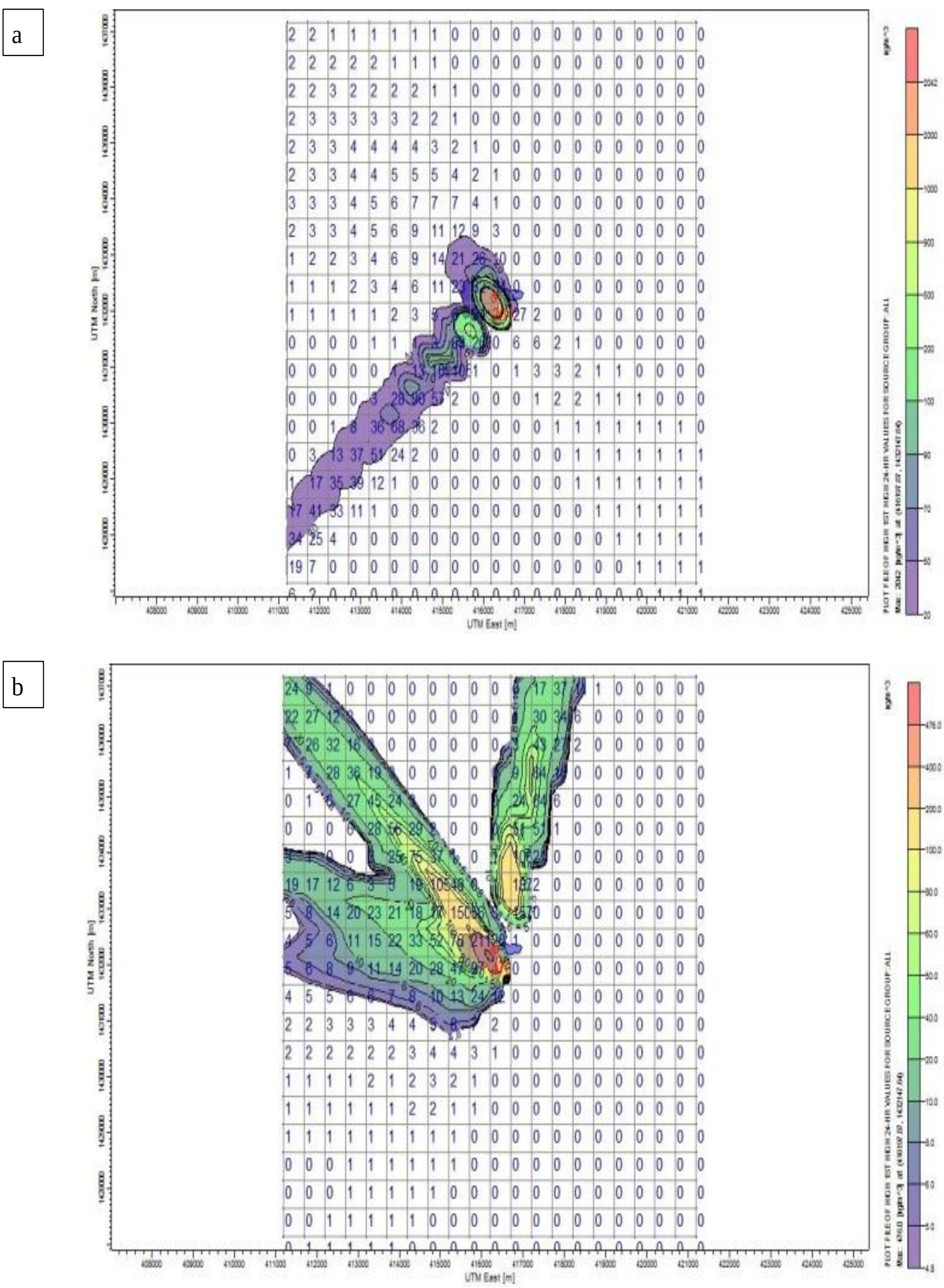


Figure 7: Dispersion of 24-hr average NOx concentrations for 26/02/2012 (a) and 25/10/2012 (b) with solid waste catches fire on 100 m X 130 m area at dumpsite.

3.4 A way forward for an effective management plan for an open MSW dumpsite

We are urging on the significance of waste minimization, resource recovery and source segregation for current predicament in MSW management. With a holistic collaboration between the public sector, private sector, and industry, waste can be handled more resourcefully and even reduced. The mixed waste dumping showed that inefficient source-based segregation practice in the city. The promotion and awareness of source-based segregation aids resource recovery and also helps in avoiding spontaneous fires due to mixed dumping. Dumpsite management measures include prohibiting all forms of deliberate burning, thoroughly inspecting and controlling incoming refuse, compacting refuse buried to prevent hot spots from forming, prohibiting smoking onsite, and maintaining good site security should be strictly followed to reduce the burden imposed by open dumpsites. Dumpsite operators to monitor the emission of explosive landfill gases (methane, hydrogen sulphide and carbon monoxide etc.) on a quarterly basis to prevent fire hazards. The infrared technology can be used to determine which loads were "hot" and required extinguishment and which ones were cool enough to be left alone. Waste to energy (W to E) treatment technologies combined with landfill mining can convert the challenging waste piles to wealth oriented revenue. Further, reclaimed land can be converted into sanitary landfills through step by step approach.

4. Conclusions

- The US EPA regulatory air quality model AERMOD was applied to simulate the spatial variation of air emissions emitted from open dumpsite for different scenarios. Simulated results showed if 1% area of dumpsite catches fire, 3.25 Km^2 area will have over ambient standard PM_{10} concentration in the southeast direction of the dumpsite. For a 2% area of the dumpsite catches fire, 5.5 Km^2 area will have over ambient standard PM_{10} concentration. Locations that are 5.3 kilometers away from the dumpsite showed higher PM_{10} concentration in this case.
- The impact of meteorology on pollutant concentrations was also investigated. The study found that pollutant concentrations were high in winter and post-monsoon seasons near the dumpsite. It was also found that low wind speeds cause high pollutant concentrations near a dumpsite, and pollutants disperse in the opposite direction wind is blowing.
- The modeling study shows catastrophic air pollution incidents can happen if fires in the dumpsite are not appropriately controlled. The simulated results will be very useful in containing air pollution and preparing strategies for control of air emissions from the open dumpsite.

5. References

1. Ainslie, B., Jackson P.L. (2009), "The use of an atmospheric dispersion model to determine influence regions in the Prince George, B.C. airshed from the burning of open wood waste piles", Journal of Environmental Management 90 (2009) 2393–2401 Sujatha P, Janardhanam PVS; "Solid waste management in Chennai city", Indian J. Edu. Inf. Manage., Vol. 1, No. 3
2. Akpofure Rim-Rukeh (2014), "An Assessment of the Contribution of Municipal Solid Waste Dump Sites Fire to Atmospheric Pollution", Open Journal of Air Pollution 3: 53-60 [4] Hezhong Tian, Jiajia Gao, Jiming Hao, Long Lu, Chuanyong Zhu, Peipei Qiu (2013), "Atmospheric pollution problems and control proposals associated with solid waste management in China: A review", Journal of Hazardous Materials 252– 253: 142– 154
3. Amit P. Kesarkar, Mohit Dalvia, Akshara Kaginalkara, Ajay Ojhab (2006), "Coupling of the Weather Research and Forecasting Model with AERMOD for pollutant dispersion modeling. A case study for PM10 dispersion over Pune, India", Atmospheric Environment 41 (2007) 1976–1988
4. Carl Renan Estrellan, Fukuya Iino (2009),"Toxic emissions from open burning", Chemosphere 80 (2010) 193–207

5. Chalvatzaki, E., Kopanakis,I., Kontaksakis, M., Glytsos, T., Kalogerakis, N., Lazaridis, M. (2010), "Measurements of particulate matter concentrations at a landfill site (Crete, Greece)", Waste Management 30: 2058–2064
6. Christopher Macleod, Raquel Duarte-Davidson, Bernard Fisher, Betty Ng, David Willey, Ji Ping Shi, Ian Martin, Gillian Drew, Simon Pollard (2006), "Modeling human exposures to air pollution control (APC) residues released from landfills in England and Wales", Environment International 32; 500–509
7. EPA (2004), "AERMOD: Description of model formulation. U.S. Environmental Protection Agency".
8. Jared Downarda, Ashish Singh, Robert Bullard, Thilina Jayarathne, Chathurika M. Rathnayake (2014), "Uncontrolled combustion of shredded tires in a landfill", Atmospheric Environment Volume 104, March 2015, Pages 195–204
9. Miller, S. T. K., Keim, B. D., Talbot, R. W., & Mao, H. (2003), "Sea breeze: Structure, forecasting, and impacts". Reviews of Geophysics, 41(3).
10. Musalaiah Modi, Venkata Ramachandra, Liyakhath Ahmed SK and Zakir Hussain (2013), "A review on theoretical air pollutants dispersion models", International Journal Of Pharmaceutical, Chemical And Biological Sciences, IJPCBS 2013, 3(4), 1224-1230
11. Obuli P. Karthikeyan, S. Murugesan, Kurian Joseph, Ligy Philip (2011), "Characterization of Particulate Matters and Volatile Organic Compounds in the Ambient Environment of Open Dump Sites", Universal Journal of Environmental Research and Technology, Volume 1, Issue 2: 140-150
12. Peter, Anju Elizbath, SM Shiva Nagendra, and Indumathi M. Nambi (2019), "Environmental burden by an open dumpsite in urban India." Waste management 85:151-163.
13. Peter, Anju Elizbath, SM Shiva Nagendra, and Indumathi M. Nambi (2018), "Comprehensive analysis of inhalable toxic particulate emissions from an old municipal solid waste dumpsite and neighborhood health risks." Atmospheric Pollution Research 9.6: 1021-1031
14. Rajesh Babu Katiyar, S. Suresh, A. K. Sharma (2013); "Characterisation Of Municipal Solid Waste Generated By The City Of Bhopal, India", International Journal of ChemTech Research, Vol.5, No.2, pp 623-628, April-June 2013
15. Ramachandra, T. V. Shruthi Bachamanda (2006); "Environmental Audit of Municipal Solid Waste Management", Technical report

Studies on Air Toxics (BTEX) at Different Locations in Gangtok (Sikkim) - a Part of Eastern Himalayas, India

Manmohan Tyagi*[1], S. K. Tyagi[2] and Ajit Joshi[1]

[1]Department of Chemistry, Mewar University, Gangrar, Chittorgarh, Rajasthan-312901, India

[2]Former Additional Director/ Scientist 'E', Central Pollution Control Board, Parivesh Bhawan, East Arjun Nagar, Delhi-110032, India.

(*Email: mmtyagi2012@gmail.com)

Running title: Studies on Air Toxics in Gangtok (Sikkim).

Abstract

Benzene is a known carcinogen causing blood leukaemia while suspected one is Ethylbenzene. Toluene and Xylene are not carcinogenic to people, though there is some proof of carcinogenicity at high concentrations in laboratory animals during recent studies. Sikkim is experiencing the effects of global warming and air pollution due to the development of factories, means of transport, population and deforestation, etc. Due to scarcity of literature, the present study was planned to assess the BTEX profile and its dependencies on Benzene in Sikkim. Five locations were chosen in Gangtok (Sikkim) for tracking the BTEX levels. The passive sampling method along with Gas Chromatograph (GC) fitted with a capillary column and Mass Spectroscopy (GC-MS) was used on a monthly basis to analyse the ambient air. Total dependencies were found in decreasing order between Benzene (B) and Toluene (T) (r^2=0.81, $p<0.01$), accompanied by Benzene and Ethylbenzene (r^2=0.71, $p<0.01$) as well as Benzene and o-Xylene (r^2=0.66, $p<0.01$). In this analysis, the overall mean T / B ratio for all the locations was 3.05±0.27, which was maximum at the Traffic intersection location and the lowest at the Commercial location. Throughout winter, BTEX levels were found to be the highest accompanied by post-monsoon, summer and monsoon season. Negative association between mean monthly rainfall, temperature, RH percentage and BTEX levels was identified. We concluded that BTEX levels are on increasing trends, which is a worrisome situation to Eco sensitive and fragile environment of Gangtok (Sikkim).

Keywords: NAAQS; VOCs; Passive sampling; Ambient air; Carcinogenic compound.

1. Introduction

Air is an important element of our life on Earth and when VOCs (Volatile Organic Compounds) such as BTEX pollute this air, it can pose a health risk to people, animals, plants and the ecosystem. The four related compounds i.e. Benzene, Toluene, Ethylbenzene and Xylenes are abbreviated as BTEX, present in crude oil, coal tar and a broad range of products of petroleum. Breathing urban polluted air is the main source of human exposure to BTEX, particularly in areas with heavy motor vehicles, cigarette smoke and fuel stations (IPCS 1996, WHO 2016). In particular, the contribution of cigarette smoke is half to BTEX compound daily exposure (ATSDR 2007a).

Gangtok is the capital of Sikkim as well as the most peaceful and beautiful place in the North-Eastern part of India. But now a day, Sikkim also faces the effects of global warming and air pollution due to factory growth, transportation means, population, deforestation, etc. So, this may be a new field for the research work on BTEX air pollution. BTEX levels have not been studied in Sikkim till date. Hence, the current study was planned to measure the air toxics i.e. BTEX at different locations in Gangtok (Sikkim).

2. Material and Method

2.1 Study area

Gangtok was selected as the study area (Figure 1**)**. Gangtok is at the centre of tourism industry of

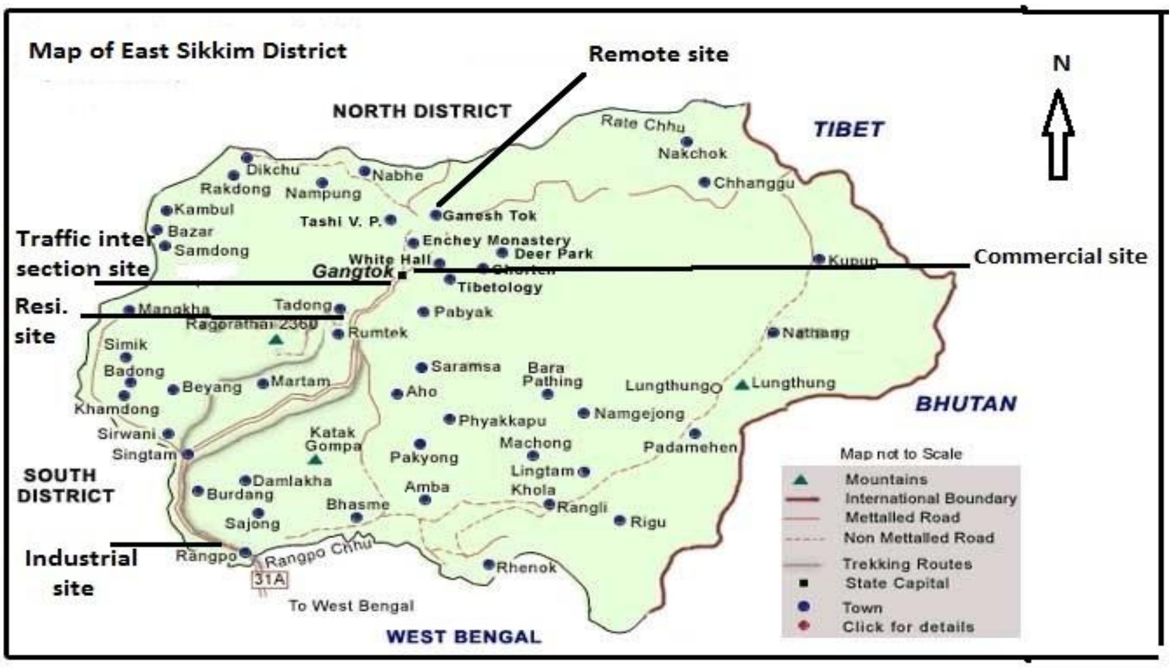


Figure 1: Location of Sampling sites and Gangtok in Sikkim

Sikkim as well as the most peaceful and beautiful place of North East Region of India. For monitoring of BTEX levels, five sites (Figure 1) were selected in Gangtok (Sikkim) i.e.

(i) Remote area: This site was selected at Bulbuley, near Sikkim Himalayan Zoological Park, Gangtok. It has a lot of greenery and almost the least polluted area of Gangtok.
(ii) Commercial area: It was at Mahatma Gandhi Marg, Gangtok. This area is town centre and the best shopping destination for tourists as well as close to National Highway 10.
(iii) Residential area: This site was at Tadong, near NHPC complex, Gangtok, which is about 06 km from Mahatma Gandhi Marg.
(iv) Traffic intersection area: At Indira Bypass, Gangtok was selected for this area. This site is situated on NH 10 and one of the busiest traffic areas.
(v) Industrial area: Due to absence of industrial area in Gangtok city, Majitar of East Sikkim district was selected as Industrial area (semi Industrial area) for this study. This is situated at NH 10 and about 34 km from Gangtok.

2.2 Sampling Method/ Experiment and Instrumentation

Field experiments (sampling and analysis) of the BTEX profile (BIS 5182, Part 11, 2006) were conducted at these sites on a monthly basis for two years i.e. from June-2014 to May-2016. Passive sampler from SKC, USA (catalogue No. 575-001) using charcoal sorbent 350 mg was performed on a monthly basis at various sites of Gangtok at a height of 2.0 to 3.0 meter above ground level. The stored samples of various stated locations were examined just after sampling had been completed for each month. The samples were desorbed twice using ultrasonication technique for 30 minute in 2 mL of carbon disulphide, a traditional solvent. Desorbed carbon disulphide experiments were dissected using Gas Chromatograph (GC) equipped with a capillary column and Mass Spectroscopy (GC-MS) fitted with model no. Agilent Technologies 7890 A GC device (Agilent Technologies 5975 C) with MSD (make Germany). SPSS software (Statistics Package for the Social Sciences) version 22, Chulalongkorn University, License (IBM Microsoft, New York, USA) was used for analysing the data. Test significance was calculated by using ANOVA- test.

3. Results and Discussion

3.1 Statistical analysis of BTEX profile in Gangtok (Sikkim)

The mean concentrations of BTEX at all the locations from June-2014 to May-2016 in Gangtok (Sikkim) were found to be the highest at Traffic intersection area (27.71±6.09 µg/m³) followed by Industrial area (18.71±3.78 µg/m³), Commercial area (15.18±3.03 µg/m³) and Residential area (12.57±2.71 µg/m³). The lowest concentration of BTEX was reported at Remote area (5.68±1.38 µg/m³). When mean concentrations of BTE were compared statistically according to the locations using ANOVA test, they were found to be statistically significant as $p<0.01$ in Table 1.

Table 1: Average BTEX (µg/m³) data at different areas from June-2014 to May-2016 in Gangtok (Sikkim)

Locations	**Benzene**		**Toluene**		**Ethylbenzene**		**o-Xylene**		**Total BTEX ± SD**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Remote area	1.01	0.61	3.29	1.11	0.79	0.28	0.59	0.22	5.68±1.38
Residential area	2.41	0.72	6.93	2.83	1.67	0.48	1.56	0.74	12.57±2.71
Commercial area	2.98	0.87	8.02	3.28	2.32	1.03	1.86	0.67	15.18±3.03
Industrial area	3.38	1.06	10.12	4.34	3.08	1.16	2.13	1.08	18.71±3.78
Traffic Intersection area	4.90	1.46	16.36	5.89	4.23	1.93	2.22	0.81	27.71±6.09
Overall Average	2.93±1.19		8.94±3.62		2.42±1.16		1.68±0.77		15.97±4.14
ANOVA test	6.89		10.93		7.11		4.98		
p value	**<0.001***		**<0.01***		**<0.01***		**0.04**		

*: statistically significant

At all the locations, the BTEX mean concentrations were found to be the highest during winter season from June-2014 to May-2016 in Gangtok (Sikkim) followed by post monsoon and summer season. The lowest concentration of BTEX was reported during monsoon season. When mean concentrations of BTEX were compared statistically according to the seasonal variation using ANOVA test, they were found to be statistically significant as $p<0.01$ in Table 2.

Table 2: Average seasonal variations with BTEX (µg/m³) from June-2014 to May-2016 in Gangtok (Sikkim)

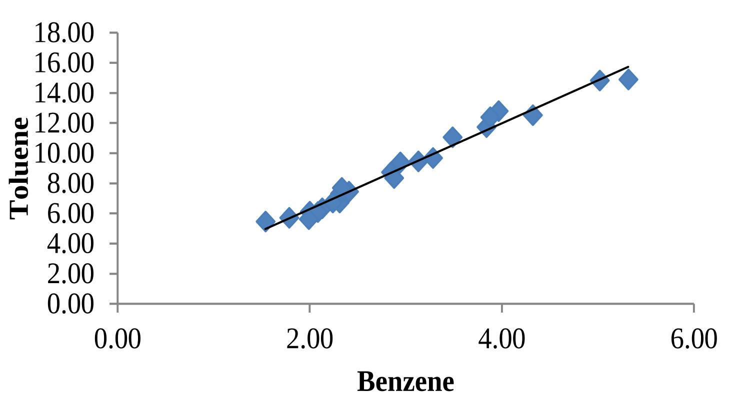
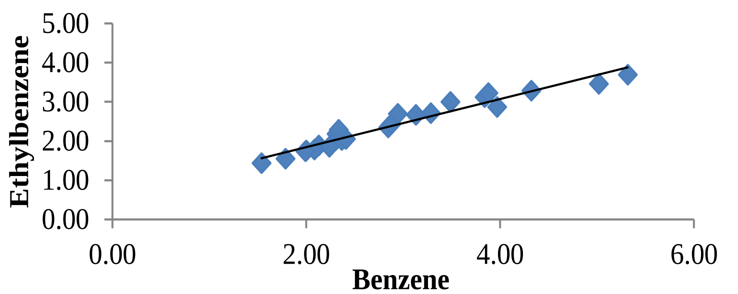
Seasons	**Benzene**		**Toluene**		**Ethylbenzene**		**o-Xylene**		**Total BTEX ± SD**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Winter	4.14	1.79	12.49	6.17	3.16	1.57	2.28	0.91	22.07±5.26
Post monsoon	2.99	1.40	9.10	4.66	2.51	1.30	1.74	0.58	16.34±3.84
Summer	2.38	1.22	7.24	4.02	2.12	1.21	1.44	0.68	13.18±3.19
Monsoon	2.05	1.11	6.42	3.80	1.78	1.02	1.12	0.50	11.37±2.92
Overall average	2.89±1.67		8.81±5.54		2.39±1.41		1.65±0.85		15.74±4.14

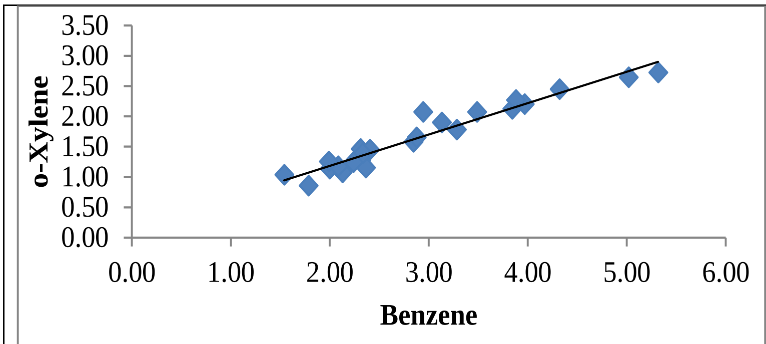
ANOVA test	17.63	21.79	29.91	11.61	
p value	**<0.001***	**<0.001***	**<0.001***	**<0.001***	

*: statistically significant

The effect of relative humidity (RH) is clearly visible during Monsoon period, which interfere in adsorption of BTEX on adsorbent. Therefore, levels observed during Monsoon were the lowest besides washing away of the pollutants by the rain.

Earlier studies (Hoque et al. 2008, Gaur et al. 2016) found very high dependencies among pairs of aromatic BTEX, which originated from same source. For the first approximation, we assumed that Benzene could possibly originate from vehicular origin. Dependencies of Toluene, Ethylbenzene and o-Xylene on Benzene were determined for all the sites. Two years data of BTEX analysis revealed that maximum dependency was found between Benzene and Toluene ($r^2 = 0.81$, $p<0.01$) followed by Benzene and Ethylbenzene ($r^2=0.71$, $p<0.01$) as well as Benzene and o-Xylene ($r^2=0.66$, $p<0.01$). Regressions equations calculated are as follows in Figure 2.

	**Benzene and Toluene:** $y = 0.19x + 0.12$, $r^2 = 0.81$
	**Benzene and Ethylbenzene:** $y = 0.14x + 0.25$, $r^2 = 0.71$



Benzene and o-Xylene :

$y = 0.24x + 0.18, r^2 = 0.66$

Figure 2: Dependencies among Benzene with Toluene, Ethylbenzene and o-Xylene at all 05 areas in Gangtok (Sikkim) along with Regression equations

3.2 Ratios of inter-species aromatic VOCs

Several authors have taken ratios of inter-species aromatic VOCs as an indicator of emission sources (Kerbachi et al. 2006, Guo et al. 2007, Khoder 2007, Gaur et al. 2016). These ratios give an insight about the origin source difference due to varying VOCs reaction rates with hydroxyl radical (OH) in the environment. Photochemical reactions lead to the decrease in large quantity of VOC species that are highly reactive in daylight time usually. While, during daylight time the increase is observed gradually of relatively less reactive species in abundance due to accumulation. The atmospheric average lifetimes of 12.5 and 2.0 days of Benzene and Toluene, respectively, are seen relatively stable (Prinn et al. 1987). This is an average lifetime, as it depends on many factors. However, the lifetime of Xylene is 7.8 hour only and generally it does not stay long in the atmosphere (Prinn et al. 1987). The interspecies ratios of the study in Gangtok (Sikkim) have been shown in Table 3.

