Declaration of Originality

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I declare that this is the true copy of my report, including all revisions, as approved by myadvisorand supervisor, and that this report has not been submitted for any other degree to any other University or Institution.

(Gaurav Kesharwani)

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Abstract

In metropolitan cities like Delhi, Mumbai etc, a large proportion of exposure to airborne pollutants, in particular particulate matter, is likely experienced during daily commuting trips due to the proximity to a number of pollution sources (vehicular traffic, industry, construction sites, etc).Brief periods of exposure to high concentrations of air pollution may have significant health impacts. Therefore it is important for better understanding of the variability in pollutant concentrations across available transport modes for commuters and authorities. Unfortunately, personal exposure to particle pollution in the transport microenvironment of Delhi to date has not been well documented.

The present study analyses exposure concentrations of particulate matter (PM1.0, PM2.5), measured along a selected route in the district of Delhi. Real-time monitoring of selected parameters was done using portable instruments (Haz Dust EPAM-5000) capable of measuring real time concentrations during trips on four different modes of transport (Ac Cab, Auto Rickshaw, DTC Bus and Non Ac Cabs). PM measurements in each mode of transportation were repeated in morning, afternoon and evening hours and monitoring has been done for each mode twice.

Trip averaged pollution exposure to commuters for PM2.5 was highest for DTC bus (819.44% higher concentration than ac cabs) in morning hours followed by auto rickshaw, Non Ac Cab and Ac Cab. Whereas in evening hours exposure in descending order was Auto Rickshaw (503.15% higher concentration than ac cab), DTC Bus, Non Ac Cab and Ac Cab. During the afternoon hours concentration of PM2.5 was highest for Auto Rickshaw. For PM1.0 trip averaged pollution exposure to commuters was highest for Auto Rickshaw (364.3% higher concentration than ac cab) in morning, afternoon and evening hours (402.4% higher concentration than ac cab) followed by DTC Bus, Non Ac Cab and Ac Cab. Except for Ac Cab higher exposure concentrations was observed for all the remaining three modes of transportations. The poor vehicle emission controls, poor vehicle maintenance, plus theslow moving traffic condition with frequent stops are believed to be the major causes of high in-vehicle levels in somepublic commuting trips.

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Chapter 1- Introduction

Poor air quality is a general wellbeing risk that numerous advanced urban communities face. Late occasions, basically in real Indian urban areas, have pulled in worldwide consideration and expanded open consciousness of the risks of air contamination, especially on human wellbeing (Fenger, 2009; Wong, 2013). In 2011, the World Health Organization (WHO) evaluated that two million passings came about because of the inward breath of dirtied air (World Health Organization, 2011). The International Agency for Research on Cancer (IARC), the specific tumor organization of the WHO, has likewise formally characterized outside air contamination and particulate matter as destructive cancer-causing agents (Loomis et al., 2013). Joined with the fast urbanization happening over the globe, air contamination is liable to end up one of the significant difficulties confronting general wellbeing in the 21st century. Notwithstanding the negative effects to human wellbeing, poor air quality has other hurtful impacts, both immediate and backhanded, on physical foundation, ecological wellbeing, environmental change, and monetary action (Mansfield et al., 1991; Vallero, 2008).

1.1 Human exposure to air pollution

Exposure is generally characterized as the immediate contact between a person and a pollutant (Otto, 1982). For airborne pollutants, this is the point of contact whereby humans can inhale the particles or gases. The idea of exposure helps researchers and strategy producers recognize the vital variables connecting contamination and human wellbeing, and empower the configuration of essential exploration and powerful strategies to guarantee focused on answers for the issue of air quality.

Exposure is an especially valuable idea since air contamination in urban ranges is very heterogeneous both spatially and transiently, because of the bunch of emanation sources inside the city, fundamentally fossil fuel burning from industry and vehicular fumes (Monn, 2001). Urban air quality is additionally influenced by scattering and change forms in the climate from the small scale (e.g. toxin aggregation in urban road ravines, and development of new particles through photochemical responses of crisply discharged gasses and particles) to the local and worldwide scales (e.g. transboundary contamination) (Salmond and McKendry, 2009). In spite of the high spatial and worldly variability in toxin focuses, unmistakably on-street engine vehicles are the most imperative wellsprings of air contaminations that urban populaces are liable to interact with in more created urban areas. Although industry is arguably a larger emitter in absolute terms, improved regulation and urban planning means factories are usually situated away from main populated areas, minimizing human exposure to industrial emissions.

The connection between activity related air contaminations and human wellbeing sway has been upheld by various epidemiological studies which indicate moderately reliable relationship between movement related air contamination and expanded danger of heart assault and respiratory disease in helpless persons and general diminished future (e.g. Hoek et al., 2002; Peters et al., 2004; Pope and Dockery, 2006). It has been proposed that for the all inclusive community, activity related air contamination could be a more vital reason for heart assaults than medication misuse, considering the pervasiveness of presentation in the vehicle microenvironment (Nawrot et al., 2011).

Therefore, regardless of the brief timeframe spent outside in the vehicle microenvironment, the nearby nearness to engine vehicles can contribute lopsidedly to aggregate presentation. Besides, in spite of the fact that a moderately short measure of time is spent in the vehicle environment, a large portion of the voyaging is done amid surge hour durations (i.e. times of extraordinary activity outflows) which are connected with high contamination fixations that contribute essentially to the aggregate day by day introduction for suburbanites (Zuurbier et al., 2010).

Individual exposure estimations utilizing little and compact sensors set near or on a person as they go about their day give precise information on the genuine air contamination levels to which individuals are exposed (Monn, 2001). These sensors record an exposure concentration, which is the convergence of toxin (e.g. particulate matter [PM]) that individuals come into contact with. Another strategy is to join settled site estimations in an assortment of "delegate" microenvironments with time-movement journals (Seaton et al., 1999). Individual checking is most perfect to straightforwardly catch the toxins that people are exposed to. However, this technique requires intensive volunteer participation and effort (Van Atten et al., 2005). A compromise is to take ‘representative’ samples of the population, which has led to fairly accurate estimate of mean and variability of population exposures.

The number of exposure studies taking into account the individual checking approach in the vehicle microenvironment has expanded as of late. Analysts every now and again utilize versatile instruments amid reproduced day by day drives. These studies have been completed in different urban communities, including London, Hong Kong, Shanghai and Barcelona, over an assortment of transport modes. One remarkable conclusion from such studies is that surrounding or foundation observing of air quality does not precisely mirror the variability of toxin fixations that individuals are presented to at road level (Gulliver and Briggs, 2004; Kaur et al., 2005a).

Plainly, exposure to movement emanations is an essential segment of contamination introduction. Nonetheless, there are few studies did in tropical urban communities, where the hot and damp conditions may have considerably graver outcomes. At present, just a modest bunch of studies in Delhi have examined introduction to pressurized canned products, measuring airborne focuses in indoor situations, for example, private pieces, yet none has taken a gander at road level presentation. The present study expects to fill this absence of data for the vehicle microenvironment by measuring the individual presentation to mist concentrates of workers on various methods of open transport including strolling.

1.2 Delhi’s air quality & commuters’ population of Delhi

This section describes the local air quality management to put the present study within the context of the actual air quality conditions in Delhi. Delhi, the capital of India, is among the ten largest metropolitan areasworldwide, with an estimated year-2011 population of 46.07 millionpeople (census of India, 2011). Particulate air contamination has been a long standing issue in Delhi. Encompassing convergences of PM2.5 and PM10 (mass groupings of airborne particles with streamlined widths, dp, under 2.5 and 10 mm, separately) are routinely among the most noteworthy on the planet and every now and again a request of size bigger than in US urban communities (Gurjar et al., 2008; Mage et al., 1996). Road transport isknown to be one of the main sources of urban pollution,although other sources linked to combustionprocesses, such as domestic residential and institutionalheating, also contribute to significant pollutantemissions in urban areas

Various health impacts of PM, from genuine to intense ones, are connected with its particular substance and physical properties. The molecule size is critical regarding more profound entrance into the lungs and fine particles are likewise transporters of dangerous air toxins including substantial metals and natural mixes. As indicated by McNabola et al 1992, it is essential that individual exposure studies are completed to evaluate the wellbeing danger of individual urban workers notwithstanding the encompassing air quality checking typically did by an administrative body in most real urban communities. Ostroet al.1982 examined that the fine particles are more unsafe to human wellbeing than 2.5 1 PM and they go about as bearer of poisonous substances. The reason for this work is to study the potential of PM 2.5 and PM 1.0 exposure to commuters using different modes of transportation. Transient exposure to hoisted in-vehicle molecule focuses has been connected with subclinical cardiovascular impacts in solid populaces (Riediker et al., 2004; Jacobs et al., 2010), and might serve as a trigger of intense wellbeing impacts.

Since the founding of the Central Pollution Control Board (CPCB), the government has placed significant emphasis on environmental conservation and management issues, including air quality. CPCB is empowered to perform function of State Pollution Control Board for all union territories.However, Section 4(4) of the Water (Prevention and Control of Pollution) Act, 1974 and section 6 of the Air (Prevention and Control of Pollution) Act, 1981 provides power toCPCB to delegate all or any of its powers and functions of a State Board in a UT under the said acts to such a person or body of persons as the Central Government may specify. The CPCB has delegated all its powers and functions as a State Board in respect of the UT of Delhi to a committee of officials as specified by the Central Government in March, 1991. (**http://delhi.gov.in).**This unit has since evolved into the present-day Delhi Pollution Control Committee (DPCC) which is in charge of monitoring and regulating the air quality of Delhi.

As of April 2016, the DPCC measures and disseminates concentrations of various criteria pollutants: PM10 (PM of aerodynamic diameter $\leq$ 10 μm), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxide (NO), ammonia, benzene ozone (O_3), and sulphur dioxide (SO_2), and the recently included PM2.5 (PM of aerodynamic diameter $\leq$ 2.5 μm) . At present, there are six ambient monitoring stations (Figure 1-1). The data from these stations are published on the DPCC website and updated. Except for PM2.5 and NO_2, which are reported as a non-averaged hourly concentration, the concentrations of SO2 and PM10 are reported as 24-hour moving averages and the concentrations of O3 and CO are reported as 8-hour moving averages. Besides publishing concentration data for criteria pollutants, NEA (National Environment Agency) uses a Pollutant Standards Index (PSI) as a health advisory. The PSI, an index developed by the United States Environmental Protection Agency (US-EPA) in 1980s, is reported as a number on a scale of 0 to 500. The PSI reflects the overall quality of air based on a set of parameters and pollutant concentrations. However, in 1999 the US-EPA replaced the PSI with the Air Quality Index (AQI) which incorporates new standards of PM2.5 and O_3. In addition to general air quality monitoring, DPCC also plays a strong regulatory role by controlling emissions at the source. This is enforced through inspections on industrial premises and monitoring stack emissions directly. Vehicular emissions are also tightly monitored, with a compulsory annual smoke measurement test for all vehicles.

Figure 1.1: Air quality monitoring station in Delhi. Source: (http://www.dpccairdata.com/dpccairdata/display/index.php).

Table1.1shows the comparison between NAAQS (National Ambient Air Quality Standrads) air quality standards with the US-EPA air quality standards and the WHO guidelines. The last column in Table 1.1 shows the state of Delhi's air quality as reported in the DPCC 2016 report. The available data suggest that the concentration of PM2.5, PM10, and SO_2, the ambient concentrations of criteria pollutants fall well below the air quality standards set by the authorities. This is partly due to increase in vehicle population in the state and change in climatic conditions of the state, which is ideal for the dispersion and deposition of pollutants (Velasco and Roth, 2012). The data shows that strong rules and regulations is needed to be formulated as well as the strong enforcement and regulatory role is required to be played by the DPCC and CPCB to curb such rising pollutant concentration.

Table 1.1: Air quality standards for US-EPA, WHO and NAAQS and annual air quality in Delhi in 2016 for the criteria pollutants.

Pollutants (Units)	Averaging Time	Air Quality Standards			Delhi Air Quality in 2016[b]
		US-EPA	WHO[a]	NAAQS	
PM 10.0 (µg/m^3)	Annual	-	20	60	869(max) 265.9(avg)
	24 Hours	150	50	100	
PM 2.5 (µg/m^3)	Annual	12	10	40	139(max) 118.1(avg)
	24 Hours	35	25	60	
CO (mg/m^3)	8 Hours	9	-	02	1.0(max) .67(avg)
	1 Hours	35	-	04	
SO_2 (µg/m^3)	Annual	-	-	50	56.33(max) 41.91(avg)
	24 Hours	-	7.09	80	
NO_2 (µg/m^3)	Annual	75	47.3	40	323.1(max) 111.1(avg)
	24 Hours	100	98.7	80	
Ozone (µg/m^3)	8 Hours	-	-	100	270.9(max) 161.4(avg)
	1 Hour	-	-	180	

[a] Standards for gaseous pollutants originally in mass concentrations, converted to volumetric concentrations using ideal gas law.

[b] Values of various parameters are calculated average of 6 ambient monitoring stations of DPCC.

Sources :(www.who.int/phe/health_topics/outdoor**air**/outdoor**air**, https://www.**epa**.gov/, (http://www.dpccairdata.com/dpccairdata/display/index.php).

The relatively high annual concentrations of PM2.5 and PM 10.0(above WHO and NAAQS air quality standards) suggest that Delhi faces an issue with fine particle pollution. Motor vehicles have been recognized as a major source of PM2.5 and PM10.0, contributing an estimated higher percentage of PM2.5 emissions and PM10.0 emissions. Rapid growth of vehicle population has contributed to higher extent on increase in emissions of particulate matters.

The total number of motor vehicles on road in NCT of Delhi as on 31st March, 2015 was 88.27 lakh, showing an increase of 6.4 per cent over previous year. The category wise number of motor vehicles in Delhi is presented in the table below (Table 1.2).

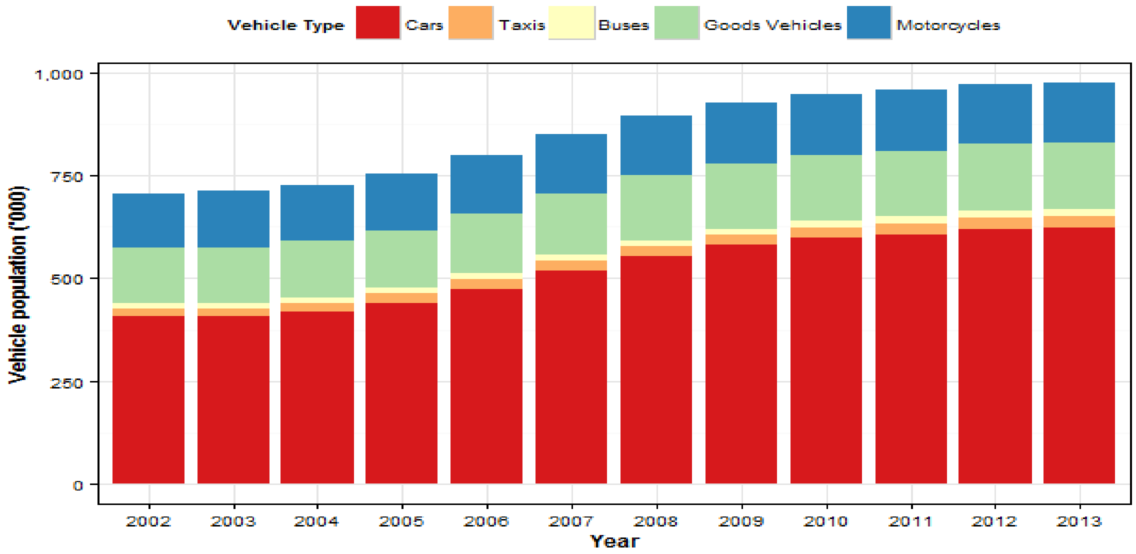

Figure 1.2 Delhi's vehicle population from 2002 to 2013 (Data from Urban transport authority).

Table 1.2 Vehicle Population of Delhi.

S.NO.	Details	Number of Vehicles		Growth Rate Percentage
		2013-2014	2014-2015	
1	Cars and Jeeps	2625250	2790566	6.30
2	Motor Cycles & Scooters	5296163	5681265	7.27
3	Ambulance	1519	1527	0.53
4	Auto Rickshaws	78750	81633	3.66
5	Taxies	74758	79606	6.48
6	Buses	19641	19729	0.45
7	Other Passenger Vehicles	11289	11284	-0.04
8	Tractors	1651	1637	-0.85
9	Good Vehicles	149147	160156	7.38
10	Others	106	28	-73.58
Total		8258274	8827431	6.89

Source: -Economic Survey of Delhi2014-2015

It may be observed from the above table that the growth rate of vehicles in Delhi during 2014-2015 was recorded at 6.89 per cent. The highest growth of vehicles during the period was observed in good vehicle at 7.38%. Annual growth rate during 2014-15 in comparison to previous year was observed in Motor Cycles & Scooter at 7.27 percent. It is 6.48% in Taxis and 6.30% in case of Car & Jeeps. The negative growth of vehicles recorded in other passenger vehicles, Tractors & others vehicles during 2014-15

However attributable to fast increments in private engine vehicle utilize, the Delhi transportation part remains a vast and developing wellspring of air contamination in that city (Narain et al., 2010). Research from around the globe demonstrates that particle concentration in transportation microenvironments on and closes roadways and inside vehicles e frequently surpasses adjacent surrounding levels. Along these lines exposures of individuals while in travel and for the individuals who live or work close roadways may not be very much described by customary air quality checking stations (Kaur et al., 2007). Fleeting introduction to hoisted in-vehicle molecule fixations has been connected with subclinical cardiovascular impacts in solid populaces (Riediker et al., 2004; Jacobs et al., 2010), and might serve as a trigger of intense wellbeing impacts.

The data in regards to the method of transportation offices utilized by workers as a part of Delhi amid the most recent two decade according to the Census of India is exhibited in the Table 1.3 beneath. DTC is the biggest open transport element in the NCR (National Capital Region). DTC works 4712 transports on 578 city courses and 18 NCR courses. 3781 low floor AC and non AC CNG transports and 924 standard floor transports convey around 39 lakh travelers every day by covering 7.87 normal km day by day. Semi low floor transports (1380 non AC) are under acquirement to supplant the standard floor transports which have outlasts their lives. Automated fare collection system through electronic ticketing machines being acquired and rolled out. The performance of DTC during 2001-02 to 2014-15 is presented in Table 1.3 and activities of DTC are presented in Table 1.4.

Table 1.3: Distribution of commuters on basis of mode of transportation in Delhi: 2001 & 2011.

Si. No	**Mode of Transportation Facilities**	**2001**			**2011**		
		Rural	**Urban**	**Total**	**Rural**	**Urban**	**Total**
	No of households	169528	2384621	2554149	79115	3261423	3340538
1.	Bicycle	48.70	36.80	37.60	44.20	30.30	30.60
2.	Scooter/ Motor cycle	20.70	28.50	28.00	38.50	38.90	38.90
3.	Car/ Van	7.30	13.40	13.00	10.80	21.00	20.70
4.	Others	38.90	43.40	43.10	34.70	37.20	37.10

Source: - Census of India 2011, Delhi Transport Department

Table 1.4: Commuters Activities of Delhi Transportation Corporation: 2014-2015.

Si. No	**Details**	**2013-2014**				**2014-2015**			
		Non-AC	**AC**	**Std**	**Total**	**Non-AC**	**AC**	**Std**	**Total**
1	Total Buses in the fleet	2506	1275	1435	5216	2500	1275	937	4712
2	Buses on the Road (daily average)	2270	1123	1174	4567	2226	1106	848	4180
3	Passengers (in lakh)	9845.33	2530.27	3492.01	15867.61	9539.25	2281.97	2366.10	14187.28
4	Daily average Passengers (in lakh)	26.97	6.93	9.57	43.47	26.14	6.25	6.48	38.87
5	Kilo meters operated daily average	4.51	2.23	1.93	8.67	4.38	2.12	1.37	7.87
6	Break down per 10000 buses	62	113	33	66	4.89	8.13	2.50	5.35

Source: - Operational Statistics of DTC 2014-2015

As it can be seen from above tables that large population of Delhi commutes daily using various modes of transportation available and are exposed every day to varying levels of pollution depending on mode of travel. Lee et al.1996 observed that in-vehicle exposures to PM can be a significant part of personal total exposure. Lyons and Chatterjee et al 2001reported that many cities and towns are now choked to a greater or lesser extent by the daily exodus from homes to offices and back. PM emissions in the urban area depends on vehicle type, engine and fuel type, cold start and hot start, speed of the vehicle, driving cycle and silt load . Particle pollution has increasingly become a severe problem due to fast industrialization and urbanization in the past two decades in India. Some studies indicate that finer PM has the strongest health effects .PM as an environmental pollutant has a quality which makes it a typical air pollutant problem.

As mentioned above, despite the increased recognition of the impacts of particle pollution from traffic on human health, personal exposure to PM has not been well documented in Delhi. Past research has shown that ambient monitoring is inadequate to capture the spatial and temporal variability of pollutant concentrationsat ground-level (Kaur et al., 2005b; Gulliver and Briggs, 2007). However, data from the DPCC road-side monitoring stations are not published nor incorporated into the PSI calculations. Local air quality researches have also focused on ambient concentrations of particulate and gaseous pollutants.

An important limitation of most existing studies exploitingnatural or policy-induced variation in air quality is thatthey have made use of aggregated data. As a consequence, these studies have not incorporated informationon the level of exposure faced by individuals.Also not much of the emphasis has been given on potential effects of PM1.0.The purpose of this work is to study the potential of particulate matter (PM2.5 and PM1.0) exposure to commuters using different mode of transportation.

1.3 Objectives

The objective of present study is to evaluate real time exposure concentration of particulate matter PM2.5 and PM1.0 to which commuters are exposed on different transportation modes in city of Delhi. The four local available modes of transportations (Ac Cab, Auto Rickshaw, DTC Bus, and Non Ac Cab) were investigated and compared during a journey in a busy and heavy traffic area during morning, afternoon and evening hours when pollution and commuter volume tends to be the highest.

The total exposure for the entire journey was investigated as well as spatial variation within the transport micro environment is presented. For providing useful information to reduce commuters’ exposure it is necessary to assess the individual contributions from the various spaces encountered during the trip. Parameters included measuring particle mass concentration of PM2.5 and PM1.0, measured using portable and battery operated instrument (Haz Dust EPAM-5000)

The overall objective of the present study can begiven as follows:

1. To determine levels of aerosol pollution that commuters are exposed to when travelling via different modes of public transport in Delhi.

2. To compare aerosol concentrations during trips on each mode of transport compare against each other.

3.To observe and analyze temporal variation of pollutant concentrations within the transport microenvironment for each mode.

1.4 Thesis outline

The present thesis consists of five chapters. Chapter 1 gives overall view of the project, significance and need for the present study and overall objectives of the thesis. Thechapters to follow consist of Chapter 2 introducing parameters of particle pollution that were measured and analyzed and present a review of commuters' exposure research work. Chapter 3 introduces instrumentation, route choice, field work including sampling procedures and data quality control. The results from observations are presented and discussed in Chapter 4 followed by Chapter 5 which summarizes the findings.

Chapter 2- Literature Review

Aspects of particle pollution in urban environments that are investigated in the present study are reviewed first. This is followed by a brief review of research regarding the fate of emissions within the transport microenvironment and city streets and finally research focusing on commuter exposure. Only selected work most relevant to the present study is considered.

2.1 Estimating exposure

Exposure is characterized as the point of contact amongst toxins and people. To understand the pathways by which pollutants and contaminants can influence people and characteristic biological systems, researchers built up the source-to-receptor theoretical structure. This structure joins issues of contamination to human wellbeing reaction, highlights the distinctive variables that add to one's introduction to different stressors, and considers input systems (Lioy and Smith, 2013). With this source-to-receptor structure, researchers of various orders can start to outline the vital exploration for focused arrangements whether at the source or at the purpose of contact and powers can start to plan successful strategies.

Ambient pollutant concentrations are oftentimes utilized as a surrogate for individual presentation in epidemiological studies. In any case, genuine introduction is unequivocally controlled by time-movement and conduct designs in an assortment of various microenvironments (Jiao et al., 2012). The average exposure is the most generally utilized term as a part of portraying introduction and it is the time-weighted average of pollutant concentration measured in the diverse microenvironments where individuals live, work, and play (Monn, 2001).

Within the source-to-receptor framework, the dose comes between the point of contact with the pollutant and resultant health impact, forming another part of the core of exposure science. Dose is the amount of material that is ingested and become absorbed or deposited in the body (Monn, 2001). For air pollutants, this is the amount of material that is deposited in the respiratory system via inhalation. The potential dose can be calculated by multiplying the average exposure by the volume of air exchanged in the lung and the time spent in the microenvironment (Monn, 2001).

2.1.1 Measuring exposure to particle pollution

Measured metrics

The particulate matter mass concentration (PM) is the primary metric utilized by administrative powers. Particles are isolated by size which decides how far the particles can infiltrate the respiratory tract. Smaller particles can achieve the most profound districts of the lungs and possibly enter the circulatory system to be transported to different parts of the body (Oberdörster et al., 2005). The two primary molecule size portions as of now directed by powers are PM10 and PM2.5 which relate to the aggregate mass groupings of particles of streamlined breadths up to 10 μm and 2.5 μm, individually. These size divisions are likewise reciprocally termed coarse and fine particles, individually. All the more particularly, coarse particles are characterized as the particles amongst PM2.5 and PM10, and their nearness is generally demonstrated by a low PM2.5 to PM10 proportion. Notwithstanding PM10 and PM2.5, the present concentrate likewise researched the presentation to PM1 (particles of streamlined distance across ≤ 1 μm).

There is developing worry that particles of much smaller size have expanded toxicological noteworthiness. For instance, roughly 80% of particles in the PM2.5 and PM10 size-portions are kept in our nasal entries (Oberdörster et al., 2005). However particles of much smaller diameter across (i.e. < 100 nm) can infiltrate further into our respiratory frameworks. The miniscule size combined with a high surface territory to unit mass or unit volume additionally builds the molecule ability to adsorb cancer-causing mixes which might be retained into the blood, expanding the danger of undesirable effects (Lighty et al., 2000; Oberdörster et al., 2005). The little size means these particles make up a unimportant segment of the general molecule mass focus, consequently a little PM10 or PM2.5 mass fixation may cloud the genuine wellbeing sway. These modest particles are generally alluded to as ultrafine particles (UFPs) characterized in the present study as particles with a measurement ≤ 100 nm, and are vastly improved evaluated by the molecule number (PN) (# particles cm-3) or dynamic surface territory (ASA) (mm2 m-3) fixations than mass focuses (Heal et al., 2012).

Particles smaller than 100 nm have been found to account for 82 – 87 % of number concentrations, whereas the slightly larger particles of 0.1 – 2.8 μm form approximately 82% of mass concentrations in European cities (Morawska et al., 2008). Based on these findings, PN is a better metric than PM1 to reflect the presence of UFPs. The unit for PN, particle cm-3, will be shortened to # cm-3 for readability from here onwards. Particles are not idealised spheres and may have both internal and external cavities. The ASA is a measure of the particle morphology, and refers to the external surface area of particles – the sites on which transfer of momentum, energy, and mass from gas to particle can take place (Keller et al., 2001). In the context of human health, ASA are locations where chemicals can come into direct contact with and be transferred to the walls of the respiratory system. Thus it may be more closely linked to the health impacts of particle pollution.

