A Study on Spatio-Temporal Variation of Respirable and Fine Particulate Matters (PM_{10} and $PM_{2.5}$) in Southern Part of Kolkata City

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(Specialization: Environmental Engineering)

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Declaration

I declare that the work described in this thesis is entirely my own. No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute. Any help or source information, which has been availed in the thesis, has been duly acknowledged.

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(Ashwini Kumar Singh)

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CHAPTER 1 INTRODUCTION

1.1 Background

Clean Environment is the most important factor for the very existence of all the living beings on earth. Fresh air, healthy soil and clean water are the components of a healthy environment without which humans cannot expect a healthy life. Unfortunately, humans seem to have been ignoring this truth for a long time now for their own greed. Industrialisation undoubtedly resulted in economic growth of the countries but in this process, fossil fuels like coal, oil and gas were burned on a large scale without having any concern of environmental degradation and problems like pollution of air, water and soil were overlooked in every possible aspect. Blunder like Ozone hole is one such infamous example of a non-sustainable economic development which held in the form Industrialisation.

Air pollution is probably the worst outcome of all these economic developments and now eventually economic development seems to be occurring at the cost of economic loss itself. It is not a hidden fact anymore that how severe the problem of air pollution is today and how it is effects our health and kills us silently. Air pollution has become a problem of prime concern for countries around the world in general and developing countries in particular and India is not an exemption in the list. In fact, there are reports from organisations like WHO and many other research works counted globally which shows developing countries with huge economy in terms of GDP like India and China are generating more pollution than the developed countries due to the undergoing works of development like infrastructures, industrialisation and Urbanisation. Globally, air pollution – indoor and outdoor – has caused nearly 7 million deaths, or 11.6% of deaths in 2012, making it the world's largest single environmental health risk (**WHO, 2014**). It has now become a headache for the Governments around the world to take necessary steps to control air pollution and mitigate its effects. Environmentalists in every corner of the world are struggling for solutions to this problem. In the recent report of 2018 in a sample size of 859 cities, 16 out of top 20 most polluted cities in the world were from India with Kanpur city being on top (**WHO, 2018**).

In general, anything other than 78% Nitrogen, 21%, Oxygen, 1% Argon, 0.03% Carbon Dioxide and other trace gases in the air is considered as pollutants. But, it is impossible to eliminate everything other than this standard composition in the air. However, it is possible to control it to a level to not impose serious health threats to humans. Government has created a list of Criteria Air Pollutants (CAP's) to monitor air quality by monitoring the concentration of these pollutants in air and they have set some permissible limits which need to be attained in order to have safe breathable air. Particulate Matters (PM's) with aerodynamic size of 2.5 µm and 10 µm or better known as $PM_{2.5}$ and PM_{10} are one of these CAP's which are monitored.

Today, $PM_{2.5}$ is the major pollutant monitored by the Environment Protection Authorities (EPA's) of every country around the world to know the air quality. In India, ever since independence, many steps had been taken by the government to improve economic condition of the country but after globalisation, India's economy has seen unprecedented growth which resulted in overcrowding of cities, rise of new industrial sectors, increase in vehicular traffic, increase in construction activities like high rise commercial and residential buildings, metros railway's , bridges, roads etc. Probably, these are few main factors which must have aggravated particulate matter pollution scenario manifold. Its concentration in air is witnessed to have been increased many times in recent years in Indian cities. Many studies had been conducted by researchers around the world on $PM_{2.5}$ and PM_{10} to know its source of generation, its spatial variation in different geographical locations, effect of meteorological factors like wind speed temperature, humidity and effect of anthropogenic factors like traffic on its concentration in the air. It was demonstrated that PM_{10} and $PM_{2.5}$ concentrations were positively correlated with temperature and relative humidity and negatively correlated with wind speed (**Zhao *et al.,* 2014**). It has been found that PM concentration level varies with season. Traffic volume also has a positive co-relation with increasing concentration of $PM_{2.5}$ and PM_{10}. Deterioration of $PM_{2.5}$ concentration is closely related to a set of critical impact factors like urbanisation rate, road freight volume (**Huang *et al.,* 2018**). Among the vehicular traffic, local diesel vehicular traffic may be important sources of airborne fine particles in dense urban areas and consequently may contribute to local variations in $PM_{2.5}$ concentrations (**Patel *et al., 2009***). The traffic–generated emissions are accounting for up to 50% to 70% of the total PM emissions in the urban areas in near vicinity of road in London, UK, more than 80% of PM emission is from the road traffic (**Wrobel *et al.,* 2000**). A significant reduction of as much as 60 % was observed in PM during nationwide truck strike period (**Sharma *et al.,* 2010**). These studies shows that vehicular traffic has a positive correlation with the high concentration of PM in Urban areas. Winters usually have high concentration of PM than summers and specially month of January and December has the highest concentration of $PM_{2.5}$ and PM_{10}.The particulate masses shows obvious seasonal patterns with high concentrations in cold seasons and low in warm seasons, especially high concentrations of $PM_{2.5-10}$ during the cold seasons. Diurnal variations of mass concentrations of $PM_{2.5}$ show major peaks during rush hours of morning and afternoon **(Cheng *et al.,* 2006)**. Even the sensitive areas like schools and Hospitals of Kolkata have high $PM_{2.5}$ concentration which is 2.5 to 3 times higher than the standard permissible limit in January, 2016 **(CSE, 2016**).

1.1.1 Socio-Economic Impact of Air Pollution

Air pollution is a major risk factor for human health today. 9 out of 10 people breathe air that breaches safe limits and as many as 7 million people are dying every year due to ambient and household air pollution ***(*WHO, *2016,*)**. Air pollution increases the risks for acute respiratory infections and exacerbates asthma. Particularly fine particles go deep into the lungs and cardiovascular system, cause stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases (COPD) (umbrella term for several progressive lung diseases) and lung cancer.

Globally, air pollution – both indoor and outdoor – caused nearly 7 million deaths, or 11.6% of deaths in 2012, making it the world's largest single environmental health risk In India, an estimated 1.5 million people died from the effects of air pollution in 2012 (**WHO, *2014***,).The number of deaths due to outdoor air pollution in China rose by about 5%, in India by about 12% between 2005 and 2010.The cost of the health impact of air pollution was about USD 0.5 trillion in India (***OECD, 2014***). About 30% of the respiratory diseases are related to personal exposure to high level ambient PM concentrations. A recent study by CSE conducted in Kolkata found that around 70 per cent of Kolkata's 18 million inhabitants suffer from respiratory problems such as asthma and lung cancer, which are caused by pollution from the city's chaotic transport sector. Studies carried out by Chittaranjan National Cancer

Research Institute have found more than 60 per cent children in Kolkata with lung function impairments compared to 24 per cent in cleaner areas (**CSE, 2016**)

Air pollution is costing societies a very large amount in terms of the value of lives lost and of ill health Reducing urban air pollution in Delhi and Kolkata can benefit an estimated amount of as much as Rs. 4896.6 million to Delhi and Rs. 2999.7 million to Kolkata (**Murty *et. al.*, 2003**). Similarly, tackling air pollution in all metro cities will have significant economic benefits for India overall.

1.2 Air Pollution and Its Significance

1.2.1 Definition of Air Pollution

United States Environment Protection Agency (USEPA) describes air pollution as, "the presence of contaminants or pollutant substances in the air that interfere with human health or welfare, or produce other harmful environmental effects"

Air pollution is the presence of one or more contaminants in the atmosphere, in sufficient quantities and of such characteristics and duration as to be threatening or may likely to threaten to be injurious to human, plants or animal life and also to the property, or which interferes with the comfortable enjoyment of life or property. So it can be explained as the interferences caused by the pollutants to human health and welfare and adverse effects to plants and animals and properties and hence causing imbalances and harmful environmental effects.

1.2.2 Sources of Air Pollution

The sources which release the contaminants into the ambient air and thereby cause the air pollution can be categorized as:

1. **Mobile transportation**- motor vehicles, railroads transport, ships, aircrafts.
2. **Stationary combustion sources** – residential, commercial, industrial sources (Power and heating sources).
3. **Industrial processes**- chemical, paper and pulp making, metallurgical industries and others.
4. **Solid-waste disposal** - refuses from residential, commercial and industrial, agricultural burning.
5. **Miscellaneous**-natural sources i.e. forest fires, volcanic eruptions.

1.2.3 Classification of Air Pollutants

1.2.3.1Based on Origin

1. **Primary Pollutants:** These are directly emitted into the atmosphere. The important primary pollutants are–oxides of sulfur (SO_2), oxides of carbon (CO, CO_2), oxides of

nitrogen (NO, NO_2, NO_3), volatile organic compounds (VOC), suspended particulate matters (SPM). Example-NO_2 is produced directly from the vehicular emissions.

2. **Secondary Pollutants**: The primary pollutants reacts with one another or is presence of sunlight and water to form new pollutants, for example sulfuric acid (H_2SO_4) formed by the chemical reaction of SO_2 and H_2O, ozone (O_3) formed by the photo-chemical reaction in between hydrocarbon (HC) and NO.

1.2.3.2 Based on the State of Matter

1. **Particulates:** These are finely divided solids (dust, smoke, fumes, and fly ash) and liquid droplets (mist, spray).

2. **Gaseous:** These forms of pollutants do not settle in the atmosphere and occupies the space and behaves as air when released into the ambient air.

1.2.3.3 Based on Chemical Composition

1. **Organic Pollutants:** The pollutants which are composed of carbon and hydrogen. Organic pollutants, in turn, may be natural or synthetic. The natural organic pollutants are those of biological origin and synthetic organic pollutants are pollutants from manufactured products or non-biological origin. These include hydrocarbons (benzene, butane, etc.), aldehydes and ketones.

2. **Inorganic Pollutants:** They are of inorganic nature which includes-oxides of sulfur, oxides of carbon, oxides of nitrogen, other inorganics (e.g. H_2S, HF, NH_3).

1.2.3.4 Based on the Tendency to Cause Cancer

1. **Carcinogenic pollutants**: The pollutants which causes cancer.

2. **Non-Carcinogenic pollutants**: These are the pollutants which do not directly cause cancer.

1.2.4 Criteria Air Pollutants (CAP)

USEPA has established national ambient air quality standards (NAAQS) under the Clean Air Act for monitoring the emissions, concentrations and the effects of six of the most common air pollutants—carbon monoxide (CO), lead (Pb), tropospheric ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) - known as “criteria” air pollutants or simply “criteria pollutants”. The USEPA has set primary NAAQS to protect public health and secondary NAAQS to protect public welfare from adverse effects of criteria pollutants, this also includes the protection against visibility impairment, or damage to animals, vegetation, or properties.

1.2.5 National Ambient Air Quality Standards (NAAQS), India

In India National Ambient Air Quality Standards (NAAQS) was established by the Central Pollution Control Board on April 11, 1994 which was notified in Gazette of India, Extra-ordinary Part-II Section 3, sub section (ii), dated May 20, 1994. After amendments in the year 1994 and 1998 the latest version was published in the year 2009; which enlisted 12 criteria pollutants. Table-1.1 states the NAAQS, 2009. Although mercury has not been notified as a part of these revised standards, research and development in standards setting and standardization of monitoring protocols for mercury is still in progress internationally

Table 1.1 National Ambient Air Quality Standards, 2009 (CPCB, 2009)

Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
		Industrial, Residential, Rural and Other Areas	Ecologically Sensitive Area	
Sulfur Dioxide (SO_2), µg/m^3	Annual * 24 Hours**	50 80	20 80	-Improved West and Gaeke Method -Ultraviolet Fluorescence
Nitrogen Dioxide (NO_2), µg/m^3	Annual * 24 Hours**	40 80	30 80	-Jacob & Hochheiser Modified (NaOH-$NaAsO_2$) Method -Gas Phase Chemiluminescence
Particulate Matter (Size less than 10µm) or PM_{10}, µg/m^3	Annual * 24 Hours**	60 100	60 100	-Gravimetric -TEOM -Beta attenuation
Particulate Matter (Size less than 2.5µm) or $PM_{2.5}$, µg/m^3	Annual * 24 Hours**	40 60	40 60	-Gravimetric -TEOM -Beta attenuation
Ozone (O_3) µg/m^3	8 Hours * 1 Hours **	100 180	100 180	UV Photometric -Chemiluminescence -Chemical Method
Lead (Pb) µg/m^3	Annual * 24 Hours**	0.50 1.0	0.50 1.0	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper -ED-XRF using Teflon filter
Carbon Monoxide (CO), mg/m^3	8 Hours * 1 Hours **	02 04	02 04	-Non dispersive Infrared (NDIR) Spectroscopy
Ammonia (NH_3),µg/m^3	Annual * 24 Hours**	100 400	100 400	-Chemiluminescence -Indophenol blue method
Benzene (C_6H_6), µg/m^3	Annual *	05	05	-Gas Chromatography (GC) based continuous analyzer -Adsorption and desorption followed by GC analysis
Benzo(a)Pyrene (BaP) Particulate phase only, ng/m^3	Annual *	01	01	-Solvent extraction followed by HPLC/GC analysis
Arsenic (As), ng/m^3	Annual *	06	06	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
Nickel (Ni), ng/m^3	Annual *	20	20	-AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper

*Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform interval.

** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring

1.2.6 Particulate Matter

1.2.6.1 Definition

Particulate matter or PM is sum of all the microscopic solids and/or liquid droplets suspended in Earth's atmosphere many of which are hazardous**.**

1.2.6.2 Constituents

This complex mixture includes both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets etc. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye whereas others are so small they can only be detected using an electron microscope.

1.2.6.3 Sources

1. Natural sources

Natural sources could be volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray are some are the most prominent sources.

2. Anthropogenic sources

Burning of fossil fuels in vehicles, burning of coal in power plants and various industrial processes, also generate significant amounts of particulates. Currently, anthropogenic sources account for about 10 % of the total mass of aerosols in our atmosphere.

1.2.6.4 Size variation of PMs

Particulate air pollution is a mixture of solid, liquid or solid and liquid particles suspended in the air. These suspended particles vary in size, composition and origin.

It is convenient to classify particles by their aerodynamic properties because:

(a) These properties govern the transport and removal of particles from the air

(b) They also govern their deposition within the respiratory system and

(c) They are associated with the chemical composition and sources of particles.

These properties are conveniently summarized by the aerodynamic diameter, i.e. the size of a unit-density sphere with the same aerodynamic characteristics. Particles are sampled and described on the basis of their aerodynamic diameter, usually called simply the particle size.

Mass and composition of PM in urban environments tend to be divided into two principal groups

1. Coarse particles: $PM_{2.5}$ < PM of particles size <PM_{10} are the coarse PMs

2. Fine particles: $PM_{2.5}$ and less are the fine PMs

PM_{10}: Inhalable particles, with diameters that are generally 10 micrometres and smaller.

$PM_{2.5}$: Fine inhalable particles, with diameters that are generally 2.5 micrometres and smaller.

1.2.6.5 Significance of particle size

The smaller particles contain the secondarily formed aerosols (gas-to-particle conversion), combustion particles and re-condensed organic and metal vapours. The larger particles usually contain earth crust materials and fugitive dust from roads and industries whereas the fine fraction contains most of the acidity (hydrogen ion) and mutagenic activity of particulate matter, although some coarse acid droplets are also present in fog.

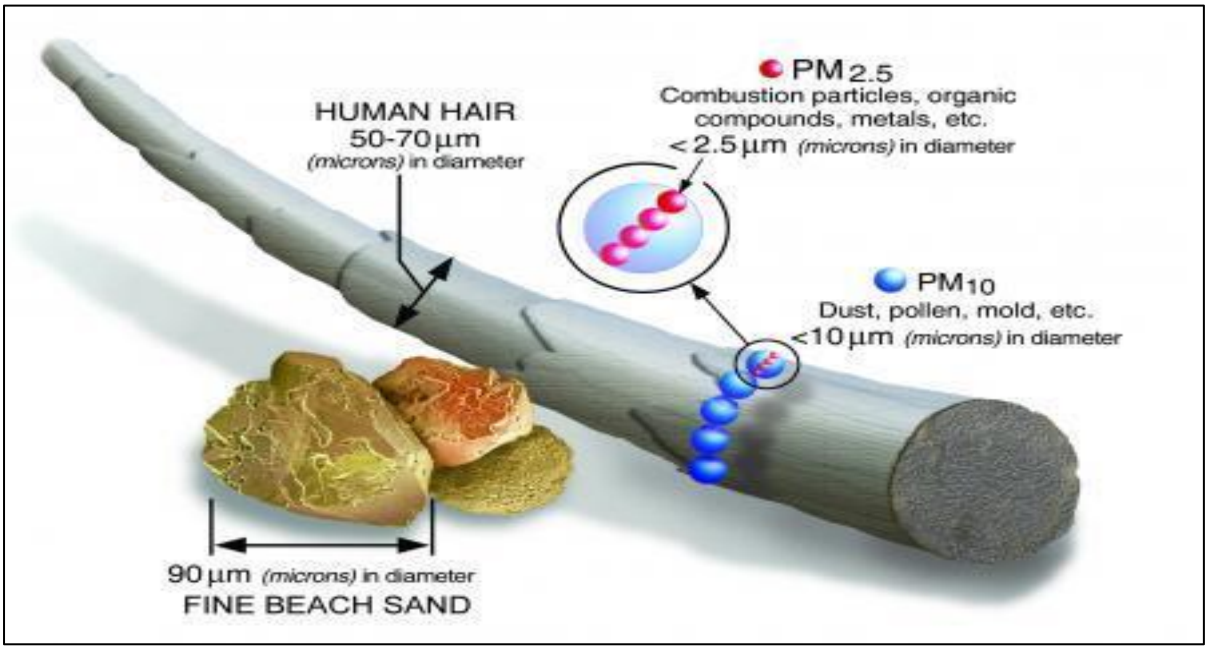

Fig1.1: Size range of Coarse, Fine & ultra-fine particulates

The average human hair is about 70 micrometres in diameter that means PM_{10} is 1/7th of our hair whereas $PM_{2.5}$ is nearly 1/28th of the our hair.

1.2.6.6 Effects of Particulate Matter (PM)

- ❖ **Human Health Effects**

The potential for causing health problems is directly linked to the size of the particles. Small particles (less than 10 micrometres in diameter) pose the greatest problems, because they reaches deep into lungs, and some may even get into bloodstreams.

Exposure to such particles can affect both lungs and heart. Numerous scientific studies have shown results showing particle pollution exposure to a variety of problems, including:

- Premature death.
- Nonfatal heart attacks
- Irregular heartbeat
- Aggravated asthma

- Chronic obstructive pulmonary diseases (umbrella term for several progressive lung diseases), decreased lung function and lung cancer
- Increased respiratory symptoms, such as irritation of the airways, coughing or difficulty in breathing.

People with heart or lung diseases, older adults and children are most likely to be affected by particle pollution exposure.

❖ **Environmental Effects**

1. Visibility impairment

Fine particles ($PM_{2.5}$) are the main cause of reduced visibility

2. Environmental damage

Particulate matter can be carried over long distances by wind and then settle on ground or water and depending on their chemical composition, the effects of this settling may include:

- making lakes and streams acidic
- changing the nutrient balance in coastal waters and large river basins
- depleting the nutrients in soil
- damaging sensitive forests and farm crops
- affecting the diversity of ecosystems
- contributing to acid rain effects.

3. Materials damage: Particulate matter can stain and damage stone and other materials, including objects which are culturally important such as statues and monuments. Some of these effects are related to acid rain effects on materials.

1.2.7 Air Quality Index (AQI)

The Air Quality Index (AQI) is an index used by the governmental agencies for reporting the daily air quality. The National Air Quality Index (AQI) was launched in New Delhi on 17th of September, 2014 under the recommendation of an Expert advisory committee and IIT Kanpur. Central Pollution Control Board (CPCB) along with the State pollution Control Boards operates the National Air Monitoring Program (NAMP) which covers 240 cities in the country.

There are six AQI categories proposed for eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb). The six categories of AQI are: Good, Satisfactory, Moderately polluted, Poor, Very poor and severe. The standard concentration for the eight pollutants on the basis of 24-hourly averaging period is provided by the NAAQS (2009), India. Based on the measured concentration of the ambient pollutant corresponding standards and the health impacts, the sub-index is calculated for each of the pollutants. The maximum AQI which reflects the worst sub-index will indicate the overall AQI.

Table 1.2 mentions the AQI Category, Pollutants and the Health Breakpoints and Table 2.4 provides with the associated health effects

Table 1.2: AQI Category, pollutants and health breakpoints (Press Information, 2014)

AQI Category (Range)	PM_{10} (24 HR)	$PM_{2.5}$ (24 HR)	NO_2	O_3	CO	SO_2	NH_3	Pb
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5-1.0
Moderately Polluted (101-200)	101-250	61-90	81-180	101-168	2.1-10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very Poor (301-400)	351-430	121-250	281-400	209-748	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430+	250+	400+	748+	34+	1600+	1800+	3.5+

Table 1.3: AQI category and its associated health impacts (Press Information, 2014)

AQI	ASSOCIATED HEALTH IMPACTS
Good (0-50)	Minimal impact
Satisfactory (51-100)	May cause minor breathing discomfort to sensitive people
Moderately Polluted (101-200)	May cause discomfort to people with lung disease such as asthma, and discomfort to people with heart disease, children and older adults
Poor (201-300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease
Very Poor (301-400)	May cause respiratory illness to people on prolonged exposure. Effect may be more pronounced in people with lung and heart disease
Severe (401-500)	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during physical activity

CHAPTER-2 REVIEW OF LITERATURES

The purpose of literature review is to describe the background knowledge of the study. This chapter will include critical points of the current knowledge which will include the substantial findings, theoretical and methodological contributions on the present topic under consideration. The subject matter of the current study has been classified into three different perspectives viz. global, national and regional.

2.1 Global Scenario

2.1.1 Temporal, spatial and meteorological variations in hourly $PM_{2.5}$ concentration extremes in New York City (Arthur T. DeGaetano *et al.*, 2004)

- Variations in the extreme percentiles of empirical hourly $PM_{2.5}$ concentration distributions from high-density network of 20 stations within New York City are statistically analyzed.
- Significant diurnal, seasonal and day-of-week variations are noted, with the highest concentrations typically found between 7:00 and 9:00 a.m., during summer, and on weekdays.
- The lowest concentrations are generally found during early morning hours (4:00–6:00 a.m.), in winter and on weekends.
- The diurnal and day-of-week patterns suggest that although anthropogenic factors may be primarily responsible for the observed diurnal cycle, meteorological conditions also have some influence.