Table 3: Toluene/Benzene (T/B), Ethylbenzene/ Benzene (E/B) and o-Xylene/ Benzene (o-X/B) concentration ratios at different sampling locations of Gangtok (Sikkim)

Locations	T/B	E/B	o-X/B
Remote	3.26	0.78	0.58
Residential	2.88	0.69	0.65
Commercial	2.69	0.78	0.62
Industrial	2.99	0.91	0.63
Traffic intersection	3.34	0.86	0.45
Overall mean ratio	**3.05±0.27**	**0.83±0.08**	**0.57±0.08**

A significant traffic emissions indicator is the high T/B ratio usually. The data (T/B ratio of 1.61–4.70) indicated the same originated emission sources of traffic and this leads to the interpretation that Benzene and Toluene are the gasoline components. It is thought that automobile exhausts are responsible for their release into atmosphere (Hajizadeh et al. 2018).

In the current study, the mean T/B ratios in Gangtok (Sikkim) for Remote, Residential, Commercial, Industrial and Traffic intersection area were 3.26, 2.88, 2.69, 2.99 and 3.34 with overall mean ratio

3.05±0.27 respectively. Observation of T/B ratio was found the highest at Traffic intersection area and the lowest at Commercial area. Observation of low o-Xylene/Benzene (o-X/B) ratios was noted at all sites (0.45 to 0.65) of Gangtok (Sikkim), which imply aging of the air mass (Hsieh et al. 2011).

3.3 Effect of seasonal variations on BTEX levels

Rainfall, temperature, relative humidity, speed of wind and dispersion are the important factors for concentration levels of air pollutants. This is also applicable to the present research work in ambient air of Gangtok (Sikkim). The lowest concentration during monsoon may be due to rain washout while the highest concentration during winter is due to low dispersion rate, low mixing height and low rate of degradation of BTEX at low temperature (Duan Xiaoyong and Li Yanxia 2017, Al-Harbi 2019).

Variation of total BTEX concentration (μg/m³) with respect to rainfall, temperature and relative humidity % in Gangtok (Sikkim) during June- 2014 to May-2016 have been shown in Figure 3. BTEX levels were observed to be maximum during winter followed by post monsoon, summer and monsoon season. It can be well appreciated that as the average monthly rainfall, temperature and RH% increase, BTEX levels fall and vice versa. Negative correlation was found among average monthly rainfall, temperature, RH% and BTEX levels.

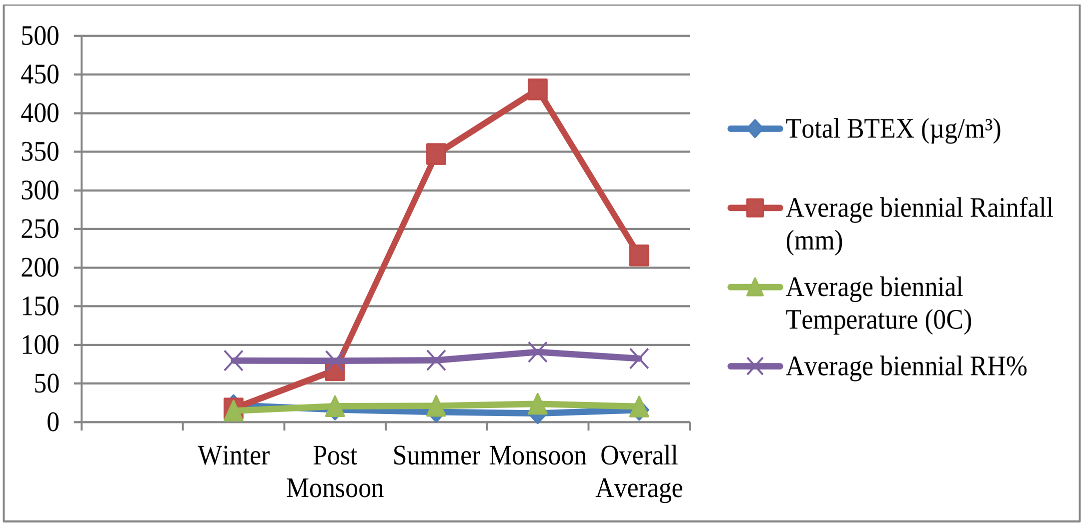


Figure 3: Seasonal variation of Total BTEX concentration (μg/m³) with Rainfall, Temperature and RH% in Gangtok (Sikkim) during June- 2014 to May-2016

3.4 Comparison of levels of Benzene with some locations of the globe

Comparison was carried out to the Benzene levels of current study with other studies performed in different cities of the world. This shows that biennial mean concentrations of Benzene during June-2014 to May-2016 at Remote, Residential, Commercial, Industrial and Traffic intersection areas of Gangtok (Sikkim) as 1.01, 2.41, 2.98, 3.38 and 4.90 μg/m³ respectively (*annual mean levels as 0.95, 2.29, 2.87, 3.23, 4.63 μg/m³ during June-2014 to May-2015 and 1.07, 2.52, 3.09, 3.52, 5.17 μg/m³ during June-2015 to May-2016 respectively*) were comparable with Indoor and Outdoor Residential urban area of California, New Jersey and Texas, USA as 2.14 ± 1.12(I) and 2.25 ± 1.39(O); 1.54 ± 1.13(I) and 1.19 ±0.66(O) and 5.29 ± 4.71(I) and 2.80 ± 2.34(O) μg/m³ (Hun et al. 2010); Industrial area of Yokohama, Japan as 2.79 μg/m³ (Tiwari et al. 2010); Urban and Traffic area of Torino; Perugia and Lecce, Italy as 2.027-2.429, 2.067-2.607; 0.592-0.918, 0.785-1.022; 0.851-.0954, 0.968-1.090 μg/m³ (Donno et al. 2018) as well as Residential and Commercial area of Chamba, Himachal Pradesh and Mukteshwar, Uttrakhand, India as 1.3 and 7 μg/m³ (Tyagi et al. 2016) respectively. While the levels of

Benzene were found higher at Residential, Traffic, Green, Industrial and Urban area of Tehran, Iran as 7.8(2.1-25.8) µg/m³ (Amini et al. 2017); Residential, Commercial and Industrial area of Kolkata, India as 13.8-72 µg/m³ (Majumdar et al. 2011) and seven locations of Pune, India as 5-20 µg/m³ (Anand et al. 2020) respectively.

4. Conclusion

The results show that BTEX pollutants are on rising trends in Sikkim. During June-2015 to May-2016 (II year), the annual average concentration of Benzene was observed to be slightly higher at only Traffic Intersection region of Gangtok (Sikkim) i.e. 5.17 µg / m^3 than its permissible value (5 µg / m^3) given by Central Pollution Control Board, Delhi.
The total mean concentrations of BTEX (µg/m³) in Gangtok (Sikkim) decrease as follows:

Area wise: Traffic intersection area (27.71±6.09) > Industrial area (18.71±3.78) > Commercial area (15.18±3.03) > Residential area (12.57±2.71) > Remote area (5.68±1.38).

Season wise: Winter (22.07±5.26) > Post Monsoon (16.34±3.84) > Summer (13.18±3.19) > Monsoon (11.37±2.92).

T/B ratio of 1.61–4.70 indicated the same originated emission sources of traffic. The literature indicated that the main source of BTEX pollution in developed countries is manufacturing, accompanied by motor vehicles etc., but in developing countries such as India the emission is mainly from motor vehicles in the ambient air. It is therefore advised that government and policy makers should concentrate on the control of BTEX concentrations at fuel level and also by traffic management, industrial and vehicular emissions, road maintenance, general awareness among people etc. So, based on these findings, the recommendations should be re-evaluated by traffic engineers and policy makers. Further rigorous analysis for the exposure measurement is urgently needed, as it is still on higher sides. The government should take instant action for controlling VOCs especially BTEX in urban area as it is a matter of concern. This study will be useful as background study in Eastern Himalayan Region for budding scientists, academicians, policy reformers and medical professionals for future studies and control strategies.

5. Acknowledgement

We are grateful to Dr Gopal Pradhan, Member Secretary, SPCB, Sikkim, Mr D P Sharma, IAS (Retd), Commissioner-cum-Secretary, Mines, Minerals & Geology Department, Govt of Sikkim, Dr Neeti Nepal, Gynaecologist, Aashirwad Clinic, Joredhara, Gangtok, Dr C K Nepal, Child Specialist, STNM Hospital, Gangtok, Mr. Sumit Tyagi, Assistant Manager, Cipla limited, Kumrek, East Sikkim and India Meteorological Department, Gangtok in order to complete this research work. We are also thankful to Mr. Kaifil Huda Ansari, TUV SUD South Asia Pvt Ltd, Okhla Industrial Area, New Delhi.

6. References

1. Al-Harbi, M. (2019). Characteristic of Atmospheric BTEX Concentrations and their Health implications in Urban Environment, Applied Ecology and Environmental Research, 17(1):33-51. Doi: http://dx.doi.org/10.15666/aeer/1701_033051

2. Anand, V.; Panicker, A.S. and Beig, G. (2020). Gaseous pollutants over different sites in a Metropolitan region (Pune) over India, Springer Nature Applied Sciences, 682:2020. https://doi.org/10.1007/s42452-020-2472-2
3. Amini, H.; Yunesian, M.; Hosseini, V.; Schindler, C.; Henderson, S. B. and Künzli, N. (2017). A Systematic review of land use regression models for volatile organic compounds, Atmospheric Environment, 171:1-16.
4. ATSDR (2007a). Toxicological profile for Benzene, US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry, USA.
5. BIS 5182 (2006). Methods for measurement of Air pollution, Part 11: Benzene, Toluene & Xylene (BTX), 2nd Revision, Bureau of Indian Standards, New Delhi.
6. Donno, A. D.; Giorgi, M. D.; Bagordo, F; Grassi, T.; Idolo, A.; Serio, F.; Ceretti, E.; Feretti, D.; Villarini, M.; Moretti, M.; Carducci, A.; Verani, M.; Bonetta, S.; Pignata, C.; Bonizzoni, S.; Bonetti, A. and Gelatti, U. (2018). Health Risk Associated with Exposure to PM_{10} and Benzene in Three Italian Towns, International Journal of Environmental Research and Public Health, 15:1672, 1-13.
7. Duan, Xiaoyong and Li, Yanxia (2017). Sources and Fates of BTEX in the General Environment and Its Distribution in Coastal Cities of China, Journal of Environmental Science and Public Health, 01, 6-106. Doi: 10.26502/jesph.9612009.
8. Gaur, M.; Singh, R. and Shukla, A. (2016). Variability in the levels of BTEX at a pollution hotspot in New Delhi, India, Journal of Environmental Protection, 07 (10):1245-1258.
9. Guo, H.; So, K.L.; Simpson, I.J.; Barletta, B.; Meinardi, S. and Blake, D.R. (2007). C_1–C_8 volatile organic compounds in the atmosphere of Hong Kong: overview of atmospheric processing and source apportionment, Atmospheric Environment, 41:1456–1472.
10. Hajizadeh, Y.; Mokhtari, M.; Faraji, M.; Mohammadi, A.; Nemati, S.; Ghanbari, R.; Abdolahnejad, A.; Fard, R.F.; Nikoonahad, A.; Jafari, N. and Miri, M. (2018). Trends of BTEX in the Central urban area of Iran: A preliminary study of photochemical ozone pollution and health risk assessment, Atmospheric Pollution Research, 9 (2):220–229.
11. Hoque, R. R.; Khillare, P. S.; Agarwal, T.; Shridhar, V. and Balachandran, S. (2008). Spatial and temporal variation of BTEX in the urban atmosphere of Delhi, India, Science of the Total Environment, 392(1):30-40.
12. Hsieh, L.T.; Wang, Y.F.; Yang, H.H. and Mi, H.H. (2011). Measurements and correlations of MTBE and BETX in traffic tunnels, Aerosol and Air Quality Research, 11:763-775.
13. Hun, D. E.; Corsi, R. L.; Morandi, M. T. and Siegel, J. A. (2010). Formaldehyde in residences: long-term indoor concentrations and influencing factors, Indoor Air, 20(3):196-203.
14. IPCS (1996). Environmental Health Criteria 186: Ethylbenzene, International Programme on Chemical Safety, World Health Organization, Geneva, Switzerland.
15. Kerbachi, R.; Boughedaoui, M.; Bounoua, L. and Keddam, M. (2006). Ambient air pollution by aromatic hydrocarbons in Algiers, Atmospheric Environment, 40:3995–4003.
16. Khoder, M. I. (2007). Ambient levels of volatile organic compounds in the atmosphere of Greater Cairo, Atmospheric Environment, 41 (3):554–566.
17. Majumdar, D.; Mukherjee, A. K. and Sen, S. (2011). BTEX in ambient air of a Metropolitan City, Journal of Environmental Protection, 2(01):11-20.
18. Prinn, R.; Cunnold, D.; Rasmussen, R.; Simmonds, P.; Alyea, F.; Crawford, A.; Fraser, P. and Rosen, R. (1987). Atmospheric trends in methylchloroform and the global average for the hydroxyl radical, Science, 238:945–950.
19. Tiwari, V.; Hanai, Y. and Masunaga, S. (2010). Ambient levels of volatile organic compounds in the vicinity of petrochemical industrial area of Yokohama, Japan, Air Quality, Atmosphere and Health, 3(2):65-75.
20. Tyagi, S.K.; Upadhyay, V.K.; Kulshreshtha, D.; Kumar, S.; Krishnamurthy, P. and Sen, A.K. (2016). Study of Background Ambient Air Quality in Northern Himalayan Regions: Uttrakhand and Himachal Pradesh, India, Indian Journal of Air Pollution Control, Vol XVI, No. 1:1-9.
21. WHO Urban Ambient (Outdoor) Air Quality Database (2016). Geneva: World Health Organization, http://www.who. int/phe/health_topics/outdoorair/ databases/cities/en/, accessed 19 May 2016.

Variability of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ in Indoor Environment of Different Socioeconomic Status Houses

Renuka Saini[1], Jitendra Swarup Sharma[2], Pradyumn Singh[3], Ajay Taneja[1]

[1]Department of Chemistry, Dr. Bhim Rao Ambedkar University, Agra, India – 282005
[2]Environment Division, Oil and Natural Gas Corporation, New Delhi, India – 110070
[3]Department of Civil & Environmental Engineering, Washington State University, Pullman, United States – 99163
(email: renukasaini@gmail.com)

Abstract

The present study aimed to highlight the concentrations of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ and their sources in three different houses of different Socio-Economic Status (SES) in Agra, Uttar Pradesh, India. Samples were collected from July 2012 to August 2012 in indoor environments of low, middle, and high-income houses having different sources and characteristics. Total 30 samples (10 from each house) were collected for 24 hours daily using GRIMM 1.109 Portable Aerosol Sampler (PAS) on mass fraction mode (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$). Highest concentrations of PM were recorded in a low-income house and the lowest was in the high-income house. In low-income house, the concentrations of $PM_{10,}$ $PM_{2.5}$ and $PM_{1.0}$ were 83.5 µg/m^3, 46.7 µg/m^3 and 33.6 µg/m^3, respectively. Whereas, in middle-income house, concentrations were 60.4 µg/m^3, 39.1 µg/m^3 and 26.5 µg/m^3, respectively. $PM_{10,}$ $PM_{2.5}$ and $PM_{1.0}$ concentrations in high-income house were 42.9 µg/m^3, 28.1 µg/m^3 and 21.8 µg/m^3, respectively. The higher concentration of PM in the low-income house was mainly because of biofuel used for cooking and heating purposes. Meteorological parameters viz., Relative Humidity (RH), Ventilation Rate (VR) and Atmospheric Temperature (AT), and Carbon dioxide (CO_2) play significant role fluctuating PM concentrations. Concentrations of PM were directly proportionate to CO_2 and AT and inversely to RH and VR.

Keywords- Indoor Air Quality, Coarse Particles, Fine Particles, Socio-Economic Status (SES), Source Identification

1. Introduction

In recent years, India has experienced major growth in the economy leading to increased urbanization, industrialization, motorization, and energy use (Colbeck et al. 2010; Singh et al. 2014). The resulting urbanization and industrialization have led to an increase in the number of industries, offices, and residences, along with several vehicles, which are causing adverse effects on outdoor as well as indoor air quality day by day (Lee et al. 2002; Gupta et al. 2002; Abu-Allaban et al. 2003; Zhang et al. 2011). Indoor air pollution is one of the key environmental problems in India (Smith 2000; Balakrishnan et al. 2004; Taneja et al. 2008; Kumar et al. 2014; Singh et al. 2014). In the past few decades, special consideration has been given to indoor air quality (IAQ) and emission rates of indoor particulate matter concentrations (Goyal and Khare 2009; Singh et al. 2014). In a tropical climate like India, the houses are naturally ventilated, and air exchange rates are generally higher and have a significant impact of outdoor air on IAQ. Hence, the concentration of indoor particles depends upon the particles generated within indoor and outdoor spaces both. Factors like ventilation rate, air leakages, and meteorological parameters also played a significant role in fluctuations of indoor PM. Anthropogenic activities like cooking, cleaning, walking, opening/closing of doors/windows are one of the major factors affecting the concentrations of coarse and fine particles (Ferro et al. 2004; Adgate et al. 2007; Gomes et al. 2007; Singh et al. 2014; Varshney et al. 2016).

In the present study, we investigated various aspects of Indoor Air Pollution (IAP) in different residential houses of different socioeconomic status, i.e. low, middle, and high-income house in Agra, India. The main purpose of the present study, was to examine the emission characteristics of the most common indoor particle sources and impact of outdoor conditions on the indoor environment, as this kind of study on the simultaneous measurement of different size segments of indoor PM and impact of outdoor PM and meteorology on them was rare (Nasir et al. 2013).

2. Methodology

For the indoor sampling of PM, three houses were selected: one from each income group: low, middle, and high in Agra, India (Figure 1).

Figure 1: Site of Agra city showing the location and area density of the study sites.

Total 30 samples (10 from each house) were collected for 24 hours daily in the monsoon season: 17 July 2012 to 15 August 2012 i.e. for 30 days. Please refer (Singh et al. 2014) for a full description of sampling protocol and PAS location in indoor microenvironments.

2.1 Instrumentation and Sampling Design

The measurement of 24-hour mass concentrations of particles was done using Grimm portable aerosol spectrometer, Model 1.109 (Grimm Aerosol Technik GmbH, Co. KG., Germany). The spectrometer was used to report the mass fraction in the environmental mode (PM_{10}, $PM_{2.5}$ and $PM_{1.0}$). The sampling interval was 5 minutes (min) and data were further analyzed hourly to investigate the effect of various activities on particulate concentrations. Grimm 1.109 PAS was set to work at a flow rate of 1.2 litres per minute (L/min) with reproducibility of plus or minus (±) 5%. PAS had on the dual working principle, the principle of light scattering at 90-degrees to record real-time measurements and the collection of total particles on 47- millimetre (mm) polytetrafluoroethylene (PTFE) filters for chemical analysis. This sampling period covered the activities for the entire day inside the houses, such as prayer time (burning candles and incenses sticks), cleaning, sweeping, and preparing food, as well as outdoor activities. PAS was placed in the living room close to head height while sitting.

The instrument was kept 1 m above the ground level and 0.5 m away from the outdoor sources of air pollutants. 2.4.

2.2 Questionnaire Survey

Residents were asked to fill the questionnaires to list their daily indoor and outdoor activity patterns, and the potential sources that may be responsible for particulate emissions. The questionnaire included a daily time/activity diary document the house characteristics and different activities such as cooking, cleaning and heating, the number of occupants, house surroundings, and other activities carried in the house's indoor and outdoor environments.

2.3 Housing Characteristics

Low-Income House: A single room house occupied by six adult members and two children, having a monthly income of ≤ 5000 Indian Rupees (INR) was selected. The house was surrounded by old and closely built houses on the narrow streets of Agra. The kitchen was adjacent to the room in a barracoon and for cooking, solid fuel like (wood, coal, and cow dung cakes) on unvented mud stoves (Chullah) was observed. The total area and volume of the living room/bedroom were 8.7 m^2 and 26.1 $m^{3,}$ respectively. On the windows, there was no glass on them, but the size of the windows was too small to have proper ventilation. Typically, during the rush hours in the morning and evening both, there was heavy traffic on the roads and there are some small-scale industries and bakeries too in the vicinity of a sampled house. Activities like open garbage burning and dumping were also witnessed during the sample period. It is noteworthy to mention that area has very few trees roads were full of dust, which is dispersing due to the vehicular and pedestrian activities.

Middle-Income House: A single-story house occupied by four members having a monthly income of ≤ 60000 INR was selected for the study. The house has a total height of 4meters (m) that is naturally ventilated with three rooms in a residential area with moderate traffic on nearby streets. The kitchen was attached to the living room. All rooms including the kitchen had single-glazed windows with wooden frames. Although the house was occupied with electrical appliances, occupants were using liquefied petroleum gas (LPG) as their primary source of cooking. The house had six windows facing outdoors with adjacent car parking, next to the living room. One door of each bedroom opens in the living room and another one opens into the backyard of the houses. The total area and volume of the living room were 34.2 m^2 and 136.8 m^3, respectively. The middle-Income house is in a less dense area with more greenery in comparison to less-income society, and activities like open garbage burning and dumping were absent. Though, vehicular density on roads was as similar as in low-income society.

High-Income House: A six-room house occupied by a four-member family with a monthly income ≥ 100000 INR was selected. PAS was placed on the ground floor (4.5 m) of a two-floored house. The house was five-year-old, a modern type with a height of 9 m and it was located in a typical residential area with light traffic on nearby streets and no such sources were present which can affect the indoor concentrations of PM. The house was mechanically ventilated, having proper heating, ventilation, and air conditioning systems. There were three bedrooms with attached bathroom, one guest room, a study room, and a living room attached to the kitchen and staircase in the house. All rooms had triple glazed windows with frames insulated by foam tape. The total area and volume of the living room were 115.5 m^2 and 519.8 m^3, respectively.

3. Results and Discussion

3.1 Particulate Concentrations

Mean concentrations of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ for the entire sampling period were determined separately for each of the three different houses, with the consideration of morning, afternoon, and evening hours (Table 1).

3.1.1. Coarse Fraction: The highest concentration of the coarse fraction was observed in the low-income house. This was attributed to the impact of burning of wood and cow dung cake, heavy vehicular traffic flow on the roads, emissions from nearby industries, and high anthropogenic activities. It was assumed that

Table 1: Summary of PM concentrations (µg/m^3) in low- middle-and high-income houses

	Low-Income Group House				***Middle-Income Group House***				***High-Income Group House***			
Concentration (µg/m^3)	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	$PM_{10-2.5}$	PM_{10}	$PM_{2.5}$	$PM_{1.0}$	$PM_{10-2.5}$
Morning												
Mean	90.8	54.3	40.1	36.5	66.6	39.1	26.0	27.4	42.2	21.0	14.3	21.2
Med	58.3	41.3	26.9	22.5	63.7	30.2	17.6	25.9	29.6	14.9	8.9	11.7
Sd	67.7	40.1	35.1	38.3	40.8	27.6	23.3	17.9	33.2	13.8	11.5	31.0
Min	33.4	15.8	11.8	8.7	18.4	13.0	10.7	4.3	17.8	7.3	4.0	4.9
Max	308.5	209.5	180.1	211.4	225.7	138.6	108.5	87.1	162.1	61.1	40.6	145.9
Afternoon												
Mean	59.7	23.1	9.5	36.5	33.5	20.4	12.2	13.1	23.9	16.2	12.0	7.7
Med	51.8	20.7	9.0	30.1	32.4	21.4	11.6	10.2	24.9	16.0	11.7	7.5
Sd	34.9	9.5	2.6	26.5	10.6	3.4	3.7	8.4	7.0	7.6	7.7	2.8
Min	15.8	9.5	6.2	6.1	20.3	14.1	8.0	4.8	12.5	7.2	4.1	4.3
Max	175.4	42.4	14.2	133.0	62.1	25.7	20.9	39.1	36.4	26.1	21.3	13.4
Evening												
Mean	101.8	64.5	52.9	37.3	76.7	57.2	41.1	19.5	62.7	50.3	42.5	12.4
Med	98.2	63.4	42.3	26.3	52.1	32.2	18.1	18.6	44.7	24.0	16.8	11.8
Sd	77.8	61.9	59.0	30.1	57.9	54.8	47.2	9.7	36.2	41.1	42.4	7.9
Min	15.8	11.6	6.9	4.2	21.3	12.3	8.6	2.4	30.9	20.7	10.6	3.5
Max	407.6	349.8	327.9	125.4	224.0	204.9	171.1	35.4	151.5	145.1	137.0	25.8

Med = Median; Sd = Standard Deviation; Min = Minimum; Max = Maximum

the coarse fraction particulate matter was mainly of outdoor origin by resuspension of road dust and vehicular activity outside the house. In each of the three houses, the daily average of PM_{10} concentrations was 83.5 µg/m^3 in the low-income, 60.3 µg/m^3 in the middle-income and 42.8 µg/m^3 in the high-income house. Figure 2 shows the diurnal distribution of PM_{10} along with other particles of the different size range in each of the three different socioeconomic houses for the morning, afternoon, and evening hours, respectively.

Mean concentrations of PM_{10} in the low-income house were 90.8 µg/m^3 (morning), 59.7 µg/m^3 (afternoon); and 101.8 µg/m^3 (evening). In the middle-income house, the concentrations were 66.6 µg/m^3 (morning), 33.5 µg/m^3 (afternoon); and 76.7 µg/m^3 (evening). Whereas, in the high-income house, concentrations of PM_{10} were 42.2 µg/m^3 during morning hours, 23.9 µg/m^3 during afternoon hours and 62.7 µg/m^3 in the evening. Time-specific ratios proved useful in identifying the effect of activity on indoor PM_{10} concentration and source identification. The time-specific evening/afternoon hours PM_{10} ratio varied between 1.7 (low-income house) to 2.6 (high-income house). Whereas, evening/morning hour PM_{10} ratio varied between 1.1 (low-income house) to 1.4 (high-income house). In a low-income house, this time specific ratio showed that PM_{10} concentrations exhibited a strong diurnal pattern with the mean concentration approximately 2 times higher during evening hours than afternoon hours. This trend continued in the middle and high-income house. Local outdoor pollution emissions, such as industrial burning, vehicular emission and indoor activities like cooking, sweeping/cleaning are responsible for the higher concentrations in the morning and evening hours.