Regardless of the quantity of epidemiological studies connecting movement contamination and human wellbeing impacts, there has been no reliable utilization of introduction metric. An assortment of various measurements for evaluating human exposure to vehicular activity are utilized, including non-pollutant related measures, for example, nearness to road (Lipfert and Wyzga, 2008). Mass fixations, PM10 and all the more as of late PM2.5, are still the most broadly utilized measurements as a part of epidemiological studies, which frame the fundamental proof for the present molecule air quality norms. Notwithstanding, there is extraordinary heterogeneity in the fixation and science of poisons in close street focuses. There are a wide range of qualities of the vehicle armada in urban communities that could influence the tailpipe emanations (Brugge et al., 2007). Watchful determination of activity introduction measurements is hence required keeping in mind the end goal to recognize the particular segments of vehicle-related outflows (counting debilitate discharges and non-ignition emanations, for example, brake wear and tear) that bring about negative wellbeing impacts (Lipfert and Wyzga, 2008). Some of these conceivable measurements incorporate PM10, PM2.5, PN and ASA, which are incorporated into the present study. There are additionally different parameters that can better record for source-based outflows, which incorporate mass groupings of dark carbon (BC), carbon monoxide (CO), and molecule bound polycyclic sweet-smelling hydrocarbons (pPAH). Lipfert and Wyzga (2008) note that such introduction gauges taking into account discharge source sort would give better confirmation to source-based control techniques since one source may radiate a blend of contaminations. This would be more practical and spread everybody over the exposure range.

2.2 Particle pollution in the transport microenvironment

The transport microenvironment has been extensively investigated because of the unique mix of conditions and processes that govern the fate of pollutant concentrations. The presence of motor vehicles as a major pollutant source distinguishes the transport microenvironment from other indoor or outdoor locations. The factors that affect pollutant concentrations within the transport microenvironment include (but are not restricted to) vehicle characteristics, road conditions, building morphology and atmospheric processes.

2.2.1 Transport emissions

Motorized transportation modes with internal combustion engines emit particles predominantly from the combustion of fossil fuel. Pollution from engine exhaust is especially important because incomplete combustion leads to emissions of many pollutants including CO, volatile organic compounds (VOCs), nitrogen and sulphur oxides, carbonaceous particles, and pPAH (Kittelson, 1998; Colvile et al., 2001; Brugge et al., 2007).

Vehicles can emanate particles specifically through motor burning, from abrasion process (e.g. wear and tear of tires, brake linings and street surface material), or in a roundabout way when particles are re-suspended because of the mechanical turbulence (Charron and Harrison, 2005; Vallero, 2008; Hertel and Goodsite, 2009). In the atmosphere, particles can experience further transformative procedures including nucleation, coagulation, dissipation, buildup, and agglomeration, which change their shape, size, and piece, bringing about very heterogeneous spatial and fleeting varieties (Lighty et al., 2000). Particles can likewise frame in the environment by means of physical and synthetic responses of essential radiated poisons. Most UFP are framed in this way, by means of the nucleation of essential radiated debilitate gasses took after by condensational development or agglomeration (Heal et al., 2012). Such particles are known as optional particles. Techniques to control movement volume have been appeared to be viable in controlling contamination at road level. In Los Angeles, USA shutting a segment of a noteworthy interstate prompted considerable diminishments in PN, PM2.5 and BC (Quiros et al., 2013b).

Stringent traffic controls in Beijing brought about reductions in ambient concentration of up to half for BC and PM10 amid the 2008 Summer Olympic Games (Wang et al., 2009). This was combined with the forceful usage of the Euro IV vehicle discharge models for new enrolled vehicles and Euro III for existing transports and taxis which likewise prompted 33%, 47% and 78% drops in emanation elements of BC, CO and UFP separately for light-obligation fuel vehicles. The presentation of blockage charges in London likewise seems to have diminished PM10 focuses at specific areas, in spite of the fact that the creators of that study did not discount other site-particular elements (Atkinson et al., 2009).

Most particles radiated by vehicles have a breadth somewhere around 10 and 100 nm, however this can contrast contingent upon fuel structure, vehicle age, driving examples, and upkeep history (Lighty et al., 2000). In London, United Kingdom (UK), Colvile et al. (2001) found that PM10 outflows from diesel vehicles are higher than fuel vehicles (67% versus 11%), notwithstanding making up just 26% of the vehicle armada. On average, diesel-fuelled vehicles additionally transmit more nanoparticles, making a bigger contribution to add up to PN contrasted with gas fuelled vehicles (Kittelson et al., 2004, 2006). These UFP are of bimodal size circulation, with an expansive extent beneath 20 nm and between 30 – 100 nm, individually, with around equivalent aggregate mass in every mode (Shi et al., 1999; Colvile et al., 2001). There has likewise been exploration on the effects of alternative fuels. The expanding utilization of compressed natural gas (CNG) in Delhi, India from 1995 to 2001 brought about a drop in the yearly mean concentration of surrounding suspended PM (from 405 to 347 μg m-3) (Goyal and Sidhartha, 2003). Bio-fuel was likewise found to prompt huge abatements in PM and vaporous toxins (counting CO and carbon dioxide [CO2]), however brought about higher PN emanations contrasted with routine diesel or gas (Kumar et al., 2010).

Driving conditions can likewise influence the molecule mass and number outflow rates. In spite of the fact that diesel vehicles by and large radiate higher molecule numbers than gas vehicles, at high motor load and speeds (~120 km h-1), gas fuelled motors have been found to emanate PN practically identical to that from diesel motors (Kittelson et al., 2001). As a rule, higher motor loads and speeds produce higher amounts of molecule discharges, particularly as far as PN (Kittelson et al., 2001). Stop-begin driving examples, for example, amid roads turned parking lots have likewise been found to prompt the capacity and arrival of bigger measures of hydrocarbons because of wasteful burning (Kittelson et al., 2001). Utilizing a portable discharges research facility (MEL), Kittelson et al. (2004) found on-street PN going between 104 to 106 # cm-3 when driving at free-streaming velocities. Beforehand, the MEL recorded lower PN values (103 to 105 # cm-3) amid congested driving conditions where the normal velocity was < 32 km h-1, (Kittelson et al., 2001). These discoveries were replicated all the more as of late by Buonanno et al. (2011) who recorded PN, total particle surface area, and PM2.5 along various streets in Cassino, Italy. They found that parts of the street with congested movement, where vehicles are constantly ceasing and beginning, displayed PN, absolute molecule surface region, and PM2.5 mean estimations of 430,000 # cm-3, 670 µm2 cm-3, and 41.4 µg m-3 individually. This stood out incredibly from estimations further not far off with vehicles driving at cruising speed (PN: 150,000 # cm-3, absolute molecule surface territory: 260 µm2 cm-3, and PM2.5: 16.5 µg m-3) (Buonanno et al., 2011).

2.2.2 Spatial and temporal distribution of particles

The city road is a heterogeneous microenvironment, with even and vertical focus angles over the road ravine (Heal et al., 2000). An extensive survey of the different variables that control UFP focuses was finished by Morawska et al. (2008). Notwithstanding the variability in discharges from vehicles, there are a large number of different elements influencing the dispersion of pollutant concentrations, including road geometry, street format, and meteorological conditions (Morawska et al., 2008; Buonanno et al., 2011).

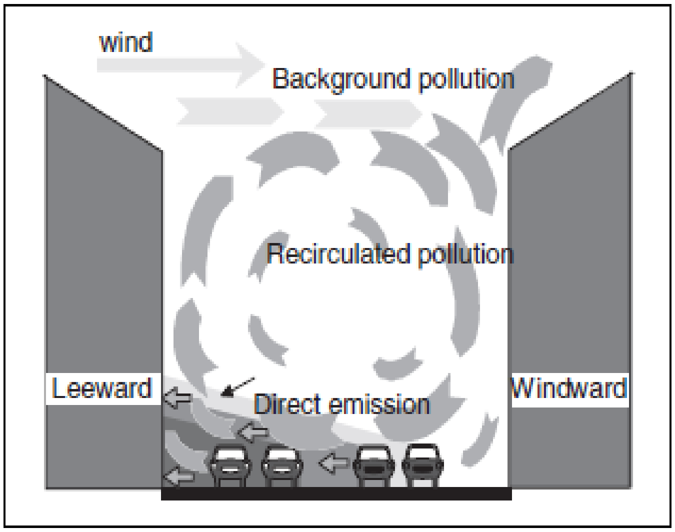

Figure2.1: Vortex flow and dispersion within the street. In the situation depicted, that wind above roof level is perpendicular to the street.(Hertel and Goodsite et al 2009).

Wind pace and directions have been found to influence pollutant scattering and evacuation forms. Shi et al. (1999) made estimations in Birmingham, UK, which propose that higher wind speeds contribute contrastingly to mass fixation than number focuses. Charron and Harrison

(2005) found that middle PM2.5 focuses diminished from 25 to 18 μg m-3 as wind rate expanded from underneath 1 to > 9 m s-1 inside a urban gully in London, UK. In any case, the convergences of coarse particles were found to increment with expanding wind speed, recommending that molecule re-suspension is a vital procedure adding to PM10 fixations (Charron and Harrison, 2005). Buonanno et al. (2011) likewise reported that higher wind speeds escalated the distinction between the windward and leeward sides of the urban ravine vortex stream. Absolute PN has been found to diminish with expanded separation downwind from the street considerably more quickly than mass focuses, which is credited to weakening with foundation air and coagulation of particles (Shi et al., 1999). Upon discharge from the fumes, particles may experience change, scattering or get to be kept. Ultrafine particles can experience fast change of a few requests of size inside seconds (Heal et al., 2012).
In the vertical measurement, particle concentration generally decreases with expanding stature. Be that as it may, there are varieties in concentration patterns for various molecule size-divisions which show diverse procedures of arrangement, advancement and transport (Salmond et al., 2010). Kumar et al. (2008) measured PN at 1, 2.25, 4.62, and 7.37 m inside a 11.6 m profound urban gorge and found the most astounding PN happening at 2.25 m, with focuses diminishing towards the street and the highest point of the ravine. Beneath 2.25 m, weakening and dry testimony forms act to evacuate particles, while with expanding tallness, the decline in PN is thought to be connected with mass trade noticeable all around over the road level. In prior work in Hong Kong, China, Chan and Kwok (2000) additionally discovered diminishing PM2.5, PM10, and all out suspended particulates (TSP) fixations with tallness. The rate of reduction was smallest for PM2.5, trailed by PM10, and TSP. This example was credited to the extent of the particles: bigger particles will probably drop out of suspension because of the impact of gravity, leaving the littler particles to diffuse upwards (Chan and Kwok, 2000).

In addition to spatial varieties, temporal variation for molecule mass and number fixations has likewise been found. In Hong Kong, China, Chan and Kwok (2001) observed that street side groupings of TSP [cut-off size ≤ 50 μm]) and PM10 displayed a yearly variety. Both TSP and PM10 were higher amid the dry winter rainstorm months of October to March (month to month mean TSP: 154.64 μg m-3 and PM10: 88.20 μg m-3) and lower amid the wet summer storm from April to September (month to month mean TSP: 90.84 μg m-3 and PM10: 64.32 μg m-3). The higher month to month found the middle value of estimations of TSP and PM10 in winter were suspected to be contributed by the overall north-easterly winds transporting particles from China, while the more successive precipitation amid summer prompted more noteworthy wash-out of particles (Chan and Kwok, 2001).

2.3 Personal exposure in the transport microenvironment

In addition to the intensity of emission sources and impacts of meteorological elements, human exposure (and measurements) is additionally represented by the conduct and action of people (Figure 2-1). Movement outflows can prompt little scale spatial variation in the vehicle microenvironment that conventional ambient estimations of air quality just don't catch (Kaur et al., 2007). In any case, the vehicle microenvironment speaks to one and only of the different areas that individuals go as the day progressed. In spite of this, studies consolidating human time-movement designs have watched that despite the fact that voyaging may take up just roughly 5 – 10% of every day, it can represent up to 21% of day by day exposures and 30% of breathed in measurements in more created nations (Dons et al., 2012).

As depicted in the past segment, the spatial and temporal distribution of airborne pollutants at ground level can be profoundly heterogeneous. Standard air quality checking stations situated over the urban shade catch diverse pollutant marks contrasted with those accomplished at road level. Keeping in mind the end goal to better comprehend the commitment of investing energy in the vehicle microenvironment to human exposure, scientists have centered their examinations on individual exposure amid every day drives. These concentrates for the most part measure worker exposure via conveying a convenient sampler on one or more courses mimicking a day by day drive.

There has been a substantial amount of research on commuter exposure to different pollutants in many different cities on a variety of transport modes, including those in the present study: bus, car, auto rickshaw etc. Some of these studies form part of more comprehensive projects on air pollution in urban environments such as the DAPPLE Project (http://www.dapple.org.uk/). Table 2-1 summaries a few studies on commuter exposure that include transport mode comparisons.

Beyond the fundamental similarities as far as utilizing versatile observing on different transport modes, there is extraordinary variation with respect to the study outline regarding routedecision, time of day estimations are made, and whether estimations are made simultaneously between transport modes (Table 2-1). For every study, the vehicle modes are generally chosen in light of their nearness in the city, and the route decision is typically dependent upon the vehicle mode(s). Where conceivable, a route is been illustrative for many commuters. Some studies have chosen numerous routes so as to think about the impact of route decision on exposure (e.g. Kaur et al., 2005; Hertel et al, 2008). The planning of the examining is likewise essential since activity volumes are known not at various times of the day. Most studies have concentrated on outings amid the surge hour time frames when movement and commutes volumes are most noteworthy; however there are studies that lead estimations for the complete duration of the day (e.g. de Nazelle et al., 2012). There are additionally varieties in the outcomes exhibited. For instance, some studies show just information from inside the vehicle amid the excursion (e.g. Knibbs and de Dear, 2010), while others present information from the whole course, which can incorporate sitting tight for open transport, strolling to the vehicle and going inside the vehicle (e.g. Tsai et al., 2008, de Nazelle et al, 2012).

Table 2-1: Summary of transport modes and parameters measured for selected studies.

Reference	**Location**	**Transport Modes**	**Param eters**	**Study Details**
L.Y.Chan et al (2002)	Guangzhou China	Subway AC bus Non Ac Bus Taxi	PM 10.0 PM 2.5 CO	They found that PM 10 and CO level is greatly influenced by mode of transport. Highest level of PM 10 and CO was obtained in a non ac bus. The ventilation condition of the transport was also crucial. Exposure levels were slightly lower in the afternoon non peak hours than in the evening peak hours. PM 2.5 inter-micro environment variation is similar to the pattern of PM 10.0. PM 2.5 to PM 10 ratio in the transport was high, ranging from 76% to 83%.
PromodKu	New Delhi	Motorcycle	PM 10	They found out that exposure to

mar et al (2014)	India	Auto Rick Shaw Car Bus	PM 2.5 PM 1.0	commuters for PM in descending order was motorcycle, auto rickshaw, bus and car in morning and bus, car, 1.0 motorcycle and auto rickshaw in evening. For PM2.5 it was motorcycle, auto rickshaw, car and bus in morning and car, bus, auto rickshaw and motorcycle in evening. Whereas for PM10 it was car, bus, motorcycles, auto rickshawin morning and car, bus, auto rickshaw, motorcycle in the evening. Sizefractions (fine/coarse) varied from 55 to 74% in morning and 41 to 54% in evening with PM 2.5 contributing to more than half the amount of PM 10.
Shivanand Swamy et al (2008)	Ahmadabad India	BRTS City Buses	PM 2.5	Variation in PM2.5 concentration levels for different 7 mode-types and presence of air-conditioning (AC) was observed during various months covering 8 the winter, summer and pre-monsoon season; location and time of day (peak and off-peak hours). They found out that mean concentration levels in all the 13 modes was highest during winters and lowest during the pre-monsoon period 14. Lower PM2.5 levels on air-conditioned BRTS buses provide a basis to support 15 policy decisions for expanding their share in the fleet.
Anil Namdeo et	New Castle, U.K	Bus Train	CO PM 10	In Mumbai, real-time exposure concentrations were measured while

al (2007)	Mumbai, India	AC Taxi Non Ac Private Car		commuting along a route by bus, train, air-conditioned taxi, and a non-air-conditioned private car. In Newcastle, real-time exposure concentrations were measured while traveling by electric vehicle, public bus, and bicycle along a route. They found that in Mumbai commuters traveling on buses and private non-air-conditioned cars are exposed to very high levels of air pollution compared with the train commuters. In Newcastle, electric vehicles and bicycles displayed the lowest exposure concentrations relative to buses.
Vania Martins, Teresa Moreno et al (2015)	Barcelona, Spain	Subway system with 8 different subway lines	PM 10 PM 2.5	Conducted study on eight subway lines, at different depths, with different tunnel dimensions, station designs and train frequencies. Measurements were performed in this subway systems system in order to characterize the airborne particulate matter (PM) measuring its concentration and investigating its variability, both inside trains and on platforms, in two different seasonal periods (warmer and colder), to better understand the main factors controlling it, and therefore the way to improve air quality. They found out that Average PM2.5 concentration on the platforms in the subway operating hours ranged from 20 to 51 and from 41 to 91 μg/ m−3 in

				the warmer and colder period. PM concentrations inside the trains were generally lower than those on the platforms, which is attributable to the air conditioning systems operating inside he trains, which are equipped with air filters.
Maria João Ramos et al (2013)	Lisbon, Portugal	Walking Bus Train Tram Subway	PM 10.0 PM 2.5	Air quality data was also collected close to a fixed air quality monitoring station which is part of the round trip route, in order to have a reference PM concentration. They found that the tram had higher PM10 concentrations and inside the subway higher PM2.5 concentrations, whilst the train ride had the lowest for both parameters. The tram microenvironment had the highest PM10 inhalation while inside the subway train presented the highest PM2.5 inhalation.
Joshua S. Apte et al (2008)	New Delhi, India	Auto Rick Shaw	Black Carbon Concentration Ultra fine particle Number	They took real-time measurements of fine particle and black carbon mass concentration (PM2.5, BC) and ultrafine particle number concentration (PN) inside a common vehicle, the auto-rickshaw, in New Delhi, India. Study found out that Measured exposure concentrations are much higher in this study (geometric mean for 60 trip-averaged concentrations: 190 microgram/ m3 PM2.5, 42 microgram/ m3 BC, 280 x10^3 particles cm_3; GSD-1.3 for all three pollutants) than reported for

				transportation microenvironments in other megacities. In-vehicle concentrations exceeded simultaneously measured ambient levels by 1.5 x for PM2.5, 3.6x for BC, and 8.4x for PN.
Bradley Bereitschaft et al (2011)	Omaha, Nebraska	Walking along sidewalks.	PM 2.5	This research examined ambient concentrations of fine particulate matter (PM2.5)across six sites situated within central Omaha, Nebraska, a mid-sized metropolitan area located in theMidwest US. The results of a linearregression analysis suggested that 56% of the variability in sidewalk PM2.5were attributable to backgroundconcentrations. Short-duration peak concentrations of up to 360 microgram/m^{3}were associated primarily withvehicle tailpipe emissions and tobacco smoke. At four of the six study sites, pedestrian volume washigher on days and times when PM2.5concentrations was comparatively low.
P Goyal et al (2001)	New Delhi, India	Vehicles in transport sector	CO SO_2 SPM	A relative comparison of ambient air concentration of pollutants, e.g. carbon monoxide (CO), sulphur dioxide (SO2),suspended particulate matter (SPM) and oxides of nitrogen (NOX), emitted from transport sector, during the years 1995-2000 (without CNG) and the year 2001 (with CNG) was been made in order to assess the impact of CNG

				vehicles on ambient air quality in Delhi. It has been found that concentration contribution of above pollutants has been reduced considerably. The annual average concentration of SPM came down to 347 from 405 |j.grrr3, which is still beyond the permissible limits.
LY Chan et al (2002)	Hong Kong, China	Bus Tram Ferry Mass Transit railway Light rail Transit	PM 10 PM 2.5	They found that commuter exposure in tram was highest among all monitored commuting modes. Higher PM 2.5 to PM 10 ratio was found in vehicles with air-conditioning system. For double deck vehicle, higher PM 10 level was obtained in lower deck. Average upper deck to lower deck PM 10 ratio was 0.836, 0.751 and 0.738 in ac bus, non ac bus and non ac tram. respectively.

2.3.1 Summary of past results

The more commonly measured metrics of aerosol pollution in commuter exposure studies are PM2.5 and PM 10.0. The results of selected studies investigating these pollutants are summarized in Table 2-2. Based on the findings of existing studies, there is no consensus regarding the ‘cleanest’ or ‘dirtiest’ transport mode. For example, the travelling by motor cycle mode exhibited the highest mean PM2.5 concentrations in Delhi (Promod Kumar et al.,2014) , but in Mumbai, travelling by buses exhibited the highest PM 2.5 concentrations (Anil Namdeo et al., 2007). A comprehensive review on commuter exposure to UFP by Knibbs et al. (2011) concluded that there is great variability in exposure concentrations across transport modes due to the interaction of numerous determinant factors. Taken as a whole, the results of these studies show that commuter exposure is highly individualized to the unique transport systems in each city.

In summary, the findings from existing literature suggest that studies on personal exposure need to be carried out for local conditions in order to better account for the human exposure to aerosol pollution. There are wide variations in vehicle, road characteristics and meteorological conditions, as well as personal decisions made during travelling that can have a strong modifying effect on exposure concentrations and eventual inhaled dose. Thus studies need to be tailored to local scenarios in order to provide useful and accurate information regarding transport-related exposures.

Chapter 3-Materials and Methodology

This chapter first presents overview of the study area and period and describes the instrument and sampling procedures employed in the present study, followed by description of the data quality assurance and data processing.

The specific transport modes and route sections investigated in the present study are referred to as capitalized proper nouns (eg. Bus, Auto Rickshaw, etc) while non-capitalized versions describes the same transport modes and sections in a more general context.

3.1 Measurement Area and Study Period

Delhi (28.61°N 77.23°E) is located in Northern India and borders with Haryana on the north, west and south and U.P to the east. Two geographic features of the Delhi region are the Yamuna flood plains and Delhi ridge. Delhi features a typical humid subtropical climate (KÖppen classification) with an average temperature ranging between 5°C to 40°C. Delhi experiences seasonal difference in temperatures and rainfall pattern because of changes in wind pattern and geographic features.

Field work for the present study was carried out between April-16 to May-16 during the drier periods in Delhi region with temperature between 30°C to 42°C. The site of the present study was chosen similar to bus route of DTC Bus number 106. The site is located in the northern and central part of Delhi and stretches from DTU gate to Old Delhi railway station (Figure 3.1) with total distance of approx 22km taking around 1hours and 15 minutes of travel time to complete the journey.

Present route was chosen because of the intense vehicular traffic and large volume of commuters who travel to and from work and recreational activities especially during the evening rush hour (17:00 – 19:00 h) and also because given route passes through one of the important residential and commercial areas of north and central Delhi. There is a dense public transport network, with many underground Metro stations and numerous bus services plying the area. In terms of built environment study route consists of Residential areas, market places, office building and medium and high rise residential buildings. This route also passes through outer ring road and by pass area where heavy vehicles movement occurs. The roads along residential areas are lined with trees at regular intervals and pedestrian sidewalks are separated from the road.

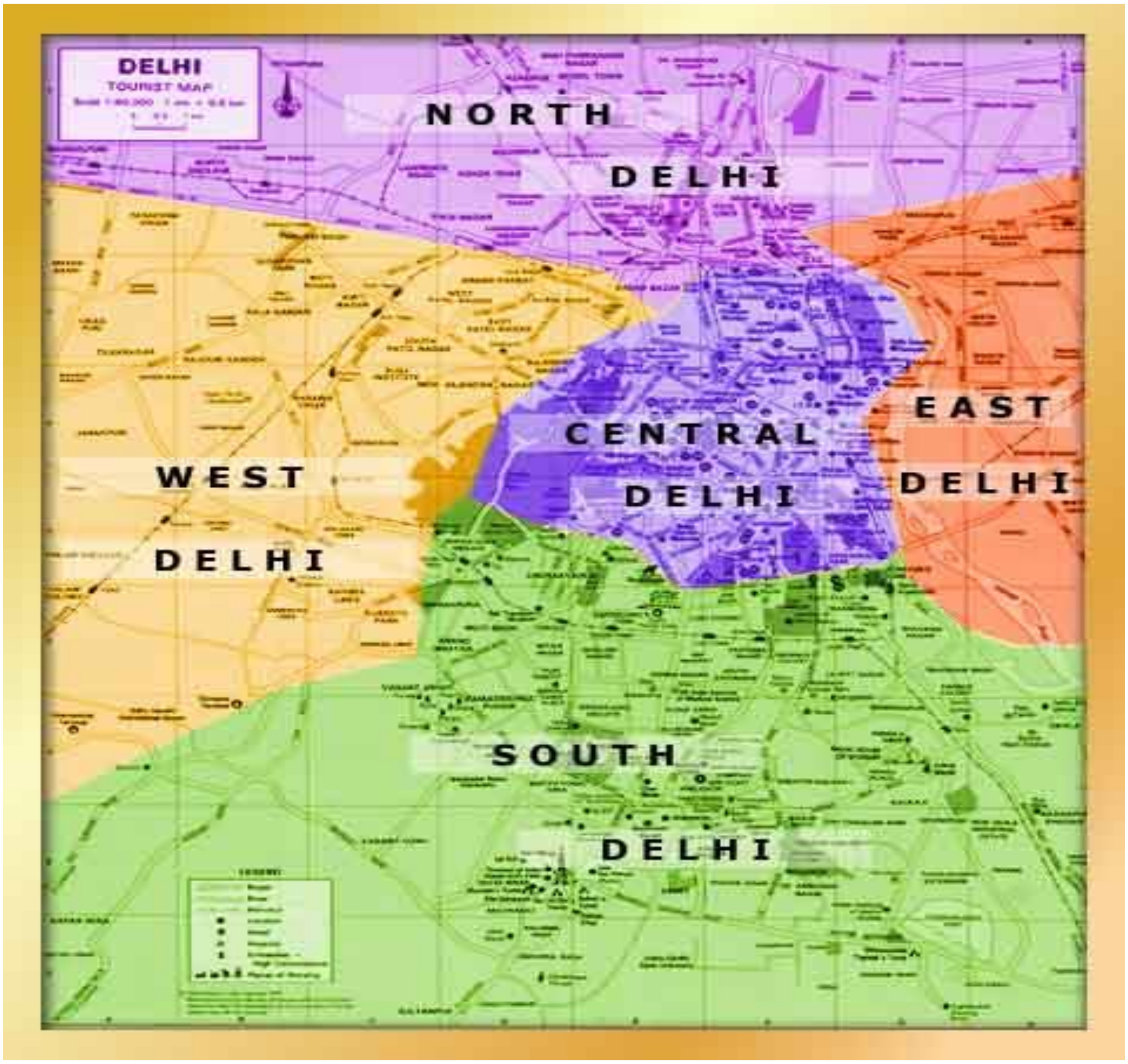

Figure 3.1 Map of Delhi. The study area starts from north and stretches up to central. (Source: One Map.sg).

3.2 Instrumentation

The mobile measurement instrument was selected in this study to measure real time exposure concentration of selected pollutants at the personal exposure level. Instrument used was potable, battery operated and capable of real time in-situ measurements with logging interval of ranging from 1sec to 10 minutes. Unlike gravimetric monitors which provide an average concentration of the particles over the entire sampling period, these real-time logging instruments offer greater flexibility for analysis. As explained previously in section 2.3.1 how certain spaces within transport microenvironment can contribute differently to overall exposure depending upon overall time spent. The instrument used for present study was HAZ-DUST EPAM-5000 and sampling interval used was 1 minutes. Two separate instruments were used for measuring PM2.5 and PM1.0 simultaneously. The following section briefly explains the measurement principles behind the sensors used.

Particulate matter mass concentration

The Haz-Dust EPAM-5000 is a high sensitivity real-time particulate monitor designed for ambient environmental and indoor air quality applications. The instrument measures real time concentration of PM1.0, PM2.5, PM10.0 and TSP. The Haz-Dust uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m3 of airborne dust particles. The two instrument used for present study was

Calibrated using Arizona Road Dust (ARD) against NIOSH method 0600 for Respirable dust with a + 10% accuracy. The calibration of the Haz-Dust can be adjusted to compensate for changes in particle composition and distribution. Before start of sampling each time the instrument was calibrated and was set to manually zero to reduce possibility of any errors.

