

**A METHOD FOR ANALYSING EPISODIC AIR QUALITY
AND HEALTH RISKS TO SEDENTARY WORKERS IN AN
URBAN TRAFFIC CORRIDOR**

A Thesis

Submitted in Partial

Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

Mitali Sahu

(Roll No. 126104020)



**DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
ASSAM, INDIA
MARCH 2019**



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ASSAM, INDIA
MARCH 2019**





Dedicated
To
My Late Grand Parents
and my Family





Department of Civil Engineering
Indian Institute of Technology Guwahati
Assam, India - 781039

CERTIFICATE

It is certified that the work contained in this thesis entitled “**A Method for Analysing Episodic Air Quality and Health Risks to Sedentary Workers in an Urban Traffic Corridor**” by **Mitali Sahu** (Roll No. 126104020) has been carried out under my supervision in the Department of Civil Engineering, Indian Institute of Technology Guwahati. I forward her thesis to submit for the award of degree of Doctor of Philosophy from this institute. I certify that she has fulfilled all the requirements according to the rules of this institute regarding the investigations embodied in his thesis and this work has not been submitted elsewhere for a degree.

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Assam, India - 781039





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STATEMENT

I hereby declare that the work contained in this thesis entitled “**A Method for Analysing Episodic Air Quality and Health Risks to Sedentary Workers in an Urban Traffic Corridor**” is carried out by me at the Department of Civil Engineering, Indian Institute of Technology Guwahati, under the supervision of Prof. Sharad Gokhale.

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Mitali Sahu

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ABSTRACT

Worldwide urbanising cities are witnessing a rapid growth in road vehicles, which in particular is centred along the heavy road network and, thus, is the main cause of deteriorating air quality in urban centres. The growth of vehicles has also increased the time of commuting and queuing at junctions, which contributes to more emissions and high air pollutant concentrations. High air pollutant concentrations in the prevailing local wind flow may lead to episodic conditions in urban traffic corridors. Short-term high air pollution has both acute and chronic effects on human health. Air quality models are vital tools to assess the impact of air pollutants on human health and the urban environment. Episodic condition does not occur throughout the day. Since it depends on several factors related to road geometry, urban density, traffic and local meteorology, a method is needed that incorporates these factors to identify the time when the episodic condition occurs, its intensity and the location within the traffic corridor. Atmospheric dispersion models are widely used to identify the pockets where the air quality is most impacted. But such applications are found on a long-hour average air quality. Often in averaging the air quality over the day, a conventional practice, short-term air pollution episodes surpass unnoticed, making air quality and health risk assessments inaccurate. And no specific method is found in the literature for carrying out such a study in an urban microenvironment. It is a challenge to identify episodic air quality, its magnitude and location for health risk assessment and its management in the traffic corridor. Given the rising menace of pollution and relevant health problems in urban centers episodic air quality needs attention.

This research is aimed at developing a methodology to identify episodic conditions caused by air pollutants (Carbon Monoxide (CO), PM_{2.5} and Black Carbon (BC)) released from the traffic in an urban traffic corridor, to determine the most episodic prone locations,

Abstract

and to estimate chronic obstructive pulmonary disease (COPD) health risks to the sedentary workers in the traffic corridor due to $PM_{2.5}$. This research has been carried out in an urban traffic corridor of the downtown of Guwahati, the fastest developing city of North-Eastern India situated in the Brahmaputra River Valley. It involves the development of indicators – one pertaining to the real CO emission scenario in the traffic corridor and second pertaining to the threshold CO emission scenario adopted from the national ambient air quality standards – which incorporate hourly average emission, population, pollutant toxicity and dimension of the corridor, and determine the time of occurrences of episodic conditions over the day. The factors which are most influencing the episodic conditions have been identified using statistical correlation analysis. The air dispersion model, AERMOD has been used to determine the episodic prone locations. The method has been applied further to BC to validate the time and spatial location of the episodic condition caused by CO. Subsequently, health risks due to $PM_{2.5}$ in the episode-prone areas have been found out in terms of the risks of ischemic heart disease (IHD), stroke, COPD, and lung cancer (LC) expected upon exposure to $PM_{2.5}$. The health risk estimates have been further supported with the help of a social questionnaire survey carried out in the traffic corridor on the participants who are sedentary workers in the shops located along the roadside. The results of the health relative risks show that the salesmen of air-conditioned shops¹ and open shops² are prone to risk due to exposure to $PM_{2.5}$. The level of exposure of both groups to $PM_{2.5}$ is different, which also resulted in different COPD symptoms for the workers of open shops having a direct exposure than the workers of air-conditioned shops having indirect exposure. The methodology developed in this research may be useful in carrying out such research in the roadside microenvironments.