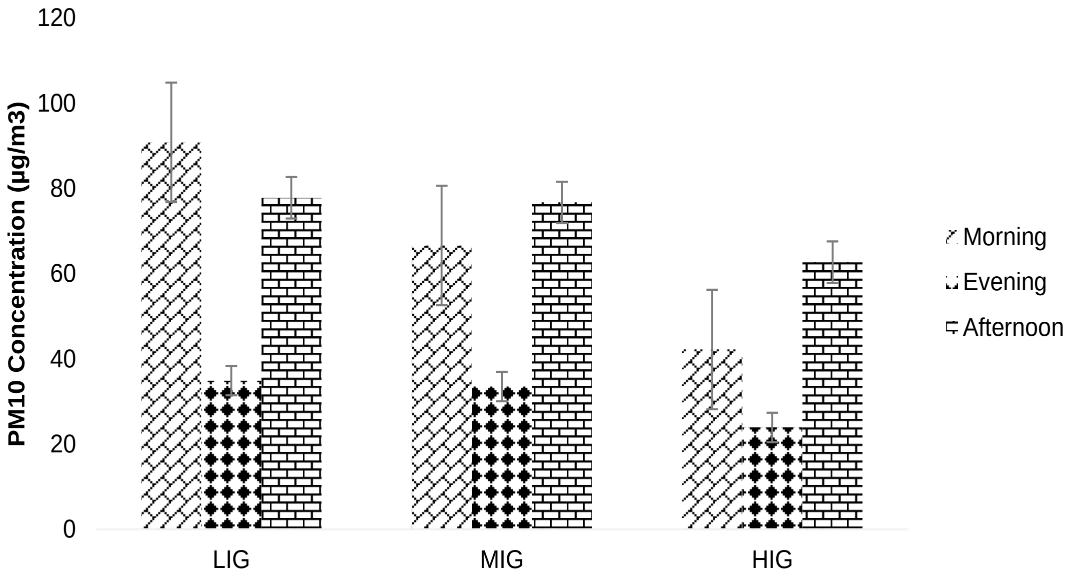


Figure 2: Variation of PM_{10} concentration during the morning, afternoon, and evening

3.1.2. Fine Fraction: The mean concentration of $PM_{2.5}$ were 46.7 µg/m^3 in low-income, 39.1 µg/m^3 in middle-income and 28.1 µg/m^3 high-income house. There was another size in the fine range fraction which was considered in this study: $PM_{1.0}$ (particles < 1.0 microns (µ)), which proved useful in identifying the fine particles not going into the coarse range. The concentration of $PM_{1.0}$ was 33.6 µg/m^3 in low-income, 26.5µg/m^3 in middle-income and 21.8µg/m^3 in high-income house. As seen for coarse particles, the maximum concentration of fine particles was recorded in a low-income house and minimum in high-income house. The overall pollution load for finer particles ($PM_{2.5}$ and $PM_{1.0}$) in each of the three income houses was lower than for coarse, possibly because finer particles got converted into coarse particles. Furthermore, like the coarse fraction, maximum concentrations of fine particles were recorded in the morning and evening, and the minimum in the afternoon hours. As shown in Figure 3, the mean concentrations of $PM_{2.5}$ in the low-income house were 54.3 µg/m^3, 23.1 µg/m^3 and 64.5 µg/m^3; in middle-income house 39.1 µg/m^3, 20.4 µg/m^3 and 57.2 µg/m^3; in high-income house 21.0 µg/m^3, 16.2 µg/m^3 and 50.3 µg/m^3 during the morning, afternoon and evening hours, respectively.

Whereas, $PM_{1.0}$ mean concentrations were, 40.1 µg/m^3, 9.5 µg/m^3 and 52.9 µg/m^3 in low-income house; in middle-income house 26.0 µg/m^3, 12.2 µg/m^3 and 41.1 µg/m^3; and in high-income house 14.3 µg/m^3, 12.0 µg/m^3 and 42.5 µg/m^3 during morning, afternoon and evening hours, respectively (Figure 4). The time-specific evening/afternoon hour $PM_{2.5}$ ratio ranged from 2.8 at a low-income house to 3.1 high-income house.$PM_{2.5}$ ratios for the evening/morning hours varied between 1.2 (low-income house) to 2.4 (high-income house). Whereas, $PM_{1.0}$ time-specific evening/afternoon hours' ratio varied from 3.3 (middle-income house) to 5.5 (low-income house); for evening/morning hours, the ratio ranges from 1.3 (low-income house) to 2.9 (high-income house). This time-specific ratio showed a clear influence of activities like cooking and cleaning during evening hours. It is noteworthy to mention that, unlike for all the sites, lowest evening/afternoon ratio for $PM_{1.0}$ was found in the middle-income house, possibly owing to the fact of the use of cooking, frying or use of cosmetic products and room fresheners during the afternoon hours. (Afshari et al. 2005) reported that air-freshener sprays also produce aerosol particles within this size range in considerable amounts

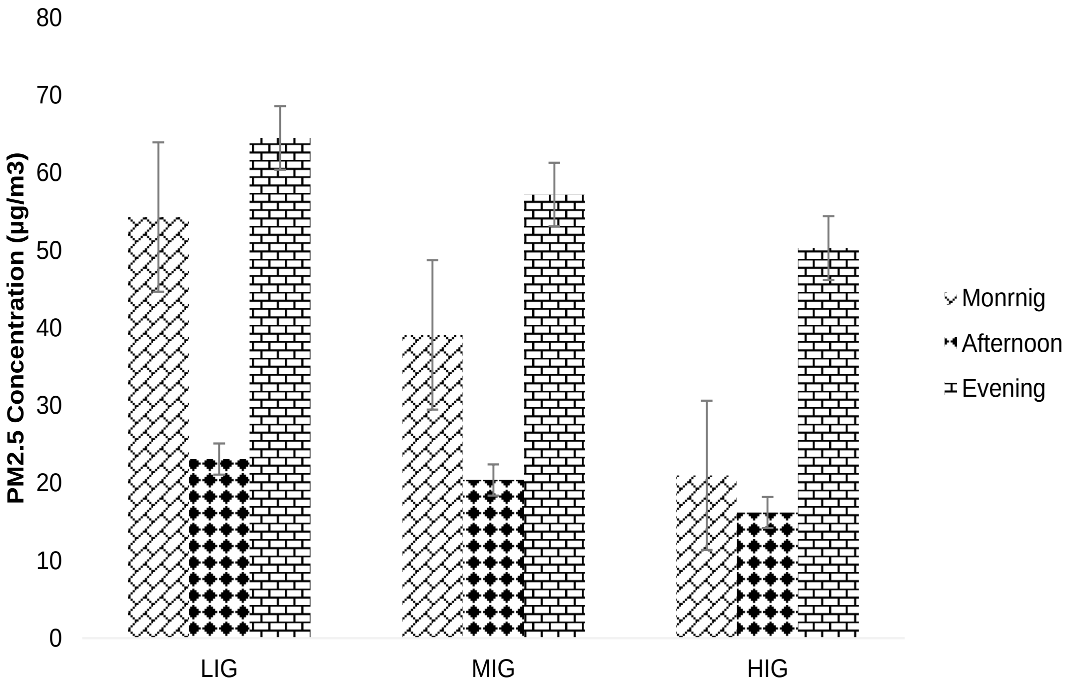


Figure 3: Variation of $PM_{2.5}$ concentration during the morning, afternoon, and evening

Whereas, $PM_{1.0}$ mean concentrations were, 40.1 µg/m^3, 9.5 µg/m^3 and 52.9 µg/m^3 in low-income house; in middle-income house 26.0 µg/m^3, 12.2 µg/m^3 and 41.1 µg/m^3; and in high-income house 14.3 µg/m^3, 12.0 µg/m^3 and 42.5 µg/m^3 during morning, afternoon and evening hours, respectively (Figure 4). The time-specific evening/afternoon hour $PM_{2.5}$ ratio ranged from 2.8 at a low-income house to 3.1 high-income house.$PM_{2.5}$ ratios for the evening/morning hours varied between 1.2 (low-income house) to 2.4 (high-income house). Whereas, $PM_{1.0}$ time-specific evening/afternoon hours' ratio varied from 3.3 (middle-income house) to 5.5 (low-income house); for evening/morning hours, the ratio ranges from 1.3 (low-income house) to 2.9 (high-income house). This time-specific ratio showed a clear influence of activities like cooking and cleaning during evening hours. It is noteworthy to mention that, unlike for all the sites, lowest evening/afternoon ratio for $PM_{1.0}$ was found in the middle-income house, possibly owing to the fact of the use of cooking, frying or use of cosmetic products and room fresheners during the afternoon hours. (Afshari et al. 2005) reported that air-freshener sprays also produce aerosol particles within this size range in considerable amounts.

Extreme concentrations of fine particles in the morning and evening hours were observed and several events were identified that might be responsible for the elevated concentrations. One of the most common activities found responsible for extreme concentrations was cooking. Cooking generates particles in the ultra-fine to a fine range of particles; ultra-fine particles further form fine particles by coagulation (Finlayson-Pitts and Pitts 2000). Cooking was done during the morning and evening hours in all three houses which released fine and ultra-fine particles. Activities such as smoking, walking, heating, candle burning, aerosol spray and opening of windows might contribute to high concentrations of the fine fraction of PM. Other activities like walking generate a considerable amount of aerosol particles in the size range of 1 µm that were possibly re-suspended from indoor surfaces (Luoma and Batterman 2001). It was a well-known fact that activities like candle burning and smoking might result in fine particles generation. Although candle and incense burning was less important indoor pollutant sources as compared to cooking, candle burning generates particles in the range of 0.03–3 µm. Whereas tobacco smoking generates in particles > 0.03 µm in diameter. In this case, fine particles were at their maximum, when people living in low-income house burns their kerosene lamps and Candle during the evening/night hours whereas smoke during the anytime of the day, which can be identified by looking a sharp peak in the data. It was worthy to mention here, that kerosene lamp/candle burning, and smoking was seen in low-income house only, which adds a significant amount in CO_2 concentration in the low-income house in comparison to a middle and high-income house.

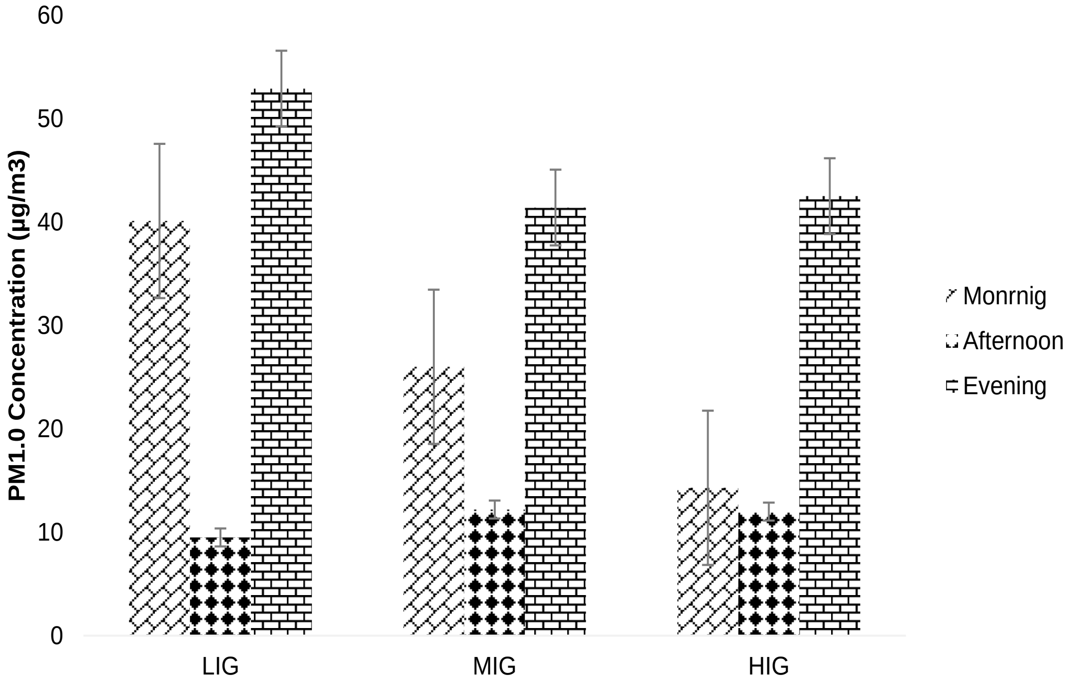


Figure 4: Variation of $PM_{1.0}$ concentration during the morning, afternoon, and evening

3.1.3. $PM_{10\text{-}2.5}$ Concentrations: To examine the contribution of fine particles in the formation of coarse particles, the difference between the concentration of PM_{10} and $PM_{2.5}$ was calculated. Average concentrations of $PM_{10\text{-}2.5}$ were 36.8 μg/m^3, 21.2 μg/m^3, and 14.6 μg/m^3, at low, middle, and high- income house, respectively. The highest $PM_{10–2.5}$ concentration was observed in low-income house and the lowest concentration in high-income house. The interquartile range (IQR) of $PM_{10\text{-}2.5}$ ranges from 23.1 μg/m^3 at evening hours and 46.5 μg/m^3 at afternoon hours in the low-income house. In the middle-income house, IQR ranges from 4.1 μg/m^3 at evening hours to 11.0 μg/m^3 at morning hours. The IQR ranges from 10.2 μg/m^3 at evening hours to 17.8 μg/m^3 at afternoon hours in the high-income house. Skewness was applied to check the distribution of data. The distribution of data in each of the three: low, middle and high-income was skewed to the right (median < mean), which indicates that the standard deviation was high, indicating the presence of some high data points in the data set. These high data points in the coarse range were due to activities involving mechanical work: walking, resuspension of dust, cosmetic products (talc) etc., which produced coarse particles (Long et al. 2000; Tucker 2000).

Coarse particle did not exhibit large diurnal variability with an evening/afternoon hour ratio of 1.40 (low-income house) and 1.46 (high-income house). Thus, PM_{10} diurnal patterns were mostly because of changes in $PM_{2.5}$ concentrations. Most of the PM was found in the fine fraction of 55.9%, 64.9% and 65.9% (<$PM_{2.5}$) in low, middle, and high-income house, respectively. Hence, it was important to mention that in indoor spaces the presence of fine particles was more than coarse particles.

3.1.4 Site-Specific Differences: Differences between houses were assessed by comparing the concentrations of coarse and fine particles with the World Health Organization standards (Duffey and Saull 2008), identifying PM generator activities and sources present in each of the three houses. In the low-income house, average PM_{10} concentration exceeded more than 1.5 times the WHO 24-hour PM_{10} standard of 50 μg/m^3 and in middle-income house, it was slightly higher than the threshold. Whereas, in the high-income house it was within permissible limits. The concentration of PM_{10} in the high-income house was almost one-half of low-income house and three-quarters of middle-income house. The $PM_{2.5}$ average concentration in each of the three houses exceeded the WHO 24-hours $PM_{2.5}$ standards of 25 μg/m^3. $PM_{2.5}$ average concentration in the low-income house was almost 2 times higher than WHO standards with more than 60 % of the daily concentrations over the WHO 24-hour mean $PM_{2.5}$ standards and it was 1.5 times higher in middle-income house, with more than 40 % of the daily concentrations were over the WHO 24-hour mean $PM_{2.5}$ standard; while in the high-income house, less than 25 % of the daily concentrations were over the WHO 24-hour mean $PM_{2.5}$ standards. As a result of it, $PM_{2.5}$ concentration in the high-income house slightly exceeded the WHO 24-hour mean $PM_{2.5}$ standards. The difference in the concentrations of PM_{10} and $PM_{2.5}$ among the sites was attributed to different sources and amount of anthropogenic activities performed. As discussed earlier the higher concentrations of PM in the low-income house might be attributed to activities like cooking by solid fuel combustion. The ample disparity in PM concentration during cooking was linked to the type of cooking and stove. As cooking on a gas stove produced more particles than cooking on an electrical stove (Dennekamp et al. 2001). Residents of a low-income house used wood, cow dung cake or biomass as a cooking fuel, whereas residents of middle-income and high-income house used LPG and both LPG and an electric stove, respectively.

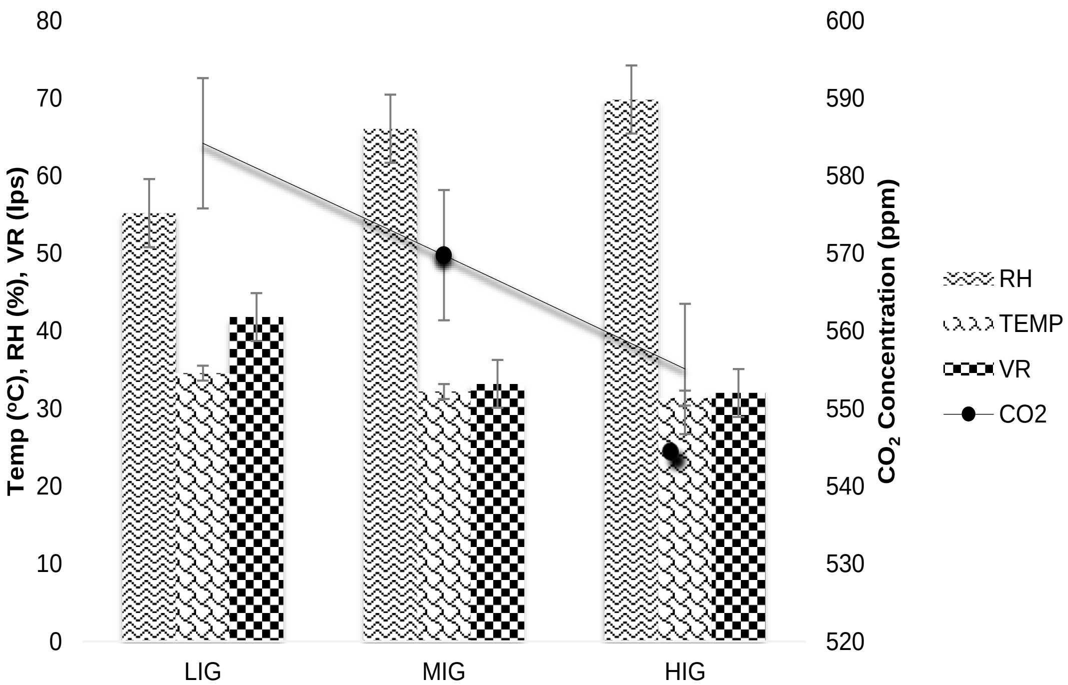


Figure 5: Variation of indoor CO_2 and meteorological parameters

Meteorological conditions have a predominant effect on governing the concentration of PM (Thatcher 1995; Tham et al. 2008). Thus, we had observed the effect of meteorological parameters on PM concentration. Biomass fuel burning in a low-income house produced more CO_2 than cooking on LPG and electric stove. Though CO_2 itself was not a pollutant, it surrogates the other pollutants (Varshney et al. 2016). The use of an electric stove/microwave oven was more pronounced than LPG in high-income house. This resulted in the more particle generation in the low-income house than the middle and high-income house. Additionally, residents living in the middle-income house used an exhaust fan in the kitchen whereas electric chimneys were used in the kitchens of high-income house. The use of an exhaust fan, electric chimney and proper ventilation was identified as one of the reasons responsible for reduced PM concentrations during cooking. Figure 5 shows the difference in meteorological parameters (CO_2, AT, VR, & RH) in low, middle- and high-income houses. RH was higher in middle and high-income house, but AT was low in the high and middle-income house in comparison to a low-income house. In middle and high-income house temperature was controlled using air coolers and air conditioning. Air coolers helped in controlling the room temperature, but they increased the amount of RH in an indoor environment (especially in the middle-income house). RH had an inverse relationship with PM concentration and electrification of conventional cooking and heating methods was the key to decrease indoor air pollution (Saini et al. 2014; Singh et al. 2014; Gautam et al. 2016; Roy et al. 2016; Saini et al. 2017). Hence, the use of rice cookers, water pots, microwaves could perform common tasks efficiently and conveniently with no or less household pollution (Smith 2014). Other activities such as heating, cleaning, dusting, population/area ratio and other activities also made a significant difference in PM generation. The concentrations of particles were elevated after extinguishing candles and lamps. There were sturdy correlations between SES, electrification and use of traditional fuels for heating and cooking (Barron and Torero 2017). Residents living in the low-income house were the ones with the lowest electric rates and the highest use of traditional fuels for cooking and heating. Whereas, residents living in middle and high-income houses were the ones with the highest electric rates and the lowest use of traditional fuels for cooking and heating. This could be the one other reason for high PM concentration in low-income house. Other house conditions like broken doors and windows panes, the opening of windows, carpet flooring, curtains, printers, and furniture also increase the indoor particle concentration. Apart from the use of traditional modes of cooking, lighting, and heating, outdoor sources also affect PM concentrations. The low-income house was also surrounded by heavy traffic and small-scale industries, had non-cemented areas and residents smoked. These effects might also result in resuspension of dust by activities like cleaning, sweeping, walking; thus, had a considerable effect on the PM levels.

4. Conclusions

The present study was an extension of our previous work (Singh et al. 2014) to evaluate the concentration of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ in low, middle, and high-income houses in Agra, India. The study showed indoor activities and disparity in lifestyle between poorer residents and privileged residents affect indoor coarse and fine particle concentrations, with the degree of effect depending upon the type of the source and on house characteristics. Several significant conclusions were drawn:

1. The maximum concentrations of both coarse and fine particles were found in the low-income house and the minimum in high-income house. The concentration of PM in the high-income house was almost one-half of the concentration found in the low-income house and three quarters in the middle-income house. This may be attributed to the disparity in the SES of the residents.
2. The average concentrations of PM_{10} compared with the WHO standard were found to be 1.5 times higher in the indoor environment of the low-income house. In the middle-income house, the PM_{10} average concentrations were higher than the threshold limit of 50 $\mu g/m^3$, while in the case of the high-income house it was within permissible limits. For $PM_{2.5}$, the average concentration in each of the three houses exceeded the WHO 24-hours $PM_{2.5}$standards of 25 $\mu g/m^3$. The concentration of $PM_{2.5}$ was 2 times higher in low-income house and 1.5 times higher in the middle-income house: while in the high-income house, the concentration is higher than the permissible limits. No comparison has been made for $PM_{1.0}$ because a standard for $PM_{1.0}$does not exist.

3. Most of the PM was found to be in the fine fraction. The fine fraction consists of 55.9%, 64.9% and 65.9% of the total accumulative mass of particulate matter (< $PM_{2.5}$) in low, middle, and high-income house, respectively.
4. A diurnal variation in PM concentration was observed in each of the three houses. High concentrations were found during the evening and morning hours than afternoon hours. These levels resulted from cooking during morning and evening hours.
5. Household activities such as cooking on stoves, indoor smoking, candle, or kerosene lamp burning and some outdoor activities were found to be major sources of PM emissions indoors.
6. Fuel selection had a significant effect on particulate pollution levels. People using bio-mass fuel in the low-income house had higher concentrations of PM than a middle and high-income house.
7. The effects of electrification were also playing a central role in this matter. The households with no or less access to electricity, use traditional fuels like candle kerosene lamps, biomass, etc. to satisfy their cooking, lighting, and heating needs generated more PM. Therefore, electrification can lead to improvements in IAQ, which helps in reducing the incidence of health effects by having lower exposure to pollutants. Everyone should access to clean, affordable, sustainable energy if thus and enabling factor for ensuring environmental sustainability.

Since the current study was for a limited period. Given the variation in SES, fuel use pattern and diurnal variations in indoor air pollutants may not be the same across the whole country. Therefore, there was recommended to further address the levels of emissions associated with coarse and fine.

5. Acknowledgements

One of the authors, Renuka Saini, gratefully acknowledges women scientist post-doctoral fellowship (Project No: F.15–45/12 (SA–II)) by University Grant Commission (UGC), New Delhi, India.

6. References:

1. Abu-Allaban, M., Gillies, J.A., Gertler, A.W., Clayton, R. and Proffitt, D. 2003. Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles. *Atmospheric environment* 37(37), pp. 5283–5293.
2. Adgate, J.L., Mongin, S.J., Pratt, G.C., et al. 2007. Relationships between personal, indoor, and outdoor exposures to trace elements in PM (2.5). *The Science of the Total Environment* 386(1-3), pp. 21–32.
3. Afshari, A., Matson, U. and Ekberg, L.E. 2005. Characterization of indoor sources of fine and ultrafine particles: a study conducted in a full-scale chamber. *Indoor Air* 15(2), pp. 141–150.
4. Balakrishnan, K., Sambandam, S., Ramaswamy, P., Mehta, S. and Smith, K.R. 2004. Exposure assessment for respirable particulates associated with household fuel use in rural districts of Andhra Pradesh, India. *Journal of exposure analysis and environmental epidemiology* 14 Suppl 1, pp. S14–25.
5. Barron, M. and Torero, M. 2017. Household electrification and indoor air pollution. *Journal of Environmental Economics and Management*, 2017, vol. 86, issue C, 81-92.
6. Colbeck, I., Nasir, Z.A. and Ali, Z. 2010. The state of ambient air quality in Pakistan--a review. *Environmental Science and Pollution Research International* 17(1), pp. 49–63.