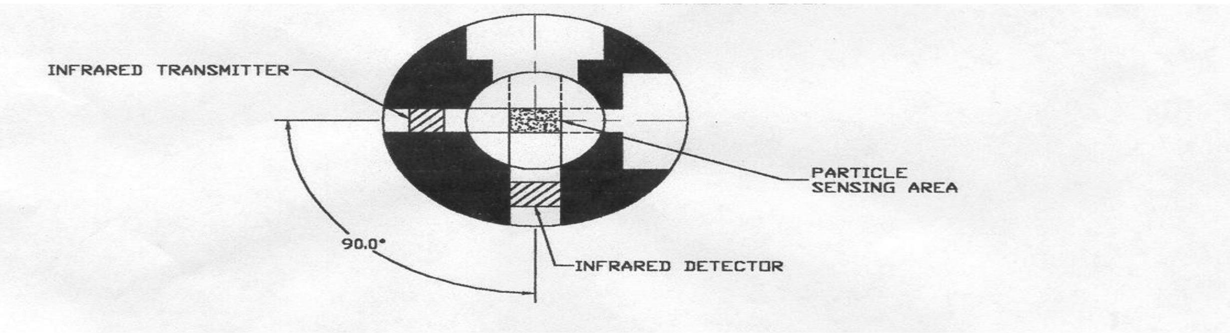

Figure 3.2 Light Scattering principle used in HAZ-DUST EPAM-5000

Figure 3.3: Instrument used in present study. a) Picture of EPAM-5000. b) Picture of impactor jet. c) Picture of sensor lid. d) Picture of impactor jet, impactor cup and impactor sleeve. (Clockwise).

3.3 Sampling design

3.3.1 Sampling route and transportation modes.

To obtain real time exposure concentration of pollutants and to capture spatial and temporal variation while commuting four different modes of transportation were selected i.e. Ac Cab, Auto Rickshaw, DTC Bus, and Non Ac Cab. A 22 km stretch route was selected starting from DTU gate via prashant vihar- jahangirpuri- azadpur-r.k bhag- clock tower market to Old Delhi railway station. Each trip on selected mode had a common starting and end point, beginning and ending at the same location and reading were measured on during one way direction. The sampling route encompasses 22 bus stops and numerous metro stations. The routes for all the selected four modes of transportation were nearly identical, except for travel time required to reach the destination point. Both Ac Cab and Non Cab required lesser time than other two modes of transportation to complete the journey along identical routes.

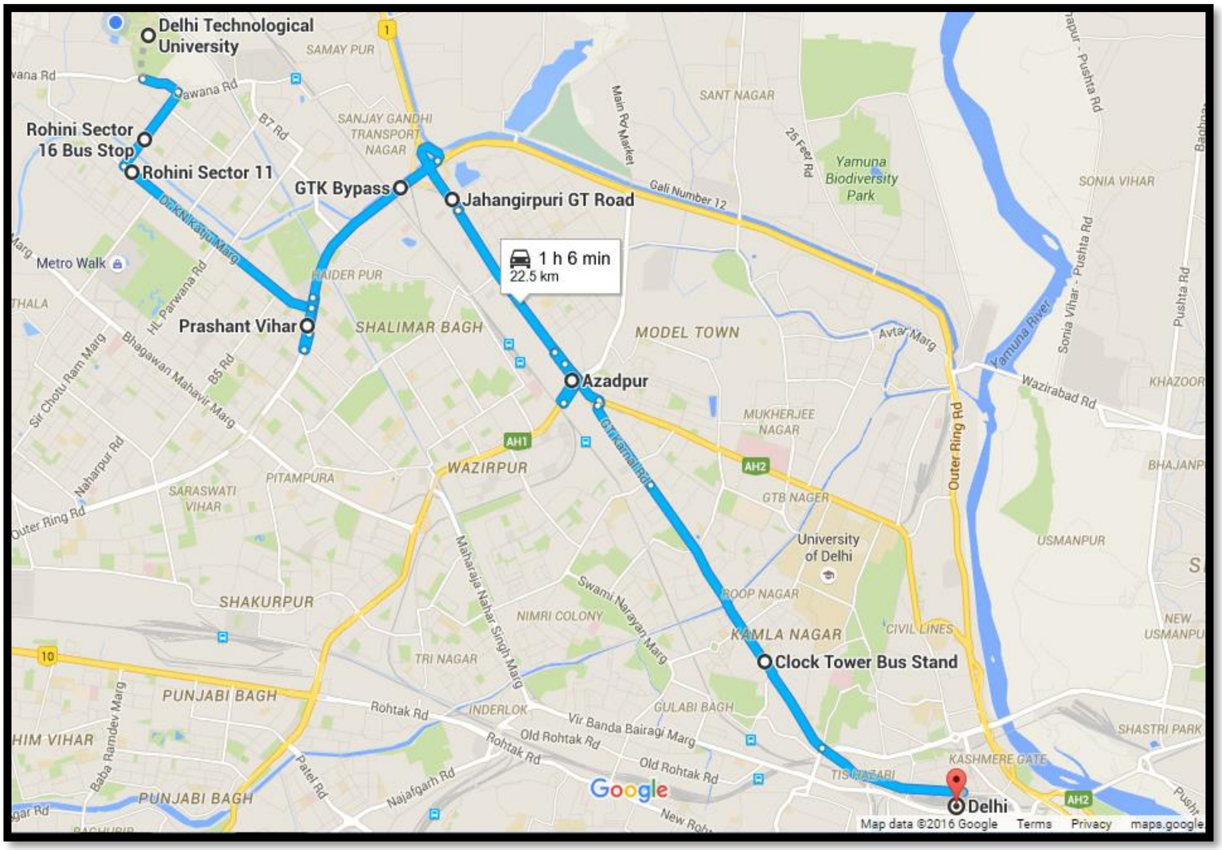

Figure 3.4 Route selected to evaluate exposure concentration on four different modes of transportation. Beginning point of route DTU gate and ending point of the route Old Delhi Railway Station. (Source: - Google Maps).

Simultaneous measurements on multiple transport modes were not possible due to equipment constraints. The distance selected and time period could better accommodate the battery life of the instrument. Although not representing the typical daily commute between home and workplace, the selected route encompasses the variety of microenvironments within the transportation network that commuters will encounter. This is also a common travelling route that visitors to the area may take. Thus the present measurements are expected to be representative of the pollution levels that commuters experience.

3.3.2 Instrument set up and sampling procedure

Due to the sensitive nature of the instruments, procedures were put in place to avoid handling errors during the measurements. Sampling was carried out by myself and volunteer from B.tech. All volunteers were trained on proper handling of instruments and had the opportunity to practice carrying the instruments prior to fieldwork. All mobile measurements were carried by team of two (myself and volunteer). Both researchers ensured that instruments were sampling the same parcel of air. Events that might be related to elevated concentrations or anomalous data were recorded during the measurements.

Transport mode sampling procedures.

Exposure measurements were carried out during predetermined scheduled period of the same day for all selected modes of transportation. The monitoring time periods intervals chosen were morning peak hours (8.00 to 10.00), afternoon hours (11.00 to 14.00) and evening peak hours (17.00 to 20.00). Although the ambient concentration of pollutants can change during this period as a consequence of the local meteorology, in particular mixing height, the concentrations at ground level of pollutants are not severely affected. It has been noted by Salmond and McKendry (2009) that the effect of the mixing height on ground level pollution tends to be negligible due to the proximity to the emission sources. Hence for the purposes of this study, traffic and weather conditions were assumed to be constant during this sampling period. Samplings were only carried out during dry weather conditions because rainfall can strongly influence the measurements and even damage sensors. Samplings after rain events were also avoided as the HAZ-DUST does not perform well in high relative humidity, which leads to difference in estimation of PM concentrations.

During study period exposure measurements were carried out by researchers thrice a day during morning hours, afternoon hours and evening hour. Measurements taken consisted of journey on each selected four modes of transportation (Ac Cab, Auto Rickshaw, DTC Bu, and Non Ac Cab) sampled consecutively one after the other. All modes of transportation transects were sampled in the same direction from start to end. On reaching the destination point we used to travel back to the starting point for the next trip. This meant there were three trips per day of sampling. On completion of particular mode for the first time as per scheduled time intervals on particular day, same mode of transportation was repeated on the next day as per schedule time intervals. This means sampling is done on particular mode of transportation twice during morning, afternoon and evening hours. It was assumed that direction of measurement had negligible effect on the measurements.

All modes of transportation used for sampling were operating on compressed natural gases. The cars used during sampling on Ac Cab and Non Ac Cab were different each time, cars used were mainly Hyundai Xcent, Toyota Corolla, Swift desire, Maruti Suzuki Wagon-R, Tata indigo. The bus used for monitoring was DTC Bus number 106.Monitoring and sampling was done on Ac Cab and Auto Rickshaw during the month of April-16 during which average mean maximum temperature was around 37-39^{o}C and average minimum temperature was around 20-25^{o}C. Sampling was done on DTC Bus and Non Ac Cab during month of May-16 during which average maximum temperature was around 36-44^{o}C and average minimum temperature was around 25-27^{o}C with maximum days experiencing hot and dry winds blowing during afternoon and evening hours. Alm et al suggested that driving speed of car and auto rickshaw should be in range of 40-50 kmph to avoid effects of winds. The driving speed of DTC bus depended on the nature and driving skills of the driver. There were slight variations experienced in actual distance travelled each day due to individual behavior. Similarly, the time taken to reach destination for each mode varied each day due to different waiting times and skills of driver. The variation in length of time spent for each trip has important implications regarding the duration of exposure and eventual dosage.

The data stored within the instrument has been converted into files using DUSTCOM software which can be opened as a spread sheet in Microsoft Excel. DustCom is a powerful and flexible Windows application software package designed for use with the Haz-Dust Particulate Monitoring Equipment. With data provided by DustCom software detailed statistical analysis and graphs for comparison between different transport modes is done. Statistical tests were carried out at 95% confidence level to identify significant differences between concentrations experienced across the different modes of transport and within different sections.

3.4 Data Quality Control

Prior to each measurement day, both instruments were synchronized to a computer clock present in the rooms. The volunteers also synchronized their wrist watch to same computer clock. This ensured that sampling time interval was consistent across both instruments used. Impactor jet, impactor cup and impactor sleeves were dismantled for cleaning purpose and were re-assembled before each day of samplings. Both the instruments were used to be recharged overnight after completion of each measurement.

Zero calibration procedures for HAZ-Dust were carried out according to manufacturer instructions before each set of measurements upon start of the sampling procedure. Instruments were left to log data for approx 99 seconds till manual zero process is complete. After successfully selecting the particle size and completing the manual zero process the instrument is ready to begin sampling.

Chapter 4- Results and discussion

4.1 Exposure level of PM2.5 in different transportation modes.

The exposure level of total twenty four trips overall (including commuting on four modes twice) were monitored and analyzed on four commuting modes from April-16 to May-16 in Delhi. The commuting duration was 60±15 minutes for all the four modes of transportation. Table 4.1 and 4.2 represents a trip averaged concentration, standard deviation and the range within which exposure levels concentration of PM2.5 lies for all four modes of transportation. Normal probability distribution curve with 95% probability limit has been chosen for analysis.

Table 4.1: Trip averaged concentration, Standard deviation and exposure level concentration range of PM2.5 for four different modes of transportation.

S.No	Time Period	Commuting Mode	Trip average concentration (in µg/m^3)	Standard Deviation (in µg/m^3)	Concentration Range (in µg/m^3)
1	Morning hours (08.00 to 10.00 hours)	Ac Cab	25.41	8.62	25.41±25.86
		Auto Rickshaw	181.91	31.95	181.93±95.86
		DTC Bus	211.71	51.45	211.71±154.35
		Non Ac Cab	120.20	38.26	120.20±114.80
2	Afternoon hours (11.00 to 13.00 hours)	Ac Cab	29.910	8.60	29.910±25.82
		Auto Rickshaw	167.82	45.18	167.82±135.54
		DTC Bus	147.21	30.70	147.21±92.10
		Non Ac Cab	119.06	28.04	119.06±84.14
3	Evening hours (17.00 to 20.00 hours)	Ac Cab	30.67	8.47	30.67±25.43
		Auto Rickshaw	212.82	84.37	212.82±253.13
		DTC Bus	177.48	62.03	177.48±186.09
		Non Ac Cab	132.40	46.83	132.40±140.50

As it can be seen from above table, person commuting through DTC bus was exposed to maximum concentration (211.71µg/m^3) in the morning hours followed by auto rickshaw, Non Ac cab and Ac Cab. Whereas in evening hours person commuting through Auto Rickshaw was exposed to maximum concentration (212.82µg/m^3) followed by DTC Bus, Non Ac cab and Ac Cab. The commuters in the car were exposed to minimum concentration during all the three time periods. Average PM2.5 exposure levels in air conditioning cab condition are lower, ranged from 25.4µg/m^3 in the morning hours to 30.67µg/m^3 in the evening hours.

Table 4.2: Trip averaged concentration, Standard deviation and exposure level concentration range of PM2.5 for four different modes of transportation (2nd time).

S.No	Time Period	Commuting Mode	Trip average concentration (in µg/m^3)	Standard Deviation (in µg/m^3)	Concentration Range (in µg/m^3)
1	Morning hours (08.00 to 10.00 hours)	Ac Cab	14.82	8.34	14.82±25.03
		Auto Rickshaw	149.96	32.73	149.96±98.20
		DTC Bus	158.09	51.29	158.09±153.89
		Non Ac Cab	118.81	36.34	118.81±109.04
2	Afternoon hours (11.00 to 13.00 hours)	Ac Cab	27.14	9.34	27.13±28.02
		Auto Rickshaw	157.50	42.15	157.50±127.55
		DTC Bus	134.00	27.83	134.00±83.50
		Non Ac Cab	125.00	31.45	125.02±94.34
3	Evening hours (17.00 to 20.00 hours)	Ac Cab	32.27	10.47	32.27±31.40
		Auto Rickshaw	146.15	83.77	146.15±251.3
		DTC Bus	166.80	50.22	166.80±150.67

		Non Ac Cab	108.941	33.78	108.94±101.35

Slight difference can be seen from above table when monitoring was done second time, as person commuting through DTC bus was exposed to maximum concentration in the morning and evening hours followed by auto rickshaw, Non Ac cab and Ac Cab. Whereas in afternoon hours person commuting through Auto Rickshaw was exposed to maximum concentration (157.50µg/m^3) followed by DTC Bus, Non Ac cab and Ac Cab. This is because of increase in heavy vehicles movement along particular stretch of the selected routes and traffic jams near commercial market place near clock tower market. The commuters in the car were exposed to minimum concentration during all the three time periods.

Different sampling observations were observed during monitoring PM2.5 concentration second time as much lower exposures were experienced while commuting through DTC Bus and auto rickshaw as compared to exposures noted during first time especially during morning and afternoon hours, which can be seen by comparing the above two table i.e. Table 4.1 and Table 4.2. This difference was observed because of significant changes in metrological conditions with days becoming more windy and humid as a result of slight rainfall few days before sampling periods.

While comparing both the above tables it can be seen that although persons commuting on cars were exposed to minimum concentration levels but the difference in concentration values were significant. Also higher concentration was experienced while commuting on Non Ac Cabs and exposure levels were comparable with Auto Rickshaw and DTC Bus especially during afternoon hours.Figure 4.1 to 4.12 represents temporal variation in concentration of PM2.5 during morning, afternoon and evening hours respectively while commuting on four different modes of transportation. Figure 4.13 to 4.24 represents temporal variation in concentration of PM2.5 when monitoring is done for the second time on four modes of transportation.

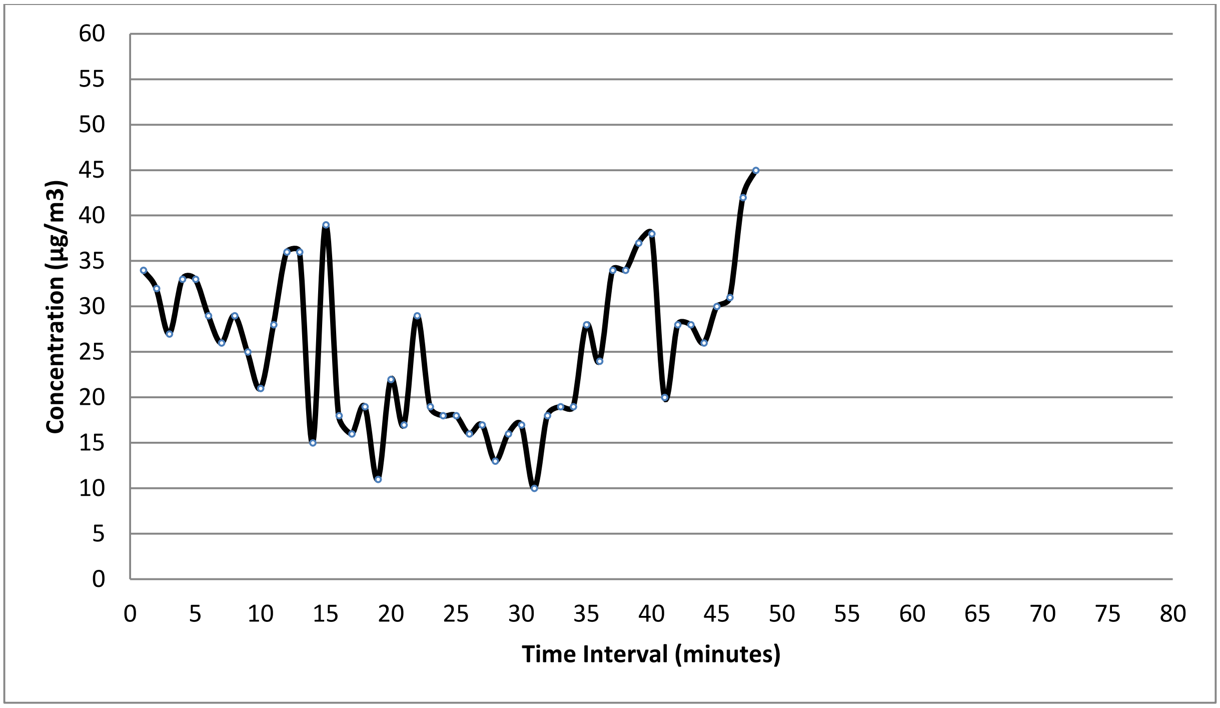

Figure 4.1: Temporal Variation in concentration of PM2.5 during morning hours (Ac Cab).

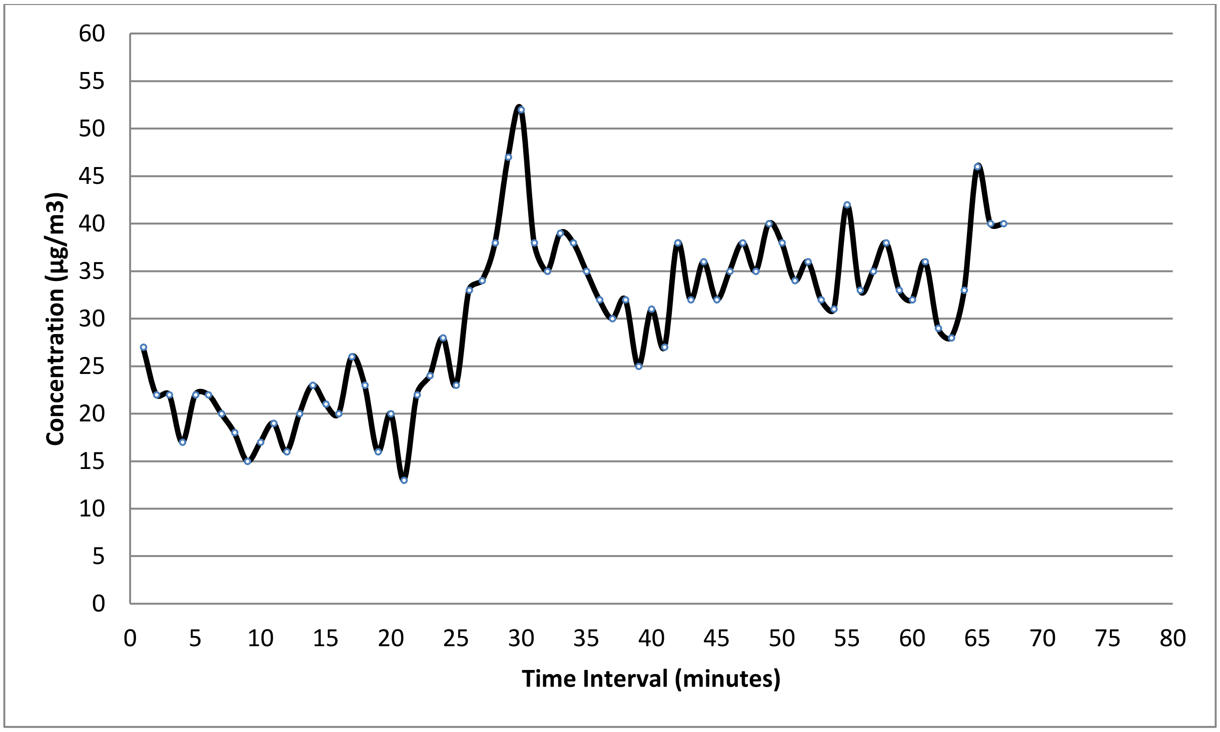

Figure 4.2: Temporal Variation in concentration of PM2.5 during afternoon hours(Ac Cab).

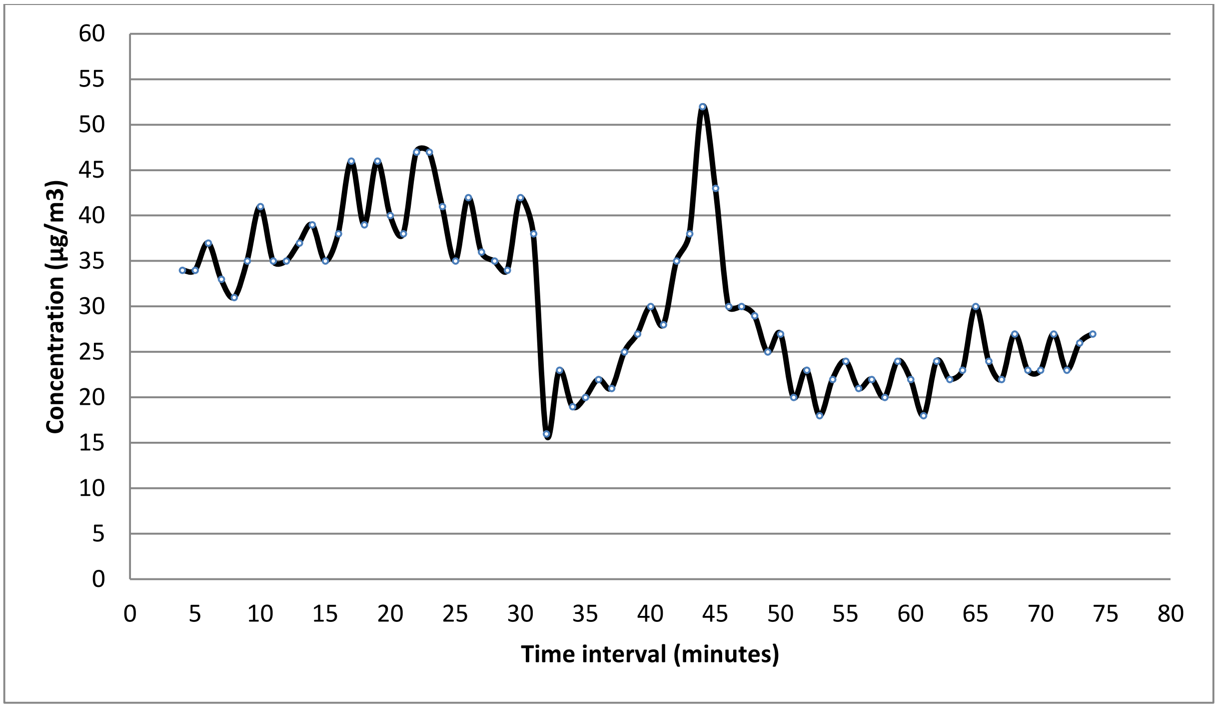

Figure 4.3: Temporal Variation in concentration of PM2.5 during evening hours (Ac Cab).

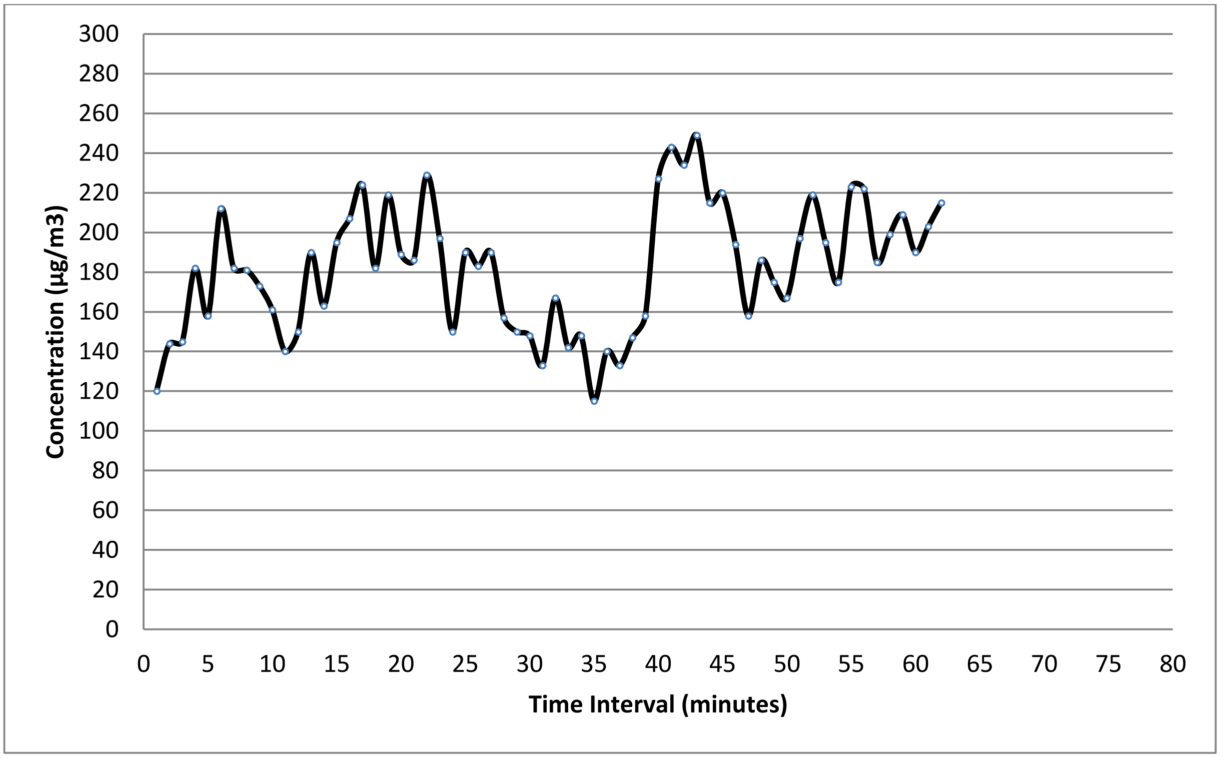

Figure 4.4: Temporal Variation in concentration of PM2.5 during morning hours (Auto Rickshaw).