¹ The shops are closed due to air conditioning system and hence are not openly exposed to traffic emissions.

² The shops are open and facing to the road and hence the salesmen are exposed openly to traffic emissions.

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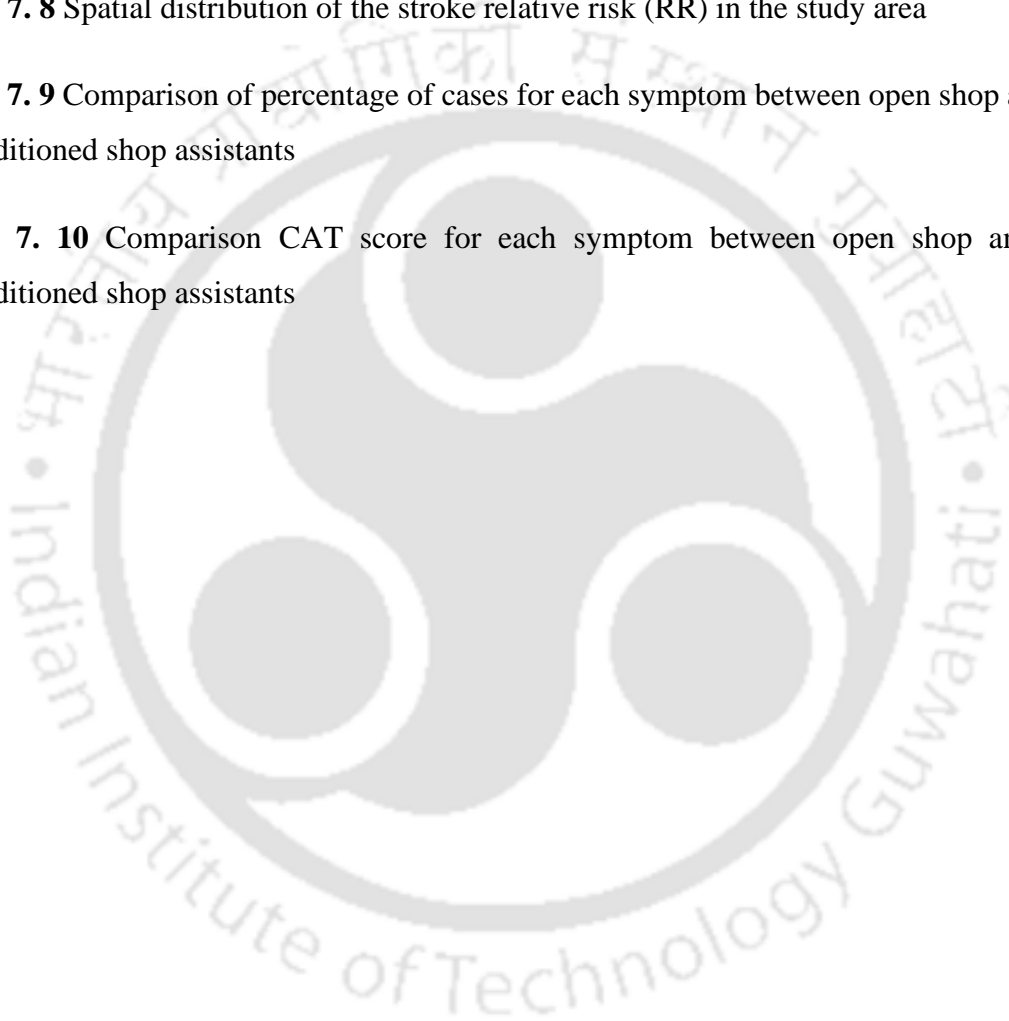
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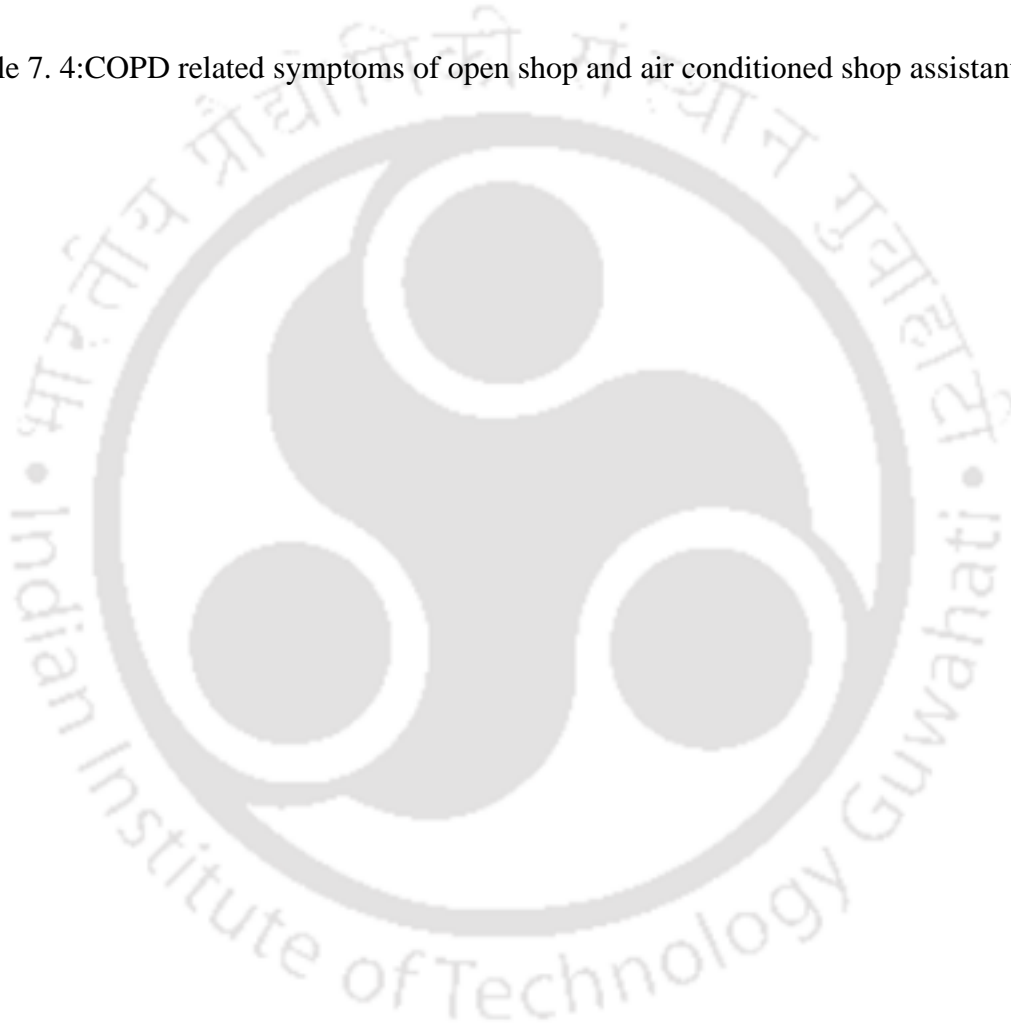