7. Dennekamp, M., Howarth, S., Dick, C.A., Cherrie, J.W., Donaldson, K. and Seaton, A. 2001. Ultrafine particles and nitrogen oxides generated by gas and electric cooking. *Occupational and Environmental Medicine* 58(8), pp. 511–516.
8. Duffey, R.B. and Saull, J.W. 2008. Technical Summary. In: *Managing Risk*. Chichester, UK: John Wiley & Sons, Ltd, pp. 15–34.
9. Ferro, A.R., Kopperud, R.J. and Hildemann, L.M. 2004. Source strengths for indoor human activities that resuspend particulate matter. *Environmental Science & Technology* 38(6), pp. 1759–1764.
10. Finlayson-Pitts, B.J. and Pitts, J.N. 2000. Particles in the troposphere. In: *Chemistry of the upper and lower atmosphere*. Elsevier, pp. 349–435.
11. Gautam, S., Prasad, N., Patra, A.K., et al. 2016. Characterization of PM2.5 generated from opencast coal mining operations: A case study of Sonepur Bazari Opencast Project of India. *Environmental Technology & Innovation* 6, pp. 1–10.
12. Gomes, C., Freihaut, J. and Bahnfleth, W. 2007. Resuspension of allergen-containing particles under mechanical and aerodynamic disturbances from human walking. *Atmospheric environment* 41(25), pp. 5257–5270.
13. Goyal, R. and Khare, M. 2009. Indoor–outdoor concentrations of RSPM in classroom of a naturally ventilated school building near an urban traffic roadway. *Atmospheric environment* 43(38), pp. 6026–6038.
14. Gupta, H.K., Gupta, V.B., Rao, C.V.C., Gajghate, D.G. and Hasan, M.Z. 2002. Urban ambient air quality and its management strategy for a metropolitan city in India. *Bulletin of environmental contamination and toxicology* 68(3), pp. 347–354.
15. Kumar, R., Kumar, D., Kumar, M., Mavi, A., Singh, K. and Gupta, N. 2014. Monitoring of indoor particulate matter during burning of mosquito coil, incense sticks and dhoop. *Indian Journal of Allergy, Asthma and Immunology* 28(2), p. 68.
16. Lee, J.-T., Kim, H., Song, H., et al. 2002. Air pollution and asthma among children in Seoul, Korea. *Epidemiology* 13(4), pp. 481–484.
17. Long, C.M., Suh, H.H. and Koutrakis, P. 2000. Characterization of indoor particle sources using continuous mass and size monitors. *Journal of the Air & Waste Management Association (1995)* 50(7), pp. 1236–1250.
18. Luoma, M. and Batterman, S.A. 2001. Characterization of particulate emissions from occupant activities in offices. *Indoor Air* 11(1), pp. 35–48.
19. Nasir, Z.A., Colbeck, I., Ali, Z. and Ahmad, S. 2013. Indoor particulate matter in developing countries: a case study in Pakistan and potential intervention strategies. *Environmental Research Letters* 8(2), p. 024002.
20. Roy, D., Gautam, S., Singh, P., Singh, G., Das, B.K. and Patra, A.K. 2016. Carbonaceous species and physicochemical characteristics of PM10 in coal mine fire area—a case study. *Air quality, atmosphere, & health* 9(4), pp. 429–437.
21. Saini, R., Singh, P., Awasthi, B.B., Kumar, K. and Taneja, A. 2014. Ozone distributions and urban air quality d ring summer in Agra – a world heritage site. *Atmospheric pollution research* 5(4), pp. 796–804.
22. Saini, R., Taneja, A. and Singh, P. 2017. Surface ozone scenario and air quality in the north-central part of India. *Journal of Environmental Sciences* 59, pp. 72-79.
23. Singh, P., Saini, R. and Taneja, A. 2014. Physicochemical characteristics of PM2.5: Low, middle, and high–income group homes in Agra, India–a case study. *Atmospheric pollution research* 5(3), pp. 352–360.
24. Smith, K.R. 2014. In praise of power. *Science* 345(6197), p. 603.

25. Smith, K.R. 2000. National burden of disease in India from indoor air pollution. *Proceedings of the National Academy of Sciences of the United States of America* 97(24), pp. 13286–13293.
26. Taneja, A., Saini, R. and Masih, A. 2008. Indoor air quality of houses located in the urban environment of Agra, India. *Annals of the New York Academy of Sciences* 1140, pp. 228–245.
27. Tham, Y.W.F., Takeda, K. and Sakugawa, H. 2008. Polycyclic aromatic hydrocarbons (PAHs) associated with atmospheric particles in Higashi Hiroshima, Japan: Influence of meteorological conditions and seasonal variations. *Atmospheric research* 88(3-4), pp. 224–233.
28. Thatcher, T. 1995. Deposition, resuspension, and penetration of particles within a residence. *Atmospheric environment* 29(13), pp. 1487–1497.
29. Tucker, W.G. 2000. An overview of PM2.5 sources and control strategies. *Fuel Processing Technology* 65-66, pp. 379–392.
30. Varshney, P., Saini, R. and Taneja, A. 2016. Trace element concentration in fine particulate matter (PM2.5) and their bioavailability in different microenvironments in Agra, India: a case study. *Environmental Geochemistry and Health* 38(2), pp. 593–605.
31. Zhang, Y.N., Xiang, Y.R., Chan, L.Y., et al. 2011. Procuring the regional urbanization and industrialization effect on ozone pollution in Pearl River Delta of Guangdong, China. *Atmospheric environment* 45 (28), pp. 4898–4906.

Trends and Statistical Analysis of Primary Air Pollutants in Saharanpur

Rajiv Kumar*[1], S. K. Tyagi[2] and B. K. Sarma[1]

[1]Department of Chemistry, Mewar University, Gangrar, Chittorgarh, Rajasthan-312901, India

[2]Former Additional Director/ Scientist 'E', Central Pollution Control Board, Parivesh Bhawan, East Arjun Nagar, Delhi-110032, India.

(*Email:rajivk966@gmail.com)

Abstract

Saharanpur is commissioner/district level city selected and it may be an emerging area for research work on air pollution. The studies in growing city like Saharanpur will give us a proper idea regarding the pattern of the increase in the air pollution in other similar cities. The experimental results obtained from the different at different site has been compared with national air quality standards (NAAQS). The present study deals with the assessment of ambient air quality trend analysis with respect to Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2), RSPM (PM_{10}) and SPM levels at selected three locations in Saharanpur city for two years fortnightly from July-2015 to June-2017. The Bureau of Indian Standards (BIS) approved national method of sampling and analysis-were used for the proposed study.

The range annual mean of SO_2, NO_2, PM_{10} and SPM concentration were reported as 11.16-13.96µg/m^3, 21.21-28.35µg/m^3, 116.65-178.98µg/m^3, 282.2-381.64µg/m^3 over two years study period. There was increasing trend at all monitoring stations. PM_{10} concentration levels exceed the prescribed National Ambient Air Quality Standards for Residential, Traffic and Industrial area. The annual average concentrations of SO_2 and NO_2 have little difference during the study period at all locations and found within the notified ambient air quality standards during July-2015- June-2017. The location wise regression & correlation analysis between SO_2 & NO_2 and PM_{10} & SPM have also been calculated. The SPM exhibits a moderate dependency on PM_{10} at Traffic intersection area. Whereas SO_2 & NO_2 and PM_{10} & SPM regression equations demonstrate no dependency relationship at residential & industrial locations.

Keyword AAQ, NAAQS, Sulphur Di-oxide, Nitrogen Di-Oxide, PM_{10} , SPM, Trend Analysis

1. Introduction

Air pollution has a great impact on human health, climate change, agriculture, and the natural ecosystem (Decker et al.,2000; Mayer et al., 2000; Molina and Molina, 2004). Air Pollution has been identified as a serious problem (Kumar and Shukla, 2016) throughout the world which causes major loss to living beings, crops, plant growth and yield. Earlier, the restrictions of air pollution to metro-politan and industrial area. But it has become a wide problem due to development of industries, transportation, population increase and deforestation in this level of city (Kapoor, et al.2013). The air pollutants can be classified as primary or secondary pollutants. The primary air pollutants are harmful chemicals which directly enter into the air due to natural events of human activities. The primary pollutant combines with some component of the atmosphere to produce a secondary pollutant (Naik, 2005). CPCB has notified 12 pollutants as criteria pollutant in ambient air. These 12 parameters are oxides of Sulphur & Nitrogen, CO, Ozone, PM_{10}, $PM_{2.5}$, Ammonia, Lead, Nickel, Arsenic, Benzene and Benzo(a)pyrene. According to World Bank study (2000), the number of premature deaths due to air pollution in India has increased by almost 30%. The physical (Mahajan S.P. 2009) addition of materials that turns the air impure or unclean and sources for such undesirable additions to atmosphere are natural and anthropogenic activities. There are various sources (Ambasht and Ambasht, 2006) (mobile & stationery sources) of air pollutants in the form of solid (particulate matters), gaseous (NO2, O3, SO2 etc.) and liquid. (Barthwal, 2002). According a WHO report-(1992) air pollution problem in metropolitan cities of India has 23 major cities of over one million people and ambient air pollution levels exceed the WHO standards in many of them (Gupta, 2008). In a more recent estimate of WHO, a total of thirteen Indian cities are amongst twenty most polluted cities of the world in terms of the particulate matter air pollution ("Ambient Air Pollution Database", World Health Organization, May 2014). In most urban areas, emissions from traffic are a major contributor of harmful pollutants such as NOx and particulate matter (Lima, 2005). Among the harmful chemical compounds the combustion of SO_2, NO_2 and some solid particulates into the atmosphere are major problem for living beings (Goyal, 2003), Therefore, four parameters namely SO_2, NO_2, PM_{10}, SPM have been selected for this study and also due to the limitation of availability of requisite infrastructure to perform other parameters in the region of study area.

2. Material and Method

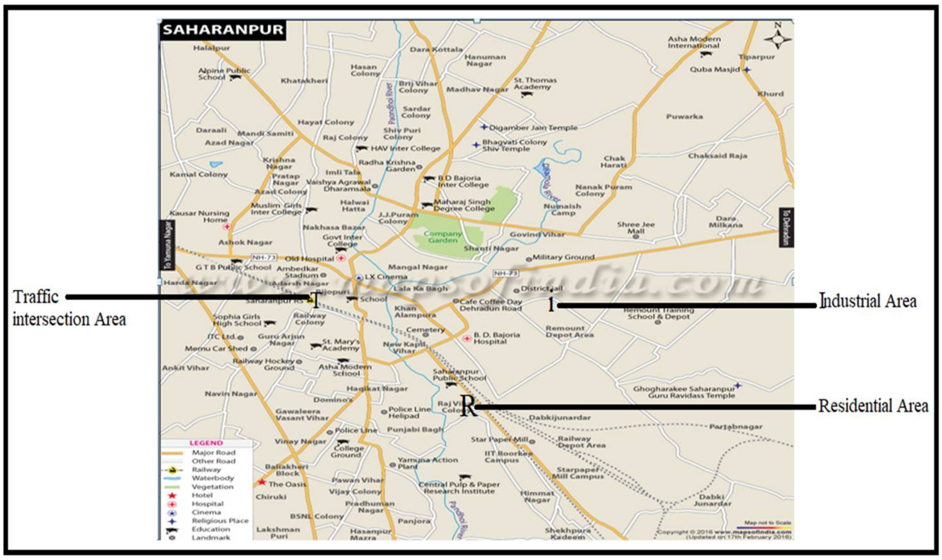
2.1 Study area

Saharanpur (fig 1) is a city and a municipal corporation in the state of Uttar Pradesh in northern India. It is the administrative headquarters of Saharanpur District and the Saharanpur Division. It's about 140 km south-southeast from Chandigarh and 170 km north- northeast from Delhi, located at 29.970 N, 77.550 E with elevation of 269 meters. The urban population of the city was 10,66,526 lakh (District census handbook Saharanpur as per 2011) with population density 10,030/km^2 and area of 106.3 km^2. Total population of Saharanpur: 34,66,382 lakh, Rural population: 23,99,856 lakh, Urban population: 10,66,526 lakh. Area : Total- 3,689.0, Rural- 3582.7, Urban- 106.3 km^2. Density of population: Total-940, Rural-670, Urban-10,030 per km. Saharanpur has tropical atmosphere as a result of the Himalayan locale over this northern district. Temperature range from an average 23.90°C during the year. Saharanpur is primarily and agricultural district. Roughly 70% of the land is under agricultural use still the region is of little importance from the point of view of pastures. Agriculture plays an important role in the economy of the district. (Fig1) The vehicular population in the city is expanding day by day. About 419961 vehicles were recorded in Saharanpur up to 2015 (ARTO, Saharanpur) and Total industries (Large, Micro, Small & Medium) recorded 3261 up to 2017.

2.2 Details of site:

For monitoring of SO_2, NO_2, PM_{10} and SPM three sites were selected in Saharanpur (Map 1) based on land use pattern i.e.

(i) Residential area (R): This site was selected as Punjabi Bag, Raj Vihar colony near Gori Shankar mandir Saharanpur, (ii) Industrial area (I): This site was at Delhi Saharanpur road, railway depot area, Himmat Nagar ARTO Office near Indian Overseas Bank Mahipalpur there are several small scale and and few large scale industry in Saharanpur, (iii) Traffic intersection Area (T): Clock tower Ambala road, Railway road: It is most of the busy and heavy traffic area of Saharanpur.



Map 1: Location of sampling sites in Saharanpur

2.3 Sampling and analysis:

The SO_2, NO_2, PM_{10} levels were measured by using respirable dust sampler (RDS-APM460NL, envirotech make fitted with gas sampling assembly). The PM_{10} & SPM were measured using PM_{10} sampler and High-volume sampler respectively at a sampling rate of 1.1 m^3 at the time interval over 24 hrs. The sampling rate of 1.0 lit/min. was used for SO_2 & NO_2 at the time interval of 4hrs over 24 hrs. at each site with a fortnightly frequency over a period of two years from July- 2015 to June- 2017.

Table 1: Sampling & analysis method for primary air pollutants

Primary Air Pollutants	Sampling & Analysis Method	IS Number and Part Number	Year
SO_2	West and Gaeke	5182, II	2006(Reaffirmed 2016)
NO_2	Jacob and Hochheiser	5182, VI	2006(Reaffirmed 2016)
PM_{10}	Gravimetric method, (Respirable dust sampler)	5182, XXII	2006 Revised 2014
SPM	Gravimetric method, (High-volume sampler)	5182, IV	1999 (Reaffirmed 2005

3. Result & Discussion

3.1 Trend and Statistical analysis of SO_2, NO_2, PM_{10} & SPM at all locations during 2015-17

Comparative trend & statistical analysis of SO_2 concentration at residential, traffic intersection and industrial area during 2015-17 is shown in figure 1 & table 2.

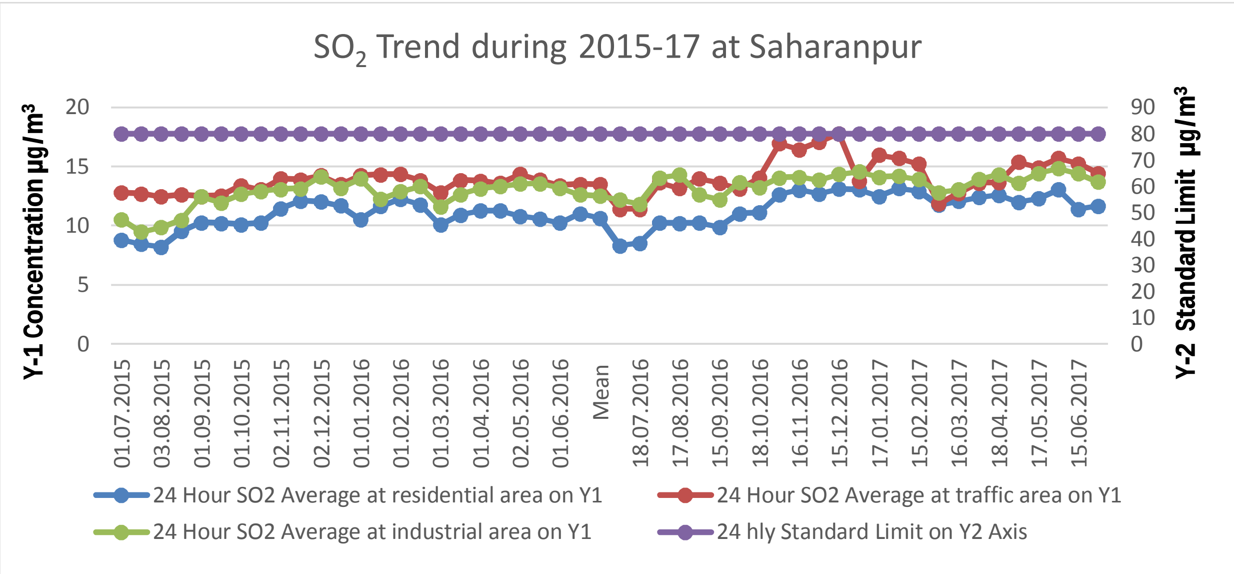


Figure 1: SO_2 trend analysis at all locations during 2015-17

Table 2: Statistical analysis of SO_2 at all locations during 2015-17

YEAR 2015-16	24 Hour SO_2 Average (µg/m^3) at Residential area	24 Hour SO_2 Average (µg/m^3) at Traffic area	24 Hour SO_2 Average (µg/m^3) at Industrial area
Minimum	8.21	12.47	9.49
Maximum	12.27	14.36	14.18
Mean	10.65	13.49	12.51
SD	1.11	0.65	1.25
ANOVA	4.2		
p-value	<0.05*		
YEAR 2016-17			
Minimum	8.32	8.32	11.85
Maximum	13.17	13.17	14.84
Mean	11.68	14.44	13.70
SD	1.44	1.76	0.83
ANOVA	2.57		
p-value	<0.05*		
24 hrs. NAAQS value	80		

*: statistically significant

The 24 hour SO_2 Mean & SD was estimated as 10.65±1.11µg/m^3, 13.49±0.65µg/m^3 and 12.51±1.25µg/m^3 respectively and the analysis of variance was calculated as 4.2 with statistically significant difference as $p<0.05$ (2015-16). The 24 hour SO_2 Mean & SD was 11.68±1.44µg/m^3, 14.44±1.76µg/m^3 and 13.70±0.83µg/m^3 respectively at residential, traffic intersection and industrial area and the analysis of variance was calculated as 2.57 with statistically significant difference as $p<0.05$ (2016-17). The concentration of SO_2 was lower than the 24 hours NAAQS standard limit. The SO_2 concentration was 12.21±1µg/m^3 during 2015-16 and 9.94±1.34µg/m^3 during 2016-17 and the SO_2 concentration was high at Traffic intersection area which shows the difference in graphical representation.

Comparative trend & statistical analysis of NO_2 concentration at residential, traffic intersection and industrial area during 2015-17 is shown in figure 2 & table 3.

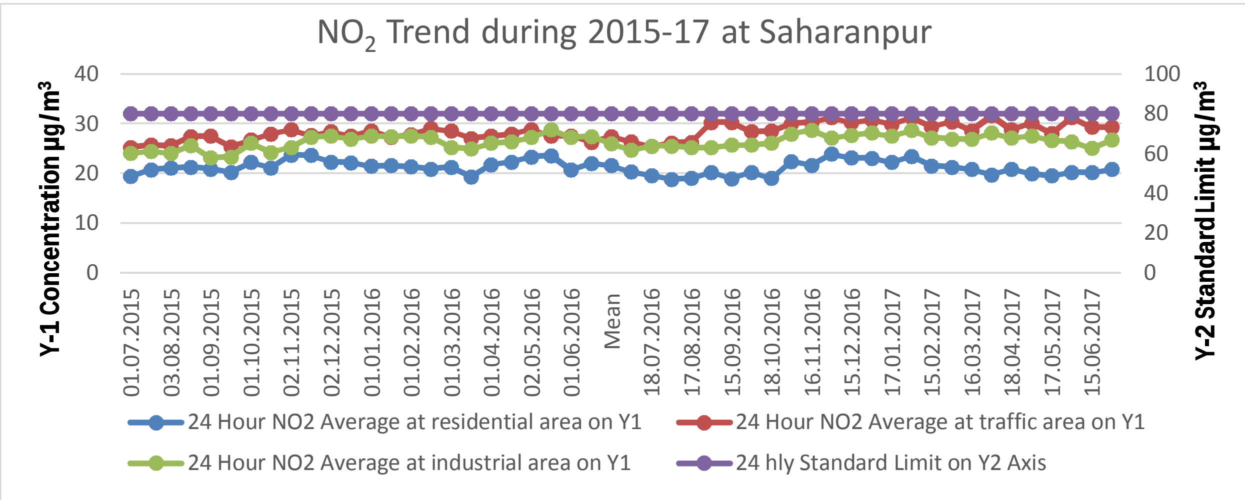


Figure 2: NO_2 trend analysis at all locations during 2015-17

Table 3: Statistical analysis of NO_2 at all locations during 2015-17

YEAR 2015-16	24 Hour NO_2 Average ($\mu g/m^3$) at Residential area	24 Hour NO2 Average ($\mu g/m^3$) at Traffic area	24 Hour NO_2 Average ($\mu g/m^3$)at Industrial area
Minimum	19.31	25.25	23.14
Maximum	23.69	29.06	28.81
Mean	21.59	27.41	26.05
SD	1.19	1.11	1.58
ANOVA	2.81		
p-value	<0.05*		
YEAR2016-17			
Minimum	18.83	25.46	24.66
Maximum	23.88	31.62	28.70
Mean	20.84	29.29	26.72
SD	1.52	1.76	1.21
ANOVA	4.26		
p-value	<0.05*		
24 hrs. NAAQS value	80		

*: statistically significant

The 24 hours NO_2 Mean & SD was estimated as 21.59±1.19µg/m^3, 27.41±1.11µg/m^3 and 26.05±1.58µg/m^3 respectively and the analysis of variance was calculated as 2.81 with statistically significant difference as $p<0.05$ (2015-16). The 24 hours NO2 Mean & SD was 20.84±1.52µg/m^3, 29.29±1.76µg/m^3 and 26.72±1.21µg/m^3 respectively at residential, traffic intersection and industrial Area. The analysis of variance was calculated as 4.26 with statistically significant difference as $p<0.05$ (2016-17). The concentration of NO_2 was lower than the 24 hours NAAQS standard limit. The NO_2 concentration was 25.01±1.29µg/m^3 during 2015-16 and 25.61±1.50µg/m^3 during 2016-17 and the NO_2 concentration was high at Traffic intersection area which shows the difference in graphical representation.

Comparative trend & statistical analysis of PM_{10} concentration at residential, traffic intersection and industrial area during 2015-17 is shown in figure 3 & table 4.

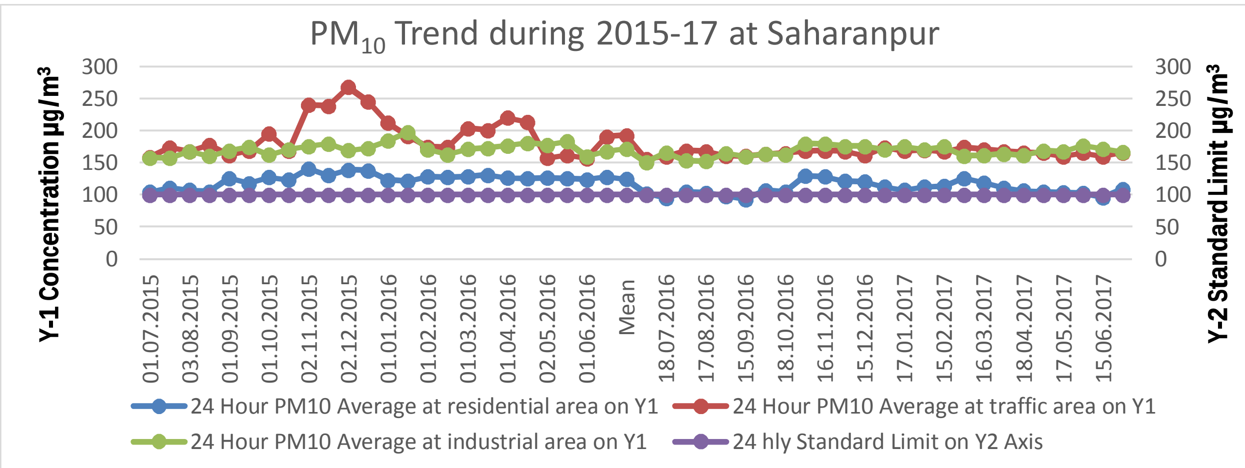


Figure 3: PM_{10} trend analysis at all locations during in 2015-17

Table 4: Statistical analysis of PM_{10} at all locations during 2015-17

YEAR 2015-16	24 Hour PM_{10} Average (µg/m^3) at Residential area	24 Hour PM_{10} Average (µg/m^3) at Traffic area	24 Hour PM_{10} Average (µg/m^3) at Industrial area
Minimum	104.14	156.60	156.95
Maximum	140.81	267.66	197.44
Mean	124.25	192.44	171.62
SD	9.59	31.75	9.55
ANOVA	1.39		
p-value	<0.05*		
YEAR2016-17			
Minimum	93.09	155.76	150.92
Maximum	129.34	174.17	179.38
Mean	109.05	165.52	166.85
SD	10.37	4.68	8.38
ANOVA	1.36		
p-value	<0.05*		
24 hrs. NAAQS value	100		

*: statistically significant

The 24 hour PM_{10} Mean & SD was estimated as 124.25±9.59µg/m^3, 192.44±31.75µg/m^3 and 171.62±9.55µg/m^3 respectively and the analysis of variance was calculated as 1.39 with highly statistically significant difference as p<0.05 (2015-16).The 24 hour PM_{10} Mean & SD was 109.05±10.37µg/m^3, 165.52±4.68µg/m^3 and 166.85±8.38µg/m^3 respectively at residential, traffic intersection and industrial Area. The analysis of variance was calculated as 1.36 with statistically significant difference as p<0.05 (2016-17). The concentration of PM_{10} exceeded than the 24 hours NAAQS standard value at all three sites. The PM_{10} concentration was 162.77±16.96µg/m^3 during 2015-16 and 147.14±7.81µg/m^3 during 2016-17 and the PM_{10} concentration was high at Traffic intersection area which shows the difference in graphical representation.

Comparative trend & statistical analysis of SPM concentration at residential, traffic intersection and industrial area during 2015-17 is shown in figure 4 & table 5.