2.1.2 Seasonal and diurnal variations of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} in the roadside environment of Hong Kong (Y. Cheng *et al.*, 2006)

- $PM_{1.0}$, $PM_{2.5}$ and PM_{10} were measured at 24-hour intervals near a high-traffic road in Hong Kong, from October 2004 to September 2005.
- Mass concentrations were determined for the three particle fractions, averaging 44.5±18.4, 55.4±25.5 and 81.3±37.7 $\mu g/m^3$ for $PM_{1.0}$, $PM_{2.5}$ and PM_{10}, respectively.
- PM2.5 was 3.7 times the U.S. EPA's annual NAAQS of 15 $\mu g/m^3$.
- Overall, $PM_{1.0}$ accounted for 44 to 69% (average 57%) of PM_{10}, while $PM_{2.5}$ accounted for 58 to 82% (average 71%) in this study.
- The particulate masses showed obvious seasonal patterns with high concentrations in cold seasons and low in warm seasons, especially high concentrations of $PM_{2.5}$ and PM_{10} during the cold seasons.
- Diurnal variations of mass concentrations of $PM_{2.5}$ were determined during July, showing two major peaks in the morning and afternoon rush hours

2.1.3 Spatial and temporal variations in traffic-related particulate matter at New York City high schools (Molini M. Patel *et al.*, 2010)

- The purpose of this study was to examine the influences of diesel traffic proximity and intensity on ambient concentrations of fine particulate matter ($PM_{2.5}$) and black carbon (BC), an indicator of diesel exhaust particles, at New York City (NYC) high schools.

- Outdoor $PM_{2.5}$ and BC were monitored continuously for 4–6 weeks at each of 3 NYC high schools and 1 suburban school. Traffic count data were obtained using an automated traffic counter or video camera.
- $PM_{2.5}$ concentrations were significantly higher at urban schools than at the suburban school, but concentrations did not vary significantly among urban schools.
- Both hourly average counts of trucks and buses and meteorological factors such as wind direction, wind speed, and humidity were found to be significantly associated with hourly average ambient BC and $PM_{2.5}$ concentrations in multivariate regression models.
- The results of the study suggest that local diesel vehicle traffic may be important sources of airborne fine particles in dense urban areas and consequently may contribute to local variations in $PM_{2.5}$ concentrations.

2.1.4 Influence of meteorological factors and emission sources on spatial and temporal variations of PM_{10} concentrations in Istanbul metropolitan area (Yurdanur S. Unal *et al.*, 2011)

- PM_{10} concentration data were collected at 10 stations for the period of 2005–2009 by Air Quality Section of Istanbul Municipality.
- Analysis was done for spatial and temporal variations of the pollutants and their possible sources in the urban zones of the city.
- PM_{10} concentrations in Istanbul showed significant variations across the city, with PM10 levels at several traffic hot points and industrial zones were exceeding EC air quality limit.
- The general temporal pattern was characterized by high concentrations in winter and low in summer.
- The number of exceedences allowed by the EU was surpassed at all monitoring sites during the analyzed years which reflect the serious pollution problem in the city.

2.1.5 Temporal and spatial distribution of $PM_{2.5}$ and PM_{10} pollution status and the correlation of particulate matters and meteorological factors during winter and spring in Beijing (Zhao CX *et al.*, 2014)

- 30 monitoring stations were selected which were recording the concentration of $PM_{2.5}$ and PM_{10} all over Beijing.
- The contamination characteristics of particulate matters were analyzed to determine the characteristics of temporal and spatial pollution variations of $PM_{2.5}$ and PM_{10}.
- The distribution of $PM_{2.5}$ and PM_{10} mass concentration in winter and spring in Beijing were derived by the Original Kriging interpolation method, and it was depicted from the figure that the concentration of particulate matters gradually increased from the northern mountain area to the southern part of Beijing.
- In the central urban area, the particulate concentration of the western region was generally higher than that of the eastern region,
- Monthly variation curve of $PM_{2.5}$ and PM_{10} mass concentration showed single peak-valley pattern: the maximum was in January and the minimum was in April;
- Daily variation indicated a good correlation between $PM_{2.5}$ and PM_{10}, both of which were significantly influenced by meteorological conditions;
- Diurnal variation curve showed a double peak-valley type.
- Meteorological factors such as daily average temperature (ºC), relative humidity (%), wind speed (wind scale), and precipitation (mm) were chosen and their individual

relationships with concentrations of PM_{10} and $PM_{2.5}$ were investigated using Spearman rank correlation analyses.

- It was demonstrated that the concentrations of PM_{10} and $PM_{2.5}$ were positively correlated with temperature and relative humidity, respectively, and strongly negatively correlated with wind speed;
- Wind speed and relative humidity were two key factors affecting the distributions of PM_{10} and $PM_{2.5}$ concentration.

2.1.6 Spatial and temporal variation of particulate matter and gaseous pollutants in 26 cities in China (Fahe Chai *et al.*, 2014)

- The spatial and temporal variations of the air pollutants were investigated in 26 pilot cities in China from August 2011 to February 2012.
- Hourly averaged SO_2, NO_2 and PM_{10} were observed in 26 cities, and the pollutants O_3, CO and $PM_{2.5}$ were measured in 15 of the 26 cities. The concentrations of SO_2 and CO were much higher in the cities in north China than those in the south.
- It was found that Fine particles account for a large proportion of airborne particles, with the ratio of $PM_{2.5}$ to PM_{10} ranging from 55% to 77%.
- The concentrations of $PM_{2.5}$ (57.5 μg/m^3) and PM_{10} (91.2 μg/m^3) were much higher than the values ($PM_{2.5}$: 11.2 μg/m^3; PM_{10}: 35.6 μg/m^3) recommended by the World Health Organization.

2.1.7 Spatial and temporal variation of particulate matter and gaseous pollutants in China during 2014-2016 (Rui Li *et al.*, 2017)

- The data of $PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3 in 187 Chinese cities during January 2014 and November 2016 were collected to analyze the spatial and temporal variation of the pollutants in China.
- It was found that the annual mean concentrations of $PM_{2.5}$ exceeded the Grade I standard of Chinese Ambient Air Quality (CAAQS) for all of the cities except several cities in Hainan, and more than 100 cities exceeded the CAAQS Grade II standard.
- The concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO and NO_2 decreased from 2014 to 2016, during this period.
- The concentrations of $PM_{2.5}$, PM_{10}, SO_2, CO and NO_2 exhibited the highest levels in winter and the lowest in summer, and evidently decreased from 2014 to 2016.
- Pearson correlation analysis indicated that all of the pollutants exhibited significant correlation with one another.
- PM_{10} was to be a major pollutant affecting the air quality of China in all of the seasons. The impacts of PM_{10} and NO_2 on the air quality increased from the east to the west of China.

2.1.8 Spatial–seasonal characteristics and critical impact factors of $PM_{2.5}$ concentration in the Beijing–Tianjin–Hebei (BTH) urban agglomeration (Tianhang Huang *et al.*, 2018)

- The Beijing–Tianjin–Hebei (BTH) urban agglomeration is China's political and economic centre which was reportedly experiencing serious particulate matter (PM) pollution, which was resulting in fundamental or irreparable damages in various socioeconomic aspects.
- This study was conducted to investigate on the seasonal and spatial distribution characteristics of $PM_{2.5}$ concentration in the BTH urban agglomeration and their critical impact factors.

- Spatial interpolation are used to analyze the real-time monitoring of $PM_{2.5}$ data in BTH from December 2013 to May 2017, and partial least squares regression is applied to investigate the latest data of potential polluting variables in 2015.
- Variation was found to be existing amongst $PM_{2.5}$ concentrations in different seasons
  1. January (133.10 mg/m^3) and December (120.19 mg/m^3) are the most polluted months,
  2. Whereas, July (38.76 mg/m^3) and August (41.31 mg/m^3) are the least polluted months.
  3. $PM_{2.5}$ concentration shows a periodic U-shaped variation pattern with high pollution levels in autumn and winter and low levels in spring and summer.
- In terms of spatial distribution characteristics, it was found that south and east of the BTH urban agglomeration were most polluted areas whereas, $PM_{2.5}$ concentration is significantly low in the north of BTH urban agglomeration.
- Empirical results demonstrate that the deterioration of $PM_{2.5}$ concentration in 2015 is closely related to a set of critical impact factors, including population density, urbanization rate, road freight volume, secondary industry gross domestic product, overall energy consumption and industrial pollutants, such as steel production and volume of sulphur dioxide emission, which are ranked in terms of their contributing powers.

2.1.9 Temporal and spatial variation of particulate matter and its correlation with other criteria of air pollutants in Lanzhou, China, in spring-summer periods (Mikalai Filonchyk *et al.*, 2018)

- This study was based on data received from 5 ground-based air-quality monitoring stations for major atmospheric pollutants and satellite sounding which provides for the use of Moderate Resolution Imaging Spectro-radiometer (MODIS) to study aerosol optical depth on the territory of the city of Lanzhou, Gansu Province.
- Data were received in the spring-summer period of 2014–2017.
- The present paper was intended to analyze the mass concentrations and spatial-temporal variation of $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 and O_3 in the city.
- When comparing and averaging the daily, monthly, and annual pollutants concentrations, it was revealed that the average $PM_{2.5}$ and PM_{10} concentrations exceeded the Chinese Ambient Air Quality Standards (CAAQS) and were 42.37 and 112.67μg/m^3, respectively.
- Of all studied days, 62.5% showed high $PM_{2.5}$ concentration, and 78.2% - high PM_{10} concentration.
- $PM_{2.5}$ and PM_{10} demonstrated a strong correlation (R^2=0.81) with $PM_{2.5}$ being about 37% of PM_{10} which indicates that decrease of PM_{10} emissions is very critical for reducing pollution with PM and thus for improving the air quality in China.

2.1.10 Spatial and Temporal Variations of PM_{10} in Chittagong City, Bangladesh (Amina Sadia *et al.*, 2018)

- Concentration of PM_{10} was measured by high volume air sampler from six sampling sites in the city.
- Differences in the monthly concentrations of PM_{10} were observed monthly
- The mean annual average of PM_{10} at all sampling sites was many times higher than the standard of Bangladesh and WHO.

2.2 Indian Scenario

2.2.1 Analysis and interpretation of particulate matter–PM_{10}, $PM_{2.5}$ and PM_1 emissions from the heterogeneous traffic near an urban roadway (Srimuruganandam *et al., 2010)*

- Diurnal, weekly and seasonal cycles of 1–h average particulate matter (PM_{10}, $PM_{2.5}$ and PM_1) had been analyzed and interpreted.
- Concentrations were measured near an urban roadway in Chennai city, India, between November 2007 and May 2008.
- In diurnal cycle, highest PM concentrations were observed during weekday's peak hour traffic and lowest PM concentrations were found during trickle traffic (afternoon and night time).
- The seasonal PM data analysis showed highest concentrations during post monsoon season (PM_{10} = 189, $PM_{2.5}$ = 84, PM_1 = 66 μg/m^3) compared to winter (PM_{10} = 135, $PM_{2.5}$ = 73, PM_1 = 59 μg/m^3) and summer (PM_{10} = 102, $PM_{2.5}$ = 50, PM_1 = 34 μg/m^3) seasons.
- The frequency distribution of PM_{10} concentrations during post–monsoon and winter seasons indicated that the PM_{10} values at the study site fall under moderate to poor categories.
- During post–monsoon and winter seasons, it was found that more than 50% of the time the 24–h average PM_{10} concentrations were violating the Indian national ambient air quality standards (NAAQS) (100 μg/m^3) and world health organization (WHO) standard (50 μg/m^3).
- The 24–h average $PM_{2.5}$ concentrations were also exceeding the NAAQS (60 μg/m^3) and WHO standards (25 μg/m^3) by 75% of time, irrespective of seasons.

2.2.2 Influence of vehicular traffic on urban air quality – A case study of Hyderabad, India (Sharma *et al.*, 2010)

- In the present study, impact of vehicular traffic emissions on black carbon aerosol mass concentration, trace gases and ground reaching solar radiation were analyzed during nationwide truck strike of 5–12 January, 2009 over urban environment of Hyderabad, India.
- A significant reduction of about 57%, 60%, 40% and 50% was observed in black carbon, particulate matter, carbon monoxide and ozone respectively during nationwide truck strike period.

2.2.3 Source apportionment of particulate matter in the ambient air of Hyderabad city, India (Gummeneni *et al.*, 2011)

- In this study Source apportionment of particulate matter (PM) had been carried out for the city of Hyderabad using the chemical mass balance model (CMB8, Ver. 8.0) in PM_{10} and $PM_{2.5}$ size modes.
- Urban particles were collected during June 2004–May 2005 during different seasons from Punjagutta site, a critical traffic corridor using Continuous Particulate Matter Analyzer.

- The measurement of PM_{10} and $PM_{2.5}$ at the site is measured throughout the day. Samples were collected in every 15 min; additionally instrument computes the total mass accumulation for every 30 min, 1-h, 8-h and 24 h average mass concentrations.
- Chemical characterization of PM_{10} and $PM_{2.5}$ was done by ICP-MS.
- Source apportionment studies were carried out to quantify the possible sources affecting region using CMB Model Ver. 8.0. The CMB8 executed separately for both coarse and fine sizes.
- Results obtained by CMB indicate the dominance of re-suspended dust (40%), followed by vehicular pollution (22%), combustion (12%), industrial (9%) and refuse burning (7%) in PM_{10}; while in $PM_{2.5}$ vehicular pollution (31%) dominated over re-suspended dust (26%), combustion (9%), industrial (7%) and refuse burning (6%).

2.2.4 Size distribution and seasonal variation of size-segregated particulate matter in the ambient air of Raipur city, India (Deshmukh *et al.*, 2012)

- In this study, size-segregated particulate matter samples were collected in Raipur, India by using eight-stage cascade impactor sampler from July 2009 to June 2010.
- The annual average concentrations and associated standard deviation of PM_{10}, $PM_{2.5–10}$, $PM_{2.5}$, and PM_1 were 270.5±105.5, 119.6±44.6, 150.9±78.6, and 72.5±39.0 µg/m^3, respectively.
- The PM_{10} and $PM_{2.5}$ concentration levels at Raipur, India were found to be well above the annual National Ambient Air Quality Standards of India of 60 and 40 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.
- Particulate matter concentrations in winter were found out to be higher than those in summer and monsoon.
- Increased energy use and dry atmospheric conditions contributed to increasing particulate matter concentrations in winter, while increased rainfall precipitation contributed to decreasing particulate matter levels in the monsoon.
- Spearman correlation analysis between PM_{10} and $PM_{2.5}$ revealed high correlation coefficients (r^2=0.85), implying that PM_{10} and $PM_{2.5}$ may have the same source of regions or that they are influenced by the same local conditions.
- The highest monthly values of air quality index occur in winter and spring whereas they are reduced in summer and monsoon.
- The analysis showed that 25% of the days was unhealthy for sensitive people, 47.4% was unhealthy or very unhealthy, while 4.1% was considered as hazardous.

2.2.5 Temporal Variation of Particulate Matter (PM) and Potential Sources at an Urban Site of Udaipur in Western India (Yadav *et al.*, 2014)

- In this study measurements of mass concentrations of particulate matters (PM_{10} and $PM_{2.5}$) and mixing ratio of carbon monoxide (CO) were made at an urban site of Udaipur (24.58°N, 73.68°E) in India from April 2010 to March 2011.
- Concentrations of $PM_{2.5}$, PM_{10} and CO show strong diurnal and seasonal variations. The highest concentrations coincide with the rush traffic and lower nocturnal boundary layer depth.
- The lowest concentrations in the afternoon hours are attributed to the dilution caused by higher boundary layer height and reduced traffic. The levels of trace constituents

during the weekend were significantly reduced compared to the weekdays of observations.

- The daily $PM_{2.5}$, PM_{10} and CO varied in the large ranges of 8–111 µg/m^3, 28–350 µg/m^3 and 145–795 ppb, respectively.
- $PM_{2.5}$ and CO show strong seasonality with higher and lower values during winter and monsoon seasons, respectively, while PM_{10} shows highest value during the pre-monsoon season. Flow of cleaner marine air and negligible biomass burning resulted in lower values in the monsoon season. Long-rang transport and extensive biomass burning caused higher values in winter and pre-monsoon seasons.
- The mass concentration of $PM_{2.5}$ tends to decrease with the increasing wind speed, while PM_{10} increases with wind speed.

2.2.6 Impact of meteorological parameters on the development of fine and coarse particles over Delhi (Trivedi *et al.,* 2014)

- Measurements of ambient particulate matters (viz., PM_{10} and $PM_{2.5}$) were made with an hourly sampling frequency at Indian Institute of Tropical Meteorology (IITM), New Delhi Branch (a residential area) during a period from December 2010 to November 2011.
- Analysis was done to understand frequency distribution of PM_{10} and $PM_{2.5}$ concentrations and the impact of meteorological parameters on the distribution of particulate matters on different time scales.
- It is found that the PM_{10} preferentially occurred in the concentration range of
    1. 301–350 µg/m^{3}during winter and post-monsoon,
    2. 251–300 µg/m^{3}during summer
    3. 51–100 µg/m^{3}during monsoon season.
- $PM_{2.5}$ preferentially occurred in the concentration range of
    1. 201–250 µg/m^3 during winter and
    2. 51–100 µg/m^{3}during the remaining seasons.
- The concentration of particulate matters (PM_{10} and $PM_{2.5}$) remained always above the National Ambient Air Quality Standards (NAAQS) except during monsoon season.
- Annual distribution of the concentration of particulate matters showed seasonality with maximum in winter and minimum in monsoon season.
- Diurnal variation of PM_{10} and $PM_{2.5}$ showed bimodal distribution with one maximum in the forenoon and the other at around mid-night.
- The observed seasonality and diurnal variability in the distribution are attributed mainly to the meteorology.

2.3 Kolkata's Scenario

2.3.1. Seasonal Variations of PM_{10} and TSP in Residential and Industrial Sites in an Urban Area of Kolkata, India (Karar *et al.,* 2006)

- The objective of the study was to investigate seasonal and spatial variations of PM_{10} and TSP (total suspended particulate matter) from November 2003 to November 2004.

- Ambient concentration measurements of PM_{10} and TSP were carried out at two monitoring sites of an urban region of Kolkata. Monitoring sites had been selected based on the dominant activities of the area.
- Meteorological parameters such as wind speed and its direction, rainfall, temperature and relative humidity were also collected simultaneously during the sampling period from Indian Meteorological Department, Kolkata.
- The 24 h average concentrations of PM_{10} and TSP were found in the range 68.2–280.6 $\mu g/m^3$ and 139.3–580.3 $\mu g/m^3$ for residential (Kasba) area, while 62.4–401.2 $\mu g/m^3$ and 125.7–732.1 $\mu g/m^3$ for industrial (Cossipore) area, respectively.
- Winter concentrations of particulate pollutants were higher than other seasons, irrespective of the monitoring sites. It indicates a longer residence time of particulates in the atmosphere during winter season due to low wind speed and low mixing height.
- Spread of air pollution sources and non-uniform mixing conditions in an urban area often result in spatial variation of pollutant concentrations.
- The higher particulate pollution at industrial area may be attributed due to resuspension of road dust, soil dust, automobile traffic.

2.3.2 Spatio-temporal characteristics of gaseous and particulate pollutants in an urban region of Kolkata, India (Gupta *et al.*, 2008)

- Air quality monitoring was in an urban region of Kolkata, consisting of residential, commercial and industrial sites having high population density and pollution.
- Concentrations of ambient SO_2, NO_2, NH_3 and PM_{10} were measured once in a week for 24 h at selected residential and industrial sites and 8 h at a commercial site.
- The meteorological parameters (wind speed, wind direction, rainfall, temperature and relative humidity) were simultaneously collected from the Indian Meteorological Department, Kolkata.
- The daily average concentrations PM_{10} were observed to be 140.1 ± 43.1 $\mu g/m^3$ at the residential site and 196.6 ± 88.2 $\mu g/m^3$ at the industrial site, respectively. The corresponding (8 h average) values at the commercial site 276.1 ± 71.4 $\mu g/m^3$.
- Winter concentrations of ambient SO_2, NO_2, NH_3 and PM_{10} were observed to be higher irrespective of the monitoring sites and duration of sampling, suggesting longer residence times of these pollutants in the atmosphere during winter due to stagnant conditions and low mixing heights.
- Spearman's rank correlation analysis showed an inverse relationship between the measured gaseous and particulate pollutant concentrations with the observed wind speed, rainfall, temperature and relative humidity.
- The data were analyzed using varimax-rotated principal component analysis for the residential and industrial sites. The results show that local emissions dominate the concentration of SO_2, NO_2, NH_3, and PM_{10}.
- The major sources of emissions affecting this urban area, include mobile sources along with contributions from industrial sources, coal-fired power plants and domestic heating.

2.4 Research Gap

During literature review it has been found that there are not much data available on the recent spatio-temporal variation of particulate pollution in Kolkata. Also, there are not any study conducted related to air quality in terms of particulate pollution near some relatively sensitive areas viz. hospital, schools and educational institutions which concerns some most vulnerable group of people like patients, children and senior citizens. It has also been found that there are temporal variation in Kolkata but there isn't any study available which was conducted in recent years to know the current diurnal, monthly and seasonal variation and particulate concentration level during such variation. To bridge this gap, a comprehensive monitoring work for particulate pollution and hourly traffic volume during peak and non-peak traffic hours of the day needs to be conducted near Hospitals, school and college in South Kolkata.

CHAPTER 3 OBJECTIVE AND SCOPE OF THE STUDY

3.1 Objective of the Study

Air-borne fine particulates are one of the most threatening pollutants to human health in particular and environment as a whole. It has been confirmed that Particulate Matters (PM) can cause both acute and chronic health effect health problems, viz. stroke, heart disease, lung cancer, chronic obstructive pulmonary diseases (COPD), cardiovascular and cerebrovascular diseases and neurological disorders. Apart from health implications, particulates also affect visibility and it concentration in air varies spatially, diurnally and seasonally due to meteorological factors and vehicular traffic. This way air pollution due to particulate matter is now a prime concern for scientists, engineers, policy makers to take necessary and effective measures to control its increasing concentration and mitigate its effect by monitoring it continuously, finding its sources and studying its spatio-temporal variation.

The objective of this study can be summarized as:

"***To study the spatio-temporal variation of respirable and fine particulate matters in South Kolkata by monitoring air quality in terms of PM_{10} and $PM_{2.5}$ around some relatively sensitive locations like hospital, children's school and women's college***"

3.2 Scopes of the Study

The scope of the proposed research can be stated as:

1. Selection of monitoring site.

2. Monitoring of Particulate Matter ($PM_{2.5}$ and PM_{10}) near selected monitoring stations during peak traffic hour of morning and evening and non-peak traffic hour of afternoon.

3. Observation of diurnal variation of the particulate fractions ($PM_{2.5}$ and PM_{10}) with the hourly traffic volume.

4. Observation on seasonal variation.

5. Observation on spatial variation of $PM_{2.5}$ and PM_{10} of the particulate fractions ($PM_{2.5}$ and PM_{10})

6. Collection of temperature data simultaneously using sensor.

7. Conduction of statistical analysis for different parameters (concentration of PM, meteorological parameters and traffic volume) considered under the purview of the study to explore prevalence of any significant correlation among them.