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SYMBOLS AND ABBREVIATIONS

<i>Abbreviations</i>	<i>Description</i>
CO	: Carbon monoxide
PM	: Particulate matter
PM _{2.5}	: Particulate matter with aerodynamic diameter less than 10 micron
PM ₁₀	: Particulate matter with aerodynamic diameter less than 2.5 micron
CPCB	Central Pollution Control Board
NAAQS	: National Ambient Air Quality Standards
L1	: CO monitoring location-1
L2	: CO monitoring location-2
L3	: CO monitoring location-3
M	: Meteorological station
ARAI	Automotive Research Association of India
PC-MUV	: Passenger car and multi utility vehicle
LHCV	: Light and heavy commercial vehicle
Q_R	: Emission for real condition
Q_s	: Emission for standard condition
I	: Indicator
I_r	: Indicator for real condition
I_s	: Indicator for standard condition

Symbols and Abbreviations

<i>Abbreviations</i>	<i>Description</i>
AERMOD	: American Meteorological Society/Environmental Protection Agency Regulatory Model
FB	: Fractional bias
NMSE	: Normalized mean square error
VG	: Geometric variance
R	: Pearson correlation coefficient
FAC2	: Factor of two
GOLD	: Global initiative for chronic obstructive lung disease
COPD	: Chronic obstructive pulmonary disease
IER	: Integrated exposure–response
LC	: Lung cancer
IHD	: Ischemic heart disease
CAT	: COPD assessment test
FEV1	: Forced expired volume during the first second
PEF	: Peak expiratory flow
FVC	: Forced vital capacity