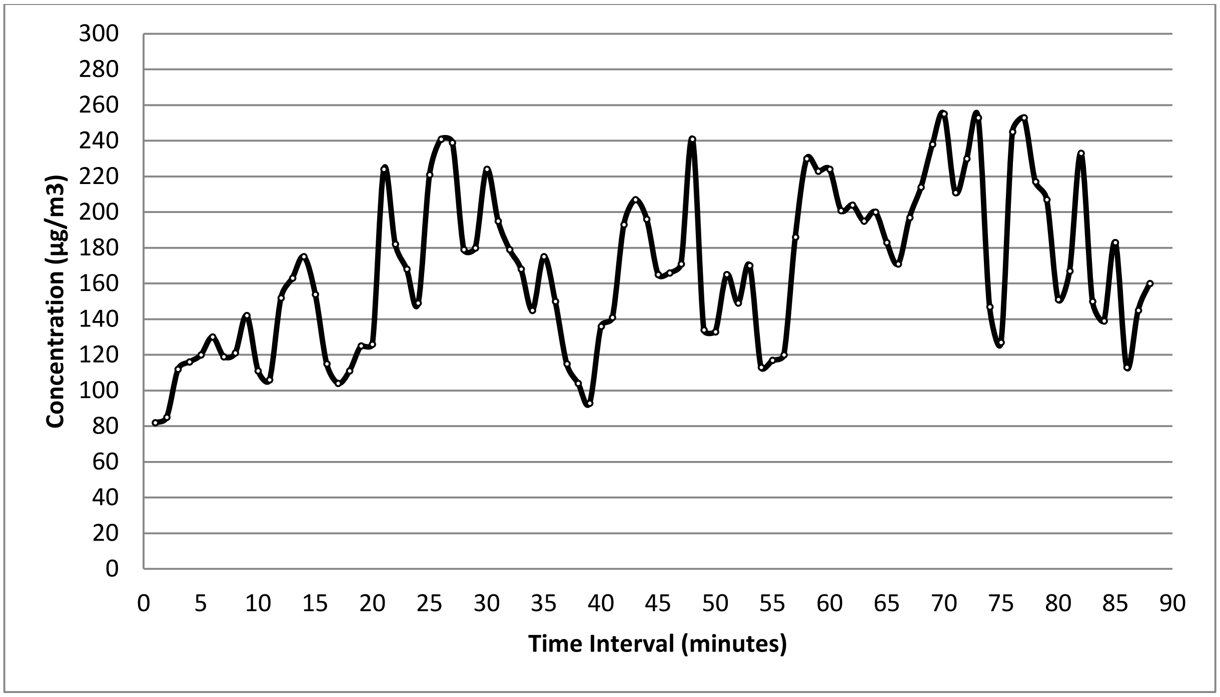

Figure 4.5: Temporal Variation in concentration of PM2.5 during afternoon hours (Auto Rickshaw).

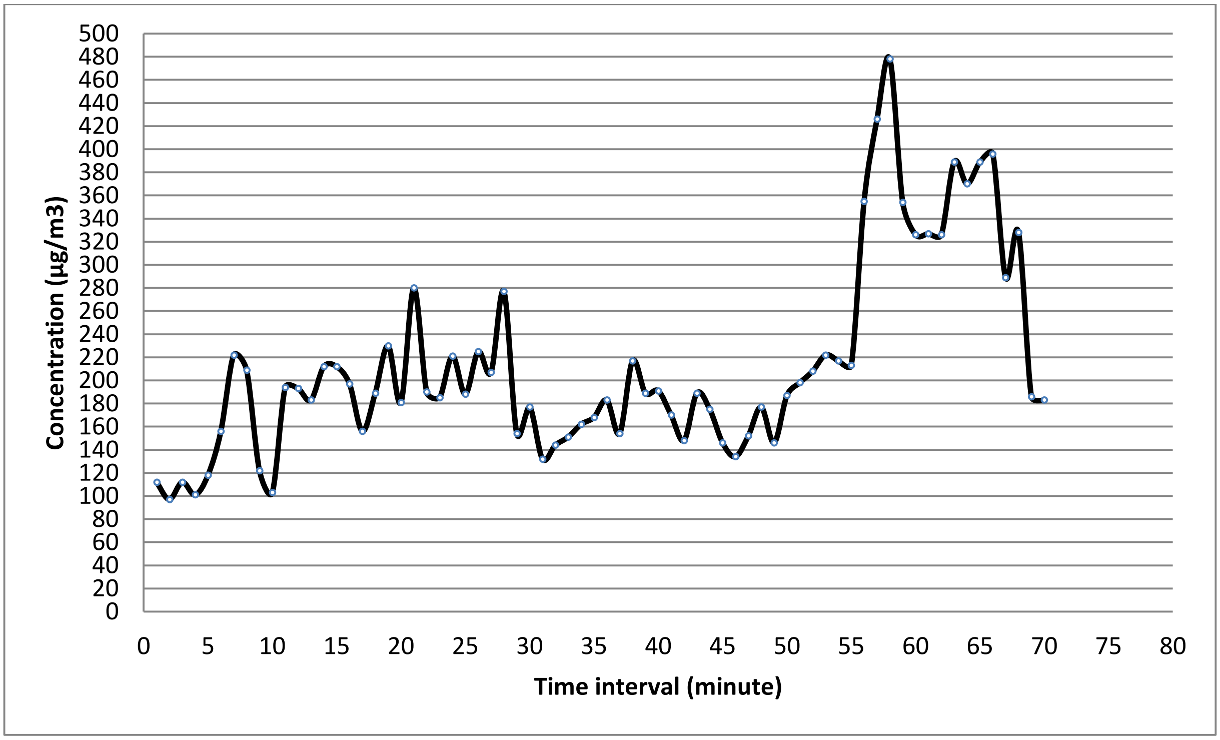

Figure 4.6: Temporal Variation in concentration of PM2.5 during evening hours (Auto Rickshaw).

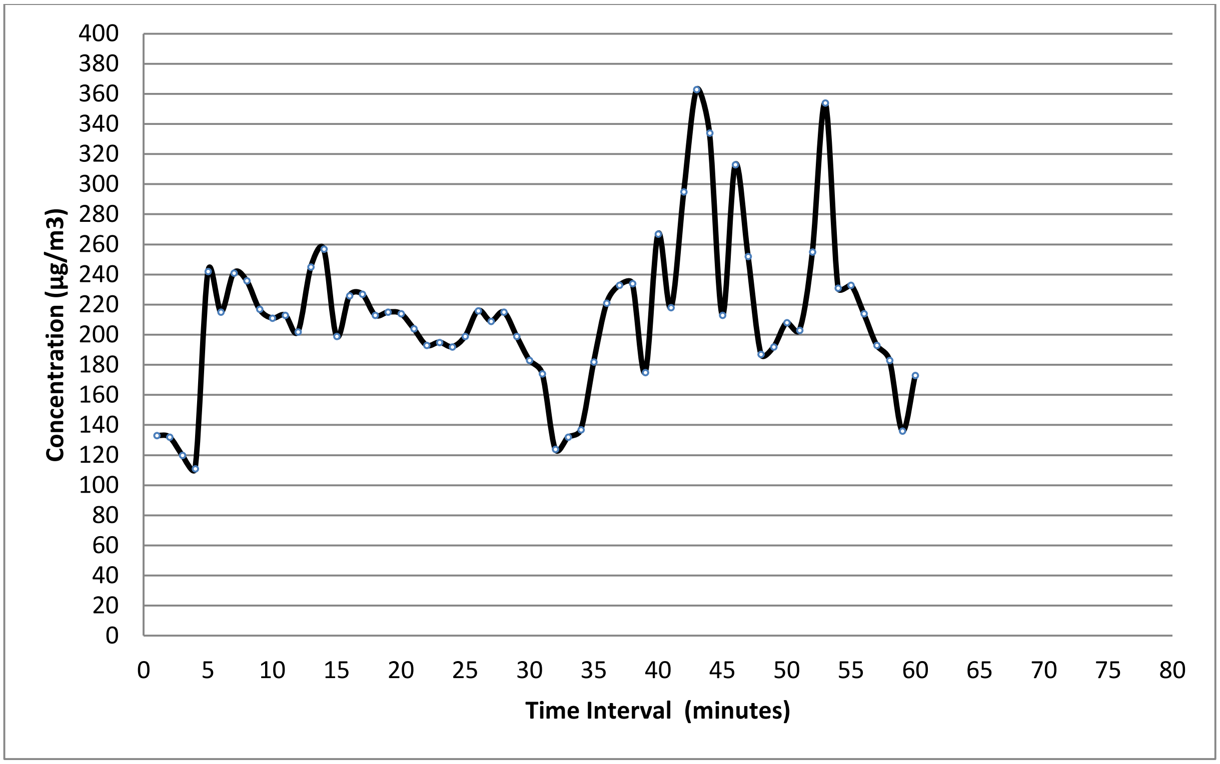

Figure 4.7: Temporal Variation in concentration of PM2.5 during morning hours (DTC Bus).

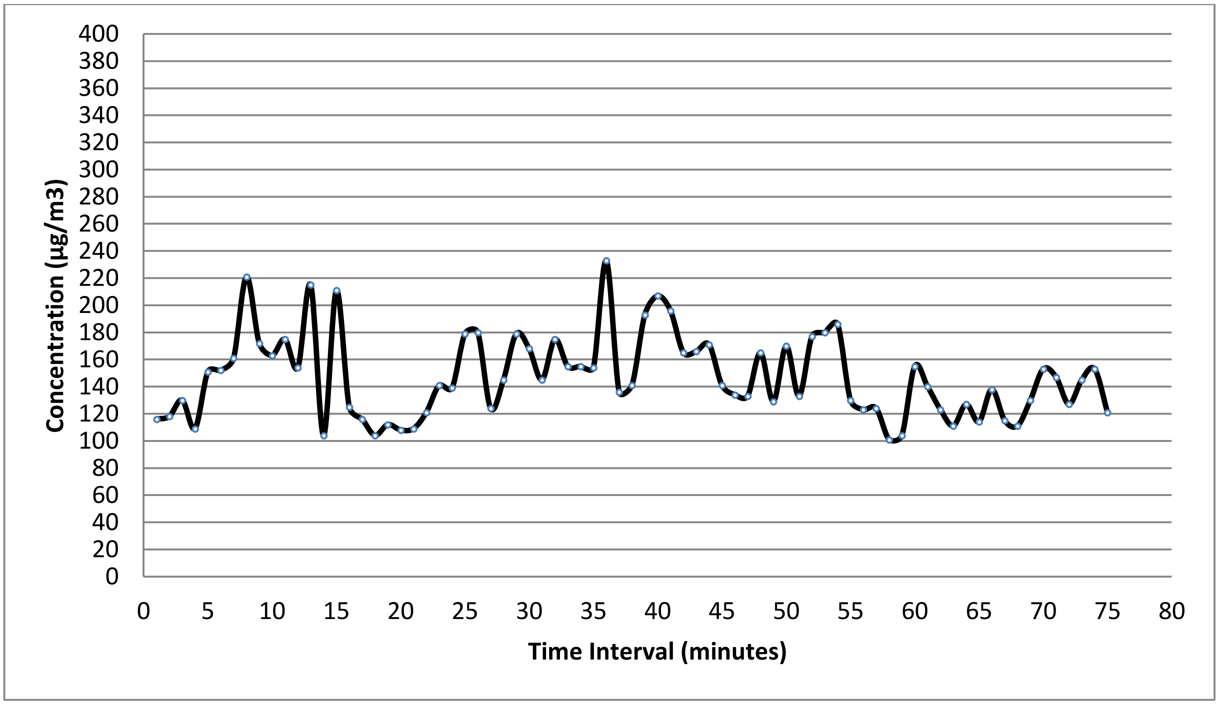

Figure 4.8: Temporal Variation in concentration of PM2.5 during afternoon hours (DTC Bus).

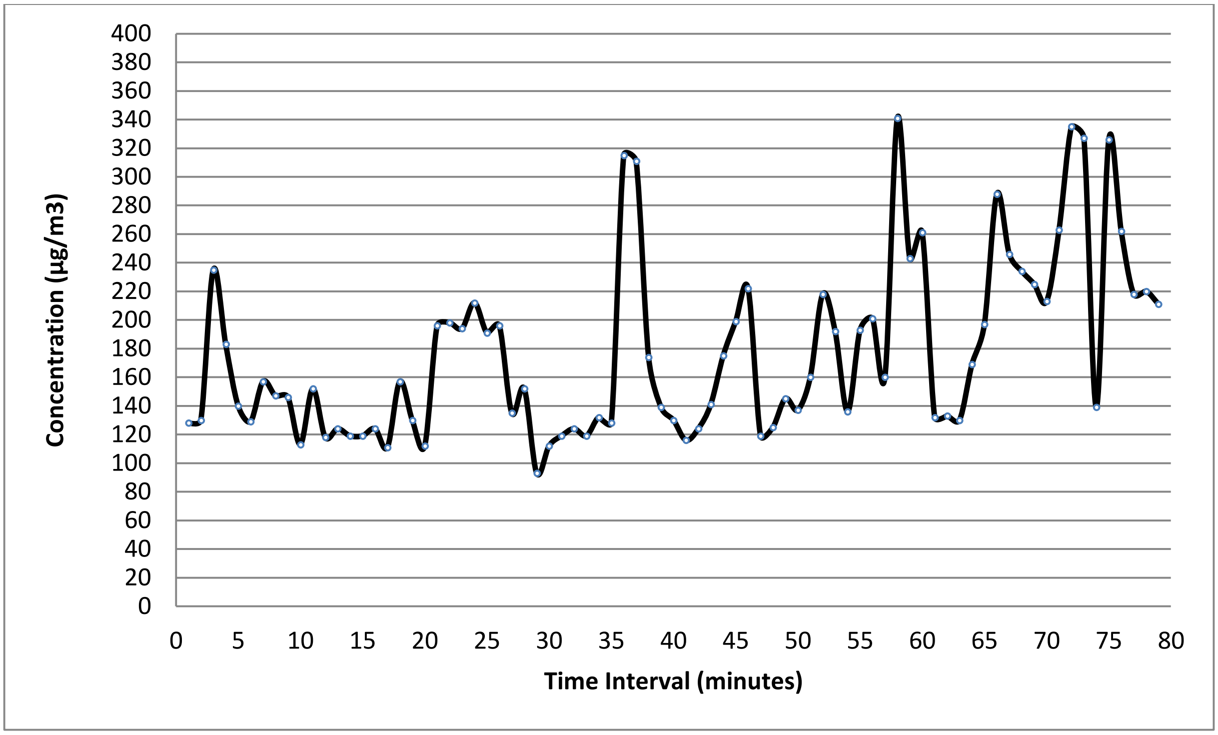

Figure 4.9: Temporal Variation in concentration of PM2.5 during evening hours (DTC Bus).

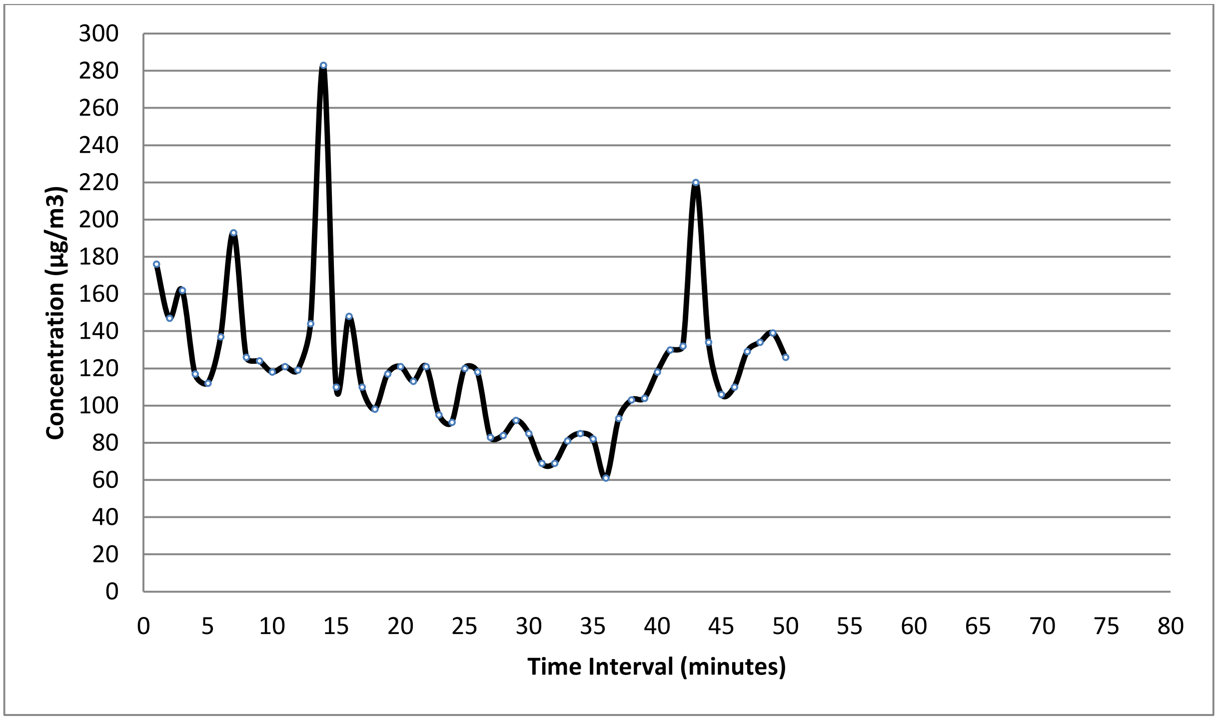

Figure 4.10: Temporal Variation in concentration of PM2.5 during morning hours (Non Ac Cab).

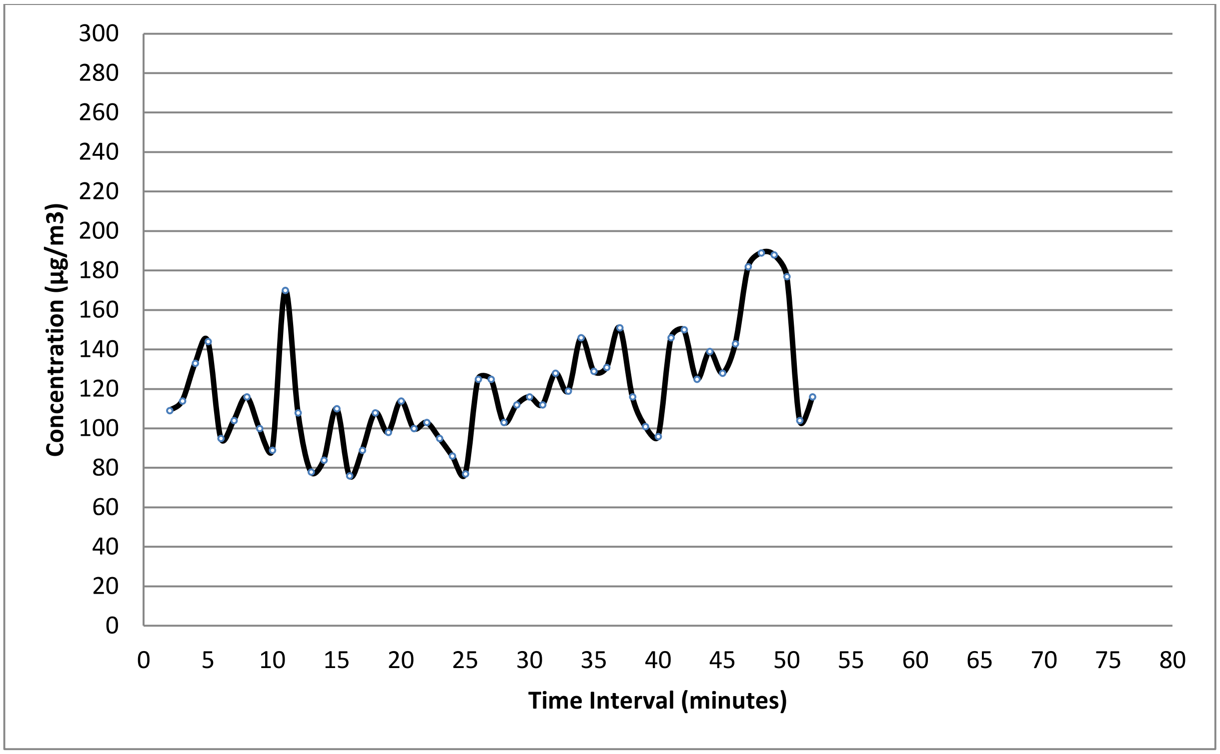

Figure 4.11: Temporal Variation in concentration of PM2.5 during afternoon hours (Non Ac Cab)

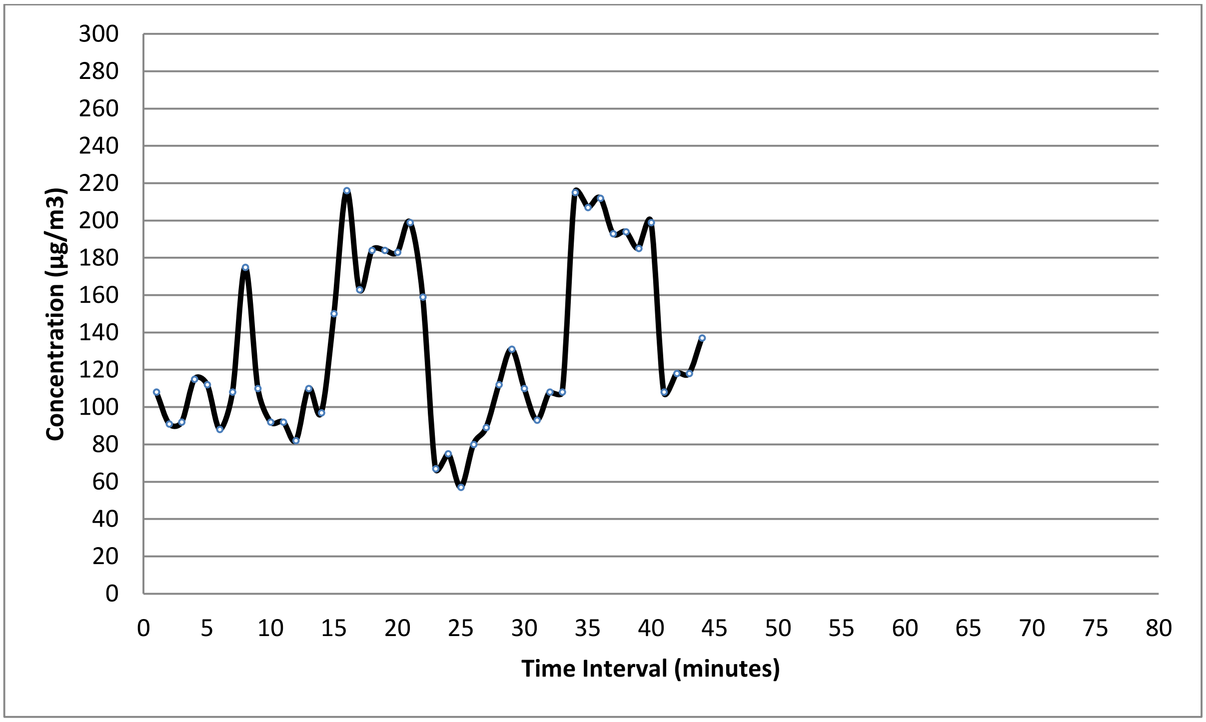

Figure 4.12: Temporal Variation in concentration of PM2.5 during evening hours (Non Ac Cab).

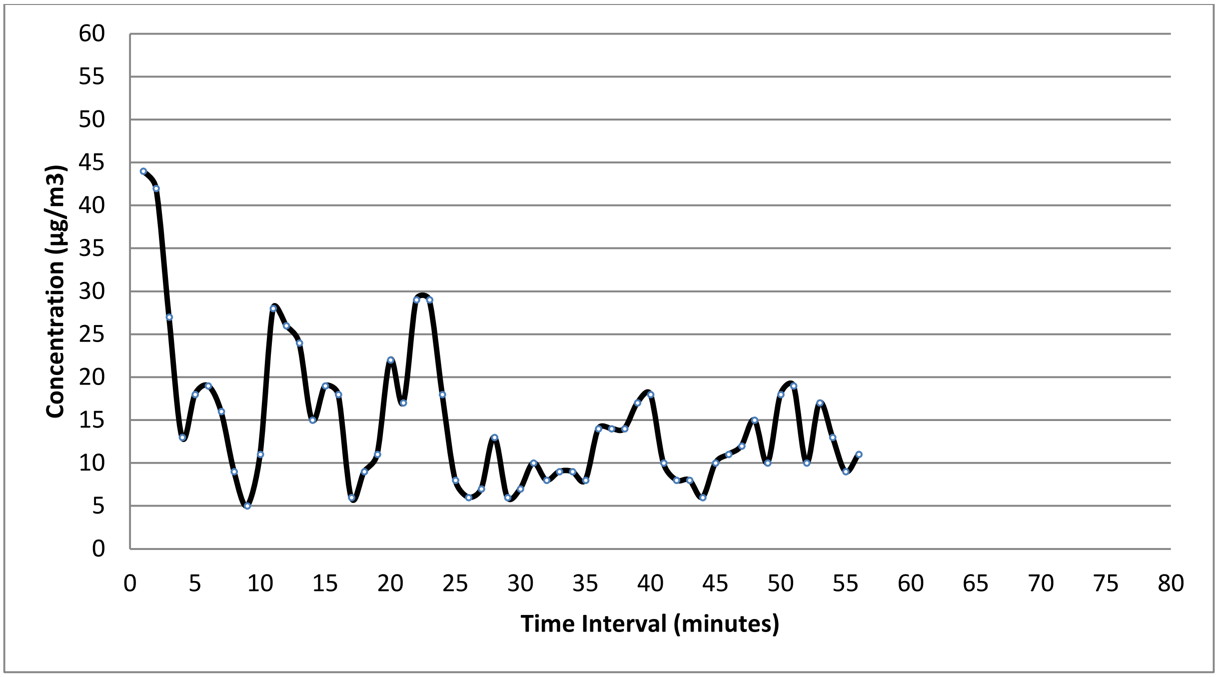

Figure 4.13: Temporal Variation in concentration of PM2.5 during morning hours (Ac Cab ,2nd time)

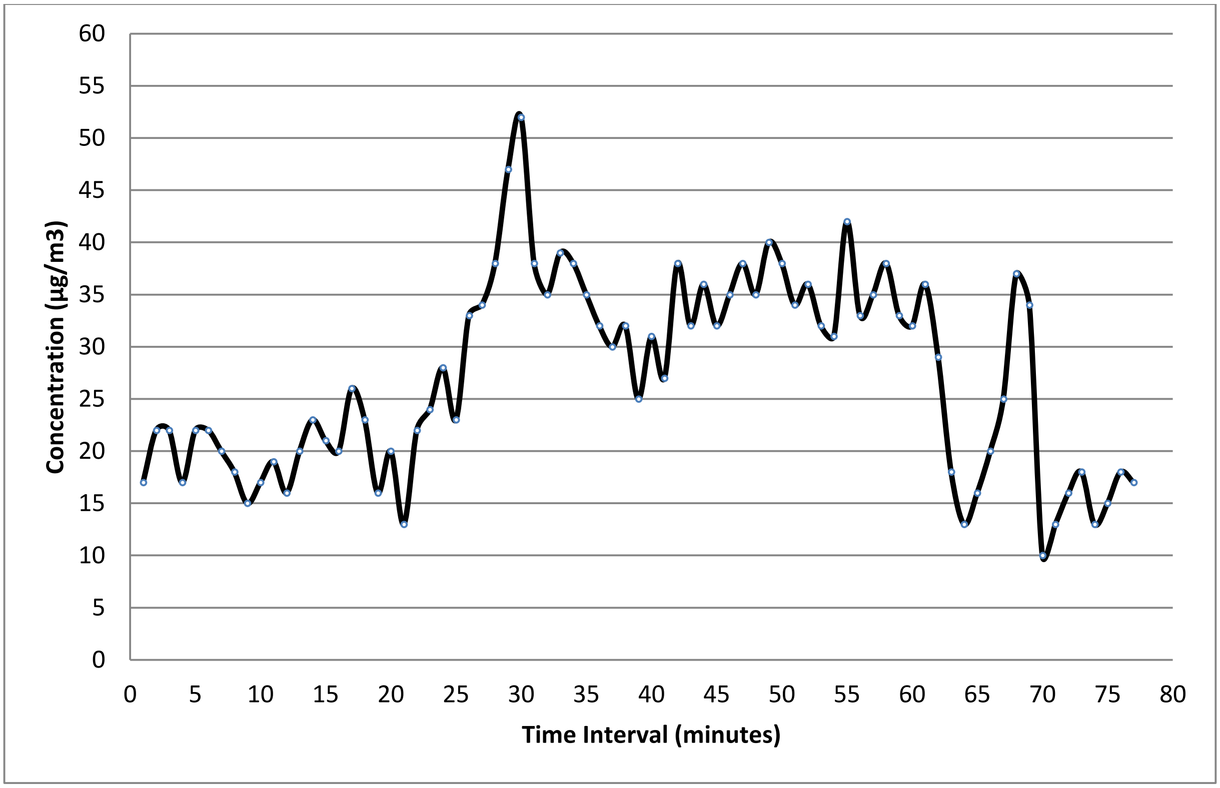

Figure 4.14: Temporal Variation in concentration of PM2.5 during afternoon hours(Ac Cab, 2nd time).