8. Study of the air quality and its possible health implications in terms of AQI based on $PM_{2.5}$ and PM_{10} data.

CHAPTER 4 METHODOLOGY AND INSTRUMENTS

4.1 Methodology

4.1.1 Study Area

Kolkata (22°82'N latitude and 88°20'E) is located in the eastern part of India, with a population of 14.1 million making it the 7th most populous city in India **(Census, 2011).** The city is bounded by the Hooghly River to the west and northwest. The core area of the city has elevations ranging from 5 to 6 m above mean sea level **(Gupta et al., 2006).** Kolkata Municipal Corporation (KMC) covers an area of 187 km^2 and an area of 1,380 km^2 includes the urban agglomeration surrounding the KMC **(Gupta et al., 2006).** Kolkata experiences a tropical savannah climate with an annual mean temperature of 26.8°C with maximum temperatures exceeding 42°C **(Karar *et al.*, 2006).** The wet and dry tropical climate of Kolkata has three distinct seasons: summer, monsoons and winter.

The year is divided into following five seasons viz. summer (April- May), monsoon (June-Sept), post-monsoon or autumn (Oct-Nov), winter (Dec-Jan) and pre-monsoon or spring (Feb-Mar) (IMD, Kolkata Tourism). Average relative humidity (RH) is 66% and 69% in winter and summer, respectively and the south-westerly winds prevails in the pre-monsoon and monsoon seasons and moderate north-westerly winds prevails for most of the year. Kolkata being located in the coastal area is influenced by sea-based disturbances, and has an average wind speed of 2 km/hr blowing throughout the year **(Karar *et al.*, 2006).**

4.1.2 Selection of Site

It has been observed from the literatures of the various case studies reviewed that spatio-temporal variation of Particulates in terms of PM_{10} and $PM_{2.5}$ have not been observed in Kolkata city for a long time.

Hence, six very sensitive locations have been selected for the monitoring programme which includes four Hospitals, one Children school and a women’s College. The purpose of selecting these stations is to focus young girls, school going children and Hospital patients. Also these locations are located on different land use patterns so it will help understand the spatial variation of the particulate pollutant. The list of the selected monitoring stations has been given below in Table 4.1.

Table 4.1 Details of the selected monitoring stations in the South Kolkata.

Station Name	Location	Land use pattern	Latitude	Longitude
KPC Hospital	Jadavpur	Semi-public+ Commercial + Residential	22.494329°N	88.373345°E
Ruby Hospital	Ruby More	Commercial+ Public+ semi-public	22.513845°N	88.402938°E
Chittaranjan National Cancer Institute	Hazra	Commercial + Residential	22.525462°N	88.346681°E
Vidyasagar State General Hospital	Behala	Commercial + Residential	22.498958°N	88.315492°E
Lady Brabourne college	Park Circus	Commercial + Residential + Semi-public	22.545734°N	88.369378°E
Future Foundation School	Tollygunj	Residential	22.480730°N	88.353782°E

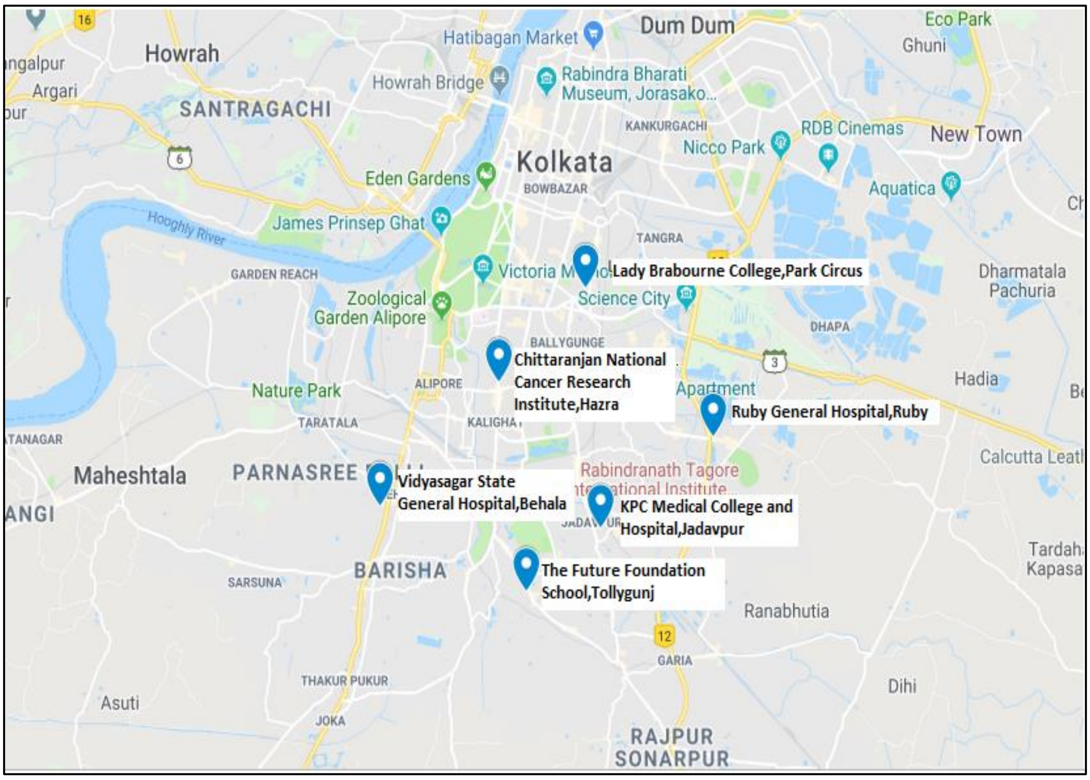

Figure 4.1: Location of monitoring stations on Google Map

4.1.3 Sampling Schedule

Monitoring for the concentration of $PM_{2.5}$ and PM_{10} were conducted simultaneously at all the stations from the month of October 2018 to April 2019 as the monitoring device used is capable of measuring $PM_{2.5}$ and PM_{10} simultaneously. To observe the effect of vehicular traffic and diurnal variation monitoring work was performed continuously during peak traffic hour of morning from 8 a.m. to 10 a.m., non-peak hour of traffic from 2 p.m. to 4 p.m. and again during peak traffic hour of 6 p.m. to 8 p.m. Monitoring device was placed at a height between 2 to 2.5 m at all the monitoring sites. It was ensured that the monitoring was conducted once in a month at all the locations and only on weekdays (Monday to Saturday). The meteorological data of temperature was also monitored using a sensor mounted on the monitoring device during all the monitoring sessions. During the study period a total of 126 monitoring sessions of 2 hours were conducted including all monitoring stations.

4.1.4 Traffic Volume Data

To know the effect of vehicular traffic on the level of $PM_{2.5}$ and PM_{10} concentration in ambient air an hourly traffic volume was counted. Number of cars, autos, buses/trucks and two wheelers were counted for a 15 minute interval and then interpolated for 1 hour. This is repeated every hour during the monitoring session of 2 hour and then hourly volume is reported in terms of Passengers Car Unit (PCU). Table 4.2 shows the PCU value for the considered vehicles in the traffic.

Table 4.2 PCU values for Car, Bus/truck, Bike and Auto (Indian Road Congress, (IRC))

Vehicle	PCU
Car	1
Bike	0.5
Auto	0.8
Bus/Truck	3.5

PCU = (no. of cars*1) + (no. of buses/trucks*3.5) + (no. of Autos*0.8) + (no of bikes*0.5)

4.2 Instruments

Since the monitoring stations are far away from each other so the requirement was to choose a monitoring device which is light weight and highly portable which can easily be carried without any damage. So in this regard a sensor based Particulate monitoring device was used which need a power source to be plugged in for continuous power supply so, a power bank was found to be best fit to serve this purpose.

4.2.1 Description of the device

Monitoring device used here has been setup to include a PM sensor (Nova PM Sensor) and a temperature sensor and runs on a "Raspberry pi" operating system.For every sensor a python program was written to collect the data from the sensor which in turns store data into a file which can easily be accessed later on from the device.

Raspberry Pi

Raspberry Pi is a low cost, credit-card sized computer. It has the ability to interact with the outside world, and has been used in a wide array of digital maker projects like in music machines, in parent detectors and in weather detection works.

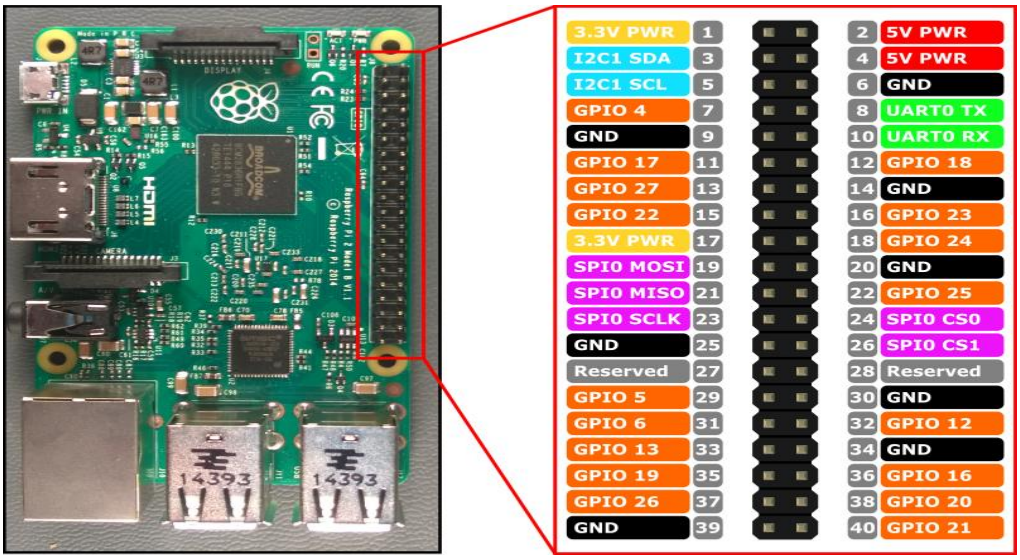

Figure 4.2: Raspberry Pi's motherboard

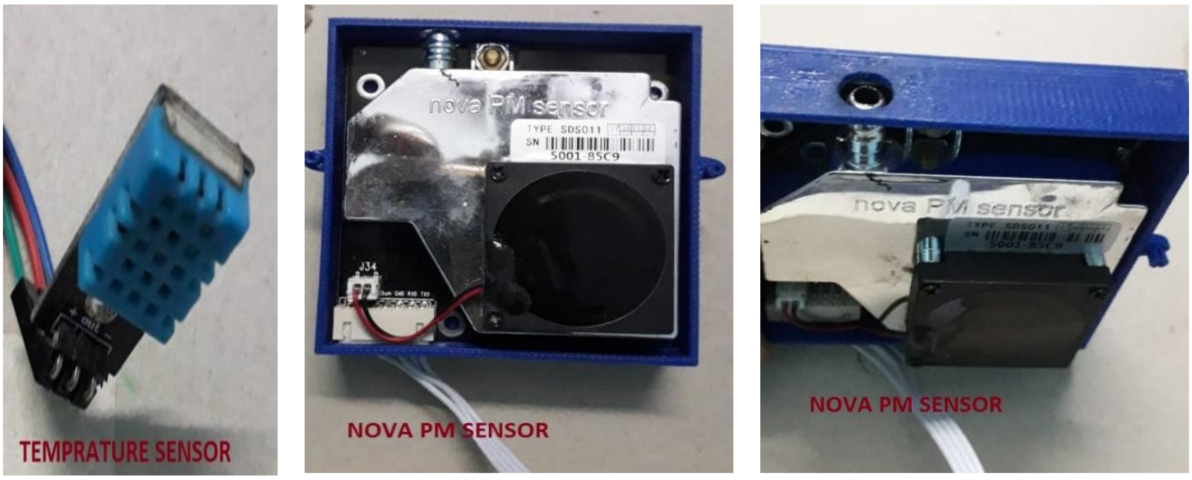

Figure 4.3: Image of temperature sensor and PM sensor in the instrument setup.

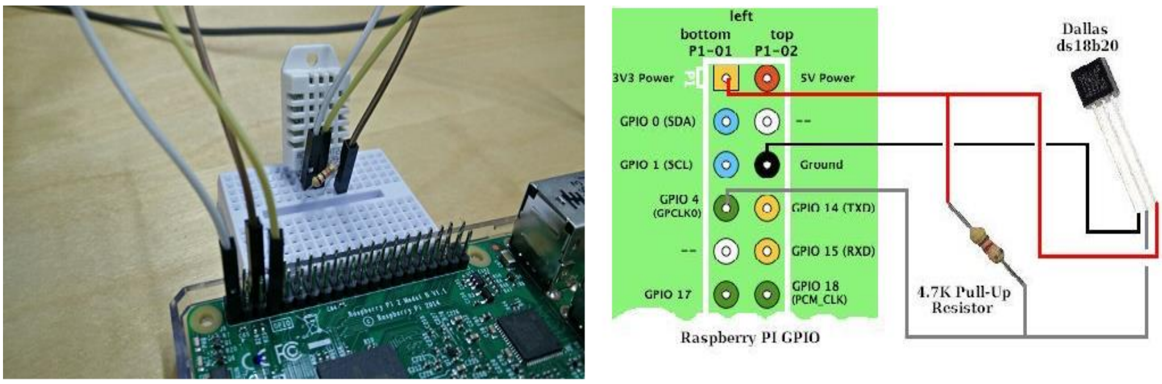

Figure 4.4: Raspberry Pi with temperature sensor circuit diagram

4.2.2 Specification of the Nova PM Sensor SDS 011

Nova PM Sensor SDS 011can get the particle concentration between 0.3 to 10 µm in the air. With digital output and built-in fan it is stable and reliable.

4.2.2.1 Working Principle:

The SDS011 uses principle of laser scattering. Light scattering induced when particles go through the detecting area. The scattered light is transformed into electrical signals and these signals will be amplified and processed. The number and diameter of particles can be obtained by analysis because the signal waveform has certain relations with the particles diameter.

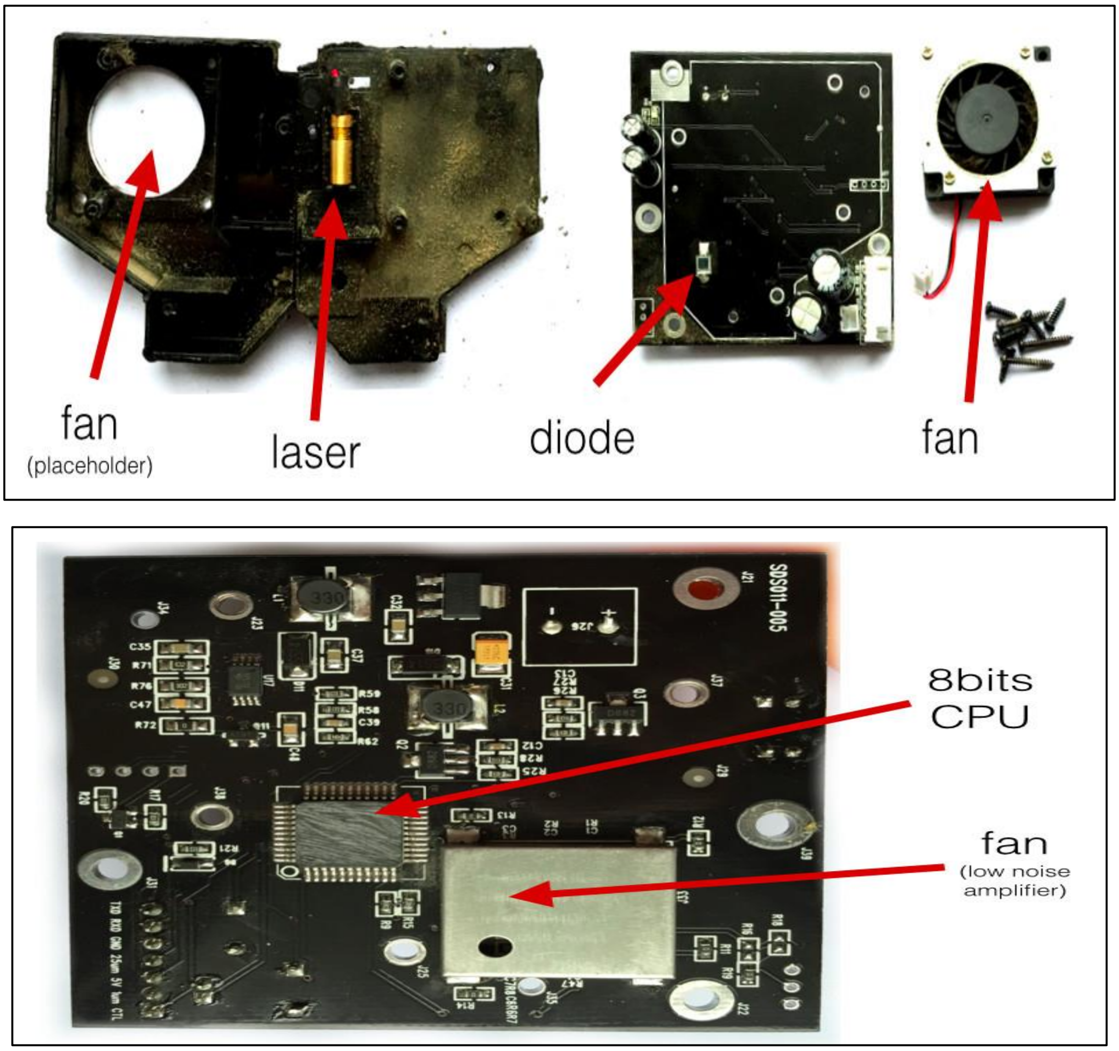

Figure 4.5: Inside image showing Laser, Fan and CPU of the NOVA PM Sensor

4.2.2.2 Technical Parameters of the Sensor

- Measuring output: $PM_{2.5}$,PM_{10}
- Range: 0.0-999.9 µg/m^3
- Power supply voltage: 5V
- Maximum working current: 100mA
- Sleep current: 2 mA

- Operating temperature range: -20-50℃
- Response time: 10 s
- Serial data output frequency 1 time/s
- Particle diameter resolution: Less than 0.3μm
- Relative error: 10%

4.2.2.3 Characteristics of Nova PM Sensor SDS011

- Accurate and Reliable: laser detection, stable, good consistency.
- Quick response: response time is less than 10 seconds when the scene changes.
- Easy integration: UART output (or IO output can be customized), built-in fan.
- High resolution: resolution of 0.3 μg/m^3.

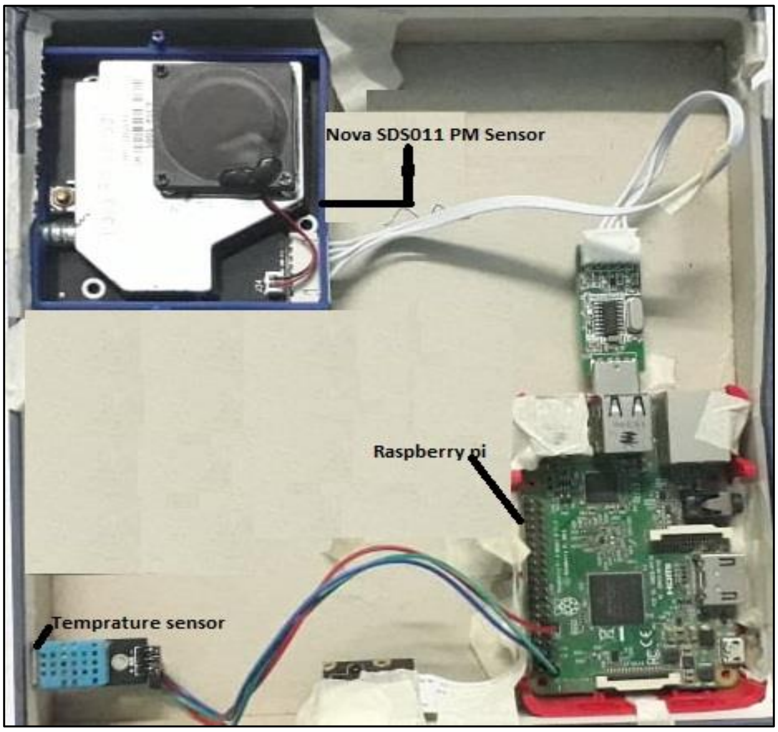

Figure 4.6 Complete setup of the Sensor based Instrument

4.2.3 Handling of the Instrument

Instrument is highly user friendly and can be used on a laptop or even on an Android or Apple handset. An application named "Mobile SSH" needs to be installed in the handset or PC which connects the handset or PC with the instrument using device's Wi-Fi and then one needs to enter user id and password to make the monitoring instrument to run to monitor and record the data. The PM sensor will sense the PM concentration level in the air which can be viewed on the screen of the connected handset or PC immediately.

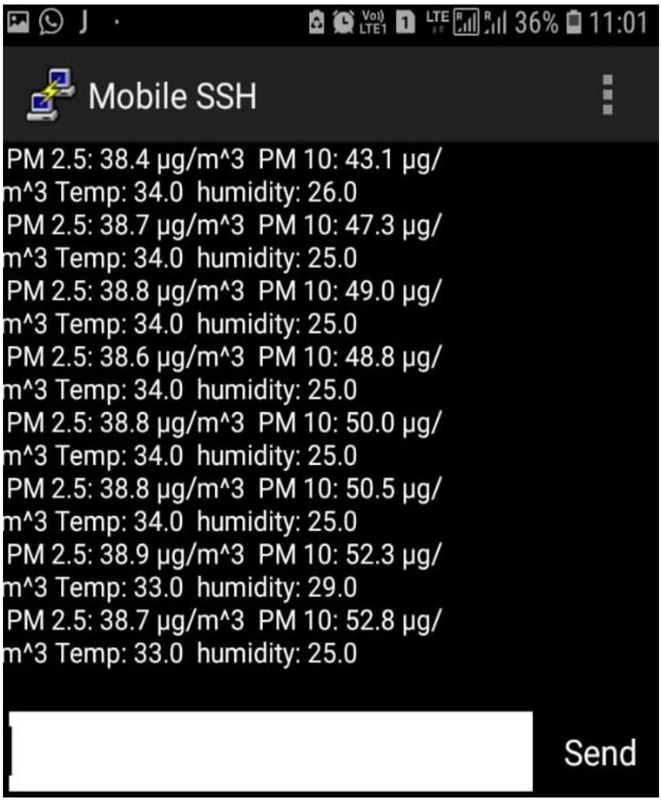

Figure 4.7 Sample image of the PM monitoring on an android handset.