1

CHAPTER

INTRODUCTION



CHAPTER 1

INTRODUCTION

1.1 GENERAL

Urbanising cities are witnessing a rapid growth in road vehicles causing of poor air quality roadside in urban centres (Branis, 2009). Since the growth is mostly centred in urban areas, time for commuting and queuing at junctions has increased by multi-fold, causing more emissions and higher air pollutant levels (Pandian et al., 2009). Common air pollutants related to traffic include particulate matter (PM), ozone (O₃), carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen dioxide (NO₂), lead (Pb), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs) (Han et al., 2006; Wong et al., 2008). People by virtue of their residences and workplaces are often exposed to a higher level of air pollution due to traffic and, thus, are prone to severe health risks. Most cities experience stagnant and calm wind conditions during morning and evening, also the peak traffic hours, another cause of poor air quality in traffic corridors. Traffic is thus, one of the most important sources of higher air pollution in cities, which have increased the exposure of the population in the urban environment.

World Health Organization (2016) updated PM_{2.5} and PM₁₀ concentrations database in which many cities all over the world was included. Concentrations for only some megacities have been presented in Table 1.1. It can be observed that developing countries are more vulnerable to high air pollutant levels. According to the Ministry of Urban Development, a typical traffic composition for Indian cities is given in Fig. 1.1. The percentage of two-wheeler is less in category 6 (9% for Bangalore, Delhi, Kolkata, Mumbai) and category 1b (6% for Gangtok and Shimla) in comparison with other cities. Public

transport is highest (44%) in Bangalore, Delhi, Kolkata, and Mumbai. Percentage of car is more in Panaji (27%), Gangtok and Shimla (28%). According to the Assam Science Technology and Environment Council (2011), more than 400,000 vehicles commute on the roads of Guwahati each day, and approximately 70% of these vehicles do not have emission clearance certificates resulting in uncontrolled emissions of air pollutants.

Table 1. 1: Air quality in megacities

Country	City/Town	PM ₁₀	PM _{2.5}	Year
		Annual mean ($\mu\text{g m}^{-3}$)	Annual mean ($\mu\text{g m}^{-3}$)	
India	Delhi	292	143	2016
Bangladesh	Dhaka	146	82	2015
Egypt	Greater Cairo	284	117 ^b	2015
Turkey	Istanbul	38	15	2016
Republic of Korea	Seoul	48	26	2016
Thailand	Bangkok	41	28	2015
Russian Federation	Moscow	28	14	2016
Pakistan	Karachi	290 ^a	88	2009
China	Beijing	92	73	2016
Pakistan	Lahore	198	68	2010
India	Mumbai	104	64	2016
India	Kolkata	136 ^a	74	2016
China	Shanghai	59	45	2016
China	Guangzhou	56	36	2016
Mexico	Mexico city	39	22	2016
Japan	Osaka city	37 ^a	17	2014
Japan	Tokyo	36 ^a	17	2014
USA	Los Angeles	57	33	2016
USA	New York	14 ^a	7	2016

(World Health Organization, 2016)

Note: a - converted from PM_{2.5}, b - converted from PM₁₀

The pollutants that are brought into the atmosphere by various sources are dispersed (advected and diffused) over a wide range of horizontal length scales, which can be classified into near-field and far-field phenomena. The near-field pollutant dispersion has very short

range (i.e. vicinity of the emitting building; within a few hundred meters of the source) rather than the entire (neighbourhood) region of significant impact (Tominaga and Stathopoulos,