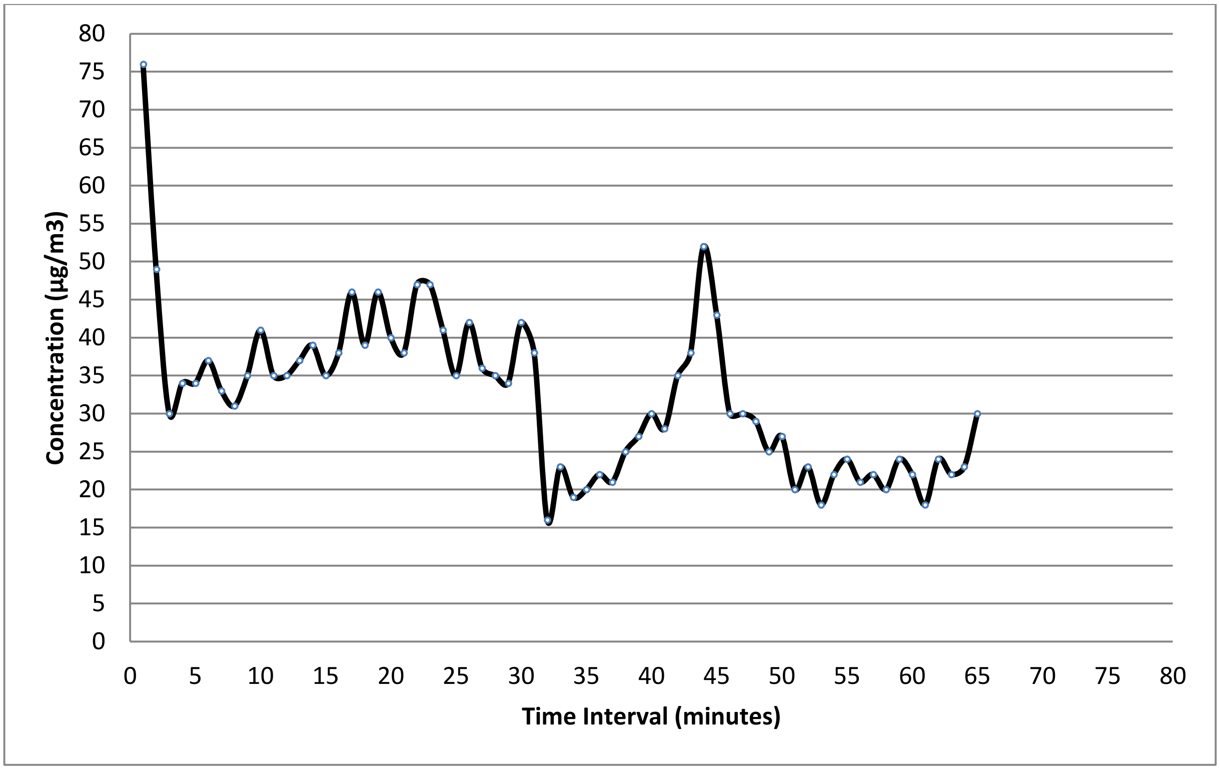

Figure 4.15: Temporal Variation in concentration of PM2.5 during evening hours (Ac Cab, 2nd time).

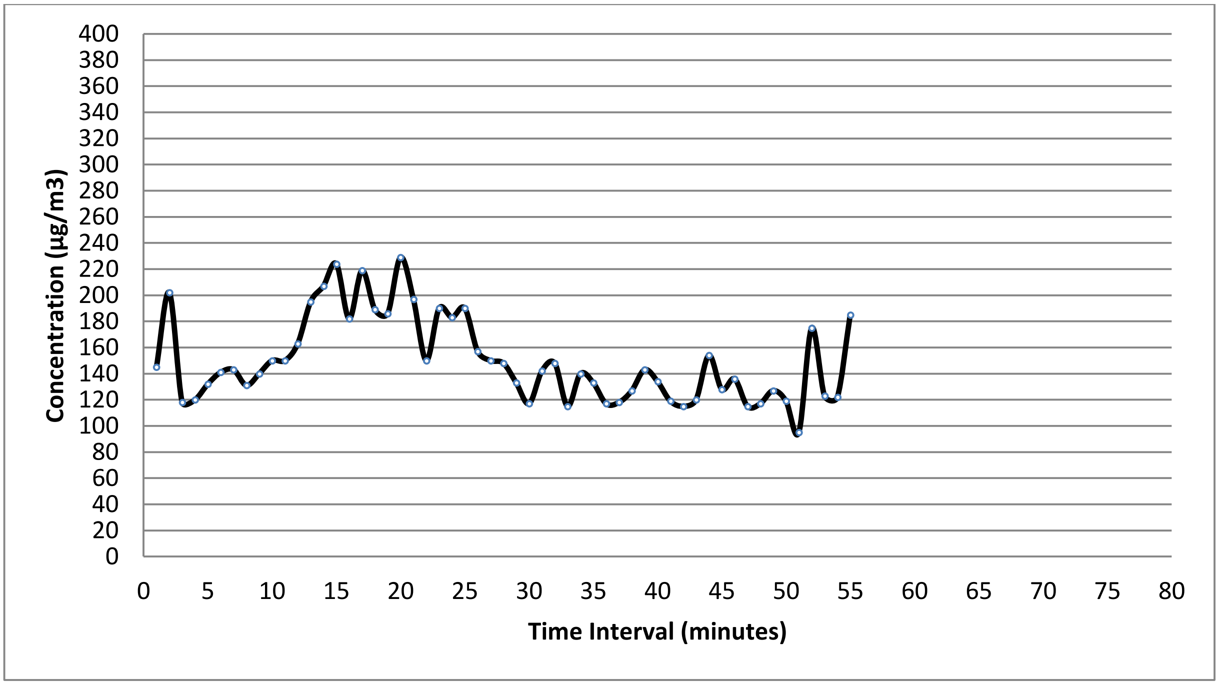

Figure 4.16: Temporal Variation in concentration of PM2.5 during morning hours (Auto Rickshaw, 2nd time)

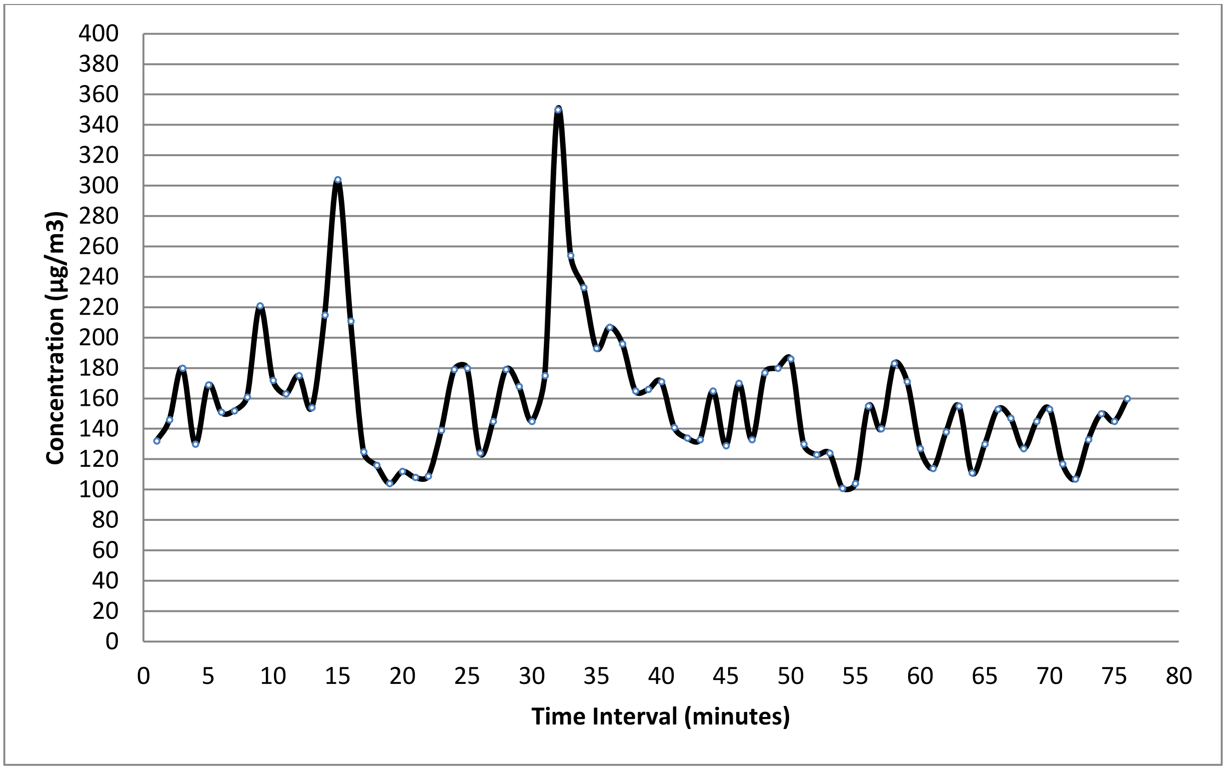

Figure 4.17: Temporal Variation in concentration of PM2.5 during afternoon hours (Auto Rickshaw, 2nd time).

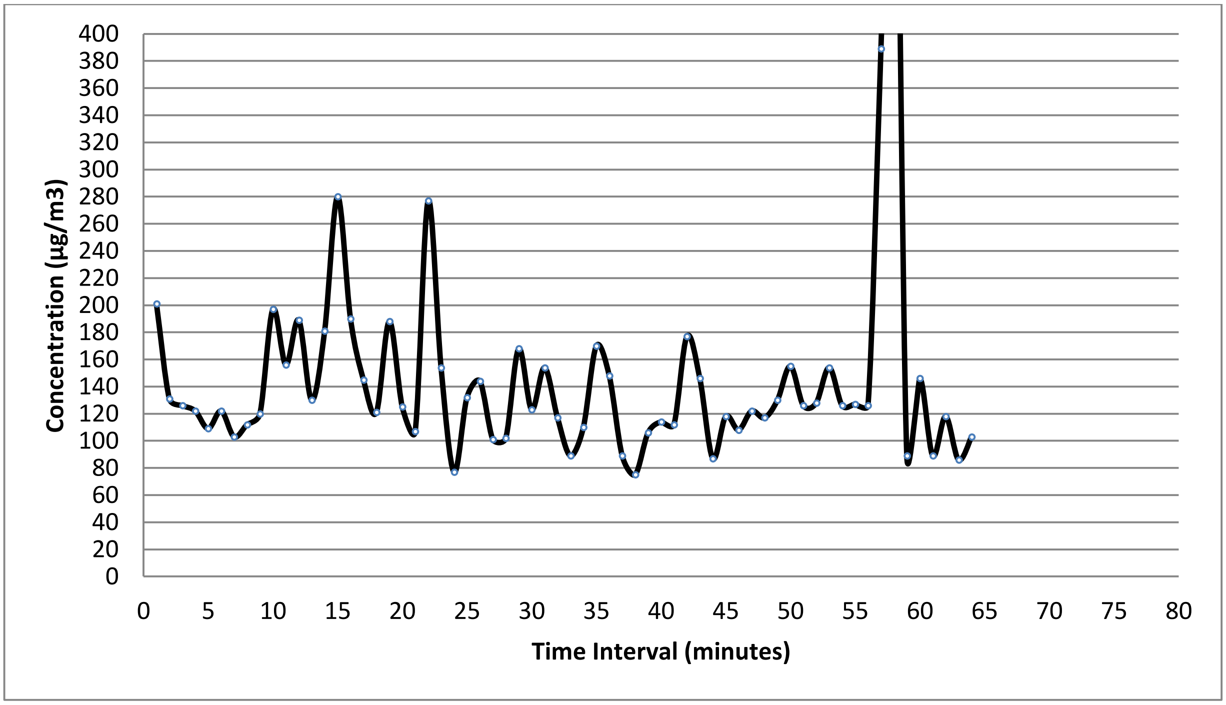

Figure 4.18: Temporal Variation in concentration of PM2.5 during evening hours (Auto rickshaw, 2nd time).

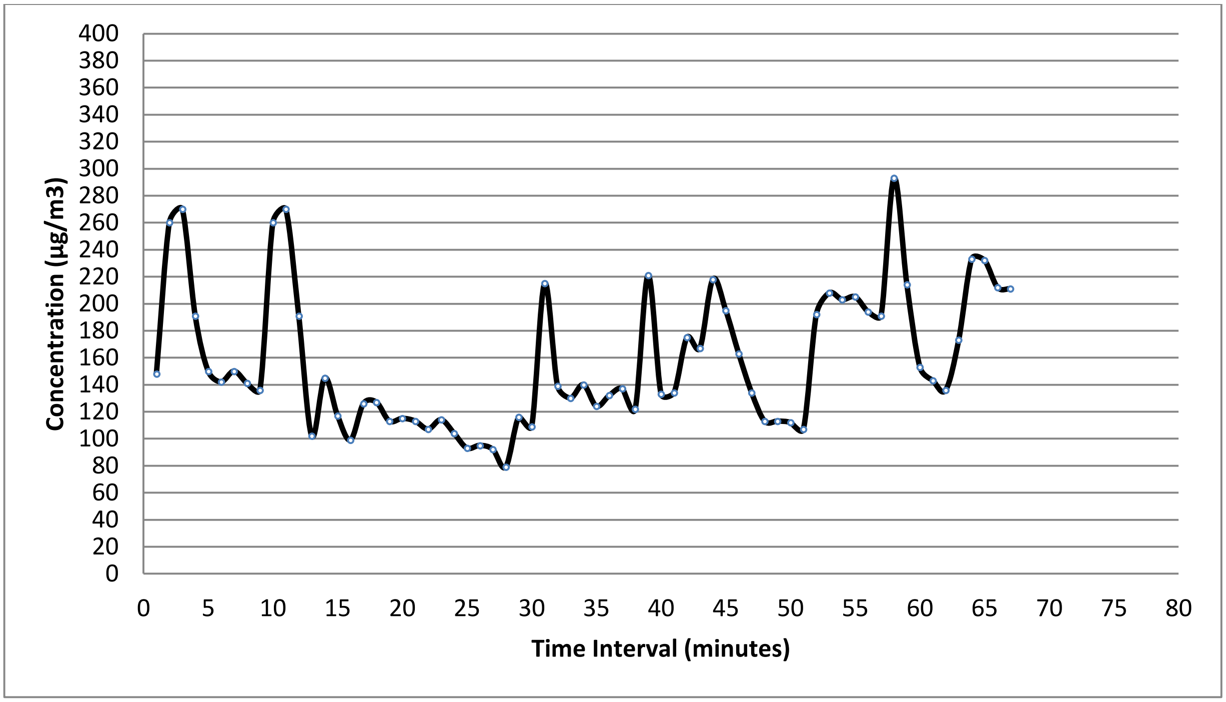

Figure 4.19: Temporal Variation in concentration of PM2.5 during morning hours (DTC Bus, 2nd time).

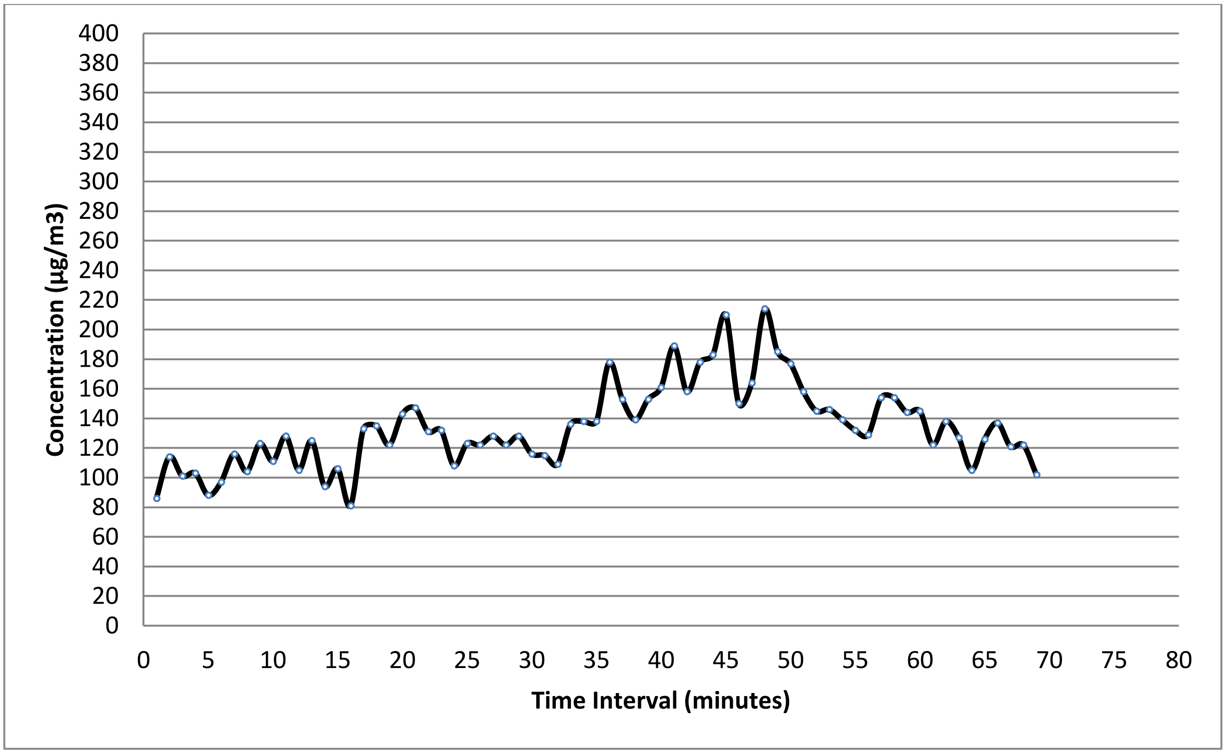

Figure 4.20: Temporal Variation in concentration of PM2.5 during afternoon hours (DTC Bus, 2nd time).

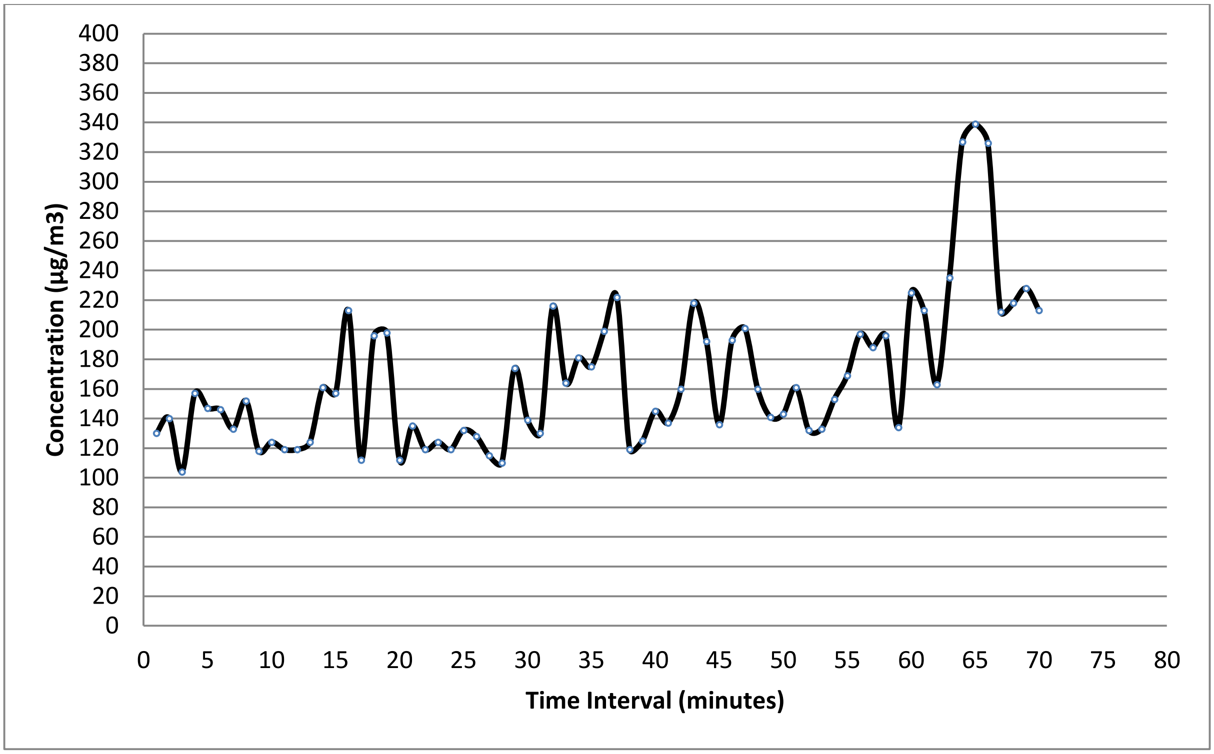

Figure 4.21: Temporal Variation in concentration of PM2.5 during evening hours (Auto Rickshaw, 2nd time).

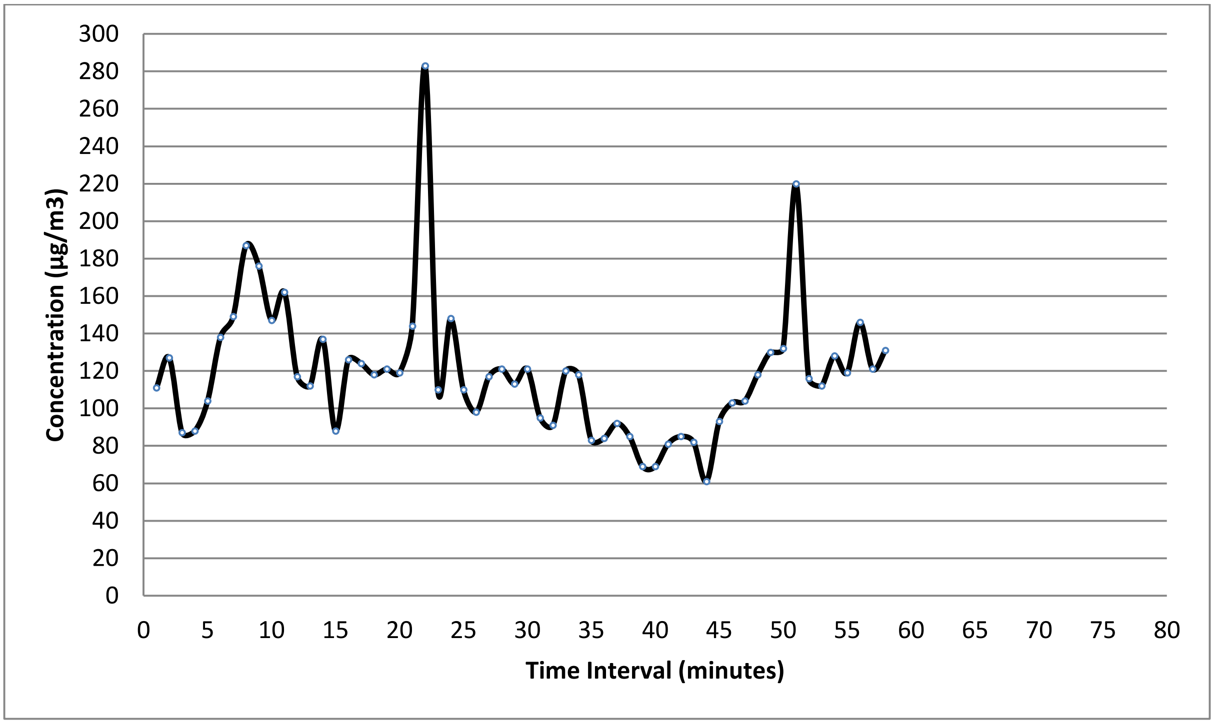

Figure 4.22: Temporal Variation in concentration of PM2.5 during morning hours (Non Ac Cab, 2nd time).

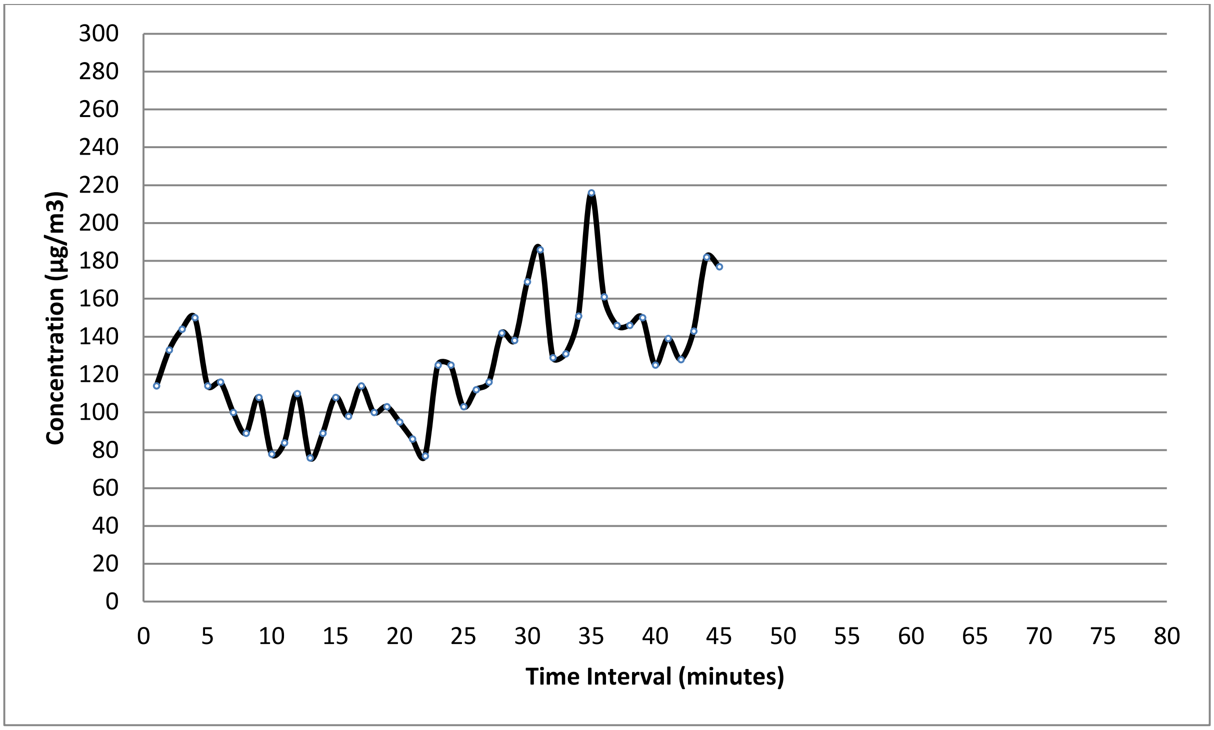

Figure 4.23: Temporal Variation in concentration of PM2.5 during afternoon hours(Non Ac Cab, 2nd time).