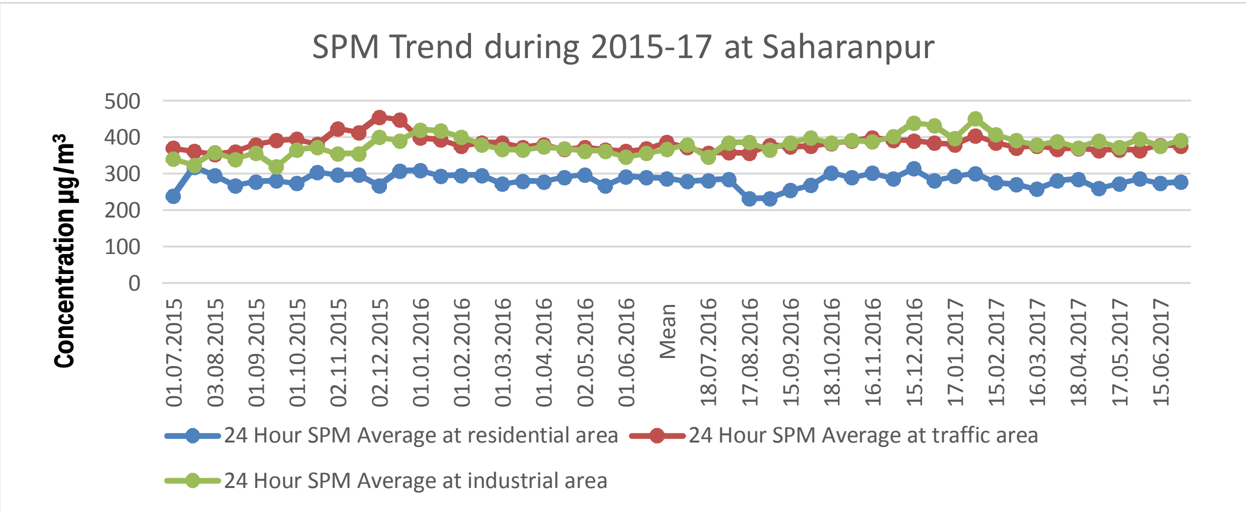


Figure 4: SPM trend analysis at all locations during in 2015-17

Table 5: Statistical analysis of SPM at all locations during 2015-17

YEAR 2015-16	24 Hour SPM Average (μg/m^3) at Residential area	24 Hour SPM Average (μg/m^3) at Traffic area	24 Hour SPM Average (μg/m^3) at Industrial area
Minimum	239.49	353.67	319.61
Maximum	318.51	456.03	366.95
Mean	287.20	386.32	366.95
SD	17.44	26.47	25.61
ANOVA	2.47		
p-value	<0.05*		
Year 2016-17			
Minimum	231.35	356.42	345.62
Maximum	314.50	405.41	451.24
Mean	277.77	376.96	392.27
SD	20.29	13.06	23.17
ANOVA	3.28		
p-value	<0.05*		
24 hrs. NAAQS value	*There is no 24 hrs. NAAQS standard value for SPM		

*: statistically significant

The 24 hour SPM Mean & SD was estimated as 287.20±17.44μg/m^3, 386.32±26.47μg/m^3 and 366.95±25.61μg/m^3 respectively and the analysis of variance was calculated as 2.47 with statistically significant difference as $p<0.05$ (2015-16). The 24 hour SPM Mean & SD was 277.77±20.29μg/m^3, 376.96±13.06μg/m^3 and 392.27±23.17μg/m^3 respectively at residential, traffic intersection and industrial area. The analysis of variance was calculated as 3.28 with statistically significant difference as $p<0.05$ (2016-17).The of SPM concentration was 346.82±23.17μg/m^3 during 2015-16 and 349±18.84μg/m^3 during 2016-17 and the SPM concentration was high at Traffic intersection area which shows the difference in graphical representation.

3.2: Correlation matrix between air pollutants during 2015-17

Table 6: Correlation between gaseous pollutants (SO_2 & NO_2) at all locations during 2015-17

Locations	Correlation between SO_2 & NO_2 r value and (p value)	
	(2015-16)	(2016-17)
Industrial area	0.63 (0.001*)	0.46 (0.02*)
Traffic area	0.61 (0.002*)	0.82 (<0.01*)
Residential area	0.46 (0.03*)	0.22 (0.31))

*: statistically significant

Strong positive correlation was found between SO_2 and NO_2 at industrial (0.63) and traffic intersection (0.61), and normal positive correlation at residential area in 2015-16 with statistical significant difference.

Strong positive correlation was found between SO_2 and NO_2 at traffic intersection area (0.82) and normal positive correlation at industrial area (0.46) in 2016-17 with statistical significant difference.

Table 7: Correlation between particulate parameter (PM_{10} & SPM) at all locations during 2015-17

Locations	Correlation between PM_{10} & SPM r value and (p value)	
	(2015-16)	(2016-17)
Industrial area	0.56 (0.005*)	0.39 (0.06)
Traffic area	0.81 (0.003*)	0.25 (0.001)
Residential area	0.22 (0.01*)	0.42 (0.04*)

*: statistically significant

Strong positive correlation was found between PM_{10} and SPM at industrial area (0.56) traffic intersection area (0.81) in 2015-16 with statistical significant difference. Normal positive correlation was found between PM_{10} and SPM at only residential area (0.42) in 2016-17 with statistical significant difference.

3.3 a: Regression analysis and inter-species dependencies between NO_2 and SO_2 at all locations during 2015-17

Dependencies of SO_2 on NO_2 were determined for all the sites. Two years data analysis revealed that maximum dependency was found at industrial area (r^2 = 0.40, $p<0.05$) followed by residential (r^2=0.36, $p<0.05$) as well as traffic intersection (r^2=0.17, $p<0.05$) exhibits weak dependency at all areas. The low value of the coefficient of determination (r^2) indicates that both are possibly from the different source, which is most likely to be fossil fuel combustion processes and motor vehicle exhaust as other sources are rare at these locations. Regressions equations calculated are as follows in Figures 5, 6 & 7.

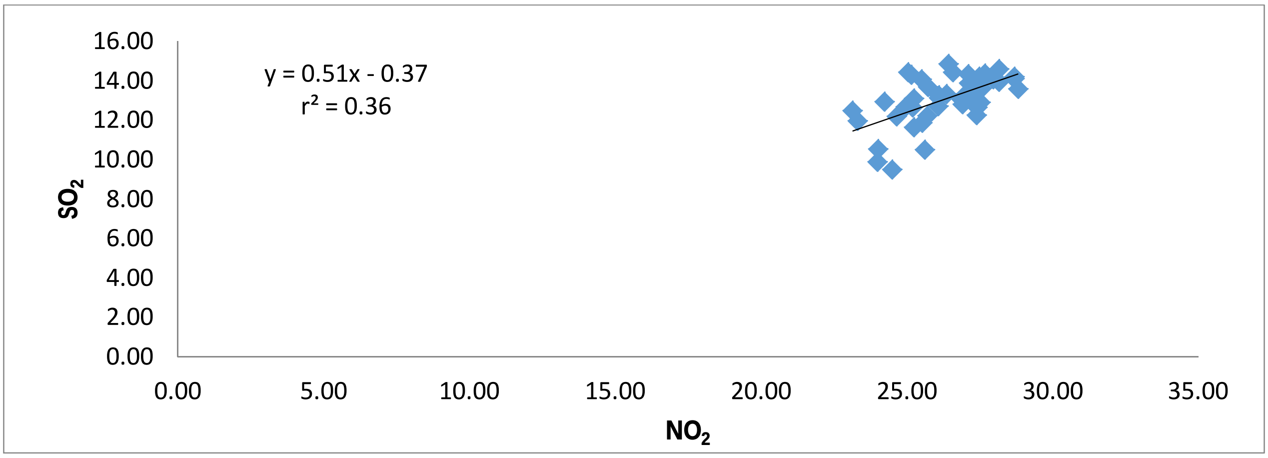


Figure 5: Regression between NO_2 & SO_2 at Residential area during 2015-17

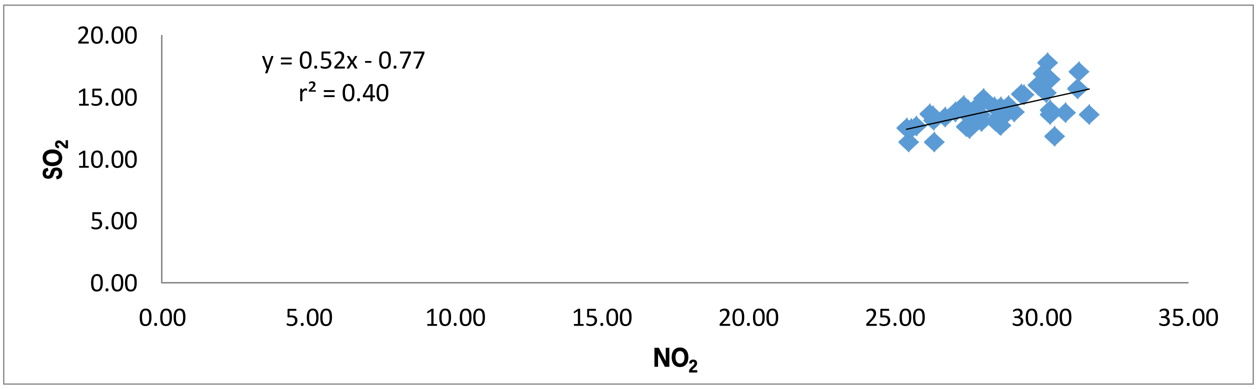


Figure 6: Regression between NO_2 & SO_2 at Industrial area during 2015-17

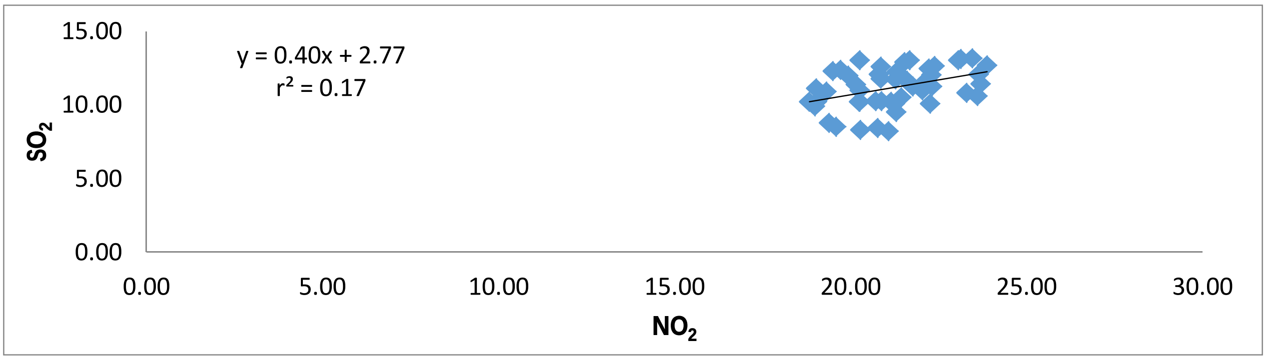


Figure 7: Regression between NO_2 & SO_2 at Traffic intersection area during 2015-17

3.3 b: Regression analysis & Inter-species dependencies between PM_{10} and SPM at all locations during 2015-17

Dependencies of SPM on PM_{10} were determined for all the sites. Two years data analysis revealed that maximum dependency was found at traffic intersection area (r^2 = 0.54, $p<0.05$). Therefore it can be said that SPM exhibits a moderate dependency on PM_{10} at traffic intersection area, Followed by industrial (r^2=0.16, $p<0.05$) as well as residential area (r^2=0.08, $p<0.05$) exhibits weak dependency on both areas. The low value of the coefficient of determination (r^2) indicates that both are possibly from the different source, PM_{10} has an industrial & vehicular source and SPM is most likely to suspended road dust, construction dust as other sources are rare at these locations. Regressions equations calculated are as follows in Figures 8, 9 & 10. PM_{10}.

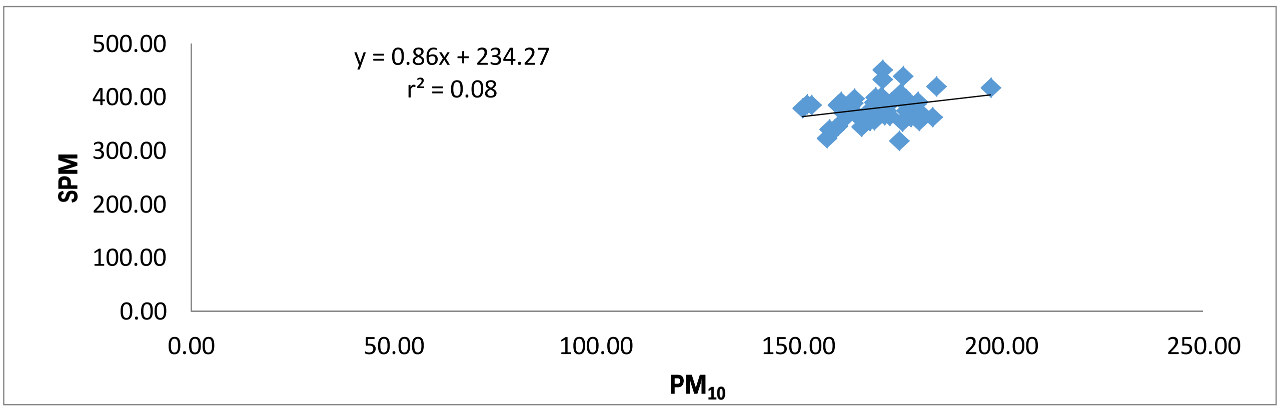


Figure 8: Regression between PM_{10} & SPM at Residential area during 2015-17

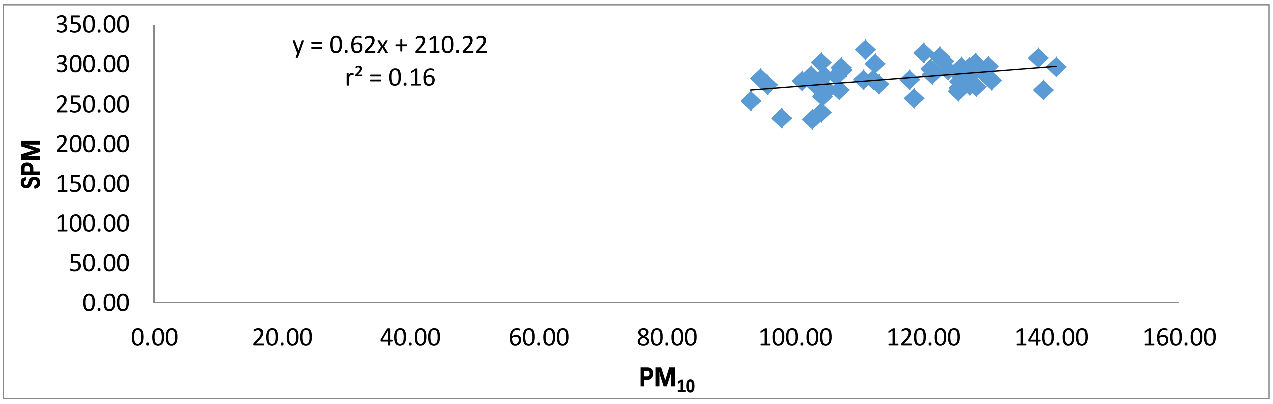


Figure 9: Regression between PM_{10} & SPM at Industrial area during 2015-17

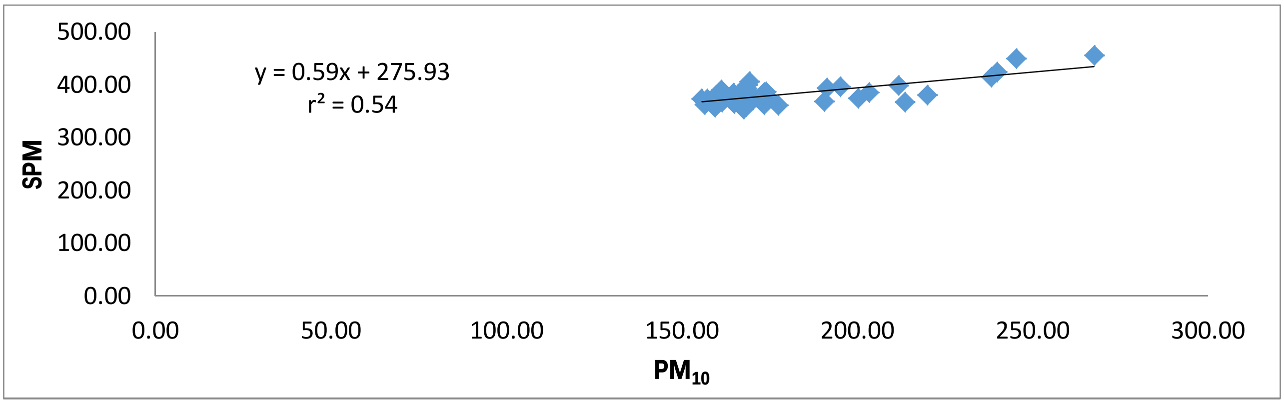


Figure 10: Regression between PM_{10} & SPM at Traffic intersection area during 2015-17

3.4 Effect of industrial & automotive emissions on Residential areas with respect to SO_2, NO_2, PM_{10} and SPM air Pollution.

According to census Govt. of India-2011, District industries centre (DIC) Saharanpur, Assistant regional transport office (ARTO) Saharanpur no. of industries of all scales in Saharanpur was 3261 during the year 2015-17. There was total no. of vehicles 419961 in Saharanpur during the year 2015 (ARTO, Saharanpur, U.P). The above mentioned data of industries & vehicles are evident of, all sources which create SO_2, NO_2, PM_{10}, SPM air pollution. Average concentration levels from July-2015 to June-2017 at residential area of Saharanpur (U.P) in respect of SO_2, NO_2, PM_{10} & SPM were found 11.16±1.27µg/m^3, 21.21±1.35µg/m^3, 116.65±9.98µg/m^3 & 282.48±18.86µg/m^3 respectively. Correlation between SO_2 and NO_2 as well as PM_{10} and SPM at residential area in Saharanpur was found statistically significant (r=0.46) in 2015-16 and statistically insignificant (r=0.22) in 2016-17 (calculated by using Pearson correlation test). The correlation between PM_{10} & SPM was statistically significant (0.22) in 2015-16 & (0.42) in 2016-17.

Further, average concentration levels of SO_2 & NO_2 at residential area are below the standard limit but PM_{10} level is high from standard limit during July-2015 to June-2017. There is no standard limit for SPM. The correlation between SO_2 and NO_2 was observed insignificant in 2016-17, whereas the correlation PM_{10} and SPM was significant of both years. The people living in residential areas or workplaces, schools and other places near high traffic roadways are at high health risk due to the elevated auto emissions. In USA, 53,000 deaths annually are due to automobile emission air pollution (Caiazzo et al,. 2013). 90 % of the cancer risk from air pollution in southern California is attributable to auto emissions (Hulsey et al,. 2004). Children are more sensitive to auto-emission health impacts due to their more breathing of air relative to their body weight than adults, more physically active and spend more times outdoors during the highest levels of pollutants. Women who live near areas of high automobile traffic during pregnancy have a 20 – 30% higher chance of having children with lung ailments. Curb side and in-traffic air contains high levels of all pollutants associated with auto emissions both particulate and gaseous pollutants.

3.5 Compliance level of national ambient air quality standard laid down for the PM_{10} by MoEF & CPCB in Saharanpur city.

The fine airborne particles have a high probability of deposition deeper into the respiratory tract and are likely to trigger or exacerbate respiratory diseases. These particles also have higher burdens of toxins like benzo(a)pyrene, lead & other metals etc., which when absorbed in the body can result in health consequences other than respiratory health effects also like cancer ,central nervous system damage. The total concentration of PM_{10} is a better indicator of health effects. It is the toxics /hazardous contents of suspended particulate matter or PM_{10} which represent the true picture of severity of health effects. PM_{10} particulate matter is readily inhalable and because of their small size, they are not filtered in the nasal path and penetrate deeply into the cardiovascular system where they cause damage. The annual average concentration of PM_{10} was slightly higher at all three locations during July-2015 to June-2017 than its NAAQS annual average limit. The number of industries in Saharanpur has increased tremendously from 2015-16 (1124) to 2016-17 (2137) by about 90% however, It seems that air pollution has increased marginally & increasing industries may be of non-polluting type (Ice, Saw, Weaving, Wooden, Agriculture equipment industries etc.). This is reflected from the concentration of gaseous pollutants was well below the NAAQS limits. The number of registered vehicles was 419961 in Saharanpur till 31 December 2015. The gaseous pollution has not increased but the particulate matter levels have increased at same level.

Table 8: Comparison of present study with levels of SO_2, NO_2 and PM_{10} in few Indian cities.

City	Year	Range of Annual Mean Conc. µg/m3			Reference
		SO2	NO2	PM10	
Delhi	2005-12	8.2 -12.5	27.6 - 62.0	134 - 253.7	Kishore et al 2019
Navi Mumbai	2014-16	18 - 20	40 - 47	119 - 152	Perli et al 2018
Kolkata	2010-11	5.4 - 8.2	43.1 - 70.7	73 - 113	Haque et al 2017
Chennai	2012	12.1 - 3.5	20.8 - 7.0	121.5 - 45.5	Guttikunda et al 2014
Lucknow	2013-15	8.4 - 1.0	2.6 - 30.1	60 - 200.4	Upadhyay et al 2017
Kanpur	2014	1.2 - 7.5	4.9 - 313	25.3 - 211.5	Guttikunda et al 2014
Moradabad	2010-12	10.7 - 19.8	18.8 - 30.5	45 - 290	Pal et al 2014
Agra	2002-13	4 - 11	17 - 38	133 - 306	Kumar et al 2016
New Tehri (Uttrakhand)	2010-11	4.0-8.0	5.0-10.0	15.0-32.0	Tyagi et al 2016
Saharanpur	2015-17	11.1 -13.9	21.2 - 28.3	116.6 -178.9	Present study 2019

4. Conclusion

The present study shows that particulate pollutants PM_{10} and SPM are mostly above permissible limits at all the sampling sites in Saharanpur during July-2015 to June-2017. Maximum SO_2, NO_2, PM_{10} and SPM concentration was reported (13.49µg/m^3, 27.41µg/m^3, 192.44µg/m^3, 386.32µg/m^3) respectively at traffic intersection area and minimum SO_2, NO_2, PM_{10} and SPM concentration was reported (10.65µg/m^3, 21.59µg/m^3, 124.25µg/m^3, 287.20µg/m^3) respectively at residential area during July-2015 to June-2016. During July-2016 to June-2017 maximum SO_2, NO_2 concentration was reported (14.44µg/m^3, 29.29µg/m^3) respectively at traffic intersection area & PM_{10} and SPM concentration was (166.85µg/m^3, 392.27µg/m^3) at industrial area and minimum SO_2, NO_2, PM_{10} and SPM concentration was reported (11.68µg/m^3, 20.84µg/m^3, 109.05µg/m^3, 277.77µg/m^3) respectively at residential area. The concentration of SO_2, NO_2 was lower than the annual NAAQS standard limit, however the concentration of PM_{10} exceed the annual NAAQS standard limit at all three sites PM_{10} concentration (124.25µg/m^3) at Residential area, (171.62µg/m^3) at industrial area and (192.44µg/m^3) at traffic intersection area. The concentrations of SO_2, NO_2, PM_{10} & SPM were found in decreasing order at area wise are as follows:

Traffic intersection area >Industrial area >Residential area. This implies that these particles are still produced by vehicles, industrial activities, and combustion of conventional fuels used for domestic and commercial purposes. The statistical analysis suggest that air pollution has increased marginally because of number of increasing industries though mostly are of non-polluting type (ice, saw, weaving, wooden, agriculture equipment industries etc.). Strong positive correlation was found between SO_2 & NO_2 (0.61-0.82) at Traffic intersection area and between PM_{10} & SPM (0.56-0.81) at all three sites during both years.

The Regression analysis between SO_2 & NO_2 exhibits a weak dependency of SO_2 on NO_2. Similarly the regression between PM_{10} and SPM at residential and industrial area exhibits weak dependency however it exhibits moderate dependency at traffic intersection area.

5. Acknowledgement

We are very thankful to Department of chemistry, Mewar University, Chittorgarh, competent authority of pollution control board UP for providing facilities to carry out these investigations.

6. References

1. Decker, E. H; Elliot, S; Smith, F. A; Blake, D. R. and Rowland, F. S; (2000). Energy and material flow through the urban environment. *Annu. Rev. Energy Environ.* 25:685–740.
2. Mayer, M; Wang, R; Webster, C. R. and Prinn, R. G; (2000). Linking local air pollution to global chemistryand climate. *J. Geophysics. Res.* 105:25-31.
3. Molina, M. J. and Molina, L. T; (2004). Mega cities and atmospheric pollution. *J .Air. Waste. Manage.* Assoc.54**:**644–680.
4. Kumar. K; Shukla, K.V; (2016).Trends analysis of ambient air pollution in Agra city-2002-2013, Indian Journal of air pollution control, Vol. xvi, No.2 & Vol. xvii, No.1.
5. Kapoor, C. S; Bamniya, B. R; Jain, S., & Kapoor, K; (2013). Status and Monitoring of Ambient Air Quality of City of Lakes 'Udaipur, (Raj.) India *Research in Health and Nutrition,* 1(1).
6. Naik, S; (2005). Studies on pollution status of Bondamunda area of Rourkela industrial complex (Doctoral dissertation).
7. Mahajan, S.P; (2009), Air Pollution Control, Common wealth of learning IISc,TERI press, New Delhi, page1
8. Ambasht, R.S; and Ambasht, P.K; (2006), Environment & Pollution, 4th edition, New Delhi, CBS Publishers & Distributors, page 162,
9. Barthwal, R.R; (2002), Environmental Impact Assessment, New Delhi, New Age International (P) Ltd. publishers, page 23
10. WHO/UNEP Report; (1992), Urban air pollution in mega-cities of the world. World Health Organisation and United Nations Environment Programme. Blackwell Publishers, 108 Cowley Road, Oxford OX4' 1JF Cambridge, UK.