CHAPTER-5 RESULTS AND DISCUSSION

The present study primarily involves assessment of the spatial and temporal variation of the concentration of particulate matter (PM_{10} and $PM_{2.5}$). The pollutant concentrations varies with the meteorological conditions like (wind speed, temperature, relative humidity, wind direction) and also with altitude and hourly vehicular traffic volume. For the purpose of the present study involving ascertainment of seasonal and temporal variation of respirable and fine particulates monitoring was done for particulate matter concentration ($PM_{2.5}$ and PM_{10}), meteorological data like temperature (°C) and hourly traffic volume. Various data were collected by conducting monitoring over three sessions of 2 hours each i.e. peak traffic hours of morning (8-10 A.M.) and evening (6-8 P.M.) and non-peak traffic hour of afternoon (2-4 P.M.), from October 2018 to April 2019; on weekdays (Mon-Sat) at six locations in South Kolkata as stated in Methodology and details of which are given in Table 4.1. Location of the monitoring sites on map has been provided in Fig 4.1. The summary of the month wise concentration of $PM_{2.5}$, PM_{10} on the monitored day along with temperature and traffic volume has been provided in Annexure- (Page no.57-63). As mentioned in the methods, particulate fractions (PM_{10} and $PM_{2.5}$) were monitored using a sensor based monitoring instrument as shown in figure 4.6.

Experimental Analysis

5.1 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature

Meteorological factors influence the diurnal variation of the particulates as found in various literatures (**Zhao CX *et al.,* 2014)**. In the present study, monitoring data collected for $PM_{2.5}$ and PM_{10} concentration during peak traffic hour of morning and evening and non-peak traffic hour of afternoon have been plotted along with temperature of the day on which data were collected for each of the six selected monitoring stations to investigate into the diurnal and monthly variation of the $PM_{2.5}$ and PM_{10} and its relation with temperature.

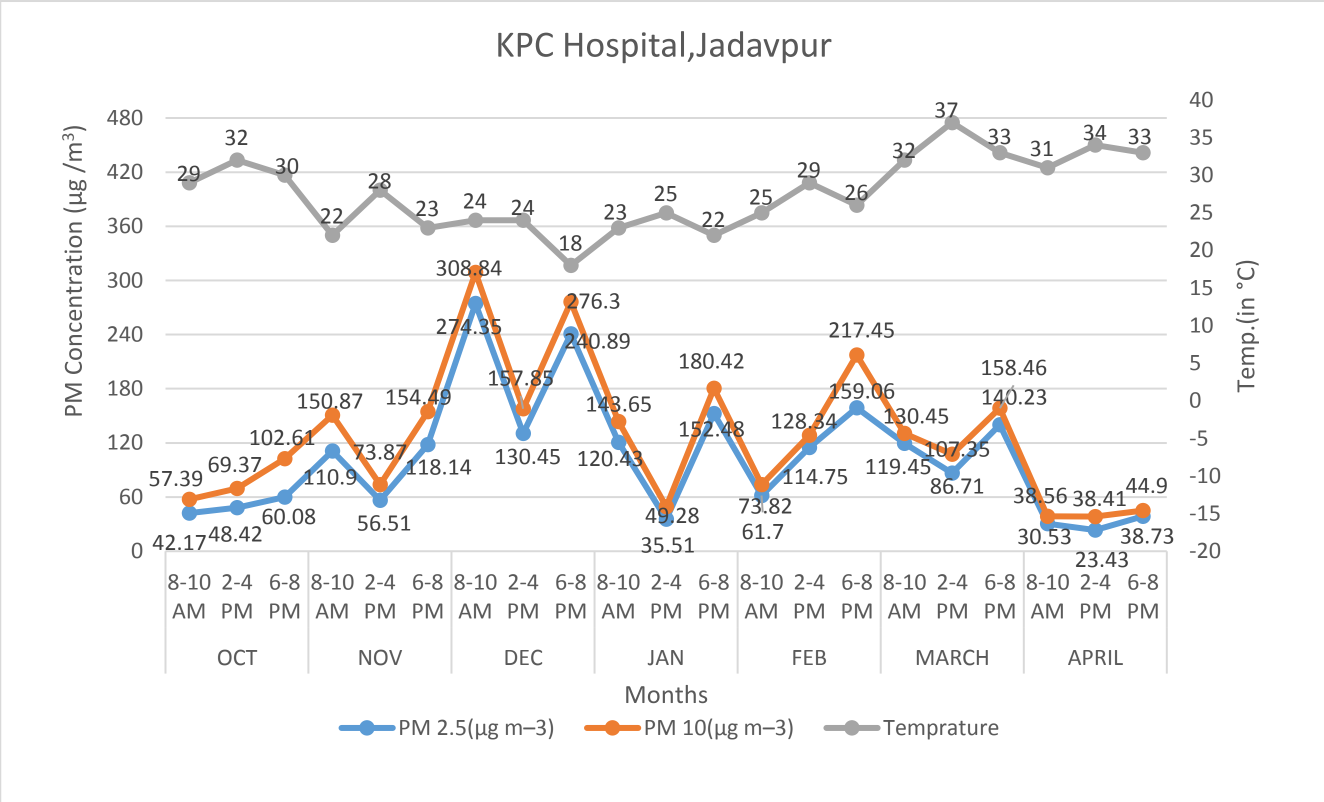

Figure 5.1 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Jadavpur

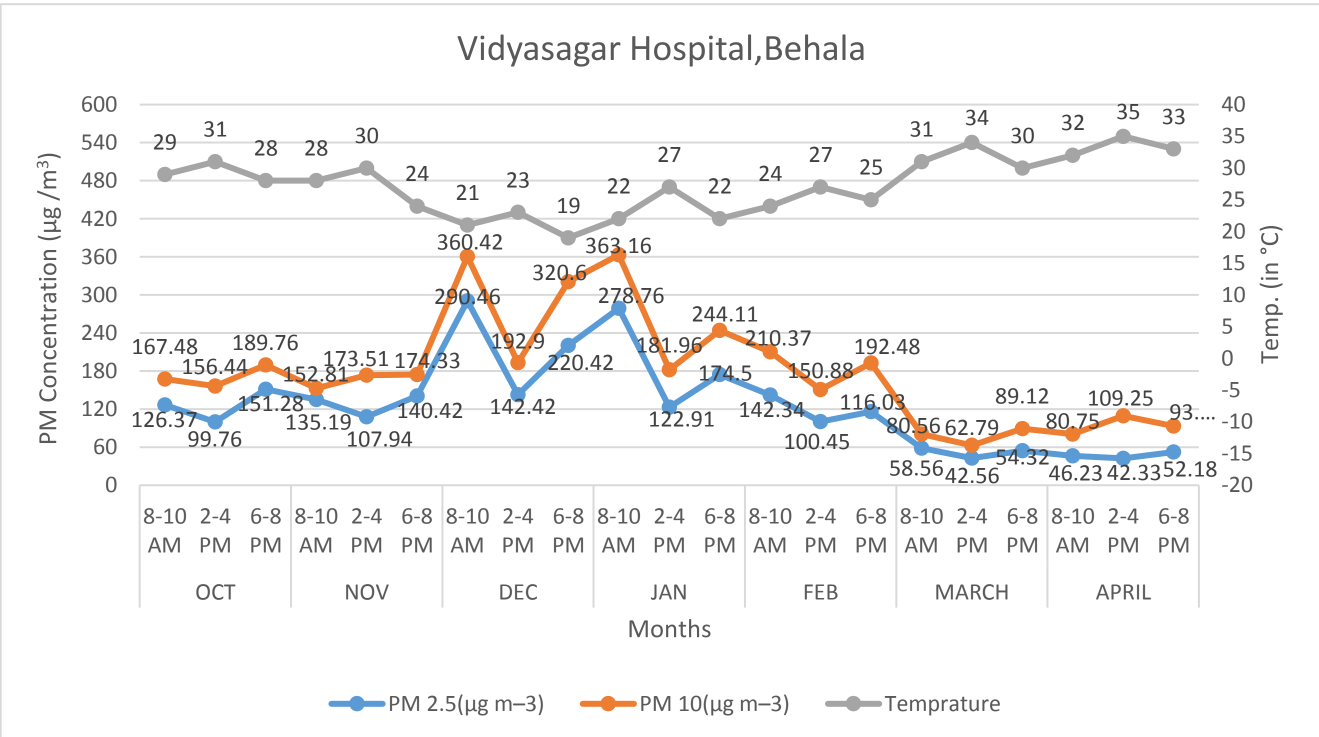

Figure 5.2 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Behala.

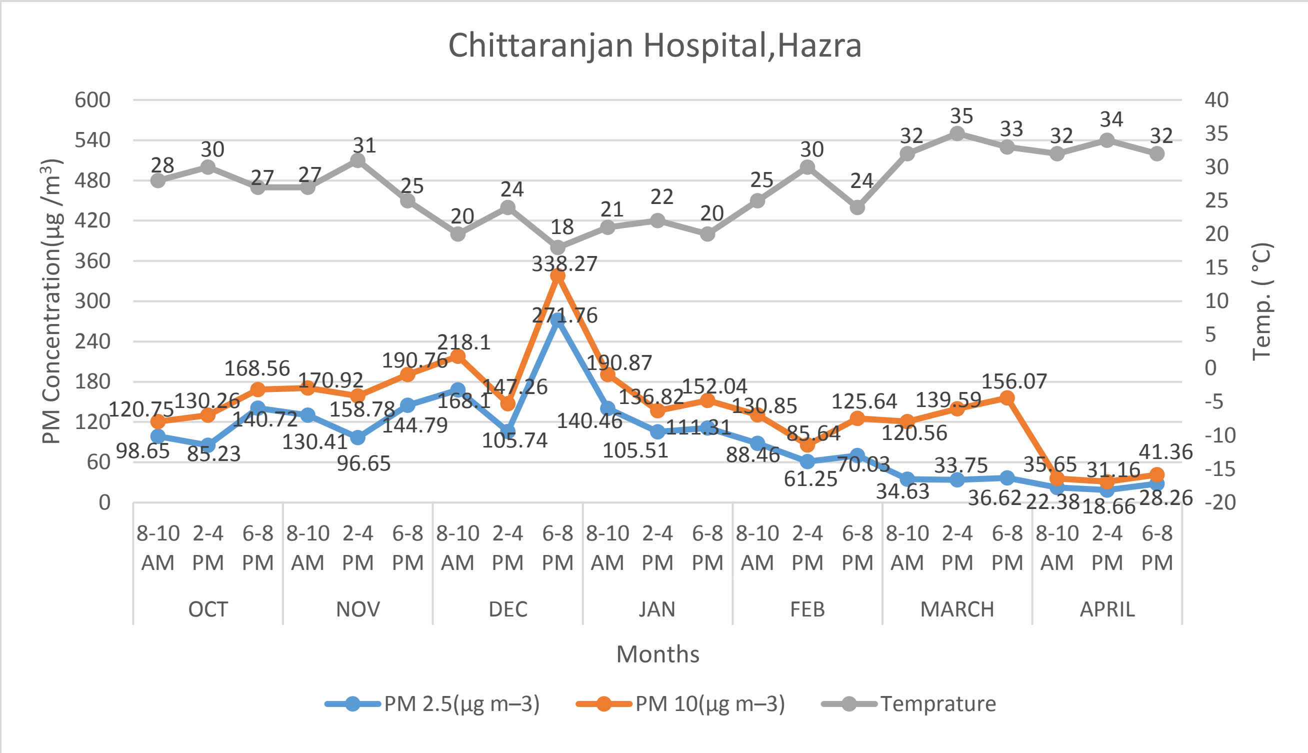

Figure 5.3 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Hazra

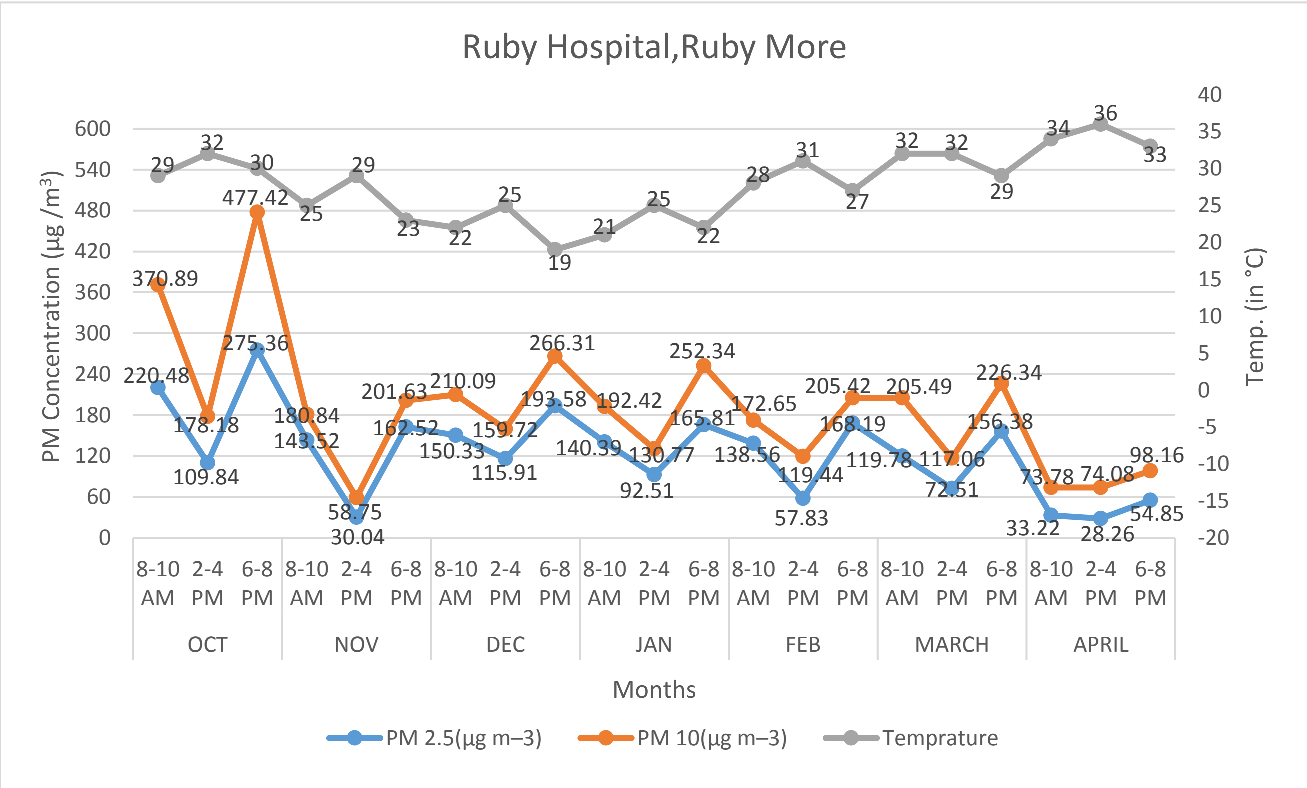

Figure 5.4 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Ruby More

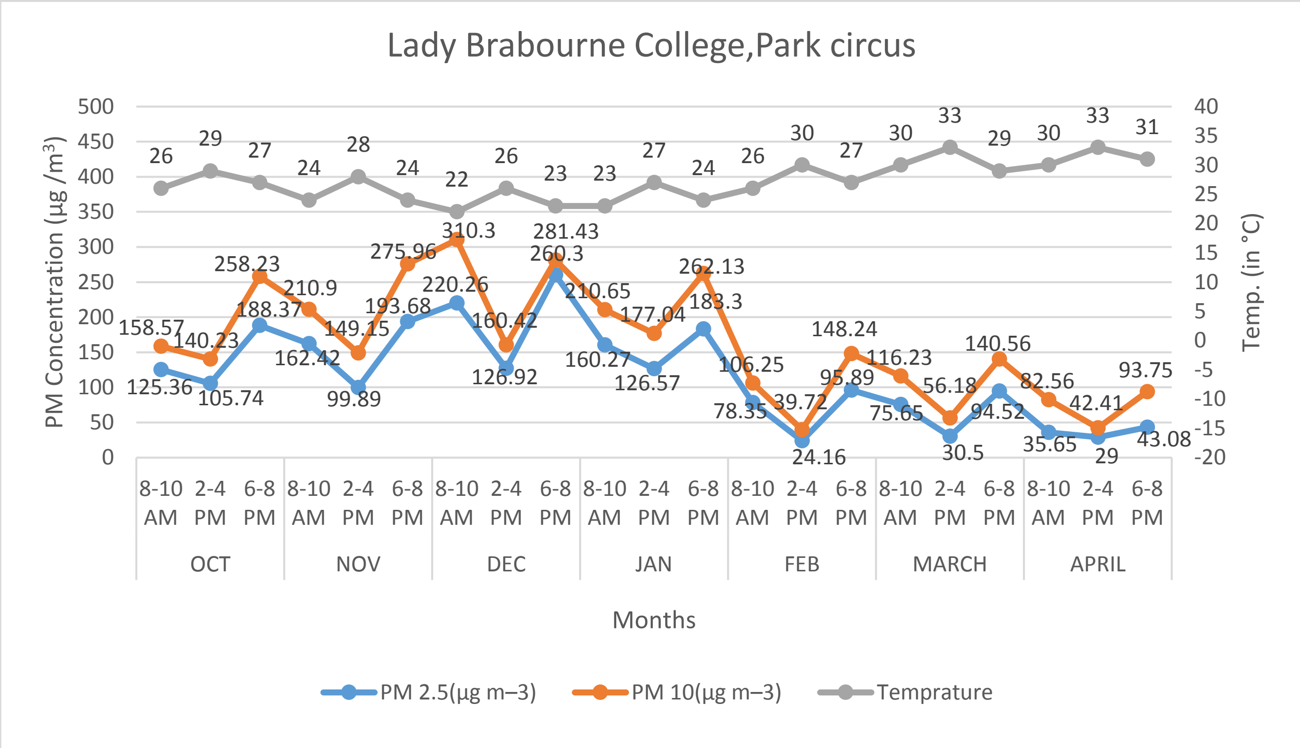

Figure 5.5 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Park Circus

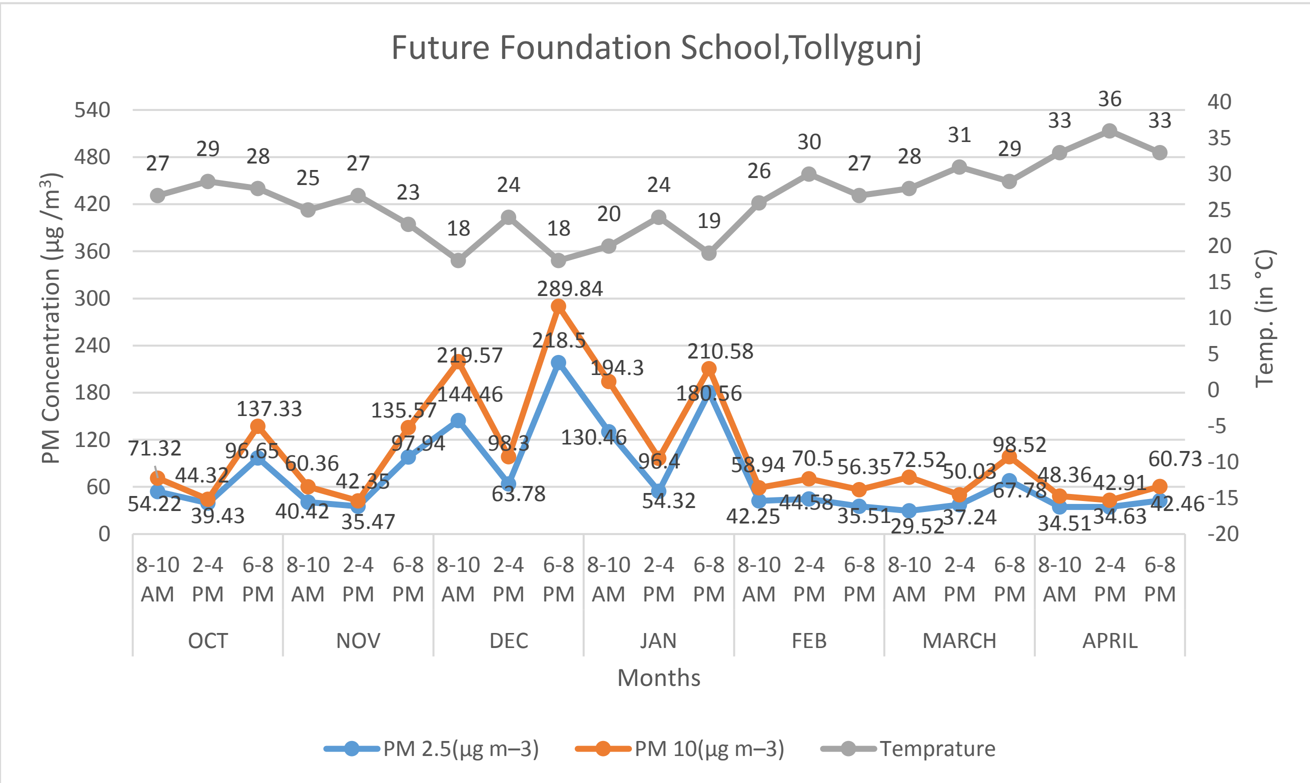

Figure 5.6 Diurnal and Monthly variation of $PM_{2.5}$ and PM_{10} with temperature at Tollygunj

5.1.1 General Observations

1. A clear diurnal variation can be observed throughout the monitoring period of October, 2018 to April, 2019 where, by and large, morning and evening has more PM (PM_{10} and $PM_{2.5}$) concentration than afternoon. Besides having lesser traffic volume during non-peak afternoon traffic hours, it can be attributed to higher afternoon temperature than those of morning and evening sessions which makes air warmer and hence dispersion of pollutants becomes easier. During morning session and more predominantly during evening with decreasing temperature the surface wind speed starts decreasing leading to occurrences of less intensive dispersion of pollutants.

2. December records for highest and April records for lowest $PM_{2.5}$ and PM_{10} concentration. $PM_{2.5}$ and PM_{10} concentration in April are within permissible daily average limits of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) as per NAAQS, 2009.

3. During the month of December, the observed values for $PM_{2.5}$ and PM_{10} concentration for morning, afternoon and evening are 3 to 4.5 times higher and concentration in afternoon is 1.5 to 2 times higher than the permissible daily average of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) as per NAAQS. The reason behind the observance of such a high concentration of particulates is that during winter with the decrease in temperature particularly during early morning and evening there are chances of formation of low level inversion layer wherein the upper atmosphere is warm and lower atmosphere is cool which results in nearly zero wind speed and hence a stable atmospheric condition prevails which causes no mixing of pollutants. In afternoon as temperature increases inversion layer breaks resulting in proper dispersion to take place and hence concentration of particulate decreases.

4. It can also be seen from the graphs that post monsoon season (October to November) and pre monsoon season (March to April) have less concentration compared to winter season (December to February).