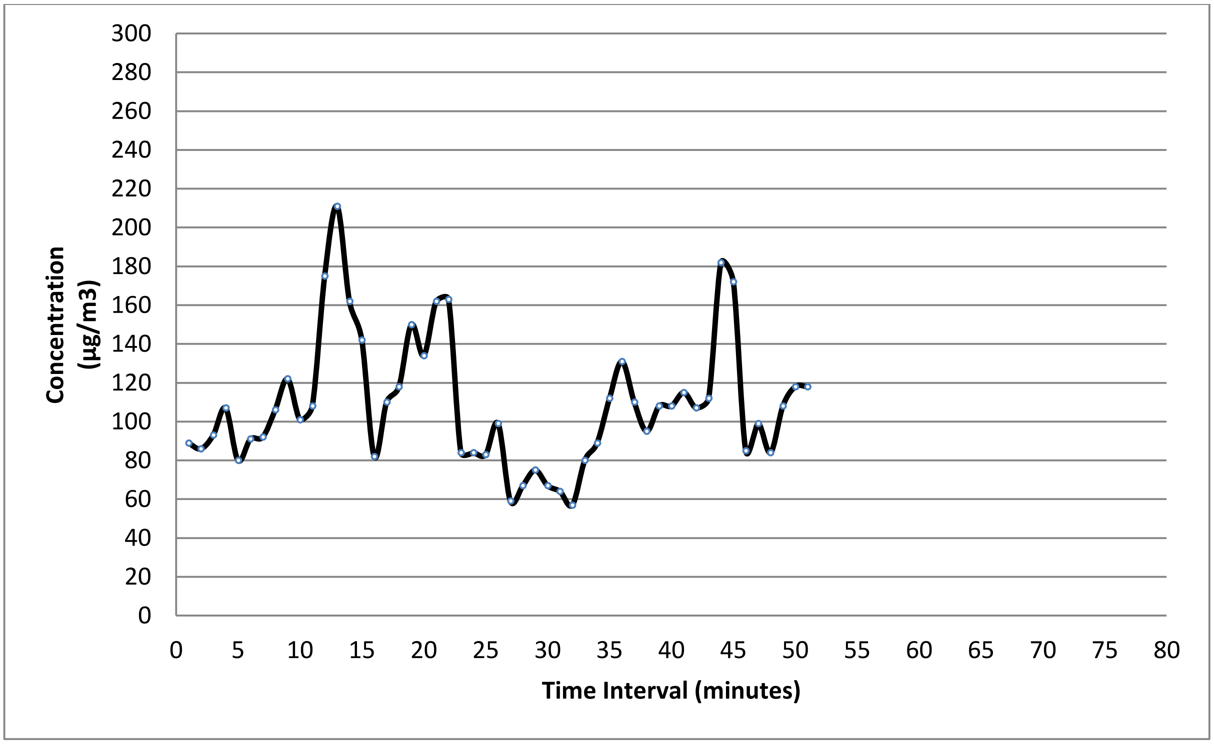

Figure 4.24: Temporal Variation in concentration of PM2.5 during evening hours(Non Ac Cab, 2nd time)

4.2 Exposure level of PM1.0 in different transportation modes.

Similar to monitoring of PM2.5 as explained in above section, monitoring and analysis of PM1.0 was also done by taking sampling records of overall twenty four trips (including commuting on four modes twice) on all four modes of transportation from April-16 to May-16. Commuting duration was similar as of PM2.5 and was 60±15 minutes. Normal probability distribution curve with 95% probability limit has been chosen for analysis. Table 4.3 and 4.4 represents a trip averaged concentration, standard deviation and the range within which exposure levels concentration of PM2.5 lies for all four modes of transportation.

Table 4.3: Trip averaged concentration, Standard deviation and exposure level concentration range of PM1.0 for four different modes of transportation.

Si.No	Time Period	Commuting Mode	Trip average concentration (in µg/m^3)	Standard Deviation (in µg/m^3)	Concentration Range (in µg/m^3)
1	Morning hours (08.00 to 10.00 hours)	Ac Cab	37.56	4.44	37.56±13.32
		Auto Rickshaw	181.77	53.66	181.77±161.00
		DTC Bus	156.36	132.19	156.36±396.58
		Non Ac Cab	125.06	24.21	125.06±72.63
2	Afternoon hours (11.00 to 13.00 hours)	Ac Cab	46.18	11.71	46.18±35.16
		Auto Rickshaw	143.03	36.82	143.03±110.48
		DTC Bus	137.46	43.76	137.46±131.29
		Non Ac Cab	121.57	38.51	121.57±115.54
3	Evening hours (17.00 to 20.00 hours)	Ac Cab	40.60	10.08	40.60±30.24
		Auto Rickshaw	211.44	65.38	211.44±196.14
		DTC Bus	184.13	93.91	184.13±281.75

		Non Ac Cab	113.21	50.94	113.21±152.81

As it can be seen from above table, person commuting through Auto Rickshaw was exposed to maximum concentration (181.77µg/m^3) in the morning hours, (143.03µg/m^3) in afternoon hours and (211.44µg/m^3) in evening hours followed by DTC Bus, Non Ac cab and Ac Cab. The commuters in the car were exposed to minimum concentration, ranged from 37.56µg/m^3 in the morning hours to 46.18µg/m^3 in the afternoon hours, higher concentration levels in afternoon hours was mainly because of dust presence of dust particles inside the cab. It can be observed that the concentrations found were much higher than the respective concentrations of PM2.5 during same periods of time, showing that fine fraction particulate matters concentrations were much higher inside ac cars.

Table 4.4: Trip averaged concentration, Standard deviation and exposure level concentration range of PM1.0 for four different modes of transportation (2nd time).

S.No	Time Period	Commuting Mode	Trip average concentration (in µg/m^3)	Standard Deviation (in µg/m^3)	Concentration Range (in µg/m^3)
1	Morning hours (08.00 to 10.00 hours)	Ac Cab	30.87	8.89	30.87±26.69
		Auto Rickshaw	135.89	39.10	135.89±117.30
		DTC Bus	135.51	38.26	135.51±114.80
		Non Ac Cab	118.15	23.07	118.15±69.21
2	Afternoon hours (11.00 to 13.00 hours)	Ac Cab	31.70	9.32	31.70±27.98
		Auto Rickshaw	146.90	45.10	146.90±135.31
		DTC Bus	128.49	26.46	128.49±79.39
		Non Ac Cab	108.82	24.85	108.82±74.55
3	Evening	Ac Cab	40.92	9.76	40.92±29.28

	hours (17.00 to 20.00 hours)	Auto Rickshaw	198.11	82.00	198.11±246.02
		DTC Bus	143.41	44.82	143.41±134.47
		Non Ac Cab	104.67	27.96	104.67±83.87

Similar difference as observed during sampling observations of PM2.5 as explained above were observed during monitoring PM1.0 concentration second time as much lower exposures were experienced while commuting through DTC Bus and auto rickshaw as compared to exposures noted during first time especially during morning and afternoon hours, which can be seen by comparing the above two table i.e. Table 4.3 and Table 4.4. This difference was observed because of significant changes in metrological conditions with days becoming more windy and humid as a result of slight rainfall few days before sampling periods.

But still person commuting through Auto Rickshaw was exposed to maximum concentration (135.893µg/m^3) in the morning hours, (146.905µg/m^3) in afternoon hours and (198.117µg/m^3) in evening hours followed by DTC Bus, Non Ac cab and Ac Cab. Figure 4.25 to 4.36 represents temporal variation in concentration of PM1.0 during morning, afternoon and evening hours respectively while commuting on four different modes of transportation. Figure 4.37 to 4.48 represents temporal variation in concentration of PM2.5 when monitoring is done for the second time on four modes of transportation.

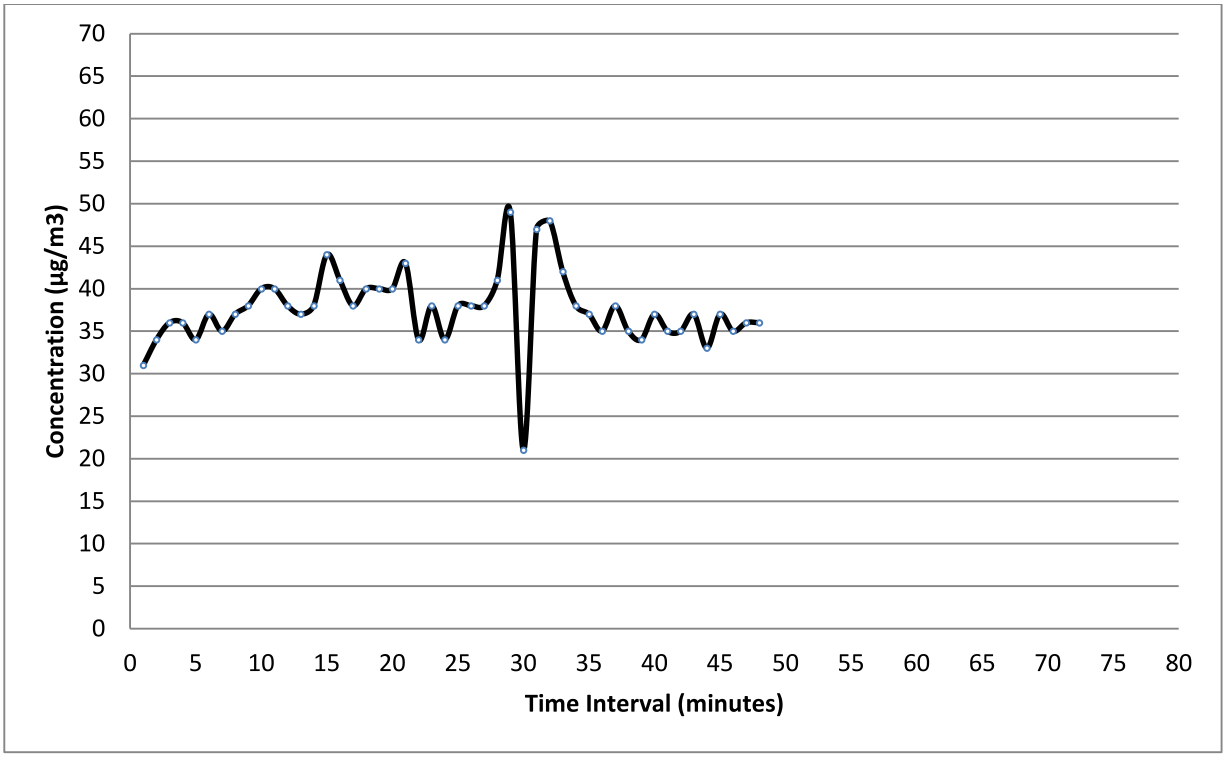

Figure 4.25: Temporal Variation in concentration of PM1.0 during morning hours (Ac Cab).

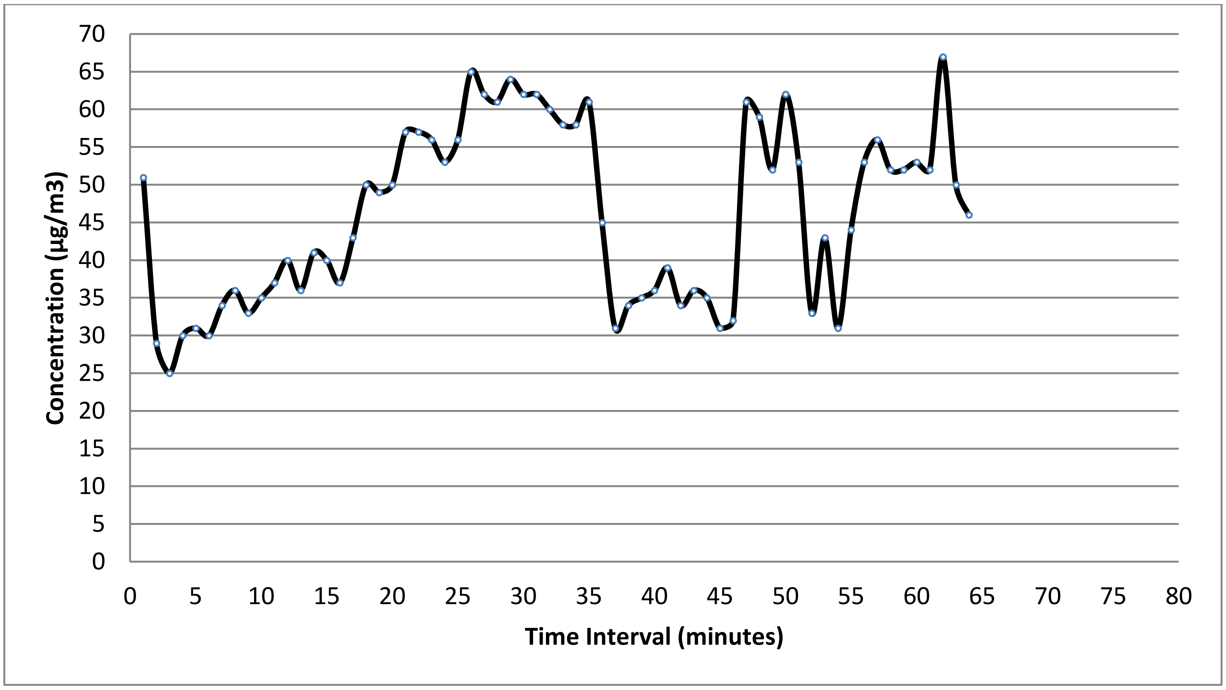

Figure 4.26: Temporal Variation in concentration of PM1.0 during afternoon hours (Ac Cab).

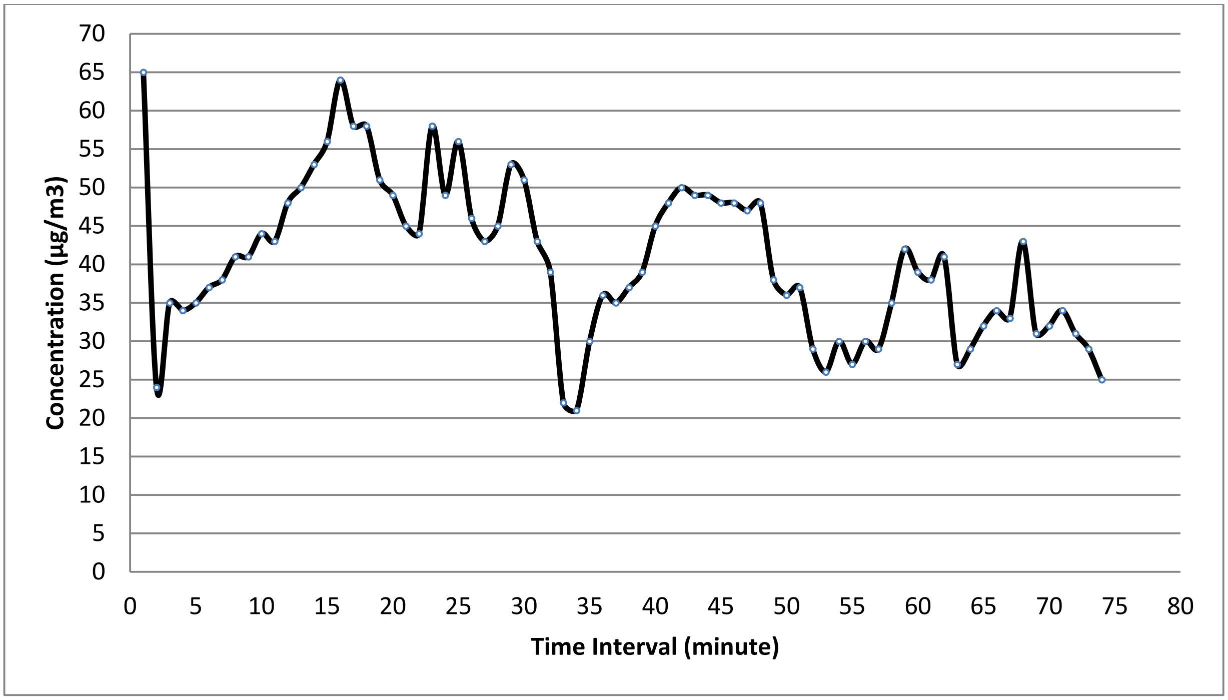

Figure 4.27: Temporal Variation in concentration of PM1.0 during evening hours (Ac Cab).

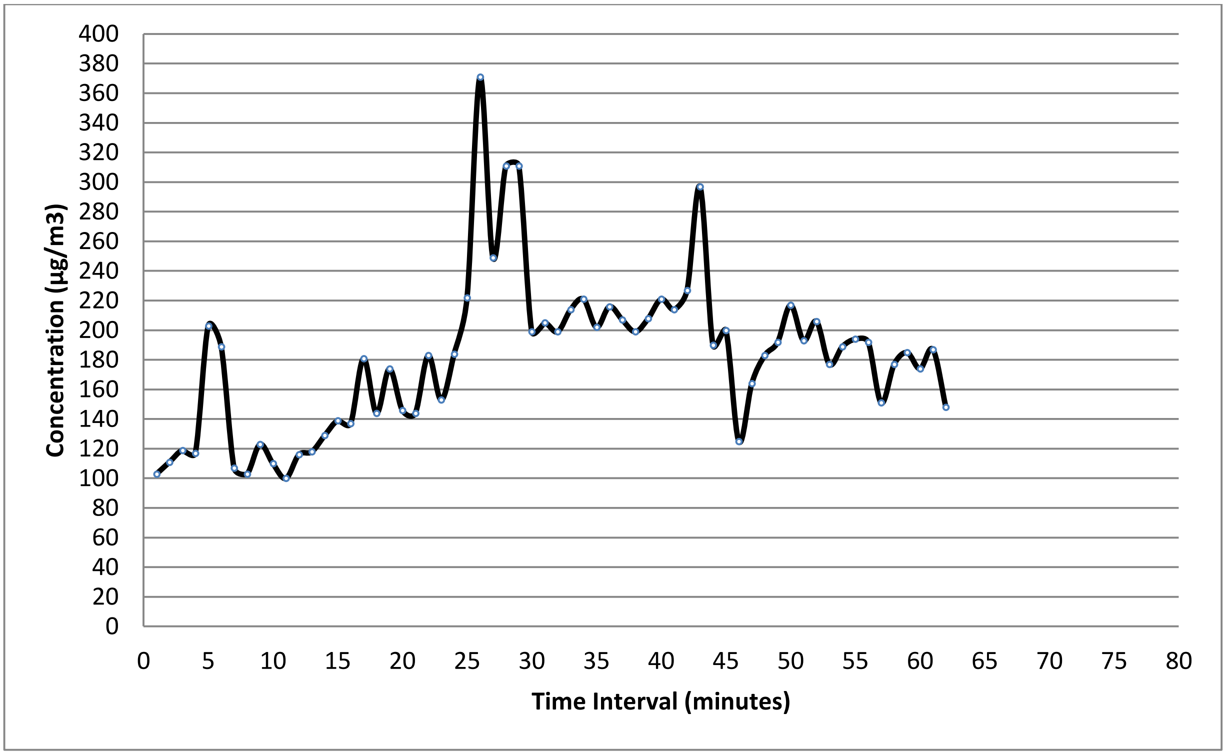

Figure 4.28: Temporal Variation in concentration of PM1.0 during morning hours (Auto Rickshaw).

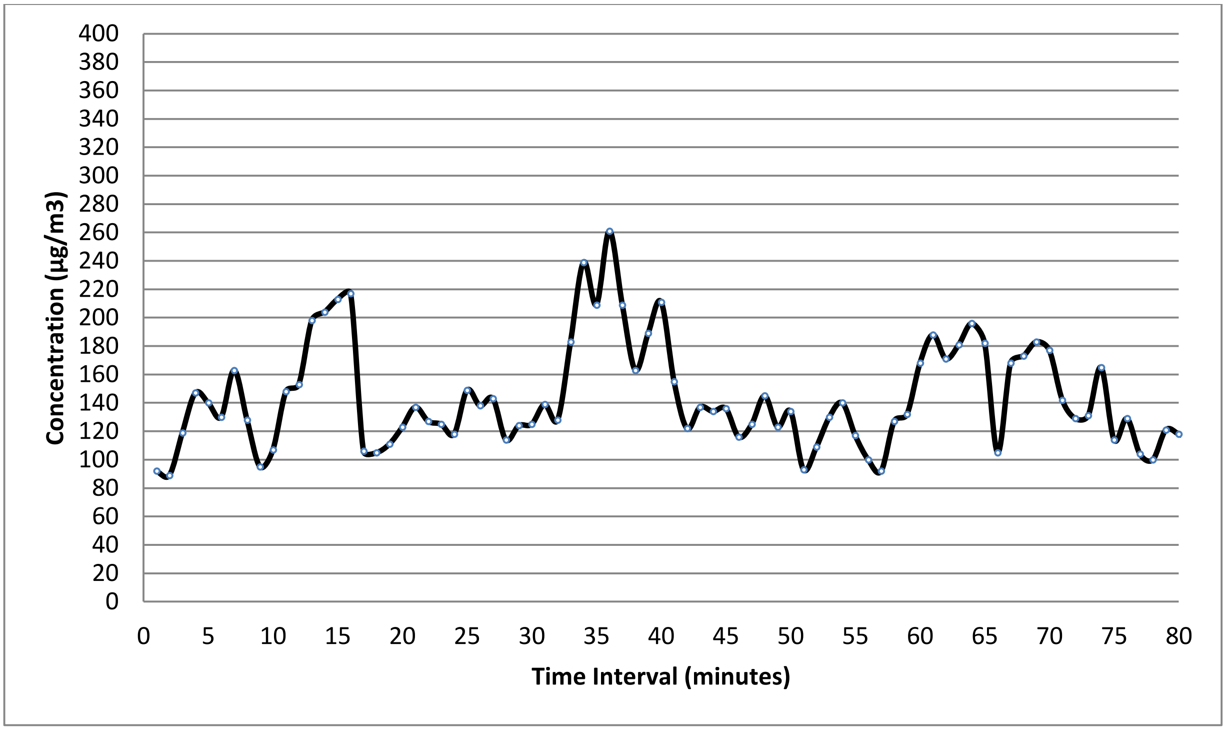

Figure 4.29: Temporal Variation in concentration of PM1.0 during afternoon hours (Auto Rickshaw).

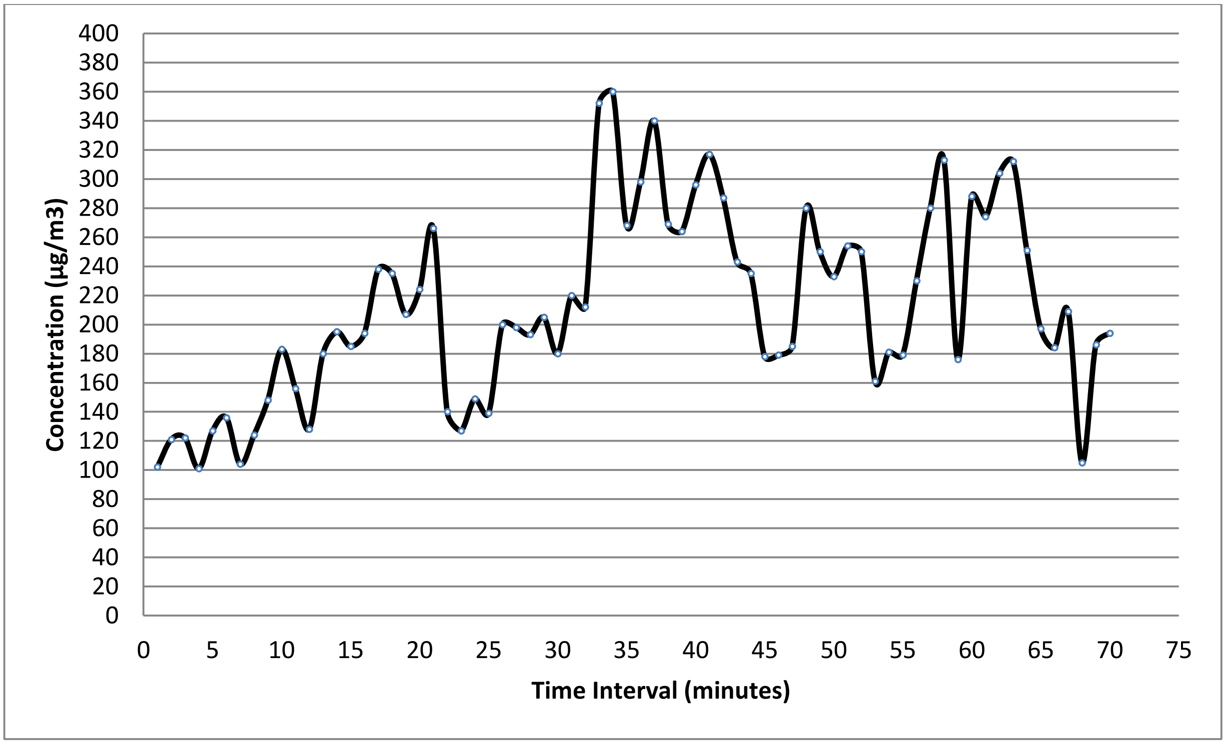

Figure 4.30: Temporal Variation in concentration of PM1.0 during evening hours (Auto Rickshaw).

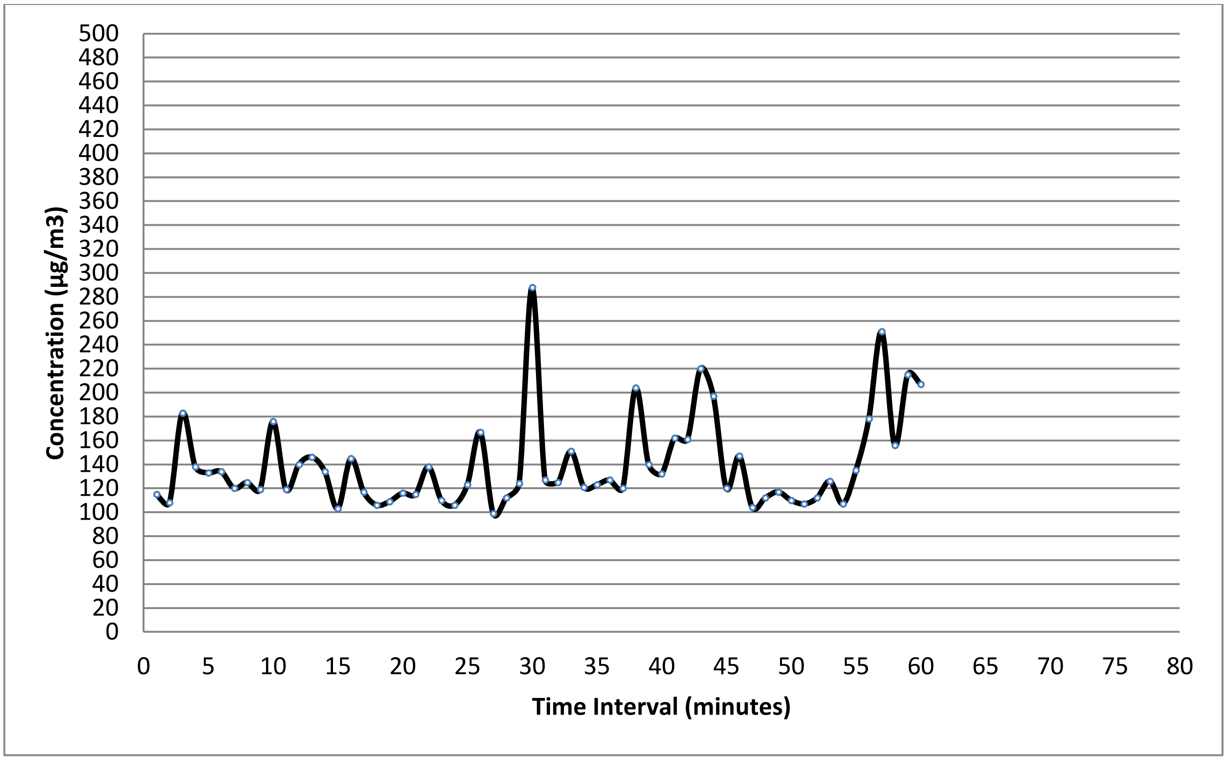

Figure 4.31: Temporal Variation in concentration of PM1.0 during morning hours (DTC Bus).