11. Gupta Usha; valuation of urban air pollution (2008). A case study of Kanpur city in India. Environ resource. Economics, Vol.41 Issue 3, PP. 315-326.
12. Lima Ling L; Hughesb Susan J; Hella W. E. E; (2005). Integrated support system for urban quality assessment, Environmental modelling and software, Vol.20, PP. 947-954.
13. Goyal, P.S; (2003). Present scenario of air quality in Delhi: A case study of CNG Implementation. atmospheric environment, Vol. 37, PP. 5423-5431.
14. Central Pollution Control Board, Ministry of Environment & Fores; (2001). Chemical laboratory test method, I, C-1 to C-30.
15. Caiazzo, F; Ashok, A; Waitz, I.A; Yim, S.H.L; Barrett, S.R.H; (2013). Air the impact of major sectors in 2005, Laboratory for Aviation and the Environment, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, August 2013.
16. Hulsey, B; Hopkins, E; Olson, E; Burg, E; and Carlson, M; (2004). Highway Health Hazards: How highway and roads cause health problems in our communities and what you can do about it, Sierra Club, 2004, 6.
17. Kishore, N; Srivastava, K. A; Nandan, Hemwati; Pandey, C. P; Agrawal, S; Singh, N; Soni, K.V; Bisht, S.D; Tiwari, S; Srivastava, K; (2019).Long-term (2005–2012) measurements of near-surface air pollutants at an urban location in the Indo-Gangetic Basin *J. Earth Syst. Sci.* 128:55, 12040-019-1070-4 Indian Academy of Sciences.
18. Perli, B; Chary Guntupalli, C.V.H; Rama Gopal, N; (2018). Ambient Air Quality Assessment in Major Petrochemical Industrial Hubs of India IOSR Journal of Engineering (IOSRJEN) ISSN (e): 2250-3021, ISSN (p): 2278-8719 Vol. 08, Issue 4 (April. 2018), VI PP 36-47.
19. Haque, S.M; and Singh, R.B; (2017). Air Pollution and Human Health in Kolkata, India: A Case Study Climate 2017, 5, 77;
20. Guttikunda, K. S; Goel, R; Mohan, D; Tiwari, G; Gadepalli, R; (2014). Particulate and gaseous emissions in two coastal cities—Chennai and Vishakhapatnam, India Air Qual Atmos Health DOI 11869-014-0303-6.
21. Upadhyay, E; Nayak, M; Biswas, J; (2017). Air Quality Status of Lucknow City–A Case Study International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 ICBA – 2016 Conference Proceedings.
22. Guttikunda, K. S.; Goel, R; Pant, P; (2014). Nature of pollution, emission sources, and management in the Indian cities, Atmospheric Environment 95, 501-510.
23. Pal, R., Mahima; Gupta, A; Tripathi, A; (2014). Ambient Air Quality monitoring and management in Moradabad, International Journal Sustainable water and Environmental systems,Vol.6, NO.2,PP.53-59.
24. Tyagi, S.K.; Upadhyay, V.K.; Kulshreshtha, D.; Kumar, S.; Krishnamurthy, P. and Sen, A.K. (2016). Study of Background Ambient Air Quality in Northern Himalayan Regions: Uttrakhand and Himachal Pradesh, India, Indian Journal of Air Pollution Control, Vol XVI, No. 1:1-9.

Analysis of "Odd-Even" Initiative on Air Pollution and Assessment of its Co-Benefits: A Case Study of Delhi

Rohit Sharma[a*], Kamna Sachdeva[b], Anu Rani Sharma[c]

[a,b] Department of Energy and Environment, *TERI School of Advanced Studies (earlier TERI University), Delhi, 10, Institutional Area, Vasant Kunj, New Delhi 110 070, India,*
[c]*Department of Natural Resources, TERI School of Advanced Studies (earlier TERI University), Delhi, 10 Institutional Area, Vasant Kunj, New Delhi 110 070, India.*
**(email:rohitsharma.teri@gmail.com)*

Abstract

Air pollution is recognized as an important health problem affecting millions of lives around the globe. Numerous studies have reported the adverse effects of increasing air pollution on the environment and human health. Delhi has been regarded as one of the most polluted cities of the world and is plagued by the challenges associated with air pollution. The ever-increasing dependence on private modes of transportation has led to a drastic increase in the number of registered vehicles plying on the roads of the city. As a result of this, vehicular pollution has emerged as an important air pollutant in the city and numerous measures are being taken to address this challenge. The "odd-even car rationing scheme" is also an emergency step taken by the Delhi's government to tackle the high levels of air pollution in the city by restricting the movement private vehicles on the basis of their license plates. The initiative has been regarded as the first step taken towards targeting the travel behavior of the commuters of the city. The present study aims to assess the impacts of the first phase of implementation of the odd-even scheme (i.e. 15th December 2015 to 30th January 2016) on the air quality of the city and also understand the opinions of an informed group of individuals regarding the relevance and adoptability of the scheme. The results of the analysis revealed that the driving restriction could not bring about the intended decline in the levels of air pollution which could be attributed to the stable meteorological conditions and low wind speed in the city during the phase of implementation. However, a tremendous decline in the levels of congestion and travel time has been reported by the commuters of the city. Moreover, it was also observed that the scheme was able to increase the levels of mass awareness about the transportation and air pollution challenges being faced by the city and hence could be considered as an important step towards sensitizing the residents of the city regarding the need of the hour.

Key words: Odd-Even policy, air pollution, congestion, perception

1.Introduction

Delhi, the capital city of one of the most rapidly emerging economies of the world has been experiencing rapid urbanization as well as economic development over the past two decades. The city housing a population of 16.78 million in the year 2017 is regarded as one of the most largely populated megacities of the world (GoI, 2017). Delhi has also been ranked as the second most populated urban agglomeration in India. Being the capital, Delhi is the socio-economic hub of India providing immense job opportunities and modern lifestyle to its inhabitants, thus attracting a large number of migrants from other parts of the country. Over the last decade, the city has seen tremendous increase in its population and level of urbanization which has in turn led to a simultaneous increase in the transportation demands. Even though the city offers world class public transportation facilities like Delhi Metro, yet the number of private vehicles plying on the roads has been constantly increasing. Delhi had approximately 8.8 million registered vehicles in the year 2014-15 (GoI, 2015; Aggarwal and Jain, 2014). It has been estimated that around 1,400 new cars are added on the Delhi roads every day (Miller, 2013). As a matter of concern, Delhi has witnessed a significant increase in traffic volume on the roads which has led to high congestion levels, road rage, accidents, and environmental pollution, thus emphasizing on the inefficiency of its transport system (Katiyar et., al 2016; Aggarwal and Jain, 2015). The ever increasing reliance on private modes of transportation has been long regarded as one of the most significant reasons for the deteriorating air quality of the city. A study conducted by the Central Pollution Control Board (CPCB) of India and the Ministry of Environment and Forests (MoEF) in 2010 revealed that vehicular exhaust is the most prominent source of particulate matter (PM_{10} and $PM_{2.5}$) pollution in Delhi (CPCB, 2010). Vehicular emissions exhibit small scale dispersion and get accumulated in confined areas leading to accumulation of air pollutants as well as degradation of the air quality of the region (Kumar et al., 2015; Sharma et al., 2013). Considering the fact that vehicular emissions remain localized in the atmosphere have been reported to produce negative impacts on human health. Numerous studies have reported that nanoparticles (Kumar et. al. 2011) and other pollutants (suspended particulate matter, SPM; Sulphur dioxide, SO_2; and nitrogen dioxide, NO_2) (Gurjar et al., 2010) released from vehicles are a cause of 11,250 and 10,500 excess deaths in Delhi every year, respectively. The current scenario of the capital, thus, presents a dire need to take voluntary actions to improve the air quality of the city. Even though numerous policy measures have been undertaken in past to address the increasing air pollution problems attributable to vehicle fleet in Delhi, yet we have not been able to achieve the desired targets.

In view of the deteriorating air quality of the city, the Delhi government initiated a bold step and introduced one of the most predominantly adopted transport demand management strategy across the world, i.e., driving restrictions based on license plate numbers. The "Odd-Even rationing scheme" was an emergency action undertaken by the Government of Delhi to arrest the high emergency peak wherein a 5 to 6 times increase in the pollution levels has been witnessed in the capital of the country. The scheme was active for the first 15 days of January 2016, which applied restriction on the movement of private cars depending upon their registration numbers. The scheme was initiated as an experiment during its first phase of implementation in order to evaluate the possibility of its re-implementation. The intervention came out as a surprise for the commuters of the city which led to a mixed response towards the intervention. The present study aims to assess the impact of the first phase of the "odd-even policy" (i.e. 15th December 2015 to 30th January 2016) on the air quality of the city and also analyze the opinion of an informed group of individuals, i.e., individuals who are aware about the issue of air pollution and are working in the field of environment management regarding the initiative. The study follows a holistic approach to assess the benefits and co-benefits of the rationing scheme, which includes interpretation of the variations in the concentration of two major air pollutants, i.e., $PM_{2.5}$ and tropospheric ozone along with the wind speed in the city for the 'pre', 'during' and 'post' time intervals.

2. Methodology

The present study adopted a two-step methodology to evaluate the impact of the first phase of "odd-even car rationing scheme" implemented in Delhi. The study is a preliminary analysis to evaluate the impact of the 'odd-even car rationing scheme" by assessing the trend of the variation in the air pollutants and meteorological parameter within the study during the implementation phase of the scheme. It was primarily done to understand whether the scheme produced any evident change in the level of air pollution of the city.

The second part of the study focused on assessing the perception of an 'aware' and 'environmentally conscious' group of individuals regarding the relevance of the implementation of this scheme. It is envisaged that a control group perception about the "odd-even" scheme can present a fair idea about the potential and importance of this strategy to address the transportation and air pollution challenges of the capital city of India.

Figure 1 represents the overall research framework of the study describing the two key approaches, i.e., air quality analysis and controlled group perception analysis. The following section of the paper presents a detailed description of the methodological steps adopted to conduct the present study.

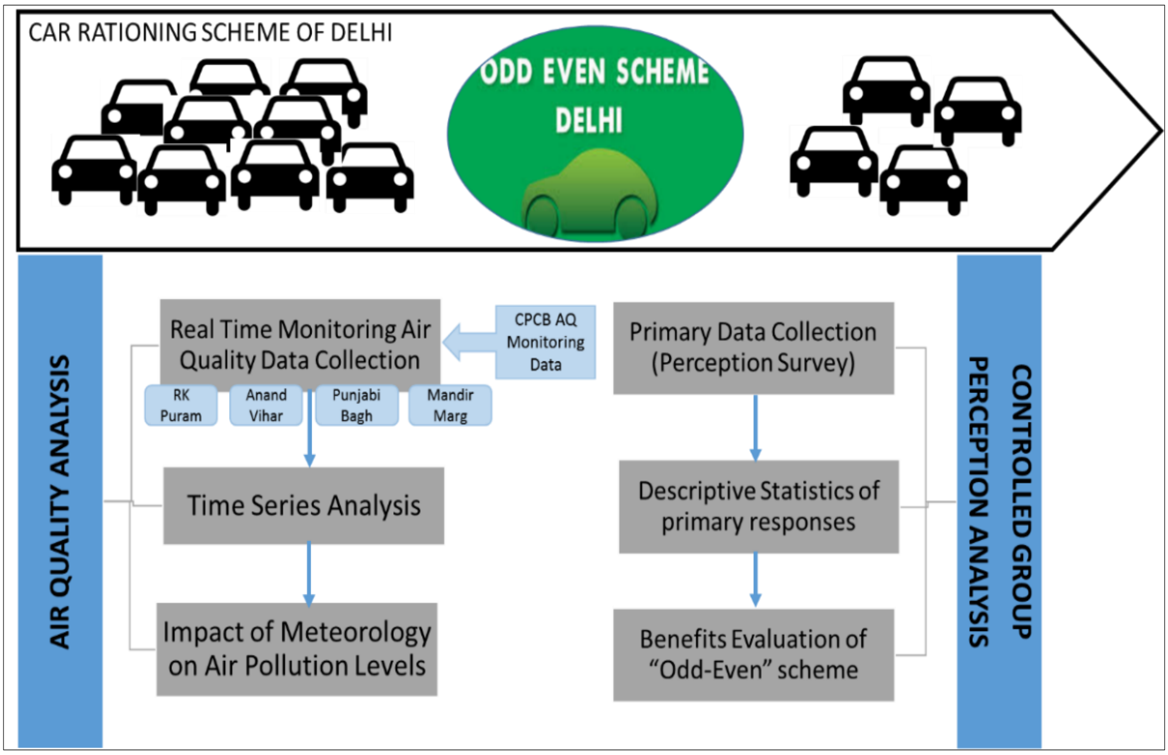


Figure 1: Research framework

2.1. Data Collection & Analysis

2.1.1. Air Quality Data

Real time air quality data was acquired from monitoring stations maintained by the Central Pollution Control Board (CPCB). Four monitoring stations, viz., R. K. Puram (RKP), Punjabi Bagh (PB), Anand Vihar (AV) and Mandir Marg (MM) were selected and real time data was downloaded for the period 15th December 2015 to 30th January 2016. The period was selected such that it would provide a fair idea about the changes in air quality in the city, if any, by the implementation of the scheme. The study assessed the hourly variation of two air pollutants $PM_{2.5}$ and tropospheric ozone (O_3) during the implementation phase of the intervention. Wind speed (WS) which is known to produce determining influence on the air quality of an area was also collected (hourly data) during the period of analysis.

2.1.2. Perception Survey: Face-to-face Interactions

The present study primarily focused on assessing the perception of an informed group of individuals, i.e., individuals who are environmentally conscious and are well aware about the mounting challenges of air pollution in Delhi city. A random perception survey regarding the relevance of the odd-even policy was conducted with the research scholars, PG students and administrative staff of TERI School of Advanced Studies between 1st January, 2016 and 15th January, 2016. TERI SAS is a leading research institute in India working in the area of environment management and research. The A total of 100 individuals were randomly approached to understand their point of views in order to develop an understanding about the acceptability of the scheme among a control group of individuals. Primary survey was conducted using an open-ended questionnaire as the primary tool to collect information related to the travel patterns and travel experiences of the respondents during the implementation phase of the scheme. Preliminary screening of the responses resulted in the incorporation of 72 (15 administrative staff; 12 housekeeping staff; 20 research scholars and 25 PG students) complete and valid responses that were included in the analysis.

2.2. Data Analysis

2.2.1. Air Quality Analysis

Real time air quality data was used for analyzing temporal variations in the concentration of $PM_{2.5}$ and tropospheric ozone (O_3). Time series analysis was conducted for three time intervals- before (15th December 2015-31st December 2015), during (1st January, 2016 -15th January, 2016), and after (16th January 2016 – 31st January, 2016) 'odd-even' implementation phase to assess if there had been a change in the concentration of the pollutants due to the implementation of the odd-even policy in Delhi. It is important to point out that due to the unavailability of data for ozone from 15th December 2015 to 21st December 2015, the pollutant concentrations have been reported from 22nd December 2015. The variation in concentration of the specified pollutants was also related with other influential parameters like wind speed and NO_2 in order to estimate whether meteorology had played an influence on the air quality of the city during the implementation phase of odd-even policy. Time series analysis was carried out to understand the daily average variation in concentration of $PM_{2.5}$ and O_3 during the study period i.e. between 15th December 2015 and 30th January 2016. The concentration of these pollutants was averaged out for the four stations considered in the analysis. However, while averaging the emissions, due consideration was given to minimize any loss of information/data.

2.2.2. Perception Analysis

The primary data collected through controlled group survey was subjected to descriptive statistics in order to draw meaningful inferences from the information gathered. Statistical graphics like pie charts and bar charts have been used to present the data regarding travel time reductions, relevance of the policy and willingness to participate in future. Considering the fact that this is a preliminary study for assessing the perspective of Delhi residents regarding the odd-even initiative, the study has been restricted to employ descriptive statistics only.

3. Results and Discussion

3.1. Temporal Analysis of air pollutants

The results of the air quality analysis have been presented in terms of temporal variations observed in the pollutant concentrations in the pre, during and post implementation phase of the odd-even scheme for all the monitoring stations included in the study. The daily mean concentrations of $PM_{2.5}$ from 16th December 2015 to 31st January 2016 as divided in the pre, during and post implementation phase of the odd-even scheme for four monitoring stations of Delhi, R.K. Puram (RKP), Punjabi Bagh (PB), Mandir Marg (MM) and Anand Vihar (AV) are presented in figure 2a, 2b, 2c and 2d, respectively. The results revealed that there had not been a significant decline in the pollutant concentrations during the implementation phase of the scheme, however a clear demarcation was observed between the first and the second week of implementation. It can be postulated that the scheme had started showing slight decline in the second week of its implementation at all the four monitoring station. However, considering the fact that the scheme targeted only the private cars, which account for only 10% of the modal share in Delhi (Sharma and Diskshit, 2016), thus making it difficult to conclude whether the variations in the levels of air pollutants during the second week of implementation phase of the scheme could be attributed to the restriction imposed on the movement of private cars. Thus, in order to understand the variations, the variations in the concentration levels were related to the wind speed (WS) reported at all the monitoring stations as presented in figure 2. The results of the analysis clearly depicted that the variations in $PM_{2.5}$ concentrations could be more precisely linked to the meteorological conditions of the city during the implementation phase of the scheme.

It can be clearly interpreted from the above figure that the concentration of $PM_{2.5}$ depicted a clear trend with the variation in the WS. The concentration levels witnessed a decline when the wind speed was high and vice-versa.

Of late, tropospheric ozone has been regarded as one of the prominent anthropogenic pollutant which has negative implications on not only the environment but also human health (Karthik L et al., 2017). A few of the studies have also reported that this pollutant has an indirect interaction with vehicle pass (Monks et al., 2015; Cooper et al., 2014) mediated through its chemistry with carbon linked compounds and oxides of nitrogen (NO_x). It has been postulated that with an increase in vehicle pass, the levels of tropospheric ozone in the atmosphere also witnesses an increase. In order to understand this trend, the present study also made an attempt to understand the variation in the levels of O_3 at all the four monitoring stations during the study period as presented in figure 3 (a), (b), (c) and (d). The trend clearly depicted a slight decline in the levels of ozone during the implementation phase of the scheme which could be attributed to the slight decline in the number of vehicles plying on roads of the city. A relatively higher dip in the concentration levels of the pollutants was observed in the second week of the implementation and leading to a prolonged effect in the 'post' implementation phase as well. Even though a declining trend in ozone levels was observed during the implementation phase, yet it is very difficult to confirm that this scheme can yield long term air quality benefits in the city. However, it can be concluded that even though the odd-even scheme could not bring the desired change in the air quality of the city, yet it was the first initiative undertaken by Delhi government which involved extensive mass involvement and produced immense awareness regarding the concerns of air pollution in the city.

3.2. Perception of control group of Individuals on Odd-Even Policy

The following section of the paper highlights the results of the perception survey conducted at TERI-SAS during the odd-even implementation phase in order to understand the opinion about the initiative of a control group of individuals, i.e., who work closely for environment and sustainability. Table 1 presents the description of the respondents consulted in the study.

Table 1: General Characteristics of Respondents at TERI-SAS

S.No.	Respondent Category	Number of Respondents	Age (Average)	Average Travel Time Reduction (in minutes)
1	Research Scholars	20	29	10
2	Administrative Staff	15	42	14
3	PG Students	25	24	20
4	Housekeeping Staff	12	25	NA

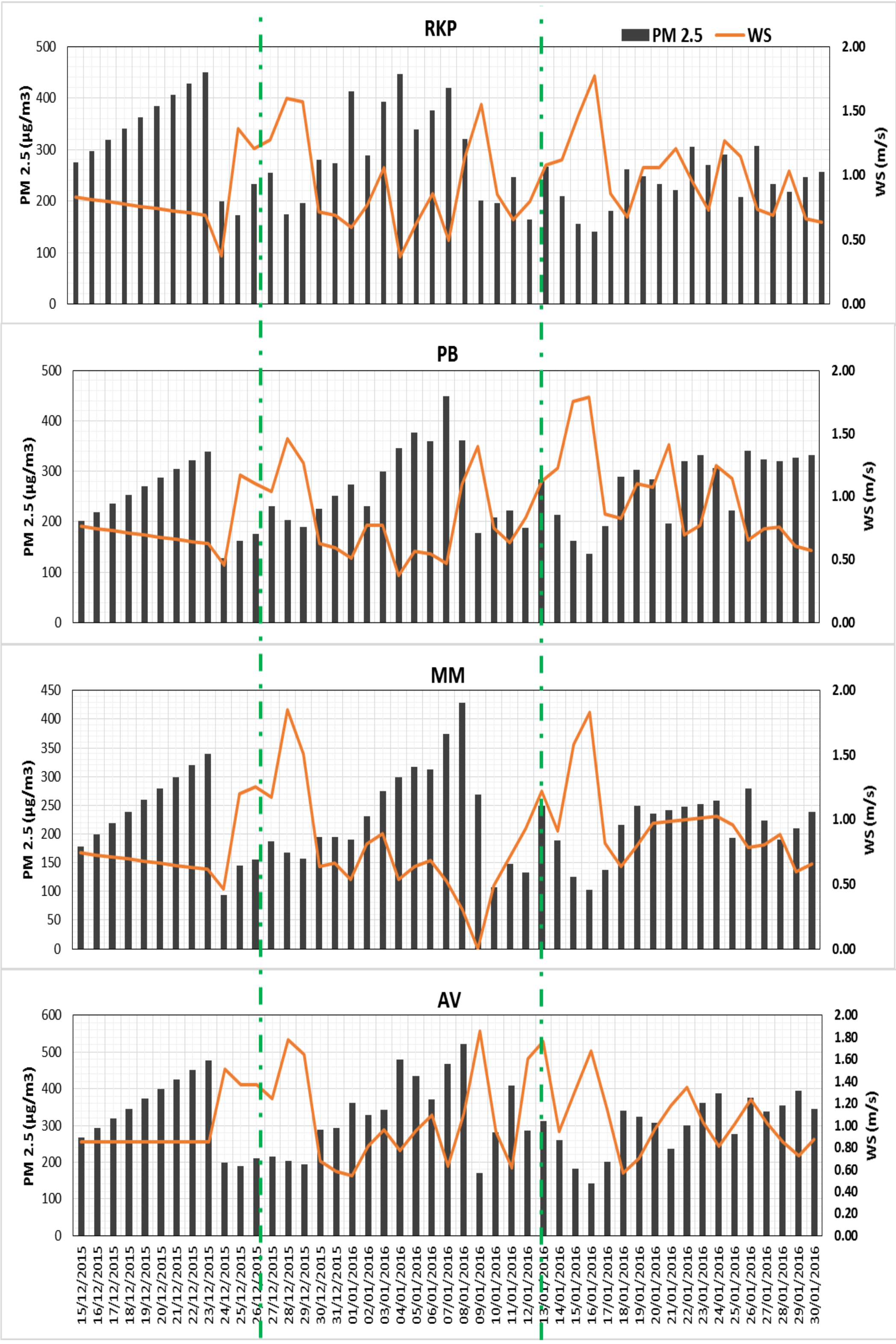


Figure 2 (a), (b), (c) and (d): Time series variation of $PM_{2.5}$ and WS at RK Puram, Punjabi Bagh, Mandir Marg and Ananad Vihar

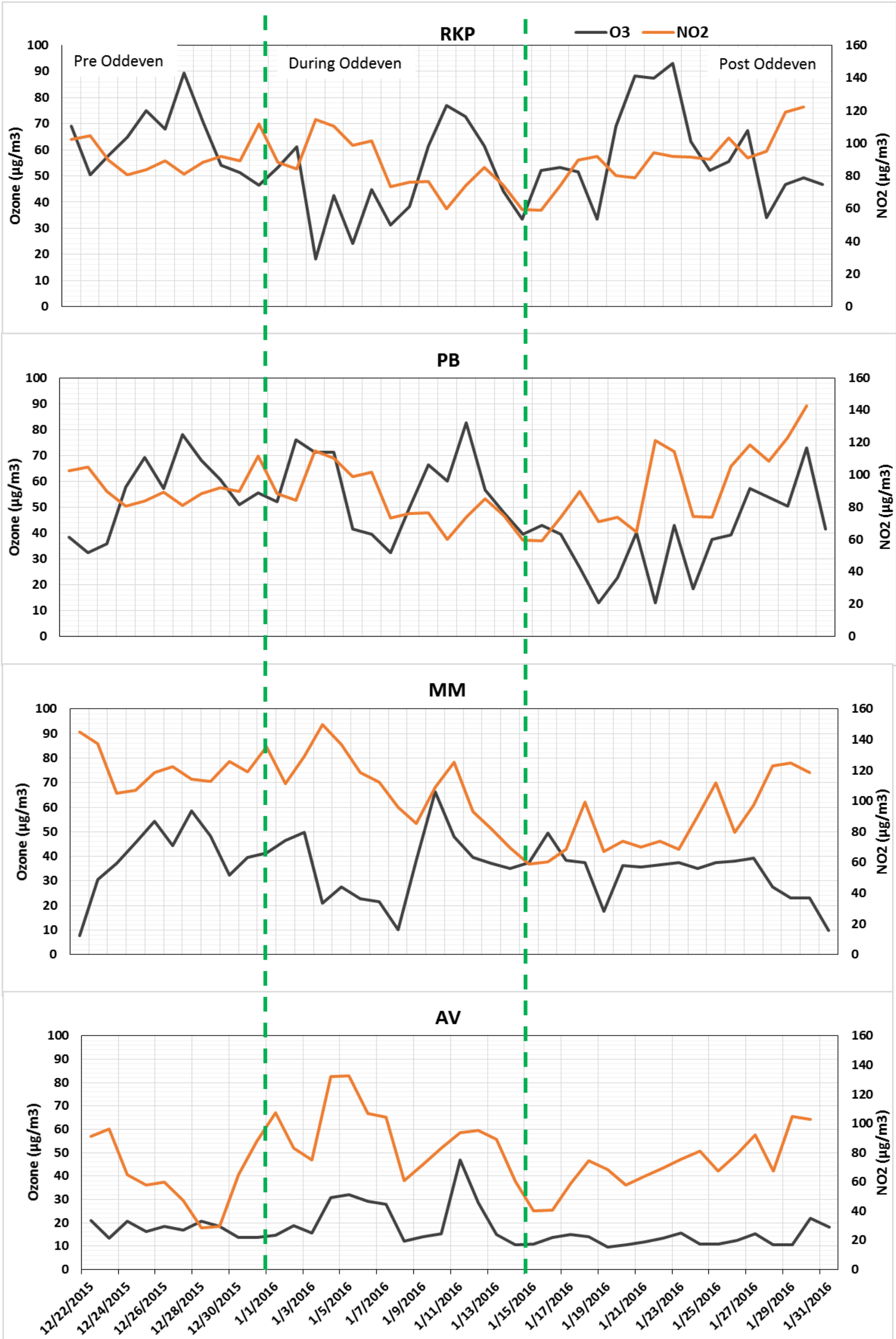


Figure 3 (a), (b), (c) and (d): Time series variation of O_3 and NO_2 at RK Puram, Punjabi Bagh, Mandir Marg and Anand Vihar

In order to quantify the reduction in travel time, the respondents were asked to report their travel mode choice for daily travel (figure 4). The results of the analysis revealed that all the vehicle users (4-W and 2-W) reported a decline in travel time and an average decline of ~15 minutes was reported by the respondents.