5. Concentration of the particulate can be seen increasing from October through November reaching maximum during December and then decreasing through January to March and recording lowest in April. However, there are exceptions such as at Behala and Tollygunj, where concentration in the month of November has been found to be more than October which may be attributed to the land use pattern of these two locations or even due to more dominance of some meteorological factors other than temperature affecting dilution/dispersion..

6. It can be clearly seen diurnally and monthly that as temperature decreases concentration of particulates increases and vice-versa. This shows that particulate concentration ($PM_{2.5}$ and PM_{10}) is inversely related to temperature of the atmosphere.

5.1.2 Specific Observations

It can be observed that at Ruby More concentration of particulates was maximum during the month of October. It is because of heavy traffic movement in the area before the festival season of Durga Puja which is the biggest celebration of Kolkata and also metro railway construction was undergoing in the area during October. Consequently, vehicular pollutant emission might have increased the concentration of $PM_{2.5}$ and resuspension of road side dust and construction dust might have increased the concentration of PM_{10} during October.

5.2 Diurnal and Spatial variation of Particulates with hourly traffic volume (PCU/Hr.)

In this section diurnal and spatial variations of $PM_{2.5}$ and PM_{10} concentrations at different monitoring locations of South Kolkata have been analysed for every month over the study period of October 2018 to April 2019. For this purpose particulate concentration ($PM_{2.5}$ and PM_{10}) data of morning, afternoon and evening sessions for each station have been plotted together with the hourly traffic volume in terms of PCU for each month over the study period.

5.2.1 Analysis for the the month of October, 2018

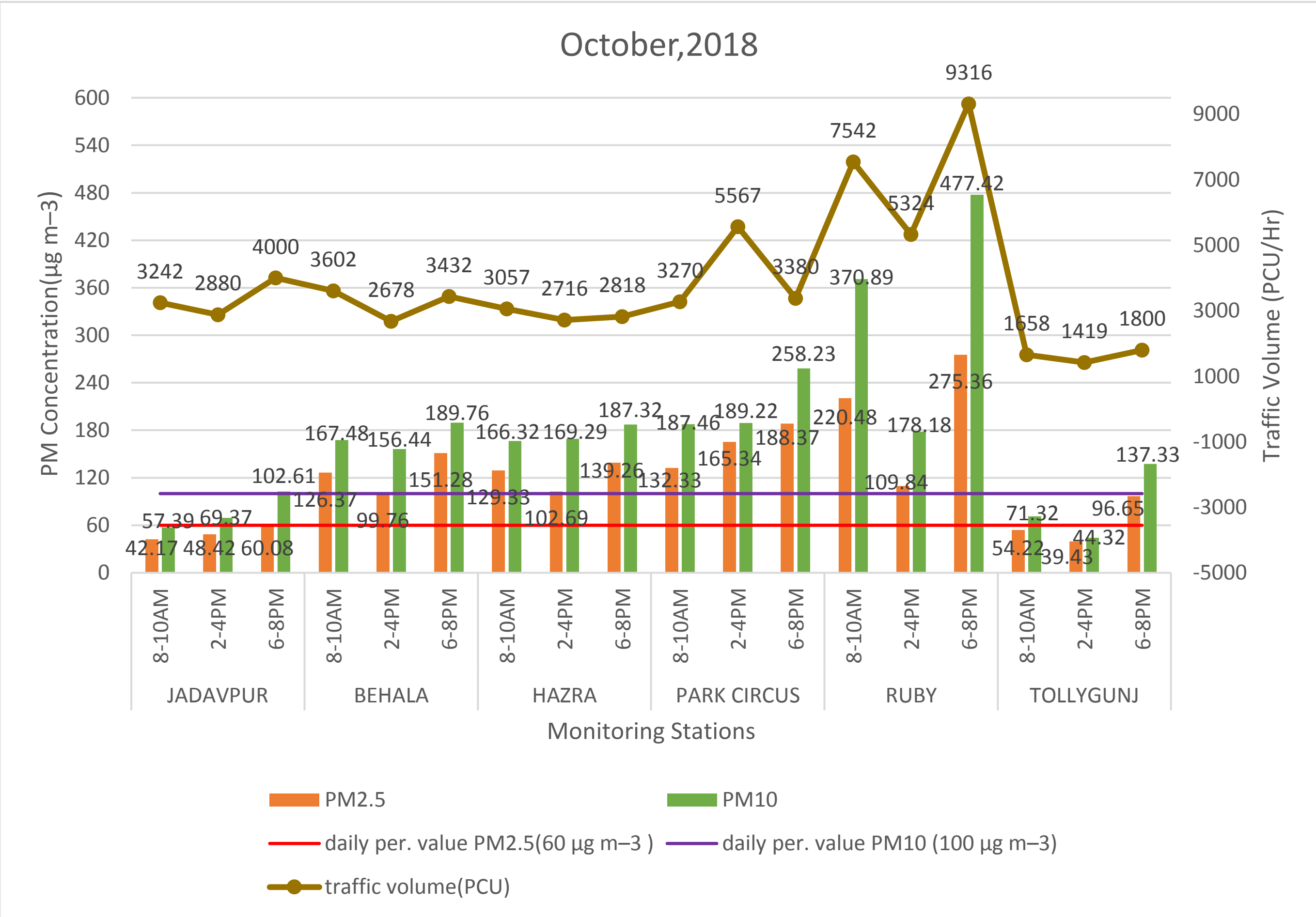

Figure 5.7 Diurnal and spatial variation with hourly traffic volume in October, 2018

1. $PM_{2.5}$ and PM_{10} concentrations at all the monitoring stations are well above the permissible daily average value of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) during all three sessions except Jadavpur and Tollygunj. Refer Table A 1.1

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low

compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Tollygunj recorded for the one of the lowest concentrations of particulates compared to other monitoring stations in month of October, which is justified by prevalence of lowest traffic volume at that monitoring spot. This can also be attributed to the shielding effect provided by trees present at relatively large numbers in and around the Tollygunj monitoring station.

4. Ruby More recorded for the highest particulate concentration which are approximately 3.5 times, 2 times and 4 times higher than the permissible daily average limits during morning, afternoon and evening respectively. Reason for such a high value at Ruby More is presence of high traffic volume before Durga Puja festival compared to other sites which resulted in high vehicular pollutant emission and suspension of road side dust in the air. Metro Railway related construction activities being continued near the Ruby More might have also added significant amount of construction dust to the ambient air.

5. Overall $PM_{2.5}$ concentration in October during morning, afternoon and evening are 0.8-3.6 times, 0.5-1.8 times and 1.6 to 3 times higher than the permissible daily average value of 60 µg/m³ respectively.

6. Overall PM_{10} concentration in October during morning, afternoon and evening are 0.6-3.7 times, 0.4-1.9 times and 1 to 4.7 times higher than the permissible daily average value of 100 µg/m³ respectively.

5.2.2 Analysis for the the month of November, 2018

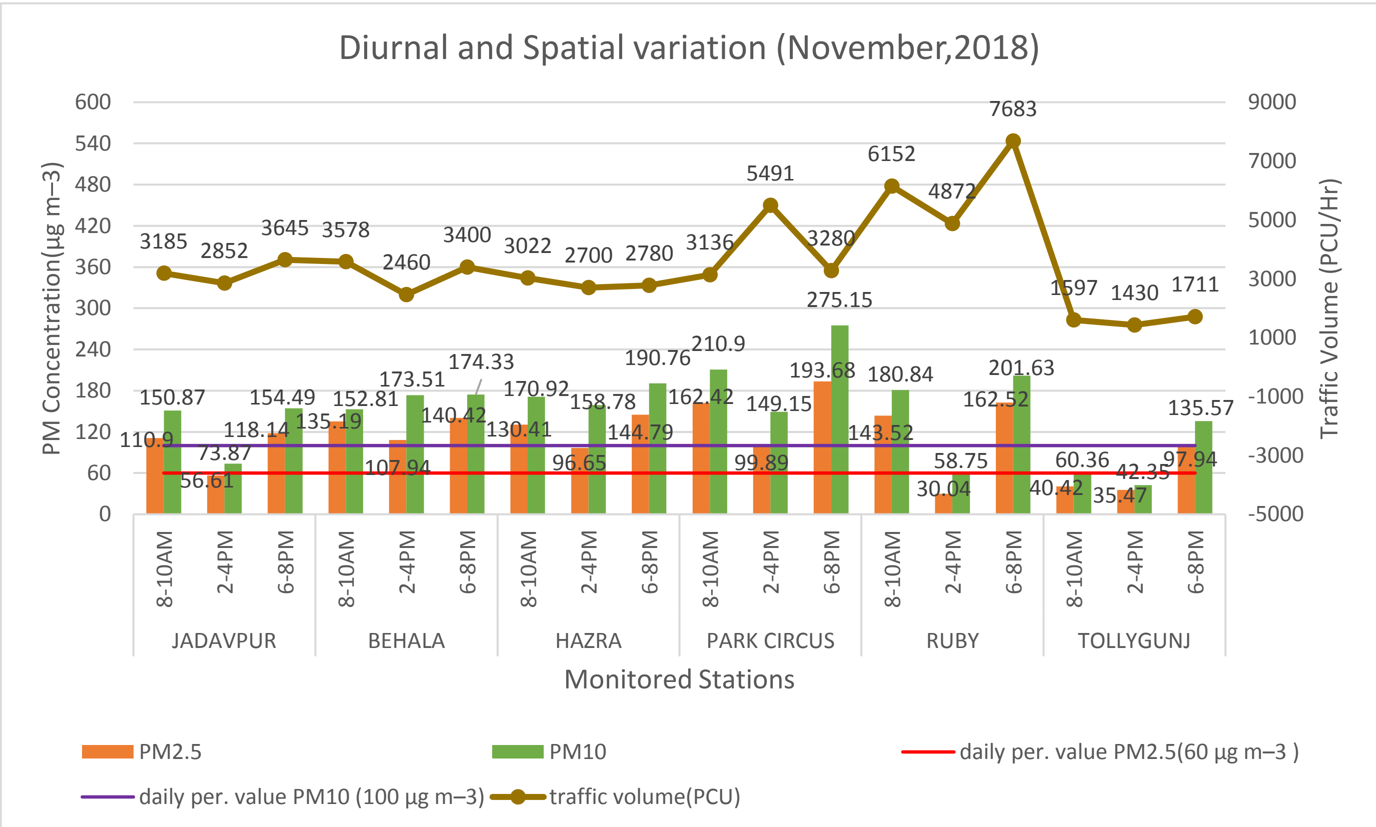

Figure 5.8 Diurnal and spatial variation with hourly traffic volume in November, 2018

1. $PM_{2.5}$ and PM_{10} concentration at all the monitoring stations are well above the permissible daily average value of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) in morning except Tollygunj, above permissible value except Jadavpur, Ruby and Tollygunj in afternoon, and above the permissible daily limit at all the monitoring stations in evening. Refer Table A 1.2

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Tollygunj recorded for the lowest concentrations of particulates compared to other monitoring stations in month November reason being the shielding effect provided by trees present at relatively large numbers in and around the Tollygunj monitoring station.

4. Monitoring station at Park Circus recorded for the highest concentration of particulates $PM_{2.5}$ and PM_{10}.

5. Overall $PM_{2.5}$ concentration in November during morning, afternoon and evening are 0.7-2.7 times, 0.5-1.8 times and 1.6 to 3 times higher than the permissible daily average value of 60 µg/m³ respectively.

6. Overall PM_{10} concentration in November during morning, afternoon and evening are 0.6-2 times, 0.4-1.7 times and 1.3 to 2.7 times higher than the permissible daily average value of 100 µg/m³ respectively.

5.2.3 Analysis for the the month of December, 2018

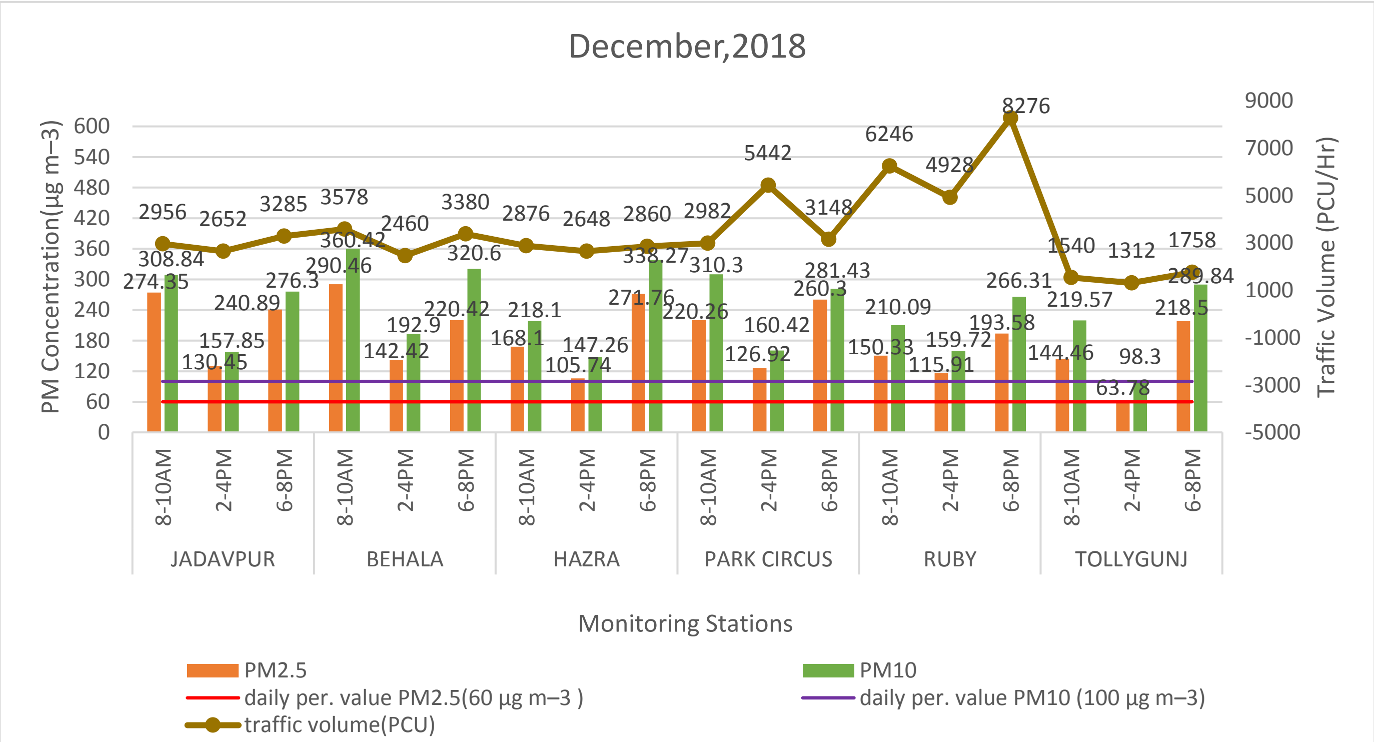

Figure 5.9 Diurnal and spatial variation with hourly traffic volume in December, 2018

1. $PM_{2.5}$ and PM_{10} concentration at all the monitoring stations are well above the permissible daily average value of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) during morning, afternoon. Refer Table A 1.3

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Tollygunj recorded for the lowest concentrations of particulates compared to other monitoring stations in month of December.

4. Behala recorded for the highest concentration of particulates ($PM_{2.5}$ and PM_{10}) during all the monitoring sessions of morning, afternoon and evening.

5. Overall $PM_{2.5}$ concentration in December during morning, afternoon and evening are 2.4-4.8 times, 1-1.3 times and 3 to 4.7 times higher than the permissible daily average value of 60 µg/m³ respectively.

6. Overall PM_{10} concentration in December during morning, afternoon and evening are 2.1-3.2 times, 1-1.9 times and 2.6 to 3.4 times higher than the permissible daily average value of 100 µg/m³ respectively.

5.2.4 Analysis for the the month of January, 2019

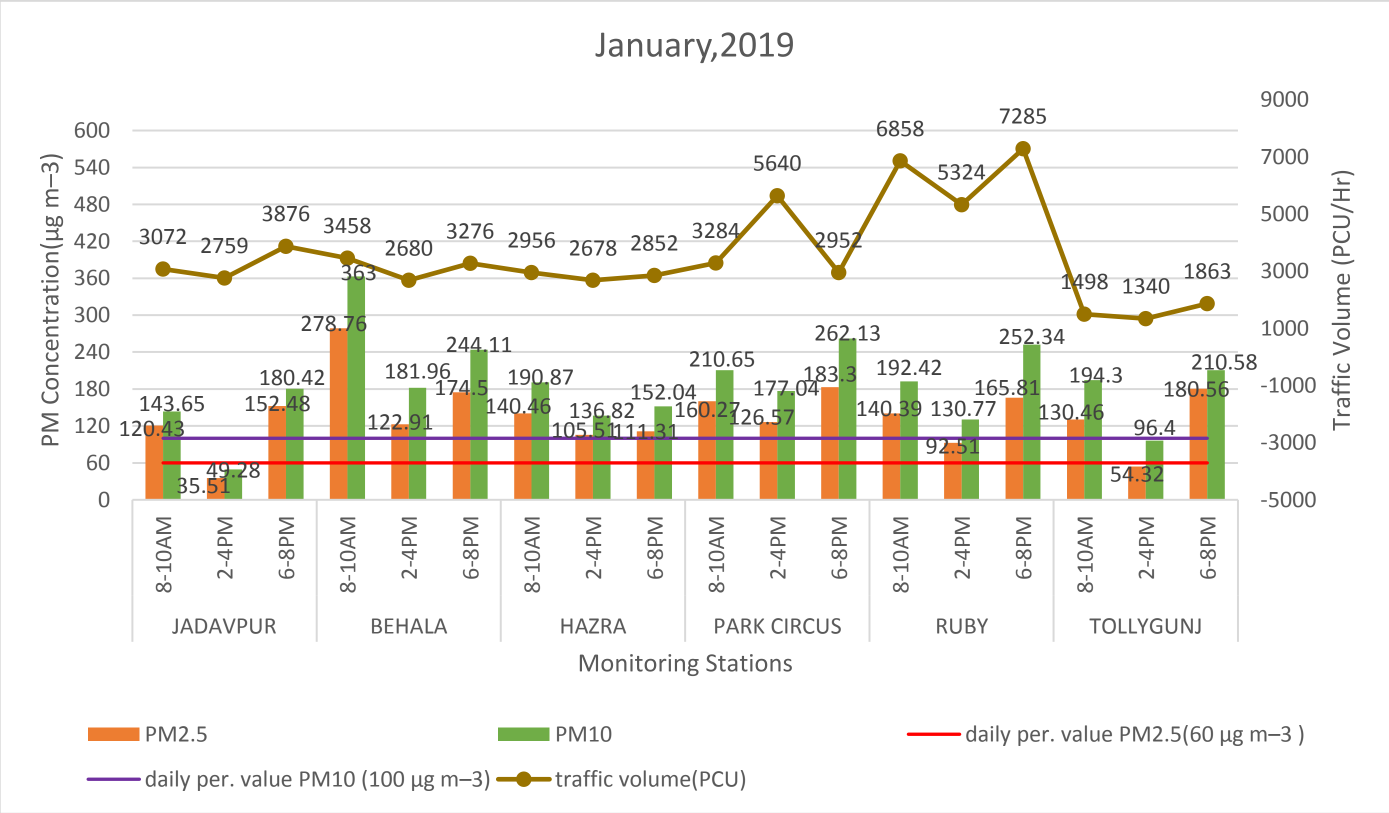

Figure 5.10 Diurnal and spatial variation with hourly traffic volume in January, 2019

1. $PM_{2.5}$ and PM_{10} concentration at all the monitoring stations are well above the daily average permissible value of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) during morning and evening monitoring sessions and above permissible values in afternoon except at Jadavpur and Tollygunj. Refer Table A 1.4

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Jadavpur recorded for the lowest concentration of particulates ($PM_{2.5}$ and PM_{10}) in the month of January.

4. Monitoring station at Behala recorded for the highest concentration of particulates ($PM_{2.5}$ and PM_{10}).

5. Overall $PM_{2.5}$ concentration in January during morning, afternoon and evening are 2-4 times, 0.9-2 times and 1.8 to 3 times higher than the permissible daily average value of 60 µg/m³.

5. Overall PM_{10} concentration in January during morning, afternoon and evening are 1.4-3.6 times, 0.5-1.8 times and 1.5 to 2.5 times higher than the permissible daily average value of 100 µg/m³.

5.2.5 Analysis for the the month of February, 2019

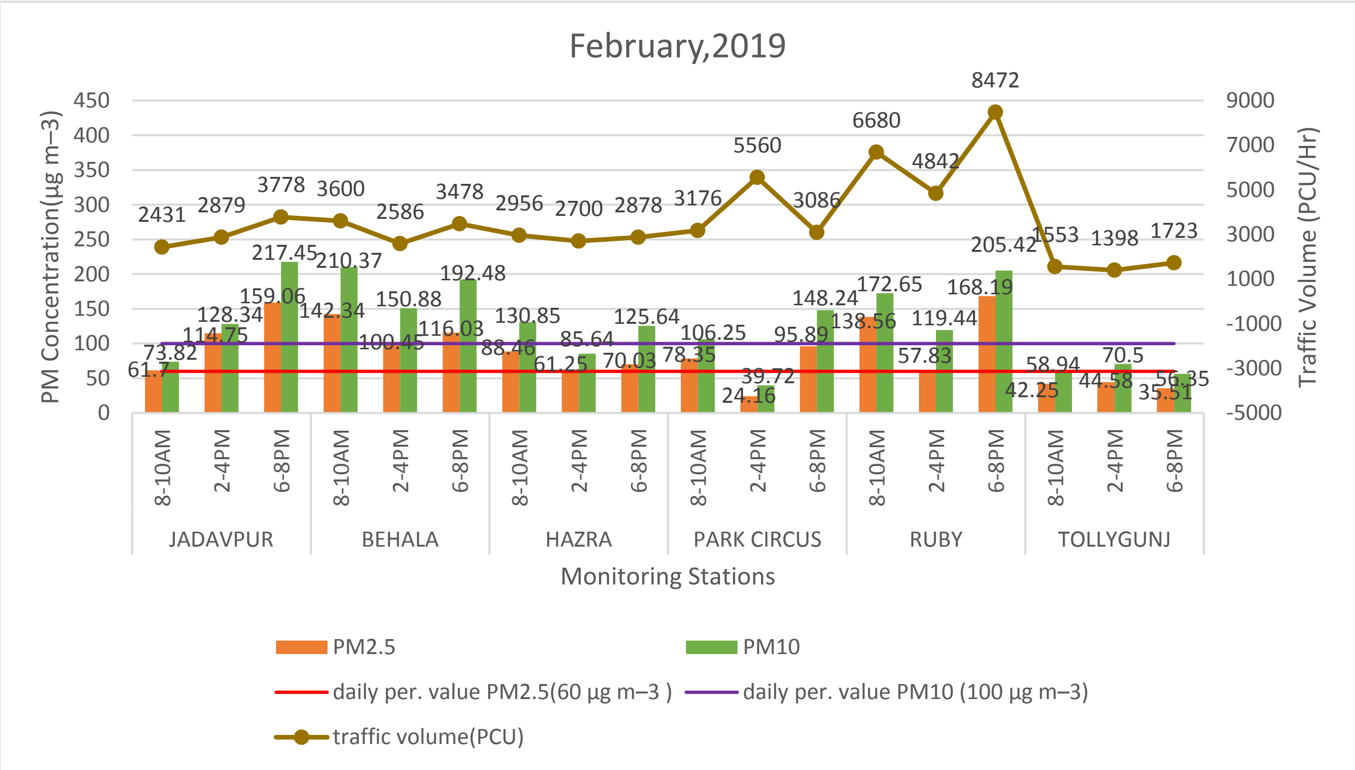

Figure 5.11 Diurnal and spatial variation with hourly traffic volume in February, 2019

1. In February $PM_{2.5}$ and PM_{10} concentration at all the monitoring stations are well above the daily average permissible value of 60 µg/m³ (for $PM_{2.5}$) and 100 µg/m³ (for PM_{10}) during morning and evening. Refer Table A 1.5

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Tollygunj recorded for the lowest concentration of $PM_{2.5}$ and PM_{10} compare to other monitoring stations in the month February, values are well below the permissible daily average limit.