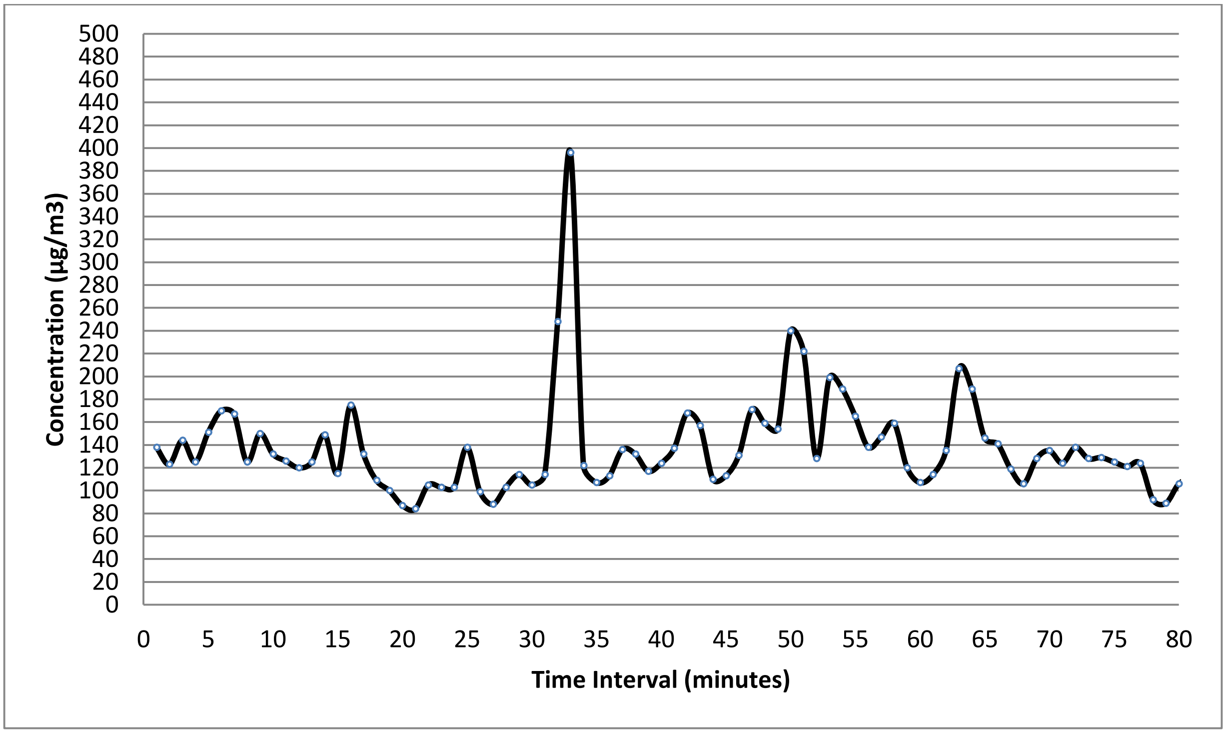

Figure 4.32: Temporal Variation in concentration of PM1.0 during afternoon hours (DTC Bus).

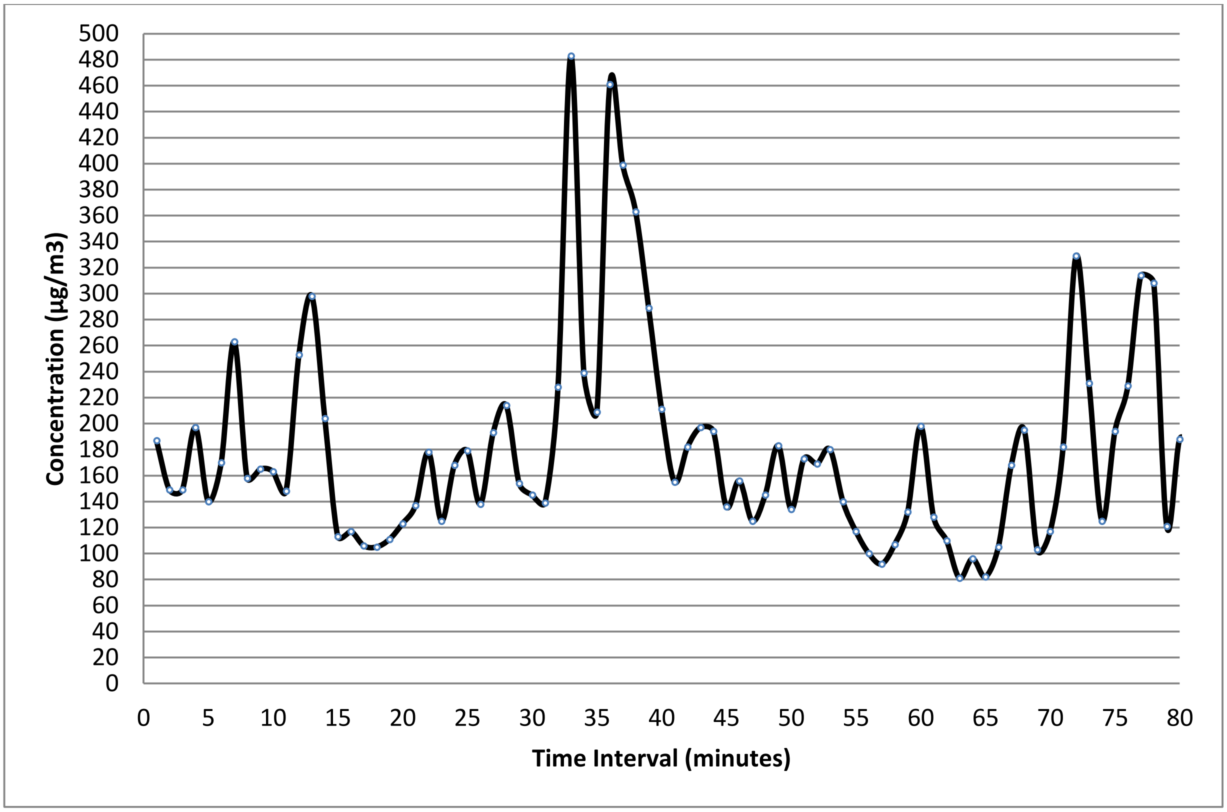

Figure 4.33: Temporal Variation in concentration of PM1.0 during evening hours (DTC Bus).

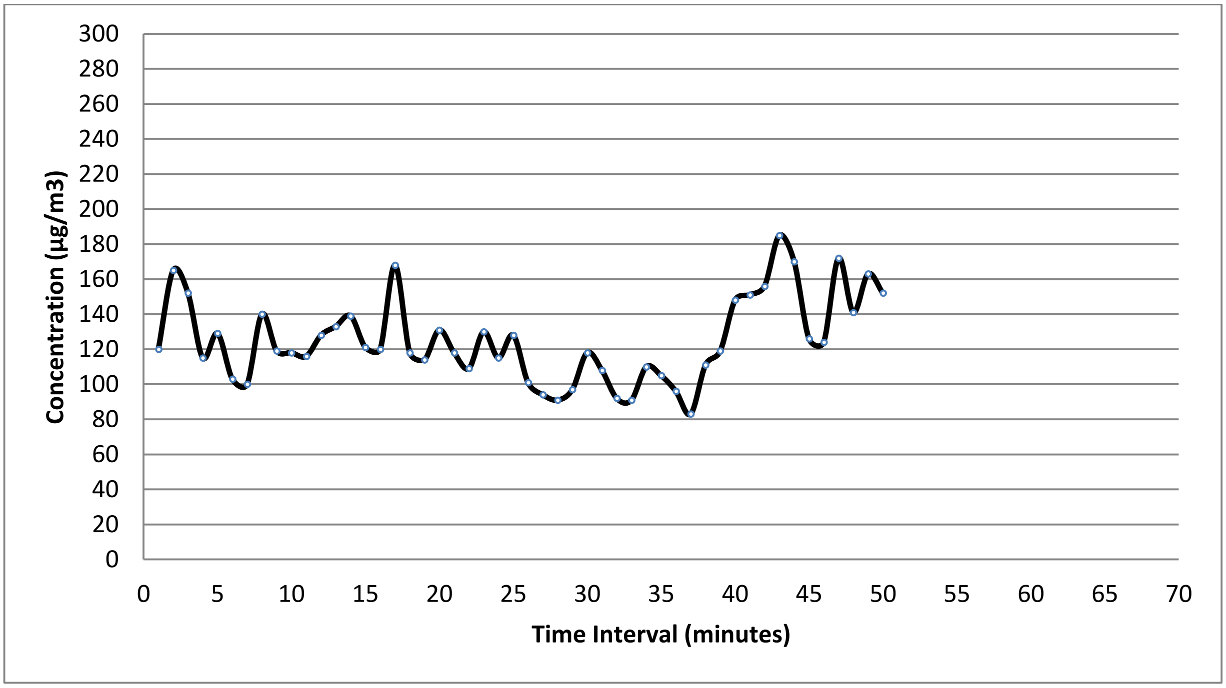

Figure 4.34: Temporal Variation in concentration of PM1.0 during morning hours (Non Ac Cab).

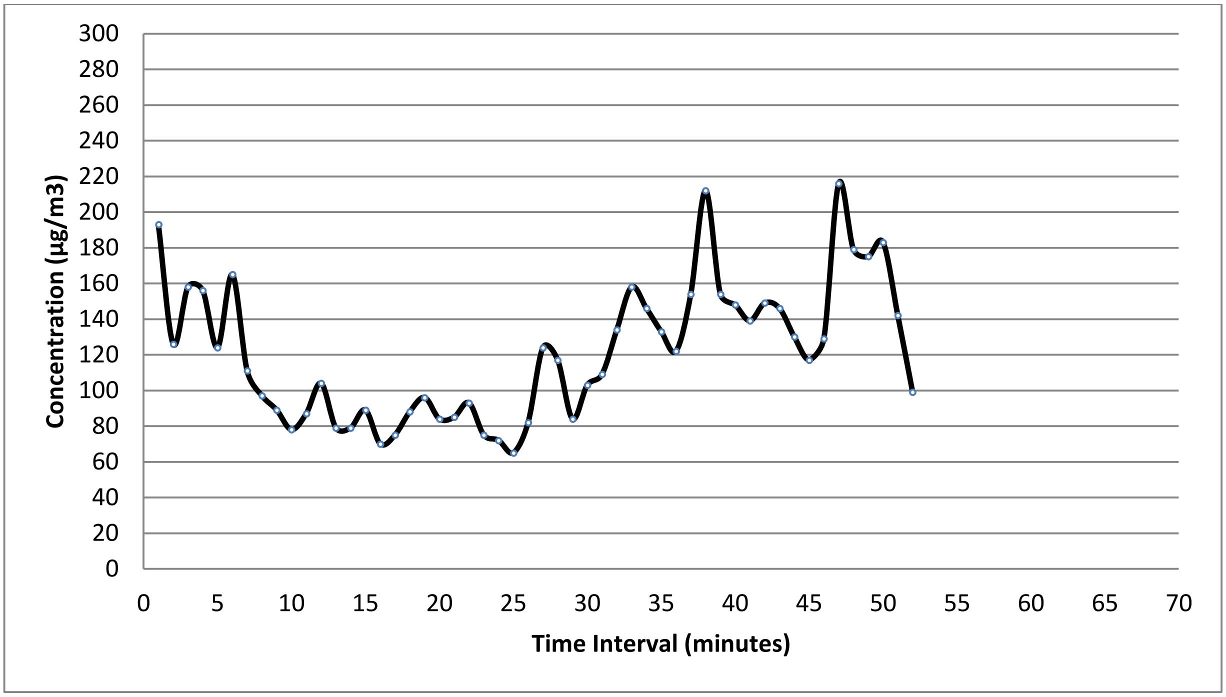

Figure 4.35: **Temporal Variation in concentration of PM1.0 during afternoon hours (Non Ac Cab).**

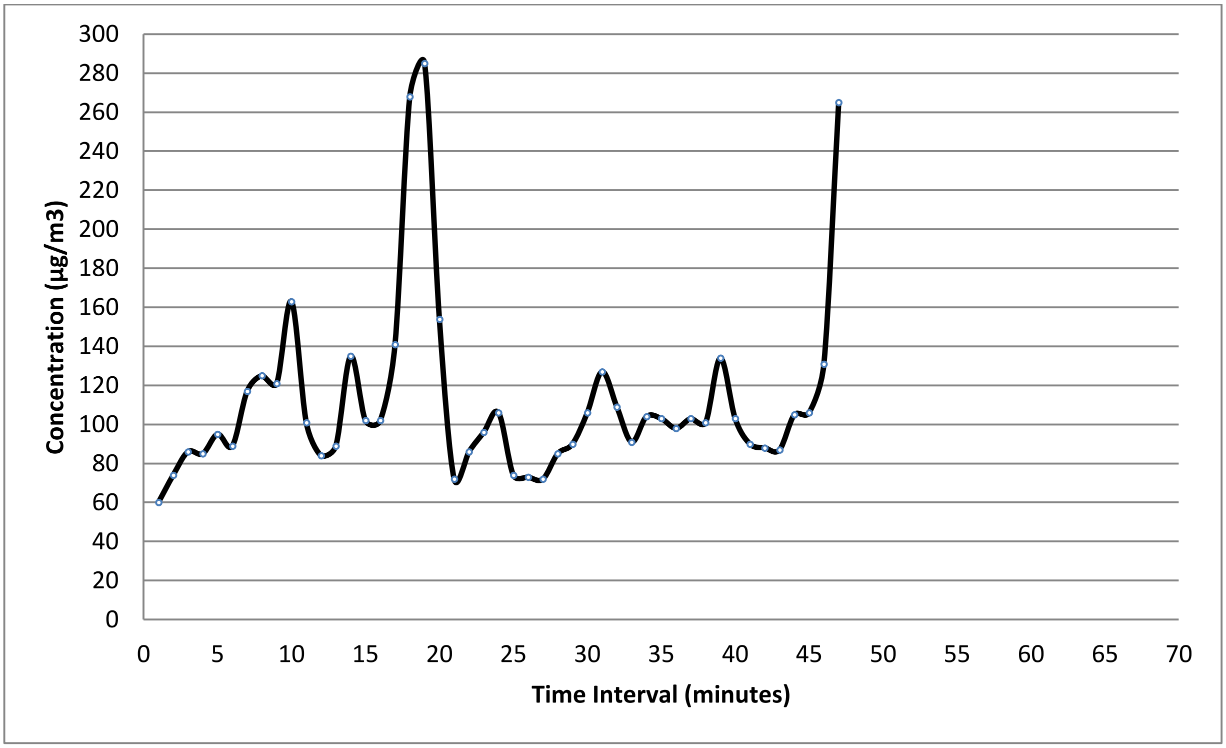

Figure 4.36: **Temporal Variation in concentration of PM1.0 during evening hours (Non Ac Cab).**

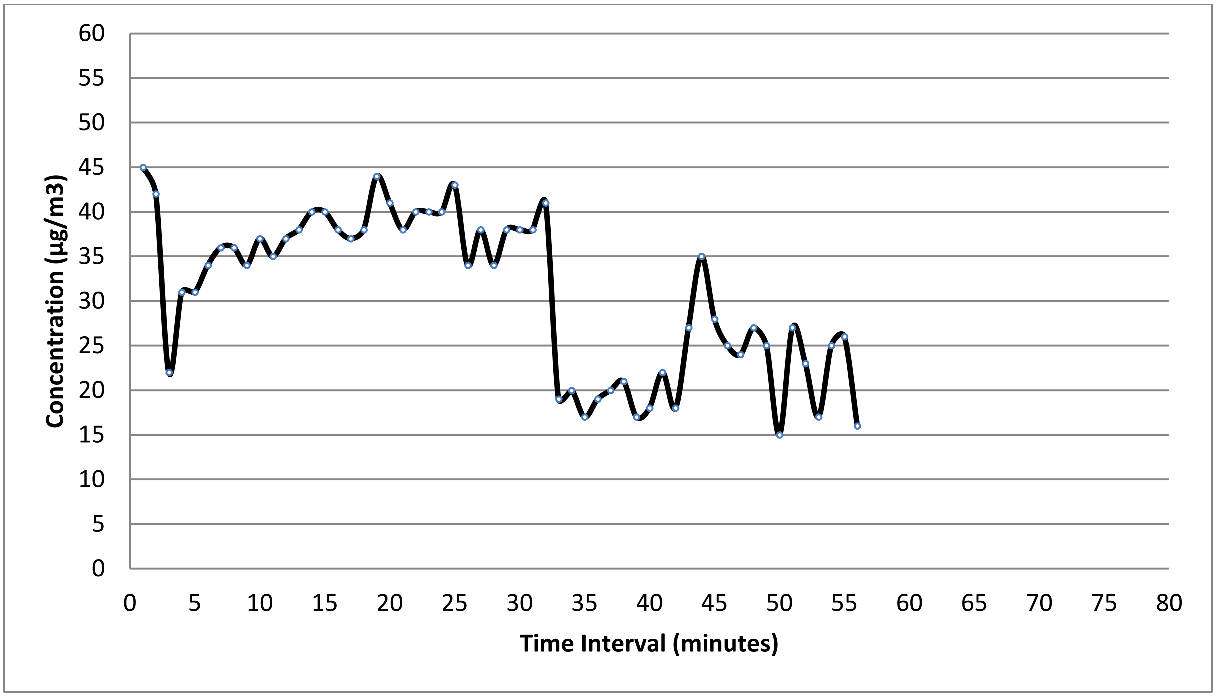

Figure 4.37: Temporal Variation in concentration of PM1.0 during morning hours (Ac Cab, 2nd time).

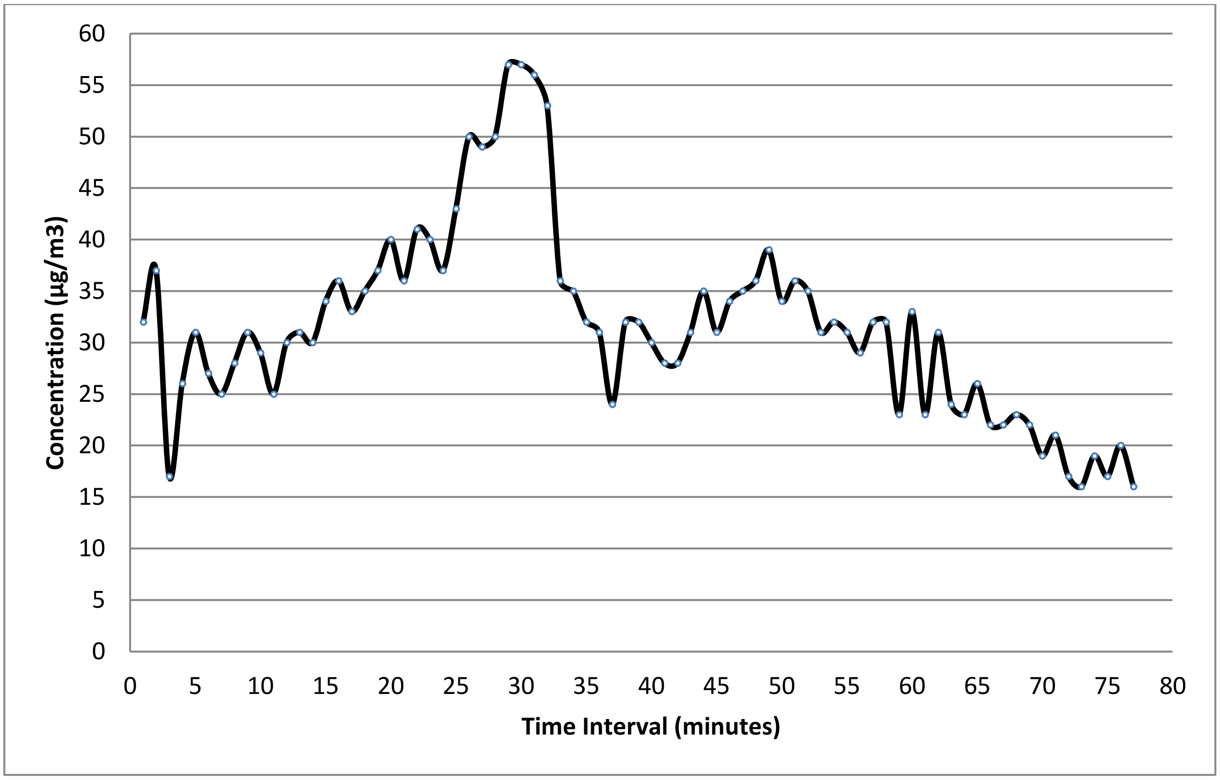

Figure 4.38: Temporal Variation in concentration of PM1.0 during afternoon hours (Ac Cab, 2nd time).

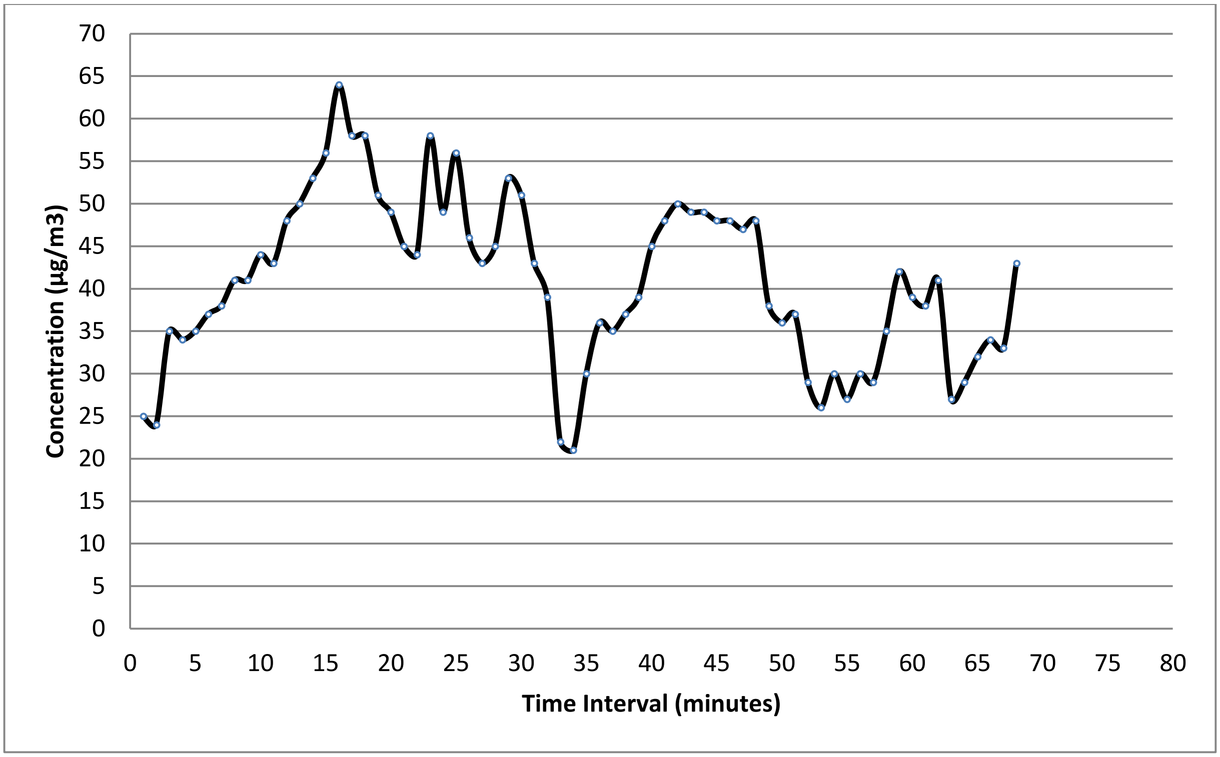

Figure 4.39: Temporal Variation in concentration of PM1.0 during evening hours (Ac Cab, 2nd time).

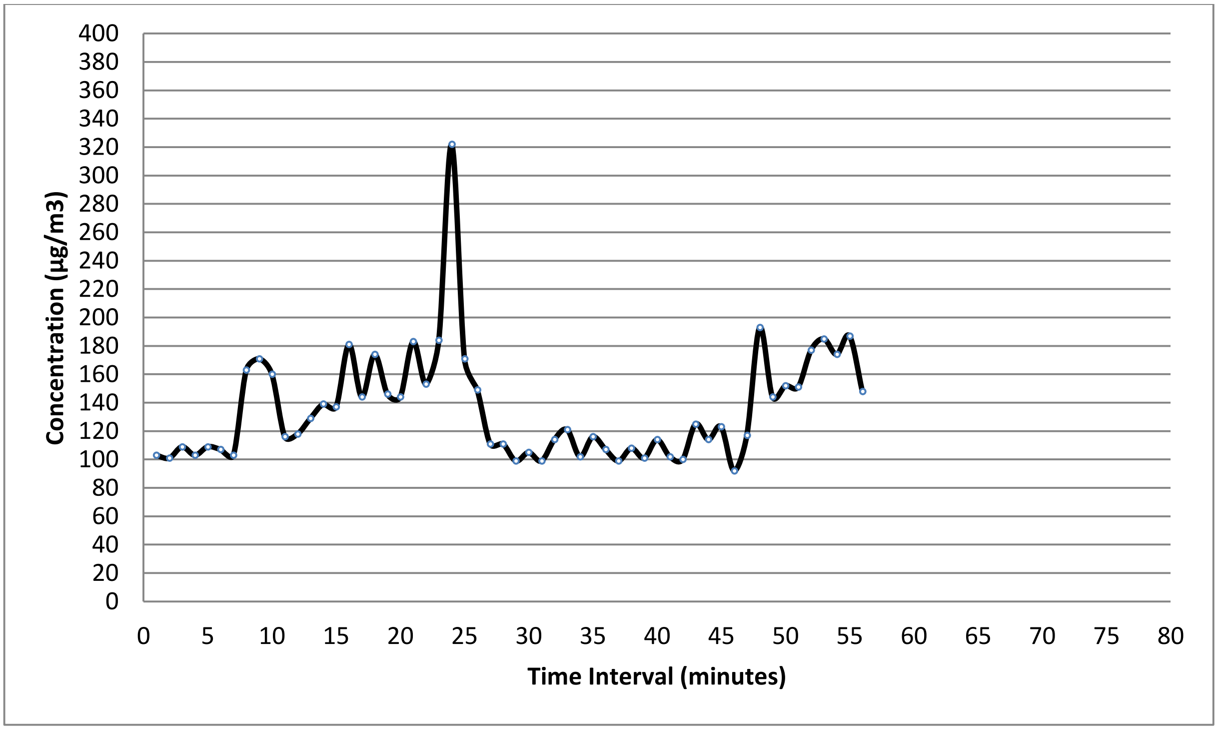

Figure 4.40: Temporal Variation in concentration of PM1.0 during morning hours (Auto Rickshaw, 2nd time).