The results of the perception survey revealed that all the respondents reported a decline in the congestion levels and travel time during the implementation phase of the odd-even scheme. The respondents also highlighted that they had witnessed a decline in the congestion levels on the roads of the city during the implementation phase of the scheme.

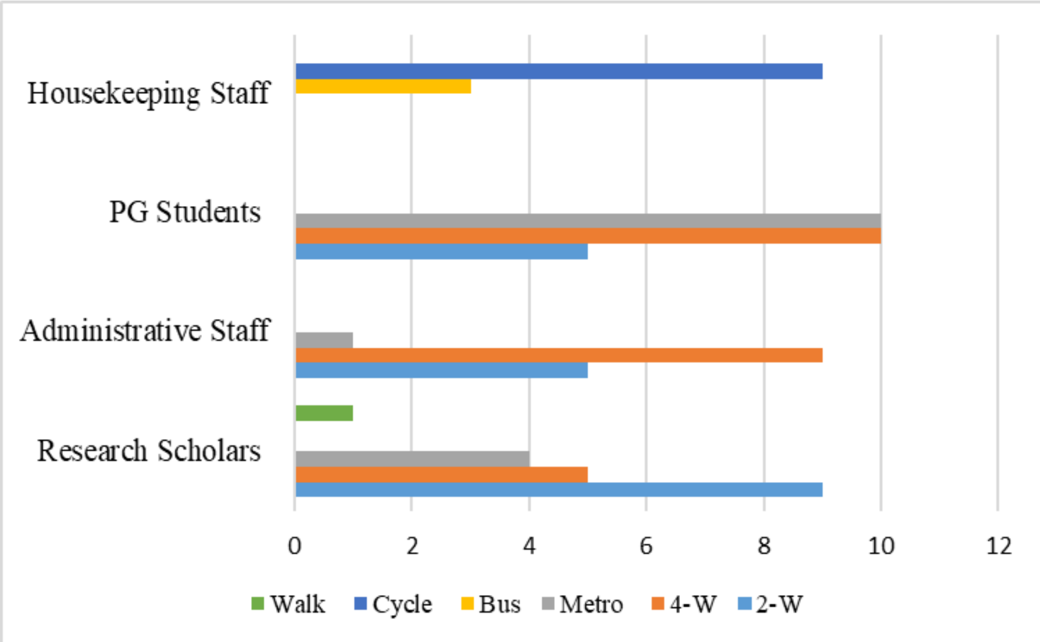


Figure 4: Travel Mode choices of respondents

In order to understand how the aware section of the society perceives about the importance of the scheme, the respondents were asked to rate the importance of the scheme on a five point Likert scale. The results of the analysis highlighted that ~64% of the respondents felt that it is an important step for the city and ~71% of the respondents were willing to participate if an initiative like this is implemented in future (Figure 5). They emphasized that even though the policy might not reduce the levels of air pollution in the city, but it has the potential to generate mass awareness and sensitize the residents of the city about the ever increasing transportation and environmental challenges.

Majority of the respondents reported that (specifically research scholars) that an initiative like 'odd-even' can be considered as a short-term option as it is difficult to yield long term-benefits in terms of reduction in air pollution. They pointed out that considering the fact that this policy directly impacts the private vehicle owners, i.e., economically stable section of the society who can afford the luxury of a car less likely to change their travel behaviour. Moreover, availability of good alternative taxi services like Ola and Uber have anyhow increased the dependency of a large section of middle class population on 4-wheelers, thus, defeating the overall attempt of the policy. In addition to this, it was also highlighted that there are a large number of sources of pollution that are prevalent in Delhi city, thus, targeting one of the smallest section, i.e., 4-W of the transport sector is not expected to produce far reaching benefits in terms of improvements in air quality.

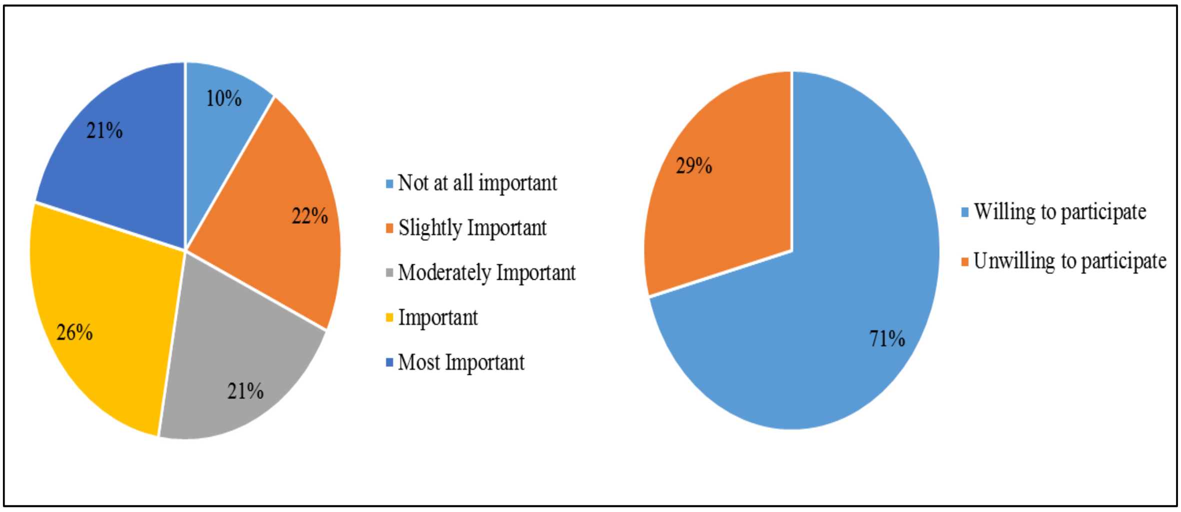


Figure 5: Importance and willingness to participate in the "Odd-Even" Initiative

4. Conclusion

The 'odd-even' rationing scheme adopted in Delhi is not the first of its kind. Various cities like Paris, Mexico, Bogota, Beijing, etc. have applied similar kind of rationing in recent years. The success of the scheme is, however, subject to various social as well as meteorological parameters. In Paris, for instance, the scheme was successful in reducing air pollution in the city to the desired level. In Beijing also, the scheme was a clear success with the implementation of a permanent ban on 20% of the vehicles on a weekday. However, with a huge population and insufficient availability of public transport, the rationing scheme in Delhi could not achieve its desired target even in terms of reduction in air pollution. On the other hand, the scheme cannot be regarded to have failed completely since the level of awareness that has been generated is non-negotiable. The willingness of people to participate clearly shows that the citizens of Delhi are now more aware of the predicament of the air quality in the city and the harmful effects it has on human life, flora and fauna. Another major factor for inability to effectively determine the reduction in GHG emissions due to fuel saved by decreased congestion on road during the implementation period is the non-availability of emission factors specifically for Indian conditions. Another limitation is the availability of real time air quality data. Even though monitoring stations have been set up at different locations across the city, fuzziness, manipulation, and missing values were observed in data. These limitations, if overcome, can improve the credibility of analysis and help the policy makers to frame better policies for the city.

Whilst, the 'odd-even' rationing scheme is an effort towards improving the air quality in the city, it still remains as the first foot forward towards tackling this national problem. The fact that air quality of a region is dynamic in nature cannot be negated, in the sense that pollution from neighboring cities also contributes to degradation of air quality. The need of the hour is to drive our efforts and policies towards the source of pollution. It is high time that we realize that burning of fossil fuel or coal for production of energy poses a huge threat to the society.

5. References

1. Aggarwal, P., Jain, S., 2015. Impact of air pollutants from surface transport sources on human health: a modelling and epidemiological approach. Environ. Int. 83, 146–157.
2. Cooper, O.R., Parrish, D.D., Ziemke, J., Balashov, N. V., Cupeiro, M., Galbally, I.E., Gilge, S., Horowitz, L., Jensen, N.R., Lamarque, J.-F., Naik, V., Oltmans, S.J., Schwab, J.,
3. CPCB, 2010. Central Pollution Control Board, Air Quality Monitoring, Emission Inventory and Source Apportionment Study for Indian Cities, National Summary Report. The Central Pollution Control Board, New Delhi, India.

4. CPCB, 2016, Real time air quality data. Available at: http://www.cpcb.gov.in/CAAQM/mapPage/frmdelhi.aspx?stateID=6
5. GNCTD, 2016. Total vehicles registered. The Transport Department of Govt. of NCT of Delhi.
6. GoI 2017, Delhi Statistical Handbook 2017, Directorate of Economics & Statistics <http://des.delhigovt.nic.in/wps/wcm/connect/doit_des/DES/Our+Services/Statistical+Hand+Book/>
7. Gurjar, B.R., Jain, A., Sharma, A., Agarwal, A., Gupta, P., Nagpure, A.S. and Lelieveld, J., 2010. Human health risks in megacities due to air pollution. Atmospheric Environment, 44(36), 4606-4613.
8. Jain, S., Aggarwal, P., Kumar, P., Singhal, S., Sharma, P., 2014. Identifying public preferences using multi-criteria decision making for assessing the shift of urban commuters from private to public transport: a case study of Delhi. Transp. Res. Part F 24, 60–70.
9. Karthik L, B., Sujith, B., Rizwan A, S., Sehgal, M., 2017. Characteristics of the Ozone Pollution and its Health Effects in India. Int. J. Med. Public Heal. 7, 56–60. doi:10.5530/ijmedph.2017.1.10
10. Katiyar, A., Singh, S.K., Haritash., A.K., 2016. Effect of Odd even schemes to combat air pollution in NCT of Delhi. International Journal of Advanced Research, 5(2), 1215-1222. doi:10.21474/IJAR01/3274
11. Kumar, P., Gurjar, B.R., Nagpure, A.S. and Harrison, R.M., 2011. Preliminary estimates of nanoparticle number emissions from road vehicles in megacity Delhi and associated health impacts. Environmental Science & Technology, 45(13), 5514-5521.
12. Kumar, P., Jain, S., Gurjar, B.R., Sharma, P., Khare, M., Morawska, L., Britter, R., 2015. New directions: can a “Blue Sky” return to Indian megacities? Atmos. Environ. 71, 198–201.
13. Miller D.J., Infrastructure 2013, Global Priorities, Global Insights, ULI and E&Y, 2013
14. Monks, P.S., Archibald, A.T., Colette, A., Cooper, O., Coyle, M., Derwent, R., Fowler, D., Granier, C., Law, K.S., Mills, G.E., Stevenson, D.S., Tarasova, O., Thouret, V., Von Schneidemesser, E., Sommariva, R., Wild, O., Williams, M.L., 2015. Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer. Atmos. Chem. Phys. 15, 8889–8973. doi:10.5194/acp-15-8889-2015
15. Sharma, M., Dikshit, O., 2016. Comprehensive study on air pollution and greenhouse gases (GHGs) in Delhi. GoI.Sharma, P., Sharma, P., Jain, S., Kumar, P., 2013. Response to discussion on: “an integrated statistical approach for evaluating the exceedance of criteria pollutants in the ambient air of megacity Delhi”. Atmos. Environ. 71, 413–414.
16. Shindell, D.T., Thompson, A.M., Thouret, V., Wang, Y., Zbinden, R.M., 2014. Global distribution and trends of tropospheric ozone: An observation-based review. Elem. Sci. Anthr. 2, 000029. doi: 10.12952/journal.elementa.000029

Air Pollution Tolerance Index of Selected Plants Growing Around IOCL Mathura Oil Refinery India

Anamika Shammi*, Mamta Ghunasham, A. K. Haritash

Department of Environmental Engineering,
Delhi Technological University, Shahbad Daulatpur, Delhi (110042) India
(E-mail:anamikashammi@gmail.com)

Abstract

Air pollution has become a serious threat in urban areas around the globe. Besides its effects on health, it adversely affects the materials and property. The present study was undertaken to evaluate the air pollution tolerance of vegetation around IOCL Mathura oil refinery and its suitability towards green belt development around the industrial zone. Some naturally growing plant species (*Azadirectha indica*, *Dalbergia sissoo*, *Ficus religiosa*, and *Calotropis procera*) were selected for determination of air pollution tolerance index in upwind and downwind region. Based on calculated values of APTI, there was insignificant difference for the values of APTI, nevertheless, the downwind samples exhibited higher levels of APTI as a result of exposure to pollutants from the refinery. The study concluded that *A. indica*, *F. religiosa*, *D. sissoo*, and *C. procera* are potential tolerant species for effective greenbelt development and management of air quality around Mathura oil refinery.

Keywords: Air Pollution Tolerance Index (APTI), Mathura oil refinery, Green belt

1. Introduction

Air pollution refers to anthropogenic introduction of harmful substances into the atmosphere that cause harm or discomfort to humans or other living organisms or damage the environment. It is one of the major problems arising due to industrialization, unplanned urbanization, alarming increase in vehicular fleet, and population growth. The problem posed by vehicles is due to the emission of CO, Pb, SOx, NOx PM etc, and motor vehicles account for 60-70 percent of the pollution in urban environment (Dwivedi *et al*. 2008; Macêdo *et al.*, 2020). Apart from effects on human health, air pollution can directly affect plants *via* leaves or indirectly *via* soil acidification. When exposed to airborne pollutants, most plants experience physiological changes before exhibiting visible damage to leaves (Liu and Ding, 2008). The atmospheric SO_2 adversely affects various morphological and physiological characteristics of plants. In urban environments, plants provide significant leaf area for impingement, absorption, and accumulation of air pollutants to reduce the pollutant (Liu and Ding, 2008). Although, a large number of trees and shrubs have been identified and used as dust filters to check the rising urban dust pollution level (Rai *et al.*, 2010), the use of plants as monitors of air pollution has long been established. The response of plants towards air pollution at physiological and biochemical level is assessed by air pollution tolerance index (APTI). Acclimatization of plants to air pollutants might change their morphological structure such as thicker epidermal cells and longer trichomes. Moreover, the evaluation of plants according to their sensitivity to air pollution in the urban areas may be of great importance for designing green belts and planning landscape of the cities (Agrawal and Tiwari, 1997; Prajapati and Tripathi, 2008). Therefore, present study was undertaken to identify air pollution tolerant vegetation (based on APTI) growing near the IOCL Mathura oil refinery. Air pollution tolerance index (APTI) can be used by landscapers to select plant species tolerant to air pollution. Four physiological and biochemical parameters including leaf relative water content (RWC), ascorbic acid (AA) content, total leaf chlorophyll (TCh), and leaf extract pH were used to develop an APTI (Liu and Ding,2008 ; Agbiare and Esiefarienrhe, 2009). It is also suggested that APTI can help in the selection of plant species for growing in industrial and urban zones where air pollution is predominant (Datta & Sinha Ray 1995). It provides a reliable method for screening large number of plants with respect to their susceptibility to air pollutants.

2. Materials and Methods

2.1 Study area

The present study was undertaken around Mathura oil refinery covering a radius of 5 km Bad village to Mahuan village (Fig. 1). Mathura city is located at 27.4924º North latitude and 77.6737º East longitude in Uttar Pradesh state, India. Representative samples of mature leaved were collected in October 2018 from the identified locations (Table 1) with a distance interval of approximately 1.0 km between each successive location; upto a distance of 5.0 kilometers downwind of Mathura oil refinery. In order to identify the effect of emission from oil refinery, samples were collected following the path from north-east to south-west since the predominant wind direction in this region is north-east. To overcome the inert-species variations for APTI and to ascertain the effect of refinery, samples of similar (naturally occurring at all nine locations) species of plants/trees were collected from the identified locations. Four species of plants/trees *i.e. Azadirectha indica* (Neem), *Dalbergia sissoo* (Sheesham), *Ficus religiosa* (Peepal), and *Calotropis procera* (Aak) were observed to be occurring at all nine locations, and were used to collect the representative samples of leaves. The collected samples were stored in transparent thick quality low density polyethylene (LDPE) bags; kept in an ice-box during transfer to the laboratory.

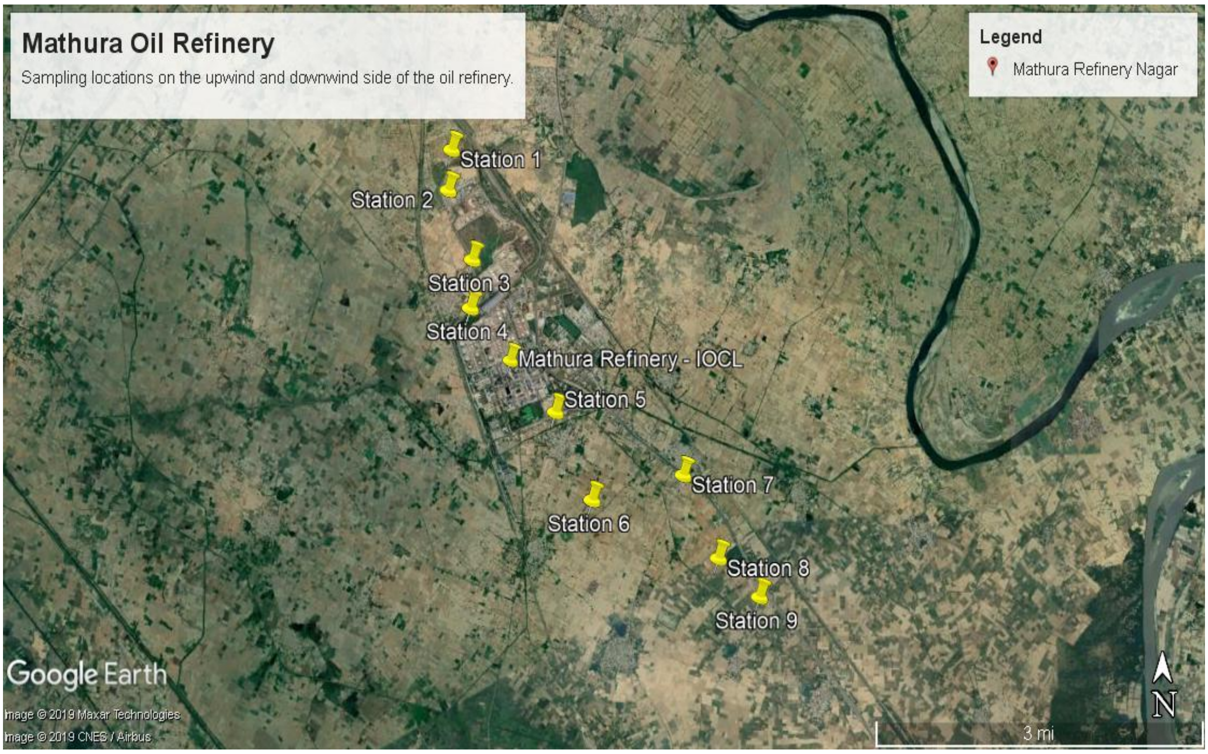


Fig. 1. Sampling locations on upwind and downwind side of the refinery

Table 1. Location of sampling sites around Mathura oil refinery

Station	Latitude	Longitude	Locations nearby
1	27°24'9.31"N	77°40'37.26"E	Bad (Industrial area)
2	27°23'51.51"N	77°40'35.46"E	Bad (Industrial area)
3	27°23'20.92"N	77°40'48.59"E	Bhainsa (Agricultural area)
4	27°22'59.67"N	77°40'47.63"E	Chharhgaon (Industrial area)
5	27°22'14.13"N	77°41'33.49"E	Dhana teja (Agricultural area)
6	27°21'35.70"N	77°41'53.27"E	Bhahai (Agricultural area)
7	27°21'46.58"N	77°42'42.40"E	Barari (Village settlement)
8	27°21'10.28"N	77°43'1.32"E	Mahuan (Agricultural area)
9	27°20'53.43"N	77°43'23.36"E	Mahuan road (Agricultural area)

2.2 Analysis of Samples

The collected samples of leaves were analyzed for pH of the cell sap, relative water content (RWC), chlorophyll content (Chl), and ascorbic acid content (AA) to determine APTI. All the analyses were performed as per the standard methods in triplicates using Analytical (AR) Grade chemicals. The pH of leaf sap was determined as per the method reported by Deepika et al., 2016; RWC as per Singh, 1977; TCh as per Arnon, 1949; and AA as per Bajaj & Kaur, 1981. After obtaining the values of parameters, APTI was calculated following the method as suggested by Singh & Rao, 1983.

$$APTI = [AA\,(TCh + pH) + RWC]/10$$

Based on APTI, the samples were categorized into four categories (tolerant, moderately tolerant, intermediately tolerant, and sensitive) as per the classification given below:

Tolerant	:	APTI > Mean APTI±SD
Moderately Tolerant	:	Mean APTI < APTI < Mean APTI+SD
Intermediately Tolerant	:	Mean APTI – SD < APTI < Mean APTI
Sensitive	:	APTI < Mean APTI – SD

3. Results and Discussion

The results obtained during the analyses are presented in Table 2. Based on the values obtained, it is observed that the pH of all the plants was slightly acidic (4.9 – *A. indica*) to near neutral (7.6 – *F.*

religiosa) in range. Individually, the average pH was 5.2, 5.5, 6.9, and 6.0 for *A. indica*, *D. sissoo*, *F. religiosa*, and *C. procera*, respectively. The pH of cell sap plays an important role in developing tolerance to environmental stress. Higher pH favours conversion of hexose sugars to ascorbic acid, which subsequently reduces the reactive oxidizing species (ROS) present in plants (Hippeli and Elstner, 1996).

Table 2. The Biochemical characteristics and APTI of collected leaf samples

S. No.	Species	Station	pH	RWC (%)	TCh (mg/g)	AA (mg/g)	APTI
1.	***Azadirechta indica***	1	6.4	86	1.91	1.86	10
		2	4.9	80	2.20	1.13	9
		3	5.0	84	1.96	1.48	9
		4	4.9	81	2.02	1.34	9
		5	4.8	85	1.05	1.16	9
		6	5.0	80	0.92	2.26	9
		7	4.9	80	1.60	1.34	9
		8	4.9	79	1.77	2.58	10
		9	5.7	70	2.31	2.78	9
Mean ± SD			**5.2±0.53**	**81±4.7**	**1.75±0.48**	**1.77±0.63**	
2.	***Dalbergia sissoo***	1	5.7	75	1.47	0.44	8
		2	5.6	83	1.50	0.56	9
		3	5.5	77	1.96	0.64	8
		4	5.5	67	1.75	0.58	7
		5	5.4	76	1.71	0.44	8
		6	5.5	81	1.78	0.58	9
		7	5.5	91	2.27	0.61	10
		8	5.5	81	2.51	0.56	9
		9	5.6	73	2.74	0.52	8
Mean ± SD			**5.5±0.1**	**78±6.8**	**1.97±0.44**	**0.55±0.1**	
3.	***Ficus religiosa***	1	6.4	82	1.41	0.29	8
		2	6.2	83	2.33	0.32	9
		3	6.7	71	3.01	0.47	8
		4	6.6	84	3.01	0.35	8
		5	6.6	96	1.49	0.29	10
		6	7.5	87	3.07	0.35	9
		7	7.6	92	2.75	0.41	10
		8	-	-	-	-	-
		9	7.6	95	2.17	0.50	10
Mean ± SD			**6.9±0.6**	**86±8.2**	**2.40±0.67**	**0.37±0.8**	
4.	***Calotropis procera***	1	6.1	81	1.26	0.32	8
		2	5.7	74	0.85	0.35	8
		3	6.0	82	0.97	0.38	8
		4	6.0	73	1.10	0.29	8
		5	5.8	83	1.27	0.70	9

		6	5.7	79	1.09	0.58	9
		7	5.8	84	0.96	0.41	9
		8	6.4	93	1.84	0.58	10
		9	6.5	76	1.56	0.61	8
Mean ± SD			**6.0±0.3**	**81±6.1**	**1.2±0.32**	**0.7±0.5**	
Mean APTI ± SD							**9 ± 0.65**

Based on the observed values of pH of cell sap, *F. religiosa* and *C. procera* can exhibit more tolerance compared to other two species. The RWC of leaves is a kind of defense mechanism of plants against drought/water-stressed conditions. The RWC may compliment for water requirement of plants for its biochemical functions. RWC may also be higher in plants not exposed to dust etc. Deposition of dust may block the stomata and thus interferes with rate of transpiration, which subsequently reduces the water and nutrient uptake from soil resulting in senescence. The average RWC in the present study was 81%, 78%, 86%, and 81% for *A. indica, D. sissoo, F. religiosa*, and *C. procera*, respectively. Based on RWC, *F. religiosa*, *A. indica*, and *C. procera* exhibited higher tolerance compared to *D. sissoo.*

The total chlorophyll (TCh) content of plants signifies its photosynthetic activity as well as the growth and development of biomass. In the present study TCh varied from 0.85 mg/g (*C. procera*) to 3.07 mg/g (*F. religiosa*). The TCh content vary from species to species, therefore, inter-species differences may not comment upon the relative tolerance towards air pollution very precisely. *F. religiosa* exhibited maximum average TCh content (2.40 mg/g) followed by *D. sissoo* (1.97 mg/g), *A. indica* (1.75 mg/g), and *C. procera* (1.2 mg/g). The differences may be attributed to the leaf size and structure, presence of hair/wax layer over the leaf, age of the leaf, exposure to sun etc. However, spatial differences of TCh for the same species may point towards exposure to oxidizing pollutants and loss of chlorophyll (Table 2). Since chloroplast is the primary site for attack, loss of chlorophyll is observed upon exposure to SO_2 and NOx gases. Therefore, loss of TCh can be used as an indicator of air pollution (Ninave et al., 2001). Higher ascorbic acid (AA) content of the plant is a sign of its tolerance against sulphur dioxide pollution (Varshney & Varshney, 1984). Being a very important reducing agent, ascorbic acid also plays a vital role in cell wall synthesis, defense, and cell division (Conklin, 2001). In the present study, average AA content was 1.77, 0.55, 0.37, and 0.7 for *A. indica, D. sissoo, F. religiosa*, and *C. procera*, respectively. Higher AA in *A. indica* may be due to the increased rate of production of reactive oxygen species (ROS) during photo-oxidation of SO_2 to SO_3 where sulfites are generated from SO_2 absorbed. Although a tool for defense in plants, higher level of AA is also an indicator of stress over the plant. In the present study, *F. religiosa* was observed to have minimum stress followed by *D. sissoo, C. procera*, and *A. indica*. Based on the values of APTI, *A. indica* was classified as tolerant species, *F. religiosa* as moderately tolerant, and *D. sissoo* and *C. procera* were intermediately tolerant. Moreover, APTI values were slightly raised (Fig. 2) in downwind region indicating that the pollutants from the refinery and Mathura city have a stress over the exposed vegetation.