4. Monitoring station at Behala recorded for the highest concentration of particulates ($PM_{2.5}$ and PM_{10}).

5. Overall $PM_{2.5}$ concentration in February during morning, afternoon and evening are 1-2.5 times, 0.5-2 times and 0.9 to 2.8 times higher than the permissible daily average value of 60 µg/m³.

6. Overall PM_{10} concentration in January during morning, afternoon and evening are approximately 0.5-2 times, 0.-1.5 times and 0.5 to 2.0 times higher than the permissible daily average value of 100 µg/m³.

5.2.6 Analysis for the the month of March, 2019

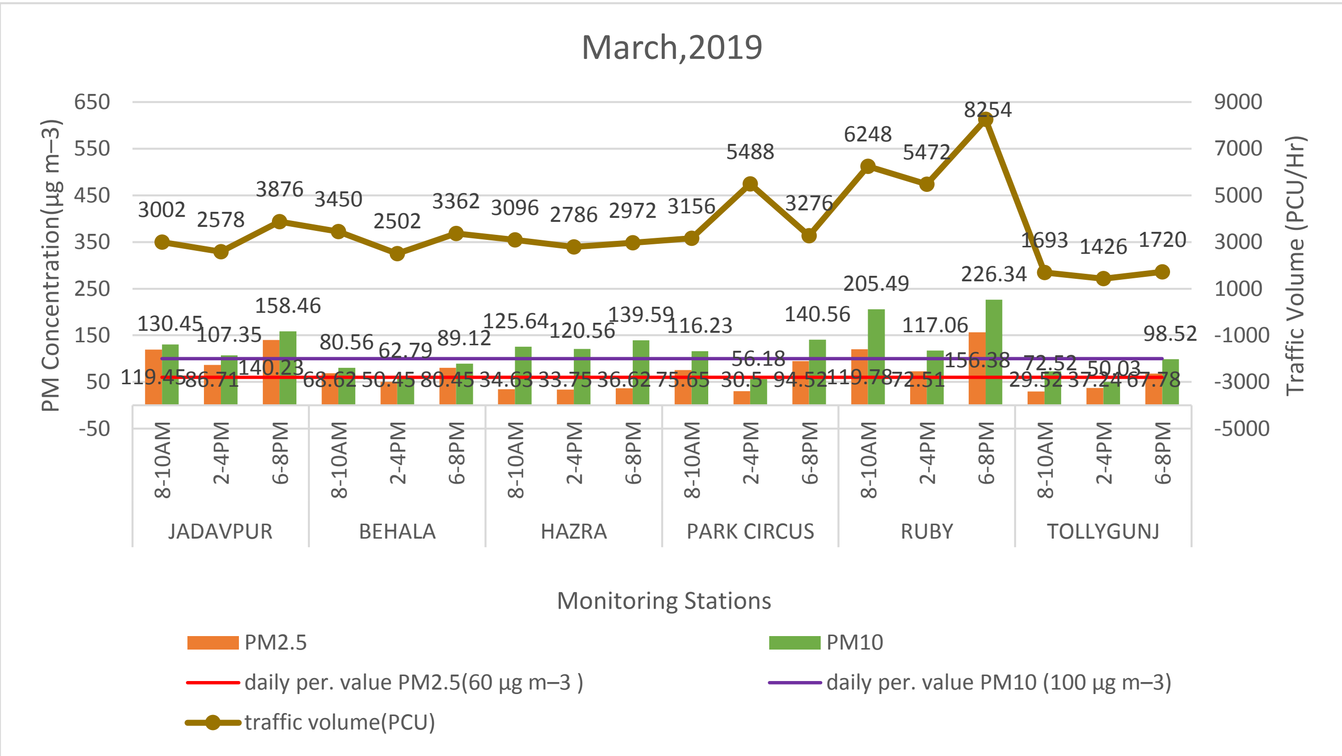

Figure 5.12 Diurnal and spatial variation with hourly traffic volume in March, 2019

1. In March, $PM_{2.5}$ concentration at all the monitoring stations except Jadavpur and Ruby are either below or slightly above the daily average permissible value of 60 µg/m³. Refer Table A 1.6

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Tollygunj records for the lowest concentration of $PM_{2.5}$ and PM_{10} compared to other monitoring stations in March and values are well below the permissible daily average limit.

4. Ruby More records the highest concentration of $PM_{2.5}$ and PM_{10} compared to other 5 stations.

5. Overall $PM_{2.5}$ concentration in April during morning, afternoon and evening are 0.5-2.4 times, 0.5-1.5 times and 1 to 2.5 times higher than the permissible daily average value of 60 µg/m³.

6. Overall PM_{10} concentration in January during morning, afternoon and evening are approximately 0.7-1.3 times, 0.5-1.2 times and 1 to 2.2 times higher than the permissible daily average value of 100 µg/m³.

5.2.7 Analysis for the the month of April, 2019

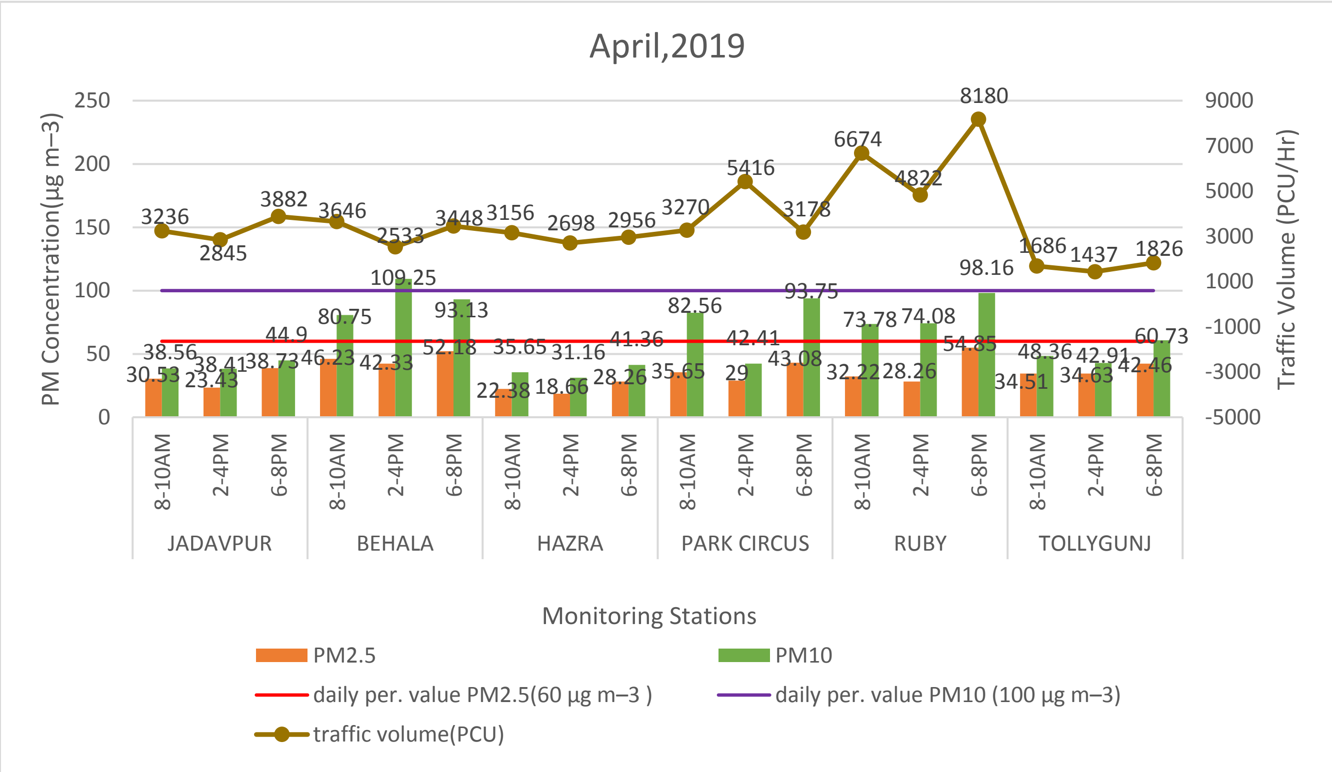

Figure 5.13 Diurnal and spatial variation with hourly traffic volume in April, 2019

1. In April, both $PM_{2.5}$ and PM_{10} concentration at all the monitoring stations are well below the daily average permissible value of 60 µg/m³ and 100 µg/m³ respectively. Which shows in April which is a summer season in Kolkata, air isn't polluted in terms of Particulate Matter. Refer Table A 1.7.

2. It is evident from the graph that vehicular traffic has a direct relation with the particulate concentration ($PM_{2.5}$ and PM_{10}). As at all the monitoring stations it is observed that vehicular traffic is more in morning and evening than afternoon and so is the variation in $PM_{2.5}$ and PM_{10} concentration except for Park Circus where in the morning and evening traffic is low compared to afternoon but still particulate concentration is higher in evening. Land use pattern is expected to have some effect on such variation.

3. Monitoring station at Behala records for the highest particulate concentration ($PM_{2.5}$ and $PM_{10)}$ compared to other monitoring stations in the month of April and values of $PM_{2.5}$ and PM_{10} are well below the permissible daily average limit except for the afternoon session.

4. Monitoring station at Hazra recorded for the lowest concentration of $PM_{2.5}$ and PM_{10} among all the 6 monitoring stations.

5.3 Temporal Variation of $PM_{2.5}$ and PM_{10} in South Kolkata

In this section, temporal variation (diurnal and monthly) in $PM_{2.5}$ and PM_{10} concentration for South Kolkata area has been analysed.

For this purpose, average $PM_{2.5}$ and PM_{10} concentration for each month has been calculated separately by averaging the $PM_{2.5}$ and PM_{10} values of each station for morning, afternoon and evening.

Table 5.1: Monthly average of $PM_{2.5}$ concentration at 6 monitoring stations during morning, afternoon and evening session

Time/ Month	**$PM_{2.5}$ (µg/m³)**						
	Oct, 2018	**Nov, 2018**	**Dec, 2018**	**Jan, 2019**	**Feb, 2019**	**Mar, 2018**	**April, 2019**
8-10 A.M.	117.48	120.48	207.99	161.80	91.94	74.61	33.59
2-4 P.M	94.25	71.10	114.20	89.56	67.17	51.86	29.39
6-8 P.M	151.83	142.92	234.24	161.33	107.45	96.00	43.26
Permissible 24 Hr. weighted average PM_{10}	60						

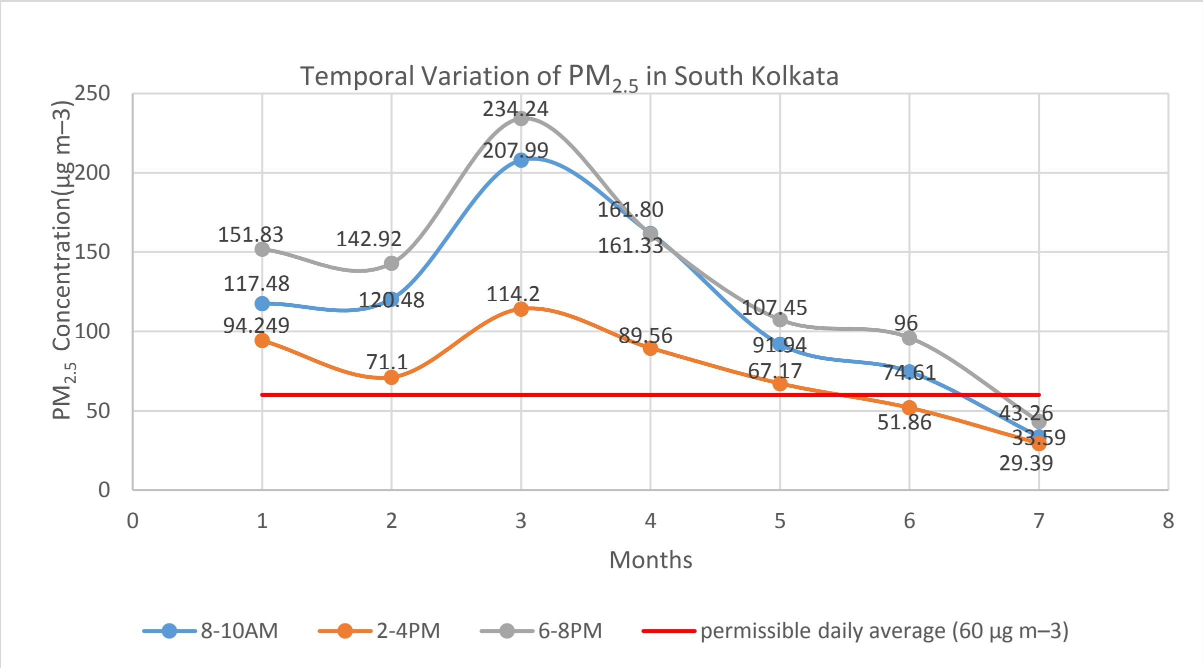

Figure 5.14 Temporal variation of $PM_{2.5}$ in South Kolkata

Note: Month 1= October 2018, **Month 2** = November 2018, **Month 3** = December 2018, **Month 4** = January 2019, **Month 5** = February 2019, Month **6** = March 2019, **Month 7** = April 2019.

- It can be seen that December records for highest $PM_{2.5}$ concentration
- In December $PM_{2.5}$ concentration is maximum during Evening peak traffic hour of 6-8 p.m.
- In December $PM_{2.5}$ concentration
    1. during evening (6-8 p.m) is 234.24 µg/m³ which is 4 times higher than daily permissible limit of 60 µg/m³
    2. during morning (8-10 a.m) is 207.99 µg/m³ which is 3.4 times higher than daily permissible limit of 60 µg/m³
    3. during afternoon (2-4 p.m) is 114.2 µg/m³ which is 1.9 times higher than daily permissible limit of 60 µg/m³
- April records for lowest $PM_{2.5}$ concentration in South Kolkata and concentration of $PM_{2.5}$ are within safe limits during all the 3 sessions.
- Diurnal variation is also clearly evident from the graph which shows that in Morning $PM_{2.5}$ concentration is high; it decreases in afternoon and then again increases and becomes maximum in evening.
- Seasonal variation is clearly visible that Winter (December and January) records for higher $PM_{2.5}$ concentration than Post monsoon (October and November) and pre-monsoon (March to April).

Table 5.2 Monthly average of PM_{10} concentration at six monitoring stations during morning, afternoon and evening sessions

Time/Month	**PM_{10} (µg/m³)**						
	Oct., 2018	**Nov., 2018**	**Dec., 2018**	**Jan., 2019**	**Feb., 2019**	**Mar., 2018**	**Apr., 2019**
8-10 A.M.	170.14	154.45	271.22	215.82	125.48	121.82	59.94
2-4 P.M	134.47	109.40	152.74	128.71	99.09	85.66	56.37
6-8 P.M	225.45	188.66	295.46	216.94	157.60	142.10	72.01
Permissible 24 Hr. weighted average PM_{10}	100						

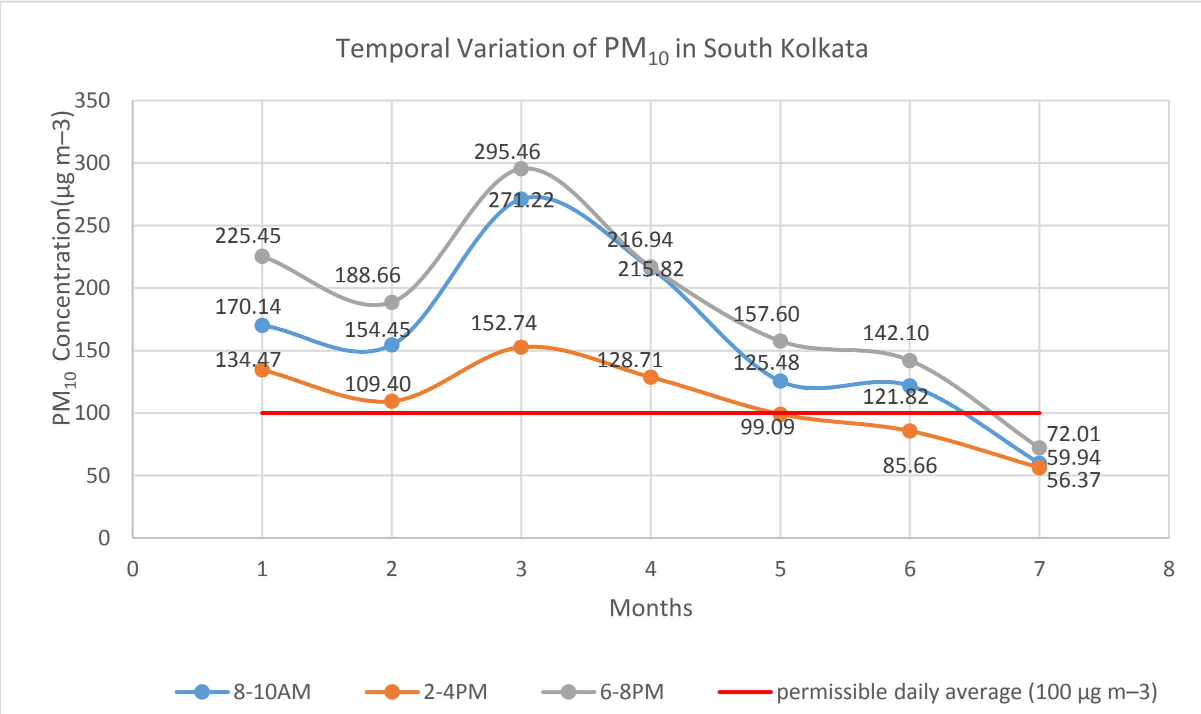

Figure 5.15 Temporal variation of PM_{10} in South Kolkata

Note: Month 1 = October 2018, **Month 2**= November 2018, **Month 3** = December 2018, **Month 4** = January 2019, **Month 5** = February 2019, Month **6** = March 2019, **Month 7** = April 2019

From the above graph,

- ➢ It can be seen that December records for highest PM_{10} concentration
- ➢ In December PM_{10} concentration is maximum during evening peak traffic hour of 6-8 p.m.
- ➢ In December PM_{10} concentration
    1. during evening (6-8 p.m.) is 295.46 µg/m³ which is 2.9 times higher than daily permissible limit of 60 µg/m³

2. during morning (8-10 a.m.) is 271.22 µg/m³ which is 2.7 times higher than daily permissible limit of 60 µg/m³
3. during afternoon (2-4 p.m.) is 152.74 µg/m³ which is 1.5 times higher than daily permissible limit of 60 µg/m³

- April records for lowest $PM_{2.5}$ concentration in south Kolkata and concentration of $PM_{2.5}$ are within safe limits during all the 3 sessions.
- Diurnal variation is also clearly evident from the graph which shows that in Morning $PM_{2.5}$ concentration is high then it decreases in afternoon and then again increases and becomes maximum in evening
- Seasonal variation is clearly visible. Winter (December and January) records for high $PM_{2.5}$ concentration than Post monsoon (October and November) and pre-monsoon (March to April).

5.4 Spatial Variation of $PM_{2.5}$ and PM_{10} in South Kolkata.

In this section, spatial variation in $PM_{2.5}$ and PM_{10}concentration in South Kolkata has been analysed.

For this purpose, average $PM_{2.5}$ and PM_{10}concentration for each monitoring station has been calculated by averaging the $PM_{2.5}$ and PM_{10} value for morning, afternoon and evening separately in each month.