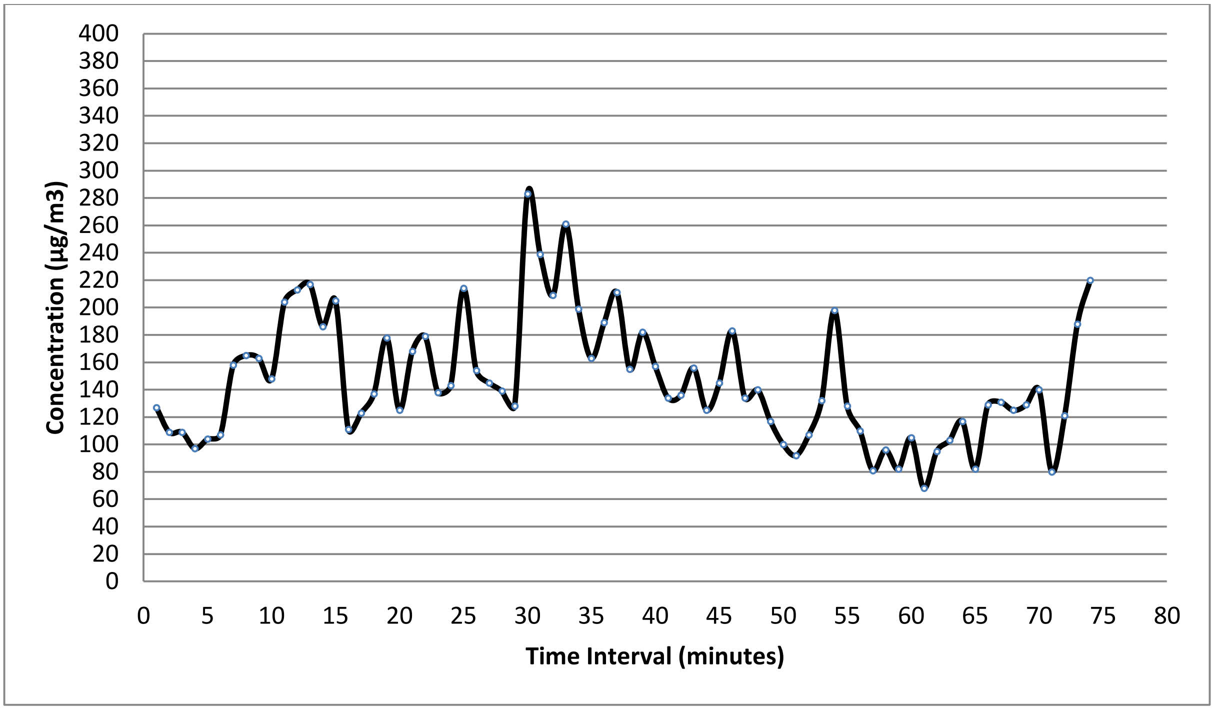

Figure 4.41: Temporal Variation in concentration of PM1.0 during afternoon hour (Auto Rickshaw, 2nd time).

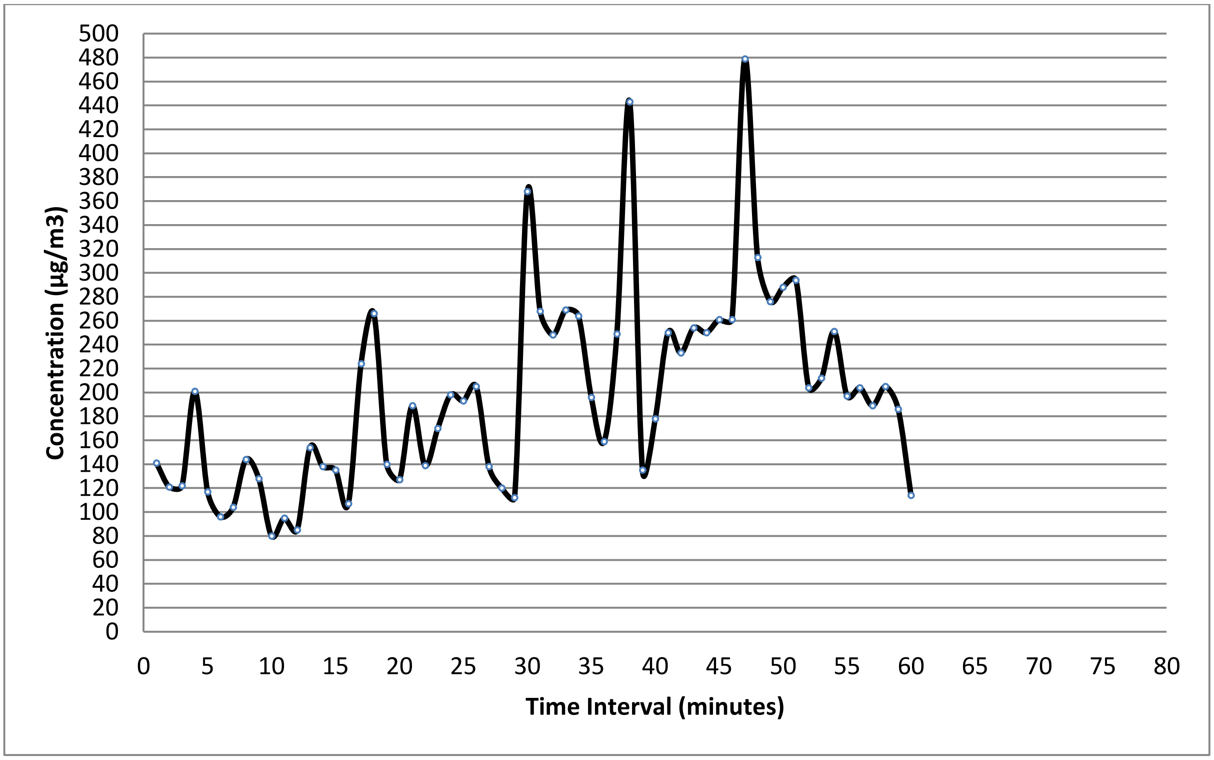

Figure 4.42: Temporal Variation in concentration of PM1.0 during evening hours (Auto Rickshaw, 2nd time).

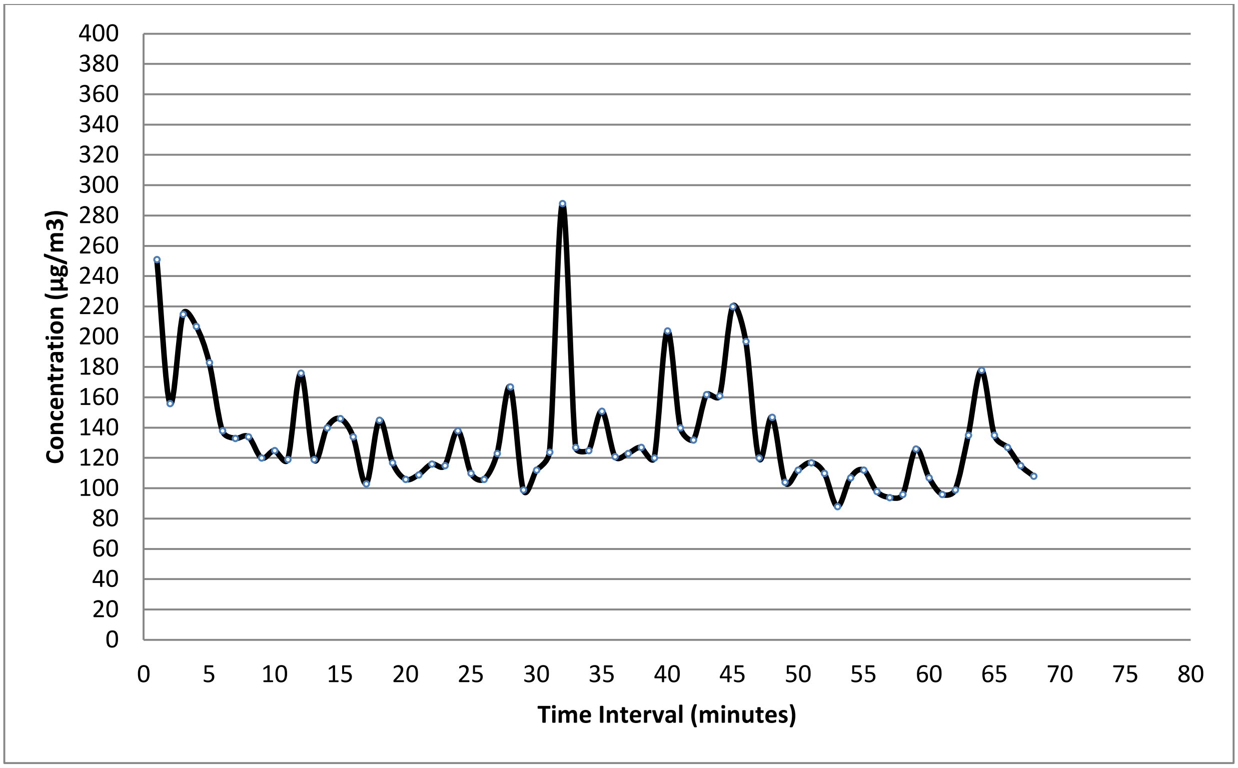

Figure 4.43: Temporal Variation in concentration of PM1.0 during morning hours (DTC Bus, 2nd time).

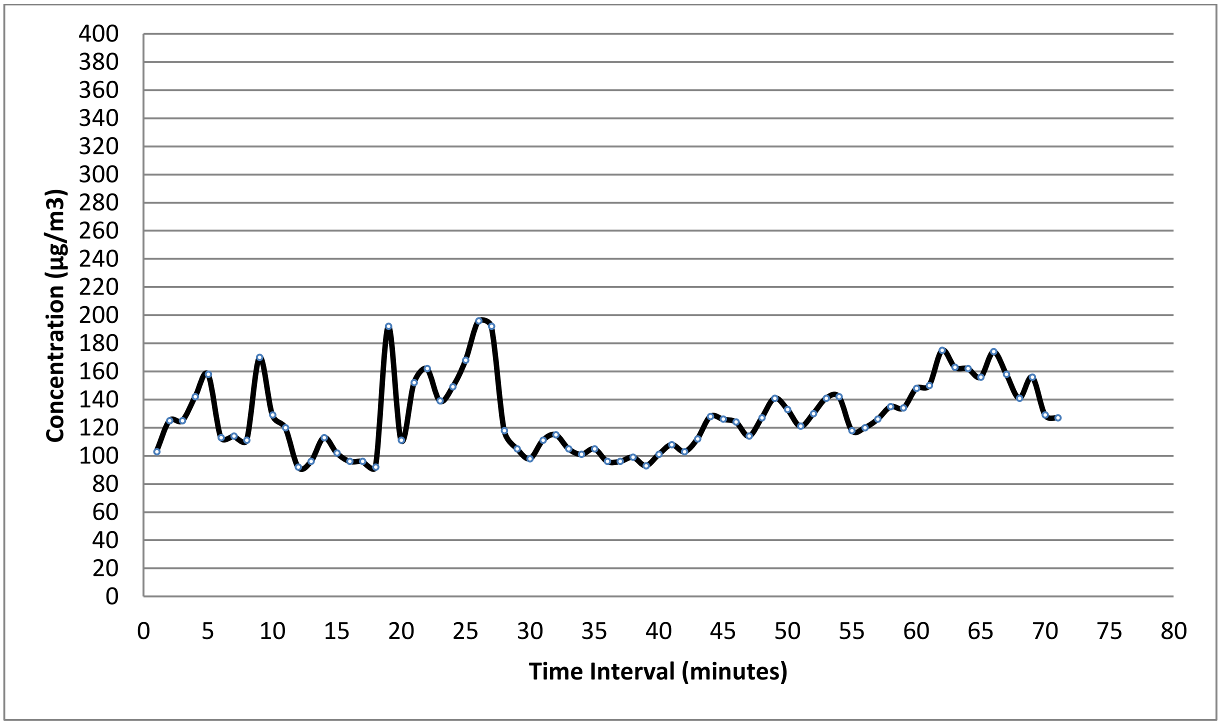

Figure 4.44: Temporal Variation in concentration of PM1.0 during afternoon hours (DTC Bus, 2nd time).

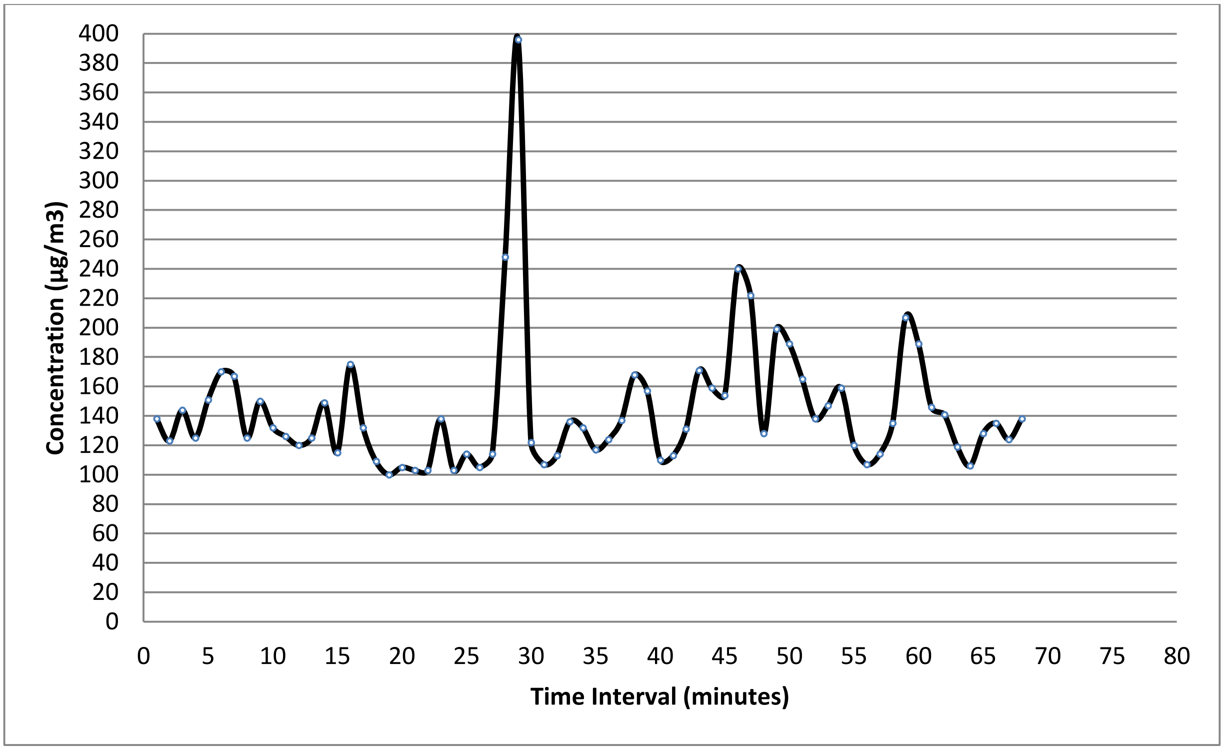

Figure 4.45: Temporal Variation in concentration of PM1.0 during evening hours (DTC Bus, 2nd time).

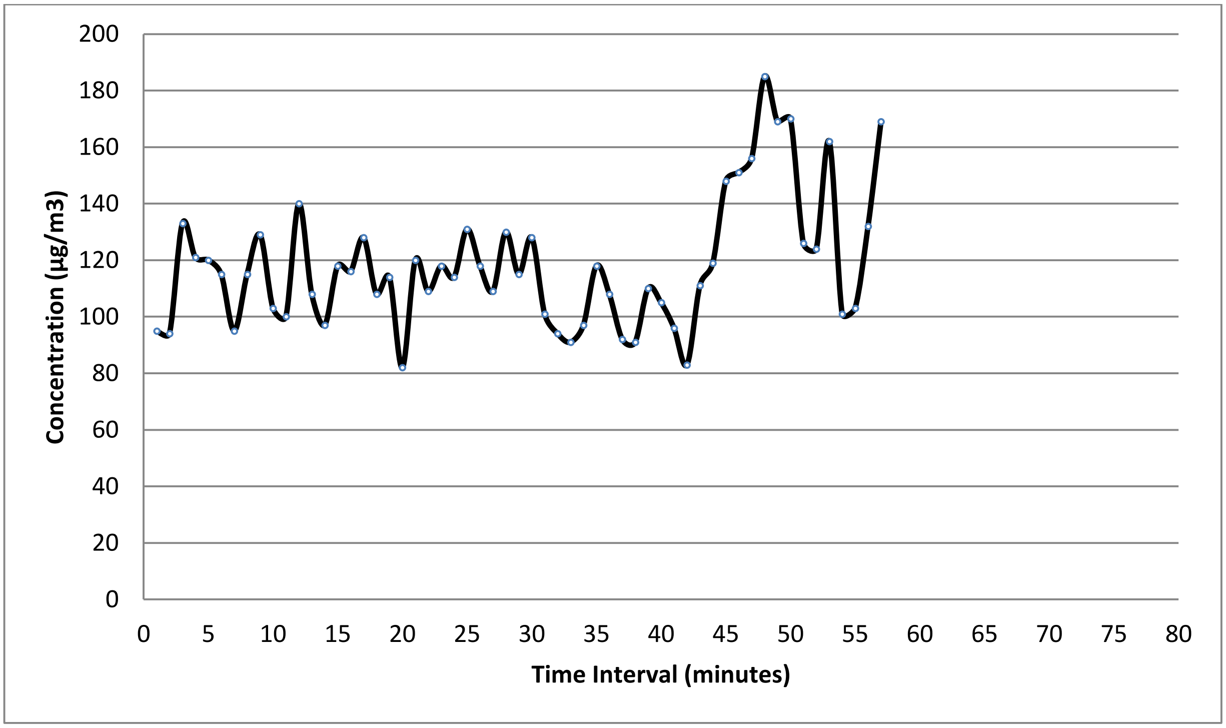

Figure 4.46: Temporal Variation in concentration of PM1.0 during morning hours (Non Ac Cab, 2nd time).

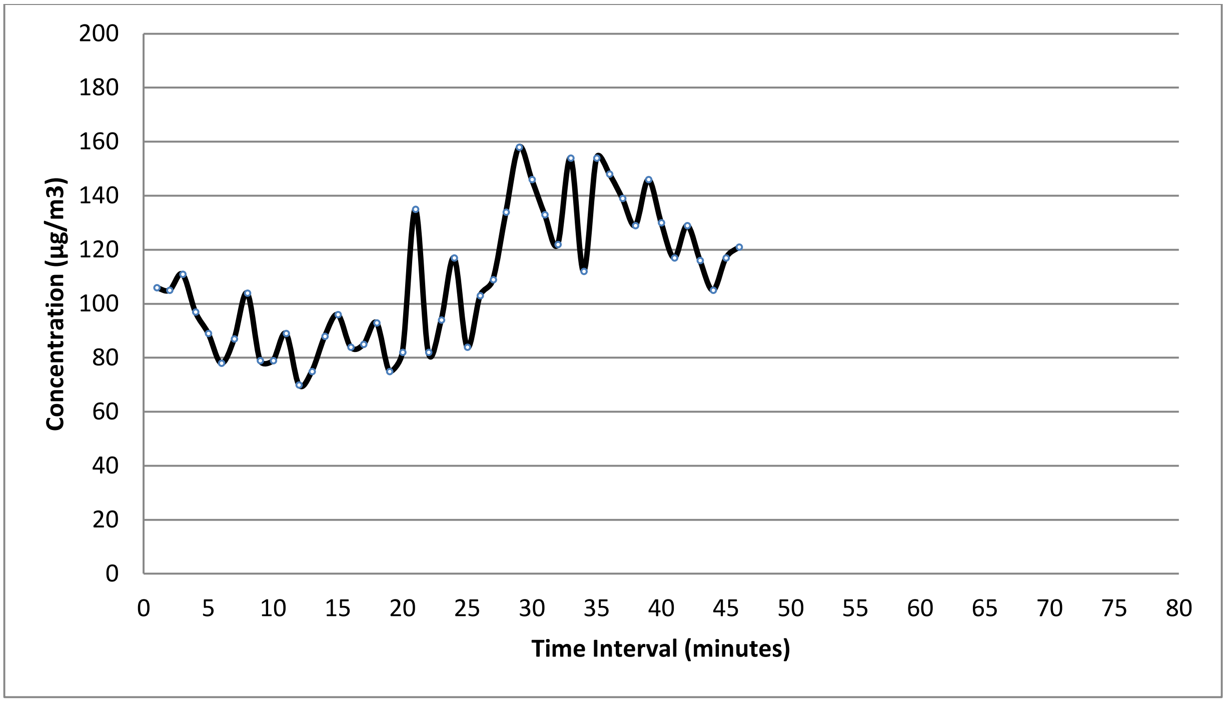

Figure 4.47: Temporal Variation in concentration of PM1.0 during afternoon hours (Non Ac Cab, 2nd time).

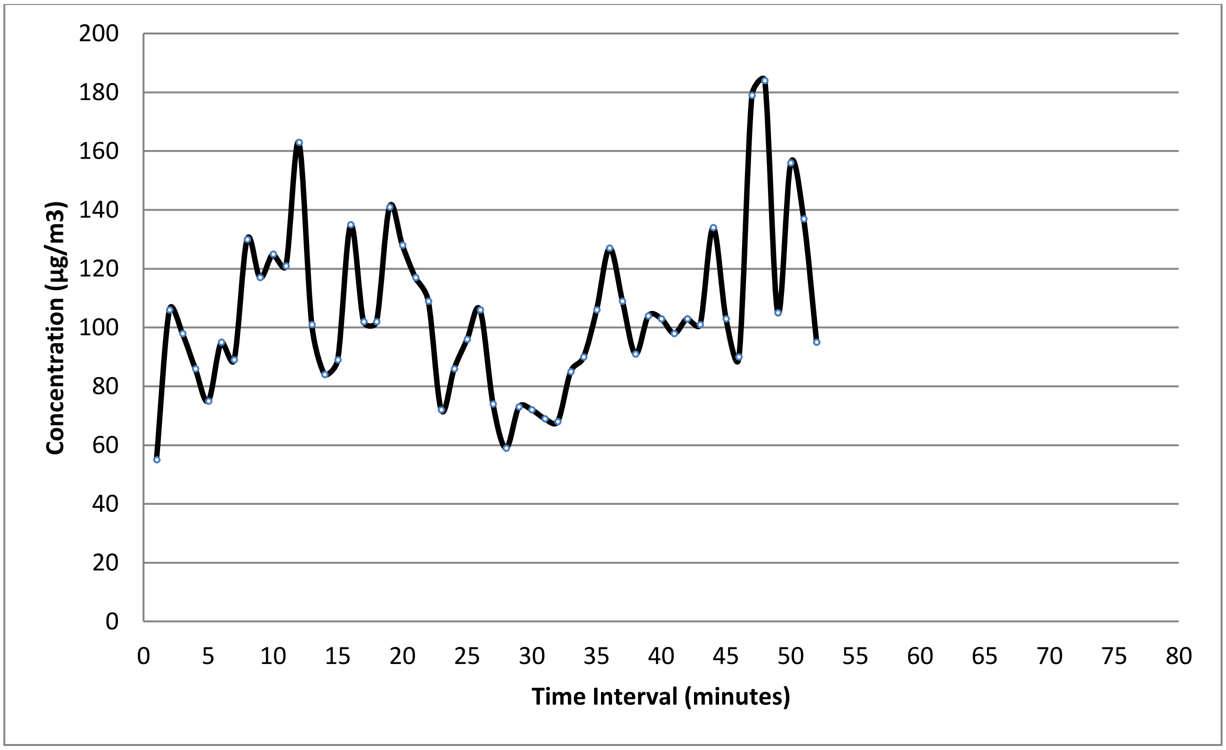

Figure 4.48: Temporal Variation in concentration of PM1.0 during evening hours (Non Ac Cab, 2nd time).

Several previous studies (Chan et al, 1999, Fernandez-Bremauntz and Ashmore, et al1995) revealed that commuter exposure to pollutants related to traffic is highly influenced by the choice of commuting micro-environment, and results of the present study found similar features for particulate matters considered. Apart from that it was also found that variations in transport micro-environment were not similar for different pollutants measured. Temporal variation as represented in above figures suggests that in-vehicle exposure of with surrounding environment, traffic conditions and the time period of commuting. Many a times much higher exposure levels were observed during later part of the trip i.e. mainly near old Delhi railway station and clock tower market area because of intense traffic and higher vehicular movement conditions specially during evening peak hours. It was observed that sometimes instrument showed higher initial concentration levels while commuting on Ac Cabs because of presence of dust particles initially inside the cab and suggesting that PM levels is highly influenced by the ventilation conditions of the commuting mode. With windows opened in non air conditioned cabs, significant increase in concentration level of both PM2.5 and PM1.0 were noted as the vehicles exhausts can easily penetrate the vehicle compartments, especially during waiting periods of traffic signals and during stop-and-go kind of traffic conditions near crowded areas. The exposure levels were only slightly lower during afternoon non-peak hours than during the peak hours. One possible explanation for this kind of result was due to insignificant change of traffic volume from 11.00 to 14.00 hours and heavy vehicle movements being allowed on the selected route during this time periods. The roads are quite busy even during the afternoon non-peak hours and also public transports provide regular services in the daytime also regardless of time of the day on the selected route which is being used extensively by the general public. Other than this, factors like meteorological conditions (mixing height, wind speed, wind direction, temperature, and relative humidity), driving conditions and vehicle to vehicle variations (e.g. extent of influence of internal pollutant sources) had impact on differences in exposure level concentrations observed during the monitoring.

Chapter 5- Conclusion

One of the important sources of particulate pollution in the cities of developing countries is vehicular traffic, where rapid growth and lack of effective transport management plans coupled with lack of land use planning and management may result in harmful level of fine particulates. The present study has been performed for measurement of two health concerned pollutants; in four different modes of transportation (Ac Cab, Auto Rickshaw, DTC Bus and Non Ac Cab) while commuting a typical urban route passing through residential and commercial areas in Delhi, India. The study provides valuable information on exposure levels of PM2.5 and PM1.0 to commuters of an area. For gaining more understanding of variability and inter relationships of particulate matters, data was analyzed for investigating temporal variations. The exposure levels of particulate showed were greatly influenced by the commuters' choice of commuting, environmental conditions, vehicle characteristics, road conditions and period of commuting. Trip averaged exposure levels observed for PM2.5 in the morning hours was maximum for DTC Bus with 11.4% higher concentration level in comparison to auto rickshaw, 54.7% higher concentration in comparison to non ac cab and much higher concentration level of 819.44% in comparison to ac cabs.Whereas in the evening hours maximum concentration was observed for auto rickshaw with 10.3% higher concentration level in comparison to DTC bus, 57.3% higher concentration in comparison to non ac cab and much higher concentration level of 503.15% in comparison to ac cabs. For PM1.0 trip averaged exposure levels observed were maximum for auto rickshaw in the morning hours with 8.84% higher concentration level in comparison to DTC bus, 31.2% higher concentration in comparison to non ac cab and much higher concentration level of 364.3% in comparison to ac cabs and in the evening hours as well the concentration was maximum for auto rickshaw with 25.03% higher concentration level in comparison to DTC bus, 88% higher concentration level in comparison to non ac cab and even much higher concentration level of 402.4% in comparison to ac cabs.The exposure levels resulted in evening peak hours were much higher than afternoon non peak hours for commutes on DTC bus and auto rickshaw with 23.16% and 41.26% higher concentration levels respectively. Exposure levels of PM1.0 were observed 70.11%, 36.53% and 29.52% (respectively in morning, afternoon and evening hours) higher concentration levels than PM2.5 inside closed Ac Cabs. Averaged concentrations were observed higher even on Non Ac cabs with 283.44%higher concentration of PM2.5 in the evening hours and

253.87%higherconcentration of PM1.0 in the morning hours in comparison to concentration levels on ac cab. Temporal variations prepared from data suggests that exposure levels are associated with surrounding traffic indicating importance of local resources, most importantly vehicular traffic and depends much on volume of traffic.

The exposure levels observed in present study was higher than those measured in most of the overseas studies. The main reason s behind such elevated exposure levels of particulate matters being loose vehicle emission control norms, slow moving traffic patterns and increased number of traffic jams because of increase in vehicle population in Delhi and frequent stops and traffic signal. As a consequence there has been increase in emission source strength. For reduction in such higher exposure levels, control measures such as improvement of traffic management and land use pattern, proper maintenance of vehicles, strict vehicle emission control norms complying with international standard must be promoted. The results of present study showed that in vehicle exposure level of particulate matter is greatly affected by use of air conditioning systems and hence higher concentration levels of PM2.5 and PM1.0 as observed in buses and taxis can be lowered substantially by the use of air conditioning systems inside them. Increase in public transportation modes especially air conditioned DTC buses must be considered as population of commuters commuting daily on DTC buses are much higher as compared to other modes of transportation and exposure levels will be lower inside Ac DTC buses as compared to normal DTC buses and also by increase in use of public transports there will be reduction in traffic volume and traffic density along the route.

Although health impacts of air pollution require further investigation in epidemiological studies, but it can be seen from the result of present study that Delhi commuters, specially professional drivers are frequently exposed to higher exposure levels of particulate matters during daily commutes and additional statistical analysis of extensive database is necessary to identify more determinants of commuters exposure to particulate matters.

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