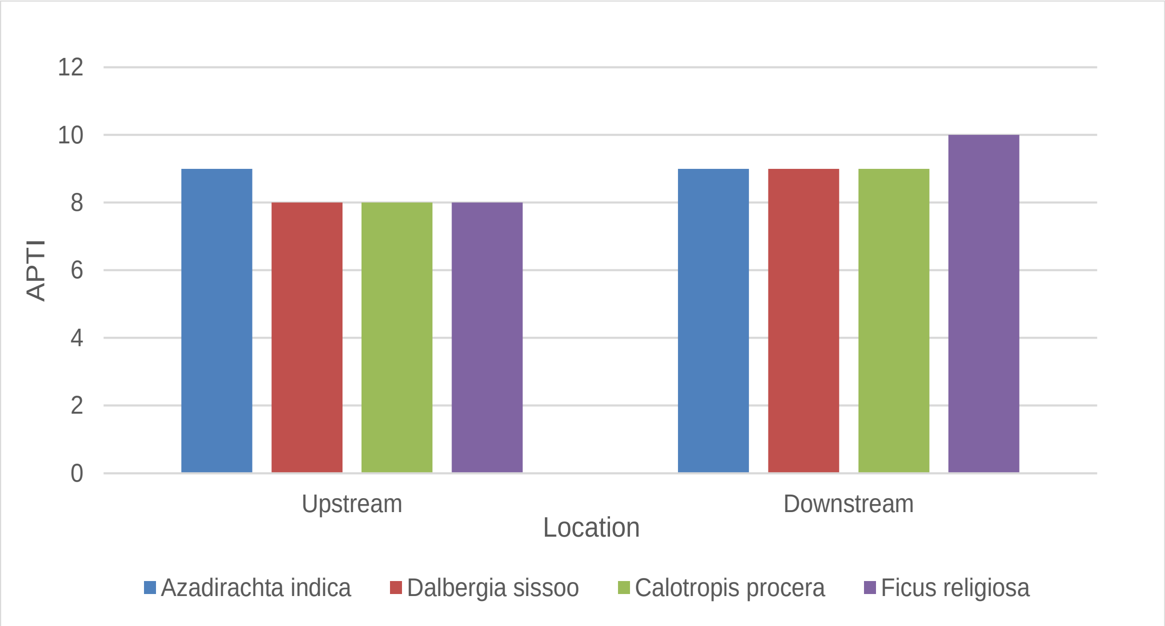


Fig. 2. Variation of average APTI in the upwind and downwind region of Mathura oil Refinery

4. Conclusion

Based on the results obtained, it is observed that most of the vegetation within 5 km Diameter of IOCL Mathura oil refinery lies under the tolerant, moderate and intermediate moderate category of APTI. The naturally growing plants like *A. indica*, *F. religiosa*, and *D. sissoo* may be used to develop a thick green belt around the Mathura oil refinery and along the highways in that region to effectively combat the problems related to air pollution besides fixing the atmospheric carbon dioxide. The results of this study may be useful for future planning.

5. References

1. Agbaire, P. O. and Esiefarienrhe, E. (2009). Air pollution tolerance indices (APTI) of some plants around Otorogun gas plant in Delta State, Nigeria. J Appl Sci Environ Manage.13 (1): 11-14.
2. Agrawal, S., and Tiwari, S. (1997). Susceptibility level of few plants on basis of air pollution tolerance index. Indian Forester, 123: 319–322
3. Arnon, D.I. (1949). Copper Enzymes in isolated Choloroplasts polyphenol oxidase in Beta vulgaris, Plant Physiology, 2: 1-15.
4. Bajaj, K.L. and G. Kaur. (1981). Spectrophotometric determination of Ascorbic Acid in vegetation and fruits. *Analyst* 106:117-120.
5. Conklin, P.L. (2001). Recent advances in the role and biosynthesis of ascorbic acid in plants. *Plant Cell Environ*. 24: 383-394.
6 Datta. S.C. and Ray, S.S. (1995). APT1 value of five different species of higher Plants from the metropolis of Calcutta. In: Environmental and adaptive biology of plants. Scientific publishers. Jodhpur, pp.289-294.
7. Deepika, Gour, P., Haritash, A.K. (2016). Air pollution tolerance of trees in an educational institute in Delhi. Intl J Environ Sci., 6: 979–986.

8. Dwivedi, A.K. and B.D. Tripathi, Shasi (2008). Effect of ambient air sulphur dioxide on sulphate accumulation in plants. J. Environ. Biol., 29: 377-379.
9. Hippeli, S., Elstner, E.F., (1996). Mechanisms of oxygen activation during plant stress: biochemical effects of air pollutants. Journal of Plant Physiology 148: 249–57.
10. Liu, Y.J. and H. Ding (2008). Variation in air pollution tolerance index of plants near a steel factory: Implications for landscape-plant species selection for industrial areas. WSEAS Trans. Environ. Dev, 4:24-32.
11. Macêdo, M. F. M., & Ramos, A. L. D. (2020). Vehicle atmospheric pollution evaluation using AERMOD model at avenue in a Brazilian capital city. *Air Quality, Atmosphere & Health*, 1-12.
12. Ninave, S.Y., P.R. Chaudhri, D.G. Gajghate and J.L. Tarar (2001): Foliar biochemical features of plants as indicators of air pollution. Bull. Environ. Contam.Toxicol.67:133-140.
13. Prajapati, S.K., Tripathi, B.D. (2008). Anticipated performance index of some tree species considered for green belt development in and around an urban area: a case study of Varanasi city. India J. Environ. Manag. 88, 1343–1349.
14. Singh A. (1977). Practical Plant Physiology, Kalyari Publishers, New Delhi.
15. Singh, S.K., Rao, D.N. (1983). Evaluation of plants for their tolerance to air pollution. In: Proceedings Symposium on Air Pollution Control, vol.1. Indian Association for Air Pollution Control, New Delhi, India; 218–224.
16. Rai A, Kulshreshtha K, Srivastava PK, Mohanty C.S. (2010). Leaf surface structure alterations due to particulate pollution in some common plants. Environmentalist 30:18-23.
17. Varshney, S.R.K. and C.K. Varshney (1984). Effects of sulphur dioxide on ascorbic acid in crop plants. Environ. Pollut., 35:285-291.

NATIONAL WORKSHOP
"Air Pollution and Health Linkages: Better Understanding for Impact Assessment, Setting Environmental Guidelines and Standards"

held on June 1, 2019 at PHD Chamber of Commerce & Industry

Organised By

Indian Association of Air Pollution Control (Delhi Chapter)

RECOMMENDATION OF THE WORKSHOP

Exposures to high air pollutants in India pose considerable human health risk. Methodologically investigated data to understand the exact linkage between various air pollutants and its impact on human health is not available. Even though the regulatory agencies are monitoring the air quality at several locations in India for almost three decades, sufficient researched data is not available on the impacts of these pollutants on human health. Environmental health data of good quality could serve as a valuable tool for estimation of the health impacts of air pollutants, which could set priorities for appropriate action. Although the Ministry of Environment, Forests and Climate Change, the Central Pollution Control Board, Indian Council of Medical Research, NTPC Limited, Public Health Foundation of India, etc commissioned few environmental health impact studies to assess the manifestations of various diseases attributable to air pollution, to establish cause-effect relationship studies to be more focussed. In 2003, the MOEF&CC has brought out a Vision Statement on Environmental Health in order to internalize the environmental health issues in setting up of environmental standards and evolving measures and action programmes for the protection of public health against pollution.

The strong linkage between development, productivity, pollution and health requires more integrated and inter-sectoral approaches to address public health issues. This will enable the government to take intervention measures for population residing near the industrial areas, urban areas having high vehicle density and exposed to heavy metals and hazardous pollutants. Vulnerable groups such as infants, old persons and children need protection against the air pollution hazards.

In order to understand and give more recognition to Air Pollution and Health linkages, IAAPC (Delhi Chapter) organized Workshop on "Air Pollution and Health Linkages: Better Understanding for Impact Assessment, Setting Environmental Guidelines and Standards"

The primary objective of the workshop was:

1. Gather scientific information (study methodology and conclusion) and cause-effect data on the relationship between air pollution and human health.
2. Utilize health-based data for developing national discharge standards and estimating disease burden in different areas on the country.
3. Use environmental health data in the policy planning and decision making related to all aspects of development.

Dr. J.S. Sharma, President-IAAPC welcomed all delegates.Dr. S.D.Attri, Dy Director General, India Meteorological Department explained the objectives of the workshop, Guest of Honour, Dr. J.P. Gupta, Chairman, Expert Appraisal Committee (Industry-2), MOEF&CC addressed the delegates and emphasized the traditional philosophies followed in India since time immemorial for sustainable development. Dr. ManoranjanHota, Former Advisor MOEF&CC & Member Expert Appraisal Committee, MOEF&CC delivered the keynote address, where he explained the Vision Document 2003 of MOEF&CC on the subject Environmental Health. In his Address the Chief Guest Dr. R.S.Dhaliwal, Head, Non Communicable Diseases, Indian Council of Medical Research,deliberated on the research work being done in the country and emphasized the requirement of applied research on air quality and health linkages. Thereafter, Mr. S.K.Gupta, Secretary-IAAPC proposed the Vote of Thanks.

The Technical Session 1: Health Studies was Chaired by Dr.K.T.Bhowmik, Addl MS, Bhagwan Mahavir Medical College, New Delhi and Co-Chaired by Prof Anubha Kaushik, Director (International), IP University, New Delhi. Following 5 presentations were made by the experts and discussed.

1. Dr. Raj Kumar (Vallabhbhai Patel Chest Institute, University of Delhi)
   Clinical Profile of Respiratory Illness due to Air Pollution and Early Diagnosis Tools

2. Dr. Poornima Prabhakaran (Public Health Foundation of India)
   Overview of PHFI Research Studies on Air Pollution & Health Outcomes

3. Dr. D. Prabhakaran (Director, Center for Chronic Condition and Injuries and Vice President (Research and Policy), Public Health Foundation of India
   Diagnostic tools for understanding air pollution linkage with Cardio Vascular Diseases

4. Dr. Arun Sharma (University College of Medical Sciences, University of Delhi)
   Research Methodologies for Assessing Health Effects of Air Pollution

5. Dr. S.K. Paliwal, (Central Pollution Control Board, Delhi)
   Requirement of Health Impact Assessment Studies for EIA Study of Thermal Power Plants

The Technical Session 2: Methodology For Health & Air Pollution Measurmentwas Chaired by Dr. B. Sengupta, Former Member Secretary, Central Pollution Control Board and Co-chaired by Dr. Rajendra Prasad, CEO Ecotech Instruments. Following 5 presentations were made by the experts and discussed.

6. Dr. Sagnik Dey (Dept of Atmospheric Sciences, IIT Delhi)
   International Methods for Conducting Air Pollution Health Impact Study Exposure Modelling: Challenges & Opportunities

7. Dr. TK Joshi (Former Head- Centre for Environ Health, MAMC) & Dr. J K Moitra (EMTRC)
   Case Studies on Health Impact Assessment due to Air Pollution from Thermal Power Plants: Overview of Methodologies

8. Dr. Pavan Tiwari (AIIMS)
   Correlation of Acute Changes in Air Quality with Emergency Admissions

9. Dr. Abhijit Pathak, CPCB, Delhi
   Linking Air Quality and Health: Need Assessment Beyond Regulatory Monitoring Practice

10. Dr. K. Krishnamurthy (NEERI - Nagpur)
    Health Impacts of Air Quality on Nagpur - Environmental and Epidemiology Based Health Risk Assessment Study on Multi-pollutants and Sensitive Populations

Following experts provided valuable concluding remarks during the Valedictory Session: Mr. Paritosh Tyagi (Former Chairman CPCB), Dr. B. Sengupta (Former Member Secretary CPCB), Dr.J. Bhasin, Former Dy Director, NEERI, Dr.J.S.Sharma, President IAAPC and Member Expert Appraisal Committee (Industry 2), MOEF&CC, Dr.S.K.Tyagi, (Former Head, Toxic Air Lab, CPCB) and Dr. Abhijit Pathak (Scientist-CPCB). The recommendations of the workshop is given below:

1. "Health in all Policies" should be the mantra for India so that remedial measures are formulated and implemented for its most polluted cities. Members of all stake-holder ministries should be involved in final policy-making for air pollution- environment, health, power, urban transport, energy, industry, renewable energy. Regular stake-holder consultation for periodic review of all policies is a must.

2. In order to stop duplication of research, a centralized registry of research work should be created, preferably by ICMR and all research projects should be listed on it. The list should be accessible online

3. It is important to avoid wastage of resources in conducting research on less important issues and avoid poor quality research work. MoEF&CCepare guidelines for all researchers in the country to carry out research on air quality and health linkages, prioritise areas of research on health impact suitable for framing national ambient air quality standards and discharge standards.

4. Ministry of Health should work towards making illness, disease, morbidity and mortality data available from hospitals, municipal corporations and district health records.

5. Ministry of Health, Ministry of Environment and Ministry of Science and Technology should provide directives in a centralized manner to prioritize research topics and allocate funds to researchers accordingly

6. Local coordination units should be made at city, district and state level to form interdisciplinary research groups involving all stakeholders to carry out exposure impact assessment studies.

7. MoEF&CC vide OM dated 19-11-2018 issued standard conditions to be stipulated in Environmental Clearance for thermal power plants:
   i. Bi-annual Health check-up of all the workers is to be conducted. They study shall take into account of chronic exposure to noise which may lead to adverse effected like increase in heart rate and blood pressure, hypertension and peripheral vasoconstriction and thus increased peripheral vascular resistance. Similarly, the study shall also assess the health impacts due to air polluting agents.

   ii. Baseline health status within study area shall be assessed and report be prepared. Mitigation measures should be taken to address the endemic diseases.

MOEF&CC should mention the methodology of data collection (secondary data) / generation (primary data), who should conduct the check-up, qualification and experience of medical professionals, etc.

8. There is an urgent need to develop a harmonised protocol for conducting Health Impact Assessments (HIA) in India .Current ground experiences in doing HIA may be drawn upon to feed into this process. Once the protocol is developed, capacity building at all levels should be initiated.

9. Integrated Environmental and Health Impact Assessment (IEHIA) is followed in many countries. HIAs must become an integral part of regulatory clearances (for large scale development projects, where the magnitude of impacts are huge) over next few years just as EIAs.

10. HIA should be commissioned and conducted by regulatory authorities and not by industry owners to avoid conflict of interest. At least the regulatory authorities should get involved and closely monitor the study process.

11. The Comprehensive Environmental Pollution Index (CEPI) is currently providing minimal emphasis on HEALTH (air pollutants-30, Soil pollutants-30, water pollutants-30 and health -10, in an index of 100). This should be revised at earliest.

12. Research at local / city (micro) level to understand the burden of diseases due to air pollution in terms of disability, morbidity, mortality and productivity losses should be initiated. (Presently the burden of disease is done at macro (district) level)

13. Long Term (15 years and more) cohort based research studies are required in India the understand the extent of health impact of air pollutants, especially in Critically Polluted Areas identified by CPCB/MOEF.

14. An integrated satellite based air quality monitoring system is required for India to get hourly $PM_{2.5}$ at 1 km radius for the entire country. This data will be useful for health impact study.

15. Air shed based delineation of areas for entire country is important and air quality management approach should be based on air shed management specially to understand the impact of air pollution on human health.

16. Personal exposure modelling tool suitable for Indian conditions, and specifying the measurement of uncertainty, should be developed by Health Institutes (PHFI, SRMC, AIIMS , CNCI, etc)

17. Issue regarding toxic components of $PM_{10}/PM_{2.5}$ (Organic Carbon, Elemental Carbon, Heavy Metals like As, Pb, Ni, Hazardous Air Pollutants, etc.) should be addressed for better understanding of health impact assessment studies.

18. Finalize the Model TOR / Guidelines for conducting health impact study CPCB / MOEF may consider constituting an Expert Committee with following members:

a. Prof. A.K. Sharma, University College of Medical Sciences, Delhi University
b. Representative from Public Health Foundation of India
c. Representative from AIIMS
d. Representative from NEERI
e. Prof. Sagnik Dey, Centre for Atmospheric Sciences, IIT Delhi
f. Representative from CPCB / MoEF
g. Representative from IAAPC(DC)


Indian Association of Air Pollution Control (DC)
National Workshop
"Air Pollution and Health Linkages: Better Understanding for Impact Assessment,
Setting Environmental Guidelines and Standards"
1st June, 2019, PHD House, New Delhi


IAAPC
Indian Association of Air Pollution Control (DC)
National Workshop
"Air Pollution and Health Linkages: Better Understanding for Impact Assessment, Setting Environmental Guidelines and Standards"
1st June, 2019, PHD House, New Delhi


IAAPC
Indian Association of Air Pollution Control (DC)
National Workshop
"Air Pollution and Health Linkages: Better Understanding for Impact Assessment, Setting Environmental Guidelines and Standards"
House, New Delhi

Instructions for Authors

The Indian Journal of Air Pollution Control aims to focus attention on all problems and their solutions related to the subject of air pollution. Authors wishing to have their papers published in the journal are requested **to send their manuscripts to the Chief Editor on email**: chiefeditorijapc@gmail.com with a copy to: iaapcdelhi@gmail.com . All correspondence regarding the manuscript will be made with the first author unless specified. Articles reporting current R & D and in-depth studies on subjects of current interest are welcomed. Submission of the manuscript for publication in the journal will imply thatit has **not been previously published** and is not under consideration for publication elsewhere; and further that, if accepted, it will not be published elsewhere. We shall particularly wish to encourage papers that are likely to be of interest to more than one professional group, either because the work is fundamental or because it reflects the best in current technology or it offers extensive critical reviews, especially of subjects of interest in the country. Papers on developments in Indian technology must pay special attention to the problems peculiar to the country. The editors assume no responsibility for the statements and opinions expressed by individual authors.

All parts of the script must be typed single-spaced. **Title page** must contain the **title of the paper,the initials and names of the authors** and **the name and address of the institution where the work was done** and a **brief running title** of not more than 50 letter spaces. The **title should be as concise** as possible, generally no more than two lines. If necessary, for clarity, a glossary of mathematical symbols may be included under an unnumbered heading 'Notation' after the acknowledgements. **Abstract** must be informative and not just indicative, and must contain the significant results reported in the paper. **Keywords**, not more than six in number, may be provided for indexing and information retrieval. The text must be divided into sections, generally starting with '**Introduction**' and ending with **'Conclusions'**. The main text should be followed by a list of **references**. **Tables** with legends must be numbered consecutively numerals in the order of occurrence in the text on the top of the table. They should be self-contained and have a descriptive title. **Figures,** in black and white, with suitable captions, should be numbered consecutively in numeral in the order of occurrence in the text at the bottom of the figure. **Equations** must be written clearly, each on its own line, well away from the text but punctuated to read with it. Units and associated symbols must invariably follow SI practice. Footnotes must be avoided. Appendices if any should be labelled A, B etc., in order of appearance. A copy of the original tables and figures must be sent separately.

References should be cited in the text by author's name and year, not by number. If there are more than two authors, references should be made in the name of the first author followed by et al in the text. **References at the end** of the paper should be listed alphabetically by author's names, followed by initials, year of publication, title of the paper, name of the journal, volume number and page numbers. **Reference to books** should include name(s) of author(s), initials, year of publication, title of the book, edition if not the first, initials and name(s) of editor(s) if any, place of publication, publisher, and chapter or pages referred to. **Reference to thesis**, must include the year, the title of the thesis, the degree for which submitted and the University.

The **reviewed manuscript**by e–mail copy in the prescribed format must be resubmitted for consideration of publication within **three months** of the receipt of the referee's comments. **In the final copy, A4 (297X 210mm) size, margin should be as follows: top 25 mm; bottom 30 mm; sides 20mm. Paper title should be in 14 pt. Arial font, (Title case) and centered. Author's names should be in 12 pt. Times New Roman, sentence case, spaced 2.5 mm (or 7 pt.) beneath the title, with Author's affiliations and addresses in 10 pt. Times New Roman spaced 1 mm (or 3 pt) below the authors name. Please include e-mail addresses in brackets. Abstract heading should be in 12 pt. Arial, sentence case with 10 mm (28 pt.) space above and 1 mm (3 pt.) below, followed by the text in 10 pt. Times New Roman justified (single spaced). Main section headings should be in 12 pt. Arial bold, numbered (with hanging indent), sentence case, left justified and 14 pt. space above and 3 pt. space below. First level sub-headings should be in 11 pt. Arial, numbered (with hanging indent), sentence case, left justified with 10 pt. space above and 3 pt. space below, and second level sub-headings should be in 10 pt. Arial italic, numbered (with hanging indent), sentence case, left justified, with 7 pt. space above and 2 pt. space below. Body text should be in 11 pt. Times New Roman justified (single spaced), first line indented 10 mm except for the paragraph following a heading. Fully justify each line, hyphenating if necessary. Insert only a single space after a sentence. Avoid hyphens at ends of two or more consecutive lines. Please send manuscripts as attachment in MS word or in printed form strictly as per instructions above**. **Manuscript must be composed in MS word with single spacing, tables and figures to be inserted as a part of the text**. **Tables and figures must be properly formatted. The** titles and/or figure numbers must not be made part of the tables and figures when inserting scanned copies. Printed copies of original diagrams/figures and tables used in the text should also be sent separately along with the final version.

INDIAN ASSOCIATION FOR AIR POLLUTION CONTROL

Delhi Chapter

Delhi Office. A-271,Okhla Industrial Area, Phase – I, New Delhi

Tel : 26812607 Fax: 26811833 E-mail : iaapcdelhi@gmail.com Web Site: www.iaapc.in

Form of Application for Membership

Particulars of the Applicant
(Please fill in Capital Letters)

1. Name in Full:…………………………………………………………………………

2. Present Position & Name of Office: ……………………………………………….

3. Address: Office:……………………………………………………………………..

   ……………………………………………………….…………..………………

   : Residence:……………………………………………….……………………

   ……………………………………………………….…………………………..

4. Tel : ………………………….Fax : ………………………Email : ………………

5. Date of Birth: Day………… Month……………… Year……………..……

6. Citizenship:…………………………………………………………………………..

7. Academic/Professional Qualifications:……………………………………………

8. Membership of Academic /:………………………………………………………..
   Professional Organizations

9. Area of Specialization:…………………………………………………..………..
   (Please be as specific as possible)

10. Reasons for desiring to become member of the Association. Please give your reply in one paragraph. : ……………………………………………………………..

    ……………………………………………………………………………………..……

11. Kind of membership applied for: Institutional / Fellow / Member Ordinary / Student Member

12. Membership Fee Structure:

Category	Admission	Permanent / Life	Annual / Renewable / Membership per year
For Indian Residents in India			
A. Institutional	Rs. 100/-	Rs. 10,000/-	Rs. 1000/-
B. Member	Rs. 100/-	Rs. 5,000/-	Rs. 500/-
C. Fellow	---	Rs. 10,000/-	---
D. Student	Rs. 100/-	Rs. 2,500/-	Rs. 250/-

To
The Chapter Secretary,
IAAPC, Delhi Chapter,
Delhi Office-A-271, Okhla Industrial Area,
Phase – I, New Delhi-20

Dear Sir,

I wish to become a member of IAAPC. Requisite details are shown in the proforma enclosed.

I have remitted the membership entrance fee of Rs. …………………and subscription fee of Rs. …………… by demand draft / cheque (for local applicants only) No. ………………….. dated ………….. for Rs……………….. drawn in favour of IAAPC – Delhi Chapter, New Delhi.

I have read the Memorandum of Association and agree to abide by them.

Thanking you,

Yours faithfully,

For Office Use Only :

Receipt No. …………… Date ………… Amount Rs. …………………………

Admitted on …………… Intimation Sent on …………………………………….

ENVIROTECH

A Pioneering Institution in the Service of Nation Since 1982

Complete Range of Ambient Air Dust Monitoring Systems

TSPM	PM 10	PM 2.5	PM 1
APM 430	APM 460 DXNL	APM 550 MFC	APM 577

DESIGNED AND DEVELOPED AS PER THE GUIDELINES PRESCRIBED BY CPCB & BIS

RELIABLE AND FIELD PROVEN SYSTEMS

IN USE EXTENSIVELY THROUGHOUT THE COUNTRY

FOR PRICE & ORDERING, PLEASE CONTACT

Envirotech Instruments Pvt. Ltd.
A-271, Okhla Industrial Area,
Phase-1
New Delhi - 110020, India

+91-11-26814139, 26813887, 41026749,
+919810038803

sales@envirotechindia.com
sales.envirotech@gmail.com

www.envirotechindia.com