Table 5.3 Seven monthly average $PM_{2.5}$ concentration at all the monitoring station

Monitoring Station	$PM_{2.5}$ (µg/m³)			
	8-10 A.M.	2-4 P.M.	6-8 P.M.	Permissible 24 Hr. Average
KPC Medical College and Hospital, Jadavpur	108.50±10.8	70.83±7.08	129.94±12.9	60
Vidyasagar State General Hospital, Behala	153.99±15.3	94.05±9.40	129.88±12.98	
Chittaranjan National Cancer Research Institute, Hazra	97.58±9.75	72.40±7.24	114.78±11.47	
Lady Brabourne College, Park Circus	122.57±12.26	77.54±7.75	151.31±15.13	
Ruby General Hospital, Ruby More	135.18±13.51	72.41±7.24	168.10±16.81	
The Future Foundation School, Tollygunj	67.98±6.80	44.21±4.42	105.27±10.53	

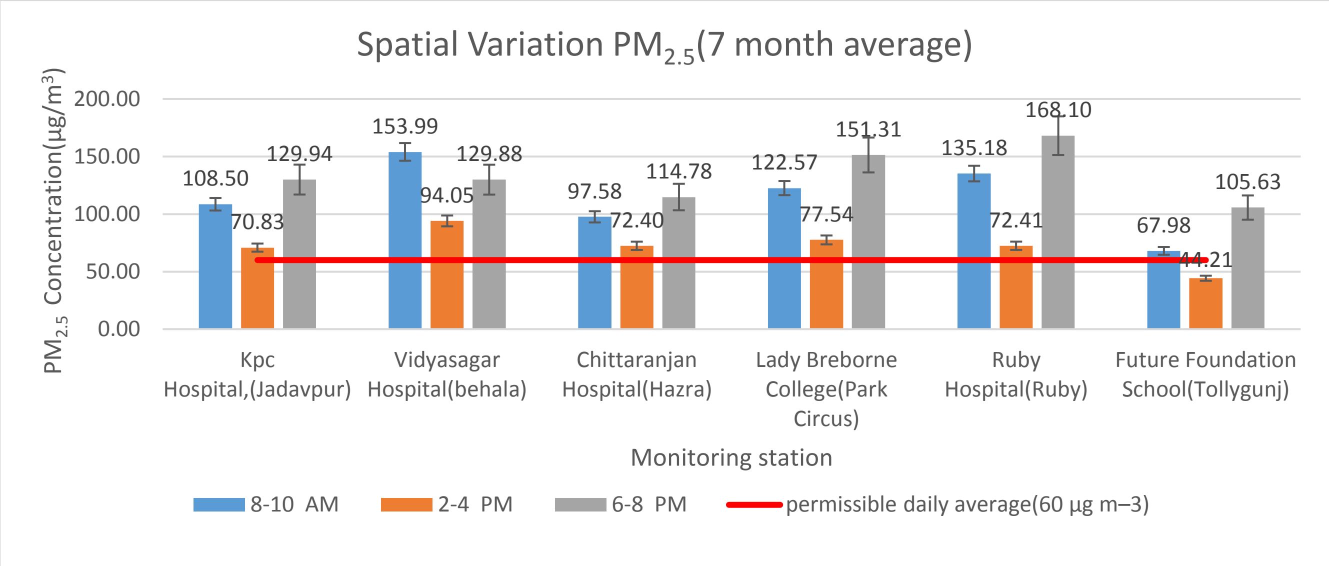

Figure 5.16 Spatial variation of $PM_{2.5}$ (7 monthly average) in South Kolkata

From the graph it can be observed that

- The Future Foundation School (Tollygunj) is the least polluted spot among all the monitoring stations in terms of $PM_{2.5}$ concentration.
- Ruby and Behala has the highest $PM_{2.5}$ concentration among other all the monitoring stations
- Overall $PM_{2.5}$ concentration is always above the permissible daily average limit of 60 µg/m³.
- Only afternoon $PM_{2.5}$ concentration at Tollygunj monitoring station is below the permissible limit of 60 µg/m³.
- Overall 7 month average $PM_{2.5}$ concentration for South Kolkata region during
    1. Morning (8-10 a.m.) is 114.30 µg/m³.
    2. Afternoon (2-4 p.m.) is 71.91µg/m³.
    3. Evening (6-8 p.m.) is 133.21 µg/m³

Table 5.4 Seven monthly average PM_{10} concentration at all the monitoring station

Monitoring Station	**PM_{10} (µg/m³)**			
	8-10 A.M.	**2-4 P.M.**	**6-8 P.M.**	**Permissible 24 Hr. Avg.**
KPC Medical College and Hospital, Jadavpur	129.08±12.91	89.21±8.92	162.09±16.2	100
Vidyasagar State General Hospital, Behala	202.22±20.22	146.82±14.68	186.22±18.62	
Chittaranjan National Cancer Research Institute, Hazra	141.10±14.11	118.50±11.85	167.53±16.75	
Lady Brabourne College, Park Circus	170.78±17.08	109.31±10.93	208.61±20.86	
Ruby General Hospital, Ruby	200.88±20.08	119.71±11.97	246.80±24.68	
The Future Foundation School, Tollygunj	103.62±10.36	63.54±6.35	141.27±14.12	

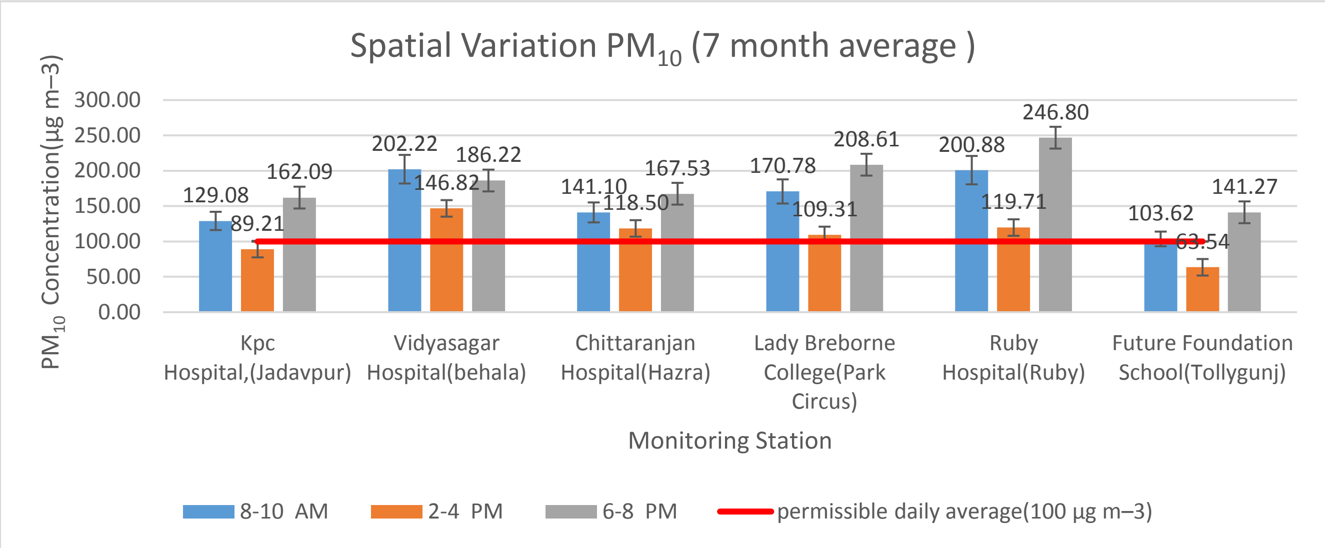

Figure 5.17 Spatial variation of PM_{10} (7 monthly average) in South Kolkata

From the graph it can be observed that

- The Future Foundation School (Tollygunj) is the least polluted spot among all the monitoring stations in terms of PM_{10} concentration.
- Ruby and Behala has the highest PM_{10} pollution among other all the monitoring stations
- Overall PM_{10} concentration above the permissible daily average limit of 100 µg/m³ at all monitoring stations during morning and evening.
- Only afternoon PM_{10} concentration at Tollygunj and Jadavpur monitoring station is below the permissible limit of 60 µg/m³.
- Overall 7 month average PM_{10} concentration for South Kolkata region during
  1. Morning (8-10 a.m.) is 157.94 µg/m³.
  2. Afternoon (2-4 p.m.) is 107.84 µg/m³.
  3. Evening (6-8 p.m.) is 185.42 µg/m³.

5.5 $PM_{2.5}/PM_{10}$ Ratio of South Kolkata Region

In this section $PM_{2.5}/PM_{10}$ ratio for each monitoring station has been discussed by using the 7 monthly average data of each monitoring station over all three monitoring sessions of the monitoring day. This will have its significance in understanding which of the selected monitoring station has more $PM_{2.5}$ content in the air and also overall percentage $PM_{2.5}$ variation diurnally and spatially.

5.5.1 Spatial Variation in $PM_{2.5}/PM_{10}$

Table 5.5: $PM_{2.5}/PM_{10}$ ratio for all the monitoring station (based on 7 month average)

Monitoring Session	$PM_{2.5}/PM_{10}$					
	Jadavpur	**Behala**	**Hazra**	**Park circus**	**Ruby**	**Tollygunj**
8-10 A.M.	0.84	0.76	0.69	0.72	0.67	0.66
2-4 P.M.	0.79	0.64	0.61	0.71	0.60	0.70
6-8 P.M.	0.80	0.70	0.69	0.73	0.68	0.75
	Hourly Vehicular Traffic (PCU/Hr.)					
8-10 A.M.	3129	3559	3397	2873	6629	1603
2-4 P.M.	2778	2558	3017	3182	5083	1407
6-8 P.M.	3806	3397	2704	5516	8210	1781

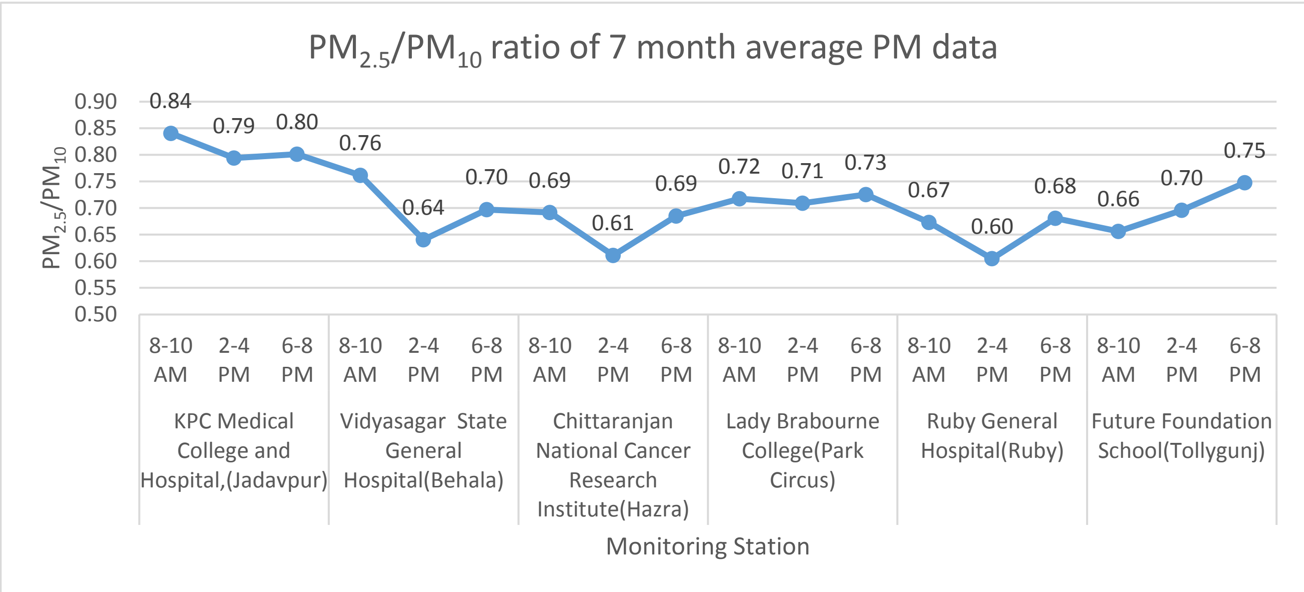

Figure 5.18: $PM_{2.5}/PM_{10}$ Ratio for 7 month average value in South Kolkata

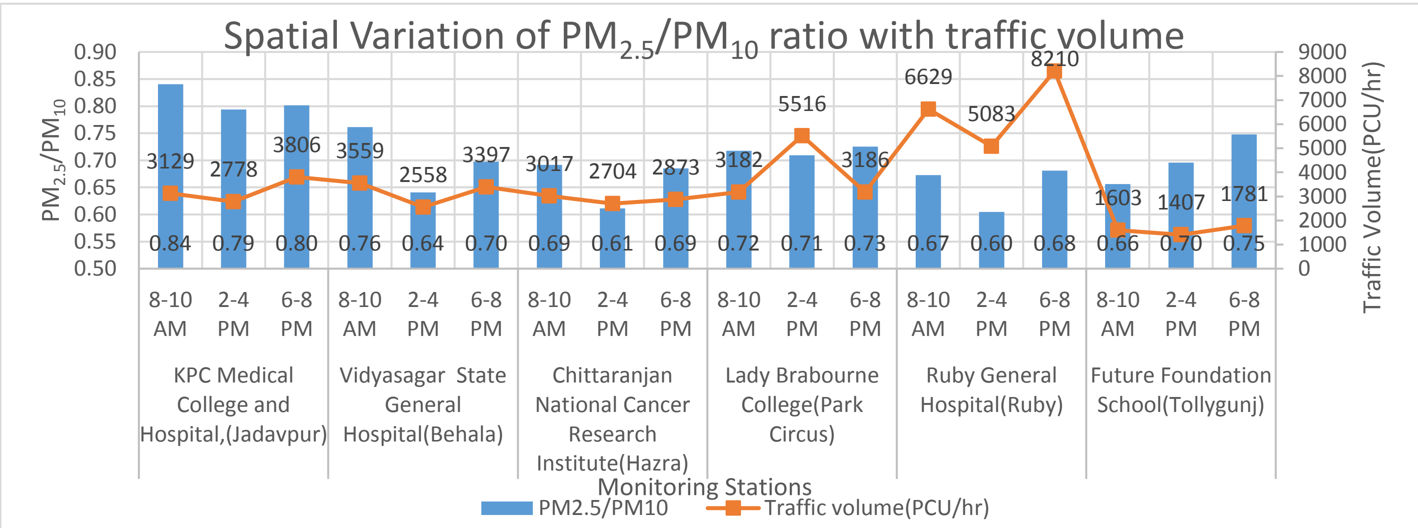

Figure 5.19 Spatial variation of PM2.5/PM10 with vehicular traffic volume (PCU/Hr) based on 7 monthly average data in South Kolkata

Following observations can be drawn from the graph,

- It can be seen $PM_{2.5}$ varies from 60% to 84% in South Kolkata.
- $PM_{2.5}$ fraction in PM_{10} can be observed to be reducing in the non-peak traffic hour of afternoon (2-4 P.M.) compared to morning and evening.
- KPC Medical College and Hospital records for more $PM_{2.5}$ content in PM_{10} than any other monitoring location.
- Monitoring Station in Hazra and Ruby More has approximately equal $PM_{2.5}$ fraction in PM_{10}. Also both these stations have the least fraction of $PM_{2.5}$ in PM_{10} among all the 6 monitoring stations.
- From figure 17 it is evident that $PM_{2.5}$ fraction in PM_{10} is decreasing in afternoon as traffic volume decreases which shows that vehicles are largely responsible for $PM_{2.5}$ fractions in air.

5.5.2 Temporal Variation in $PM_{2.5}/PM_{10}$

Table 5.6 Monthly $PM_{2.5}/PM_{10}$ Ratio for morning afternoon and evening

Monitoring session	Months						
	Oct, 2018	Nov, 2018	Dec, 2018	Jan, 2019	Feb, 2019	Mar, 2019	Apr, 2019
8-10 A.M.	0.69	0.78	0.77	0.75	0.73	0.61	0.56
2-4 P.M	0.70	0.65	0.75	0.70	0.68	0.61	0.52
6-8 P.M	0.67	0.76	0.79	0.74	0.68	0.68	0.60

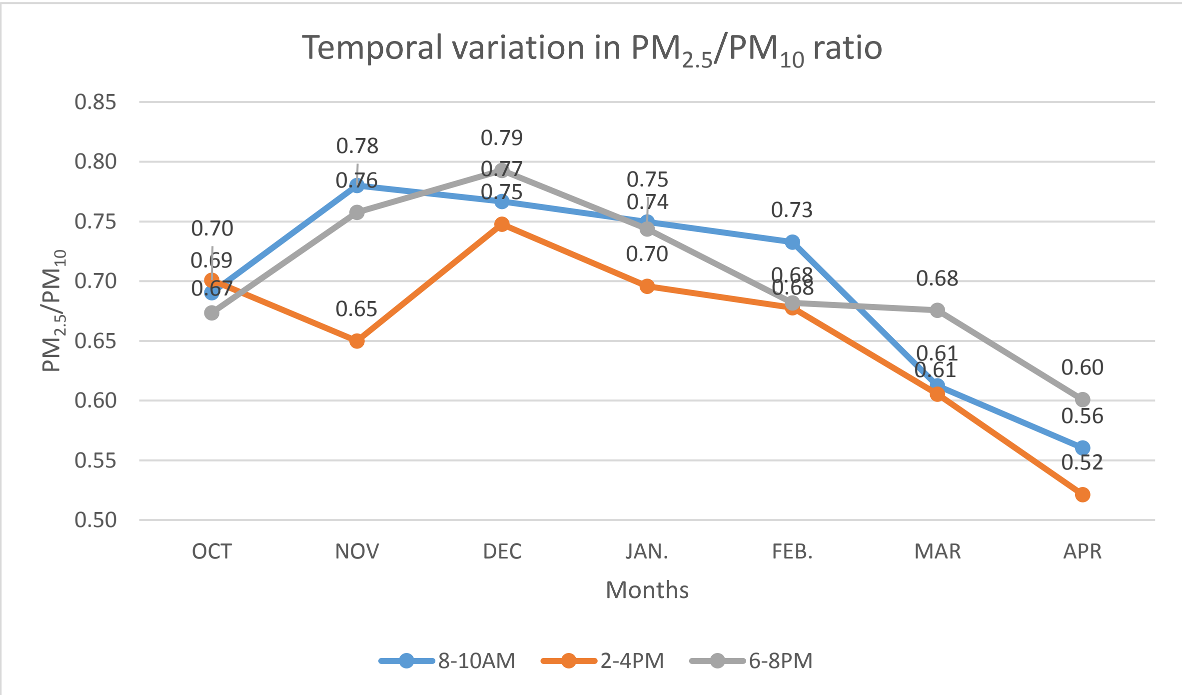

Figure 20: Temporal Variation of $PM_{2.5}/PM_{10}$ ratio in South Kolkata

From the graph following conclusions can be drawn,

- Non-peak traffic hour of afternoon (2-4 P.M.) has less $PM_{2.5}$ fraction in PM_{10} than morning and evening peak traffic hour

- It can be seen that in December $PM_{2.5}$ has the highest fraction in PM_{10}.
- Winter has more $PM_{2.5}$ fraction in PM_{10} than post monsoon and pre monsoon season.
- $PM_{2.5}$ fraction in PM_{10} is least in April (Summer Season).

5.6 Air Quality Index and Health Effect

In this section air quality of each of the six selected monitoring stations, overall air quality of South Kolkata (based on 7 monthly average data) and month wise air quality variation (based on average value of each month) in terms of AQI have been calculated and shown in tabular form (Table 5.9 and 5.10). AQI has been calculated based on the CPCB guidelines.

5.6.1 Air quality for each station in terms of AQI

AQI has been calculated for seven monthly average value of $PM_{2.5}$ and PM_{10} for each monitoring station and tabulated in the following table.

Table 5.7 AQI for each monitoring station

AQI DESCRIPTION	GOOD (0-50)	SATISFACTORY (51-100)	MODERATELY POLLUTED (101-200)	POOR (201-300)	VERY POOR (301-400)	SEVERE (>401)

Monitoring Station	Monitoring Session	Sub Category($PM_{2.5}$)		Sub Category(PM_{10})		AQI of the session	Avg. AQI
		$PM_{2.5}$ (µg/m³)	AQI	PM_{10} (µg/m³)	AQI		
KPC Medical College and Hospital, Jadavpur	**8-10 A.M.**	108.50	261	129.08	120	261	308
	2-4 P.M	70.83	135	89.21	89	135	
	6-8 P.M	129.94	308	162.09	142	308	
Vidyasagar State General Hospital, Behala	**8-10 A.M.**	153.99	326	202.22	168	326	326
	2-4 P.M	94.05	211	146.82	131	211	
	6-8 P.M	129.88	308	186.22	157	308	
Chittaranjan National Cancer Research Institute, Hazra	**8-10 A.M.**	97.58	223	141.10	128	223	282
	2-4 P.M	72.40	140	118.50	113	140	
	6-8 P.M	114.78	282	167.53	145	282	
Lady Brabourne College, Park Circus	**8-10 A.M.**	122.57	302	170.78	147	302	302
	2-4 P.M	77.54	157	109.31	107	157	
	6-8 P.M	151.31	324	208.61	172	324	
Ruby General Hospital, Ruby	**8-10 A.M.**	135.18	312	200.88	167	312	337
	2-4 P.M	72.41	140	119.71	113	140	
	6-8 P.M	168.10	337	246.80	198	337	
The Future Foundation School, Tollygunj	**8-10 A.M.**	67.98	125	103.62	103	125	250
	2-4 P.M	44.21	85	63.54	64	85	
	6-8 P.M	105.27	250	141.27	128	250	
Overall AQI of South Kolkata	**8-10 A.M.**	114.30	280	157.94	139	280	310
	2-4 P.M	71.91	138	107.84	105	138	
	6-8 P.M	133.21	310	185.42	157	310	

As we can see, four out of the six monitoring stations fall in the Red category (Very Poor) and two fall in the Yellow category (Poor). The possible health impact on people living in and around these monitoring stations have been listed below

Based on AQI, NAAQS has suggested the type of diseases expected to occur, details of which is provided in Table1.3.

Table 5.8: Expected health impacts of poor air quality near selected monitoring stations as per AQI.

Monitoring Station	AQI category	Possible health Impacts
KPC Medical College and Hospital, Jadavpur	**Very Poor**	May cause respiratory illness to people on prolonged exposure. Effect may be more pronounced in people with lung and heart disease
Vidyasagar State General Hospital, Behala	**Very Poor**	May cause respiratory illness to people on prolonged exposure. Effect may be more pronounced in people with lung and heart disease
Chittaranjan National Cancer Research Institute, Hazra	**Poor**	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease
Lady Brabourne College, Park Circus	**Very Poor**	May cause respiratory illness to people on prolonged exposure. Effect may be more pronounced in people with lung and heart disease
Ruby General Hospital, Ruby	**Very Poor**	May cause respiratory illness to people on prolonged exposure. Effect may be more pronounced in people with lung and heart disease
The Future Foundation School, Tollygunj	**Poor**	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease

Table 5.9 Monthly Air Quality for South Kolkata in terms of AQI

AQI DESCRIPTION	GOOD (0-50)	SATISFACTORY (51-100)	MODERATELY POLLUTED (101-200)	POOR (201-300)	VERY POOR (301-400)	SEVERE (>401)

Months	Monitoring Session	Sub Category($PM_{2.5}$)		Sub Category(PM_{10})		AQI of the session	Avg. AQI
		$PM_{2.5}$ (µg/m³)	AQI	PM_{10} (µg/m³)	AQI		
October, 2018	8-10 A.M.	117.48	291	170.14	147	291	325
	2-4 P.M	94.25	211	134.47	123	211	
	6-8 P.M	151.83	325	225.45	184	325	
November, 2018	8-10 A.M.	120.48	301	154.45	136	301	318
	2-4 P.M	71.10	135	109.40	107	135	
	6-8 P.M	142.92	318	188.66	159	318	
December, 2018	8-10 A.M.	207.99	368	271.22	221	368	388
	2-4 P.M	114.20	280	152.74	135	280	
	6-8 P.M	234.24	388	295.46	245	388	
January, 2019	8-10 A.M.	161.80	332	215.82	177	332	332
	2-4 P.M	89.56	198	128.71	119	198	
	6-8 P.M	161.33	332	216.94	178	332	
February, 2019	8-10 A.M.	91.94	204	125.48	117	204	257
	2-4 P.M	67.17	122	99.09	99	122	
	6-8 P.M	107.45	257	157.60	139	257	
March, 2019	8-10 A.M.	74.61	147	121.82	115	147	218
	2-4 P.M	51.86	86	85.66	86	86	
	6-8 P.M	96.00	218	142.10	128	218	
April, 2019	8-10 A.M.	33.59	55	59.94	60	60	72
	2-4 P.M	29.39	49	56.37	56	56	
	6-8 P.M	43.26	72	72.01	72	72	

Between post monsoon and winter season (October to January) the overall air quality of South Kolkata has been found to be “Very poor”. But, in the subsequent months quality of air can be seen improving. Between February and March quality improved to “poor” from “very poor” and further improved to “satisfactory” in the month of April. So in April only sensitive group of people like those suffering from asthma or heart diseases and children are supposed to be at health risk.

CHAPTER 6 CONCLUSIONS

Based on the results of the study conducted following conclusion have been drawn:

- Both $PM_{2.5}$ and PM_{10} are more in morning then decreases in the afternoon and again increases in evening which shows a clear diurnal variation in the Particulate Matter concentration.
- December records for the highest concentration of $PM_{2.5}$ and PM_{10} for the 3 monitoring sessions during the study period of October, 2018 to April, 2019
- Particulate pollution is more in winter period (December to February) than post monsoon period (October to November) and pre-monsoon period (March and April) period.
- Traffic has a direct impact on diurnal variation in particulate matter ($PM_{2.5}$ and PM_{10}) concentration. PM concentration is mostly high during peak traffic hours of morning and evening than non-peak traffic hours of afternoon.
- Particulate matter concentration in air has been found to be inversely related with temperature. Both diurnally and monthly, it has been found that as temperature increases PM concentration decreases and vice-versa.
- Air in South Kolkata is safe to breathe in April as far as PM pollutant concentration in the air is concerned. During April all the monitored station were found to have $PM_{2.5}$ and PM_{10} concentration within permissible daily average limit.
- In spatial variation it has been seen that "The future Foundation School" in Tollygunj is least polluted in terms of particulate matter concentration. Except December and January the station shows $PM_{2.5}$ and PM_{10} concentration within permissible daily average limit (as per NAAQS) during morning, afternoon and evening hours
- Though mostly it has been found that increasing temperature reduces the PM concentration and vehicular traffic increases PM concentration in air, still there were some exception found in the study for both of these conclusions which shows that other meteorological factors and land use pattern can also influence the PM concentration in a specific location which needs to be studied in an elaborate manner.
- $PM_{2.5}$ concentration (7 monthly average) of south Kolkata during
  4. Morning (8-10 a.m.) is 114.30 µg/m³.
  5. Afternoon (2-4 p.m.) is 71.91µg/m³.
  6. Evening (6-8 p.m.) is 133.21 µg/m³
- PM_{10} concentration (7 monthly average) of south Kolkata during
  4. Morning (8-10 a.m.) is 157.94 µg/m³.
  5. Afternoon (2-4 p.m.) is 107.84 µg/m³.
  6. Evening (6-8 p.m.) is 185.42 µg/m³.
- The observed overall $PM_{2.5}$ and PM_{10} concentration (7 monthly average) in South Kolkata were always above the permissible daily average values as per NAAQS. Hence, it is primarily important to take necessary steps to curb down the pollution which may include controlling vehicular traffic movement.
- $PM_{2.5}$ fraction in PM_{10} varies from (60 to 84) % in South Kolkata.
- Generally, $PM_{2.5}$ fraction in air reduces during afternoon non peak traffic hour (2-4 p.m.) which records less traffic volume compared to morning and evening, this

provides clear hint that vehicular emission is one of the major sources for $PM_{2.5}$ fraction

- It can be seen that in December $PM_{2.5}$ fraction in PM_{10} is the maximum.
- Winter has more $PM_{2.5}$ fraction in PM_{10} than post monsoon and pre monsoon seasons.
- $PM_{2.5}$ fraction in PM_{10} reduces significantly in April (Summer Season).
- Based on the AQI Jadavpur, Behala, Ruby More and Park circus lie in the "Very Poor" air quality category. People around these areas are expected to have respiratory diseases on prolong exposure of air quality with such level of particulate concentration in air (as found in results). Whereas, Hazra and Tollygunj area fall in the category of "Poor" which means people in and around these areas are expected to have breathing discomfort on prolonged exposure of such a quality of air.
- Overall air quality (seven monthly average) of South Kolkata as per AQI on the basis of particulate concentration is found to be lying in the category of "Very poor".
- Based on AQI, from October to January air quality of South Kolkata was "Very poor". Between February and March it improved and became "Poor" and it further improved and became "Satisfactory" in the month of April.

CHAPTER 7 FUTURE SCOPE OF STUDY

Particulate concentration in ambient air depend on many other meteorological factors like wind speed, pressure, temperature and humidity as observed in literature review. But all these parameters highly varies locally based on the land use pattern of the locality, tree cover, Water body in the locality and all these have co-relation with each other and PM concentration. Whereas in the present study only temperature data have been simultaneously with the PM data. So the future scope of study is described below:

1. In order to make any concrete comment on spatial and temporal variation (diurnal, monthly or seasonal) it is strongly advisable to conduct spatio-temporal study based on land use pattern and by monitoring meteorological factors locally.

2. In the present study, data has been collected only on six monitoring stations in South Kolkata. But in order to have more precise study on current status of particulate pollution in Kolkata, number of monitoring stations and frequency of data collection need to be increased.

3. A comparison study can be done between weekdays and weekends.

4. A correlation study can be conducted based on the locally collected meteorological data in order to understand the correlation of particulate matter with meteorological factors.

5. An epidemiological study can be conducted in order to know the socio-economic impact of particulate pollution.

6. Background data can be monitored to assess the exact contribution of major sources.

REFERENCES

Air Quality Index (AQI), Press Information, 2017). Retrieved from: http://pib.nic.in/newsite/PrintRelease.aspx?relid=110654

Air Quality Index. Retrieved from: http://pib.nic.in/newsite/erelcontent.aspx?relid=54189

B. Srimuruganandam, Nagendra, S., Madanayak, S., 2010. Analysis and interpretation of particulate matter–PM10, PM2. 5 and PM1 emissions from the heterogeneous traffic near an urban roadway. Atmospheric Pollution Research 1(3), 184-194

Census of Kolkata, 2011. Retrieved from https://web.archive.org/web/20120507135928/http://www.censusindia.gov.in/2011-prov results/paper2/data_files/India2/Table_2_PR_Cities_1Lakh_and_Above.pdf

Centre for Science and Environment (CSE) Report, 2016. Retrieved from: https://www.cseindia.org/kolkata-residents-breathe-in-air-which-has-3-5-times-higher-pollution-levels-than-the-ambient-level-that-is-already-several-times-higher-than-the-permissible-limit-action-must-gather-momentum-says-cses-kolkata-study-6250

Chai, F., Gao, J., Chen, Z., Wang, S., Zhang Y., Zhang J., Zhang H., Yun Y., Ren C., 2014. Spatial and temporal variation of particulate matter and gaseous pollutants in 26 cities in China 26(1), 75-82.

Cheng, Y., Ho K.F., Lee, S.C., Law, S.W., 2006. Seasonal and diurnal variations of PM1.0, PM2.5 and PM10 in the roadside environment of Hong Kong. China Particuology 4(6), 312-315.

DeGaetano, A.T., Doherty, O.M., 2004. Temporal, spatial and meteorological variations in hourly PM2.5 concentration extremes in New York City. Atmospheric Environment 38(11), 1547-1558.

Deshmukh, D.K., M.K. Deb, Mkoma S.L., 2012. Size distribution and seasonal variation of size-segregated particulat)e matter in the ambient air of Raipur city, India. Air Quality Atmosphere & Health 6(1).

Filonchyk, M., Yan, H., Li, X., 2018. Temporal and spatial variation of particulate matter and its correlation with other criteria of air pollutants in Lanzhou, China, in spring-summer periods. Atmospheric Pollution Research 9(6), 1100-1110

Gummeneni, S., Yusup, Y., Chavali, M., Samadi, V., 2011.Source apportionment of particulate matter in the ambient air of Hyderabad city, India. Atmospheric Research 101(3), 752-764.

Gupta, A.K., Karar, K, Ayoob S., John K., 2008. Spatio-temporal characteristics of gaseous and particulate pollutants in an urban region of Kolkata, India. Atmospheric Research 87(2), 103-115.

Huang, T.H., Yu, Y., Wei Y., Wang H., Huang W., Chen X., 2018. Spatial–seasonal characteristics and critical impact factors of $PM_{2.5}$ concentration in the Beijing–Tianjin–Hebei (BTH) urban agglomeration. PLoS One 13(9), e0201364.

Karar, K., Gupta, A. K., Kumar, A., Biswas, A. K., 2006. Seasonal variations of PM 10 and TSP in residential and industrial sites in an urban area of Kolkata, India. Environmental monitoring and assessment, 118(1-3), 369-381

Lia, R., Cui, L. Li, J., Zhao, A., Fu, H., Wu, Y. Zhang, L., Kong, L., Chen, J., 2017. Spatial and temporal variation of particulate matter and gaseous pollutants in China during 2014-2016. Atmospheric Environment 161, 235-246.

Murty, M.N., Gulati, S.C., Banerjee A., 2003.Health benefits from urban air pollution, abatement in the Indian subcontinent.

National Air Quality Index, CPCB. Retrieved from http://www.indiaenvironmentportal.org.in/files/file/Air%20Quality%20Index.pdf

Patel, M.M., Chillrud, S., Correa, J.C., Hazi, Y., 2010. Spatial and temporal variations in traffic-related particulate matter at New York City high schools. Environmental Health Perspectives 118(9), 1338-43.

Sadia, A., Uddin, M.M., Rahman, M.M., Hassan K., 2018. Spatial and Temporal Variations of PM_{10} in Chittagong City, Bangladesh. International Journal of Advances in Science Engineering and Technology, 6(1) ISSN (p) 2321 –8991.

Sharma, A.R., Kharo, S.K., Badarinath, V.S., 2010. Influence of vehicular traffic on urban air quality – A case study of Hyderabad, India. Transportation Research Part D Transport and Environment 15(3), 154-159.

OECD, The Cost of Air Pollution, 2014. Health Impacts of Road Transport. Retrieved from https://www.oecd.org/environment/tools-evaluation/the-cost-of-air-pollution-9789264210448-en.htm

Trivedi, D.K, Ali, K., Beig G., 2014. Impact of meteorological parameters on the development of fine and coarse particles over Delhi. Science of The Total Environment 478, 175–183.

Unal, Y. S., Toros, H., Deniz A., Incecik S., 2011. Influence of meteorological factors and emission sources on spatial and temporal variations of PM10 concentrations in Istanbul metropolitan area. Atmospheric Environment 45(31), 5504-5513.

WHO global ambient air quality database, 2018. Retrieved from: https://www.who.int/airpollution/data/cities/en/

WHO, Air pollution estimates, 2014. Retrieved from: https://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

Wrobel, A., Rokita, E., Maenhaut W., 2000. Transport of traffic-related aerosols in urban areas. Science of The Total Environment 257, 199-211.

Yadav, R., Sahu, L.K., Nisar, S., Jaaffrey, A., Beig G., 2014. Temporal Variation of Particulate Matter (PM) and Potential Sources at an Urban Site of Udaipur in Western India. Aerosol and Air Quality Research 14(6), 1613-1629.

Zhao, C.X., Wang, Y.Q., Wang, Y.J., Zhang, H.L., Zhao, B.Q., 2014. Temporal and spatial distribution of $PM_{2.5}$ and PM_{10} pollution status and the correlation of particulate matters and meteorological factors during winter and spring in Beijing. Huan jing ke xue 35(2), 418-27.

ANNEXURE 1.0

Table A 1.1: Monitoring data for the month of October, 2018

Monitoring station	Date	Session	October,2018			
			$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	05/10/2018	8-10 a.m	42.17	57.39	3242	29
	05/10/2018	2-4 p.m.	48.42	69.37	2880	32
	05/10/2018	6-8 p.m	60.08	102.61	4000	30
Vidyasagar State General Hospital, Behala	08/10/2018	8-10 a.m	126.37	167.48	3602	29
	08/10/2018	2-4 p.m.	99.76	156.44	2678	31
	09/10/2018	6-8 p.m	151.28	189.76	3432	28
Chittaranjan National Cancer Research Institute, Hazra	12/10/2018	8-10 a.m	129.33	166.32	3057	28
	11/10/2018	2-4 p.m.	102.69	169.29	2716	30
	11/10/2018	6-8 p.m	139.26	187.32	2818	27
Lady brabourne College, Park Circus	04/10/2018	8-10 a.m	132.33	187.46	3270	26
	04/10/2018	2-4 p.m.	165.34	189.22	5567	29
	04/10/2018	6-8 p.m	188.37	258.23	3380	27
Ruby General Hospital, Ruby	10/10/2018	8-10 a.m	220.48	370.89	7542	29
	10/10/2018	2-4 p.m.	109.84	178.18	5324	32
	10/10/2018	6-8 p.m	275.36	477.42	9316	30
The Future Foundation School, Tollygunj	30/10/2018	8-10 a.m	54.22	71.32	1658	27
	30/10/2018	2-4 p.m.	39.43	44.32	1419	29
	30/10/2018	6-8 p.m	96.65	137.33	1800	28

Table A 1.2: Monitoring data for the month of November, 2018

Monitoring station	Date	Session	October,2018			
			$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	17/11/2018	8-10 a.m.	110.90	150.87	3185	22
	17/11/2018	2-4 p.m.	56.61	73.87	2852	28
	17/11/2018	6-8 p.m.	18.14	154.49	3645	23
Vidyasagar State General Hospital, Behala	21/11/2018	8-10 a.m.	135.19	152.81	3578	28
	21/11/2018	2-4 p.m.	107.94	173.51	2460	30
	20/11/2018	6-8 p.m.	140.42	174.33	3400	24
Chittaranjan National Cancer Research Institute, Hazra	15/11/2018	8-10 a.m.	130.41	170.92	3022	27
	15/11/2018	2-4 p.m.	96.65	158.78	2700	31
	15/11/2018	6-8 p.m.	144.79	190.76	2780	25
Lady brabourne College, Park Circus	22/11/2018	8-10 a.m.	162.42	210.90	3136	24
	22/11/2018	2-4 p.m.	99.89	149.15	5491	28
	24/11/2018	6-8 p.m.	193.63	275.15	3280	24
Ruby General Hospital, Ruby	29/12/2018	8-10 a.m.	143.52	180.84	6152	25
	29/12/2018	2-4 p.m.	30.04	58.75	4872	29
	29/12/2018	6-8 p.m.	162.52	201.63	7683	23
The Future Foundation School, Tollygunj	27/11/2018	8-10 a.m.	40.42	60.36	1597	25
	27/11/2018	2-4 p.m.	35.47	42.35	1430	27
	27/11/2018	6-8 p.m.	97.94	135.57	1711	23

Table A 1.3: Monitoring data for the month of December, 2018

Monitoring station	Date	Session	October,2018			
			$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	22/12/2018	8-10 a.m	274.35	308.84	2956	24
	21/12/2018	2-4 p.m.	130.45	157.85	2652	24
	21/12/2018	6-8 p.m	240.89	276.30	3285	18
Vidyasagar State General Hospital, Behala	31/12/2018	8-10 a.m	290.46	360.42	3578	21
	01/01/2018	2-4 p.m.	142.42	192.90	2460	23
	31/12/2018	6-8 p.m	220.42	320.60	3380	19
Chittaranjan National Cancer Research Institute, Hazra	28/12/2018	8-10 a.m	168.10	218.10	2876	20
	27/12/2018	2-4 p.m.	105.74	147.26	2648	24
	28/12/2018	6-8 p.m	271.76	338.27	2860	18
Lady brabourne College, Park Circus	26/12/2018	8-10 a.m	220.26	310.30	2982	22
	26/12/2018	2-4 p.m.	126.92	160.42	5442	26
	27/12/2018	6-8 p.m	260.30	281.43	3148	23
Ruby General Hospital, Ruby	24/12/2018	8-10 a.m	150.33	210.09	6246	22
	25/12/2018	2-4 p.m.	115.91	281.43	4928	25
	25/12/2018	6-8 p.m	193.58	159.72	8276	19
The Future Foundation School, Tollygunj	29/12/2018	8-10 a.m	14.46	266.31	1540	18
	28/12/2018	2-4 p.m.	63.78	98.30	1312	24
	28/12/2018S	6-8 p.m	218.50	289.84	1758	18

Table A 1.4: Monitoring data for the month of January, 2019

Monitoring station	Date	Session	January,2018			
			$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	08/01/2019	8-10 a.m.	120.43	143.65	3072	23
	07/01/2019	2-4 p.m.	35.51	49.28	2759	25
	07/01/2019	6-8 p.m.	152.48	180.42	3876	22
Vidyasagar State General Hospital, Behala	04/01/2019	8-10 a.m.	278.76	363.00	23458	22
	03/01/2019	2-4 p.m.	122.91	181.96	2680	27
	03/01/2019	6-8 p.m.	174.50	244.11	3276	22
Chittaranjan National Cancer Research Institute, Hazra	29/01/2019	8-10 a.m.	140.46	190.87	2956	21
	28/01/2019	2-4 p.m.	105.51	136.82	2678	22
	28/01/2019	6-8 p.m.	111.31	152.04	2852	20
Lady brabourne College, Park Circus	22/01/2019	8-10 a.m.	160.27	210.54	3284	23
	21/01/2019	2-4 p.m.	126.57	177.04	5640	27
	21/01/2019	6-8 p.m.	183.30	262.13	2952	24
Ruby General Hospital, Ruby	10/01/2019	8-10 a.m.	140.39	192.42	6858	21
	09/01/2019	2-4 p.m.	92.51	130.77	5324	25
	10/01/2019	6-8 p.m.	165.81	252.34	7285	22
The Future Foundation School, Tollygunj	30/01/2019	8-10 a.m.	130.46	194.30	1498	20
	30/01/2019	2-4 p.m.	54.32	96.40	1340	24
	30/01/2019	6-8 p.m.	180.56	210.58	1863	19

Table A 1.5: Monitoring data for the month of February, 2019

Monitoring station	Date	Session	February,2018			
			$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	15/02/2019	8-10 a.m.	61.70	73.82	3212	25
	15/02/2019	2-4 p.m.	114.75	128.34	2879	29
	16/02/2019	6-8 p.m.	159.06	217.45	3778	26
Vidyasagar State General Hospital, Behala	11/02/2019	8-10 a.m.	142.34	310.37	3600	24
	13/02/2019	2-4 p.m.	100.45	150.88	2586	27
	12/02/2019	6-8 p.m.	116.03	192.48	3478	25
Chittaranjan National Cancer Research Institute, Hazra	19/02/2019	8-10 a.m.	88.46	130.85	2956	25
	18/02/2019	2-4 p.m.	61.25	85.64	2700	30
	18/02/2019	6-8 p.m.	70.03	125.64	2878	24
Lady brabourne College, Park Circus	16/02/2019	8-10 a.m.	78.35	106.25	3176	26
	14/02/2019	2-4 p.m.	24.16	39.72	6680	28
	14/02/2019	6-8 p.m.	95.89	148.24	3086	27
Ruby General Hospital, Ruby	22/02/2019	8-10 a.m.	138.56	172.65	6680	28
	22/02/2019	2-4 p.m.	57.83	119.44	8472	27
	22/02/2019	6-8 p.m.	168.19	205.42	8472	27
The Future Foundation School, Tollygunj	21/02/2019	8-10 a.m.	42.25	58.94	1553	26
	21/02/2019	2-4 p.m.	44.58	70.50	1398	30
	21/02/2019	6-8 p.m.	35.51	56.35	1723	27

Table A 1.6: Monitoring data for the month of March, 2019

Monitoring station	Date	Session	March,2018			
			$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	13/03/2019	8-10 a.m.	119.45	130.45	3002	32
	13/03/2019	2-4 p.m.	86.71	107.35	2578	37
	13/03/2019	6-8 p.m.	140.23	158.46	3876	33
Vidyasagar State General Hospital, Behala	27/03/2019	8-10 a.m.	68.62	80.56	3450	31
	26/03/2019	2-4 p.m.	50.45	62.79	2502	34
	26/03/2019	6-8 p.m.	80.45	62.79	3362	30
Chittaranjan National Cancer Research Institute, Hazra	25/03/2019	8-10 a.m.	80.45	89.12	3096	32
	25/03/2019	2-4 p.m.	34.63	125.64	2786	35
	25/03/2019	6-8 p.m.	33.75	120.56	2972	33
Lady brabourne College, Park Circus	28/03/2019	8-10 a.m.	36.62	139.59	3156	33
	27/03/2019	2-4 p.m.	75.65	116.23	5488	29
	27/03/2019	6-8 p.m.	30.50	56.18	3276	29
Ruby General Hospital, Ruby	11/03/2019	8-10 a.m.	94.52	140.56	6248	31
	11/03/2019	2-4 p.m.	119.78	205.49	5472	32
	11/03/2019	6-8 p.m.	72.51	117.06	8254	29
The Future Foundation School, Tollygunj	19/03/2019	8-10 a.m.	29.52	72.52	1693	28
	19/03/2019	2-4 p.m.	37.24	50.03	1426	31
	19/03/2019	6-8 p.m.	67.78	98.52	1720	29

Table A 1.7: Monitoring data for the month of April, 2019

Monitoring station	Date	Session	March,2018			
			$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	Traffic Vol. (PCU/hr)	Temp. (°C)
KPC College and Medical College, Jadavpur	12/04/2019	8-10 a.m.	30.53	38.56	3236	31
	12/04/2019	2-4 p.m.	23.43	38.41	2845	34
	12/04/2019	6-8 p.m.	38.73	44.90	3882	33
Vidyasagar State General Hospital, Behala	20/04/2019	8-10 a.m.	46.23	80.75	3646	32
	18/04/2019	2-4 p.m.	42.33	109.25	2533	35
	20/04/2019	6-8 p.m.	52.16	93.13	3448	33
Chittaranjan National Cancer Research Institute, Hazra	10/04/2019	8-10 a.m.	22.38	35.65	3156	32
	10/04/2019	2-4 p.m.	18.66	31.16	2698	34
	11/04/2019	6-8 p.m.	28.26	41.36	2956	32
Lady brabourne College, Park Circus	18/04/2019	8-10 a.m.	35.65	82.56	3270	30
	19/04/2019	2-4 p.m.	29.00	42.41	5416	33
	19/04/2019	6-8 p.m.	43.08	93.75	3178	31
Ruby General Hospital, Ruby	13/04/2019	8-10 a.m.	32.22	73.78	6674	34
	13/04/2019	2-4 p.m.	28.26	74.08	4822	36
	13/04/2019	6-8 p.m.	54.85	98.16	3180	33
The Future Foundation School, Tollygunj	14/04/2019	8-10 a.m.	34.51	48.36	1686	33
	14/04/2019	2-4 p.m.	34.63	42.91	1437	36
	14/04/2019	6-8 p.m.	42.46	60.73	1826	33