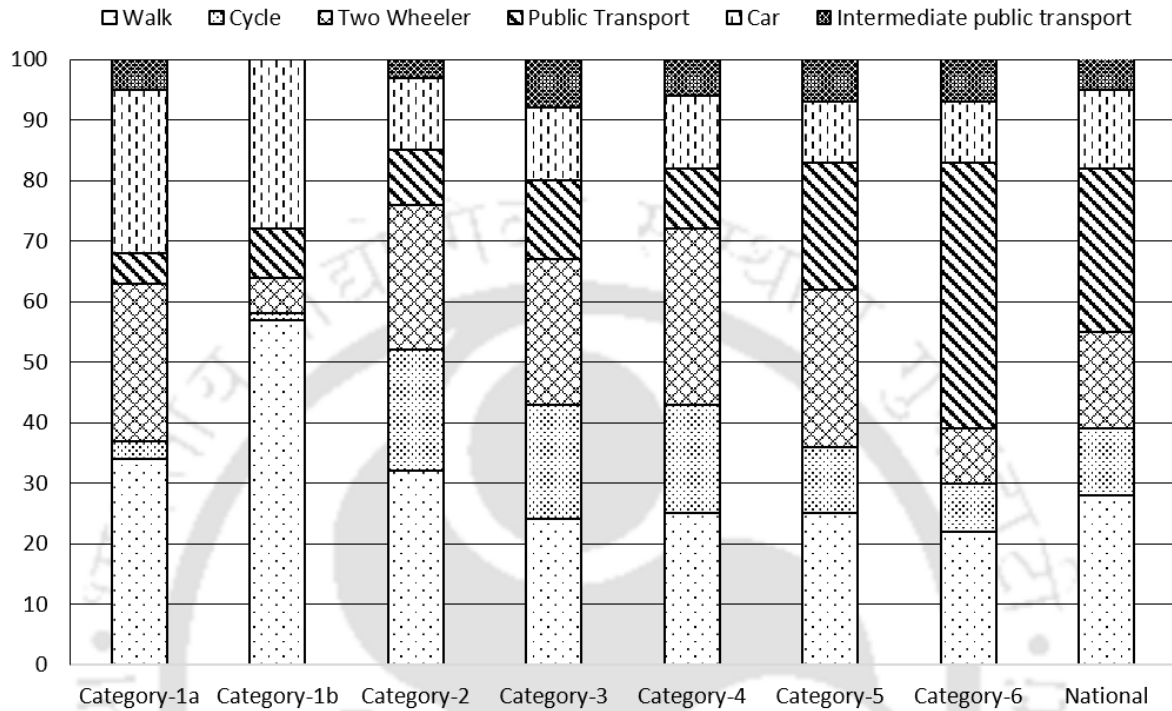


Fig. 1. 1 Traffic composition (%) of India, (source: traffic report, Ministry of Urban Development, 2008)

*Cities under the categories

Category-1a	Panaji
Category-1b	Gangtok, Shimla
Category-2	Pondicherry, Bikaner, Raipur, Bhubaneswar, Chandigarh, Hubli Dharward
Category-3	Guwahati, Amritsar, Trivandrum, Madurai, Agra, Bhopal, Kochi, Patna, Varanasi
Category-4	Nagpur, Jaipur, Kanpur, Surat
Category-5	Pune, Ahmedabad, Hyderabad, Chennai
Category-6	Bangalore, Delhi, Kolkata, Mumbai

2013). The traffic composition is heterogeneous¹ in India, which complicates the dispersion of emission in the near-field atmosphere and also contributes to the higher air pollutant levels. Meteorology, road geometry, road side characteristics play a great role in the dispersion of air pollutants in atmosphere (Gokhale, 2011). In urban areas, at junctions, times for commuting and queuing have increased causing more idling emissions and higher pollutant concentrations (Pandian et al., 2009; Gokhale and Pandian, 2007). CO is an important air pollutant in traffic and traffic related epidemiological studies. High concentrations of CO generally occur in cities with heavy traffic intensity and congestion. CO is an air toxicant, which can cause mild to severe health effect depending on the exposure time and the individual's health condition. CO even in low concentration [less than National Ambient Air Quality Standard (NAAQS) which is 4 mg m^{-3} in 1 hour average] may show significant health impacts on individuals. Two-wheeler riders and pedestrians are more prone to exposure to higher concentrations in urban centres as they are directly exposed to that ambient condition (Kumar et al., 2018). The frequency of concentration exceedances over NAAQS has been increased during peak as well as non-peak hours (Gokhale and Khare, 2007). These exceedances most often lead to air pollution episode or create episodic conditions. Cities regularly face severe air pollution related to PM in winter due to emissions of particles and precursor gases, complex terrain and poor ventilation and vertical mixing (Rutllant and Garreaud, 2004, Gallardo et al., 2002). These conditions result in higher PM concentrations ($>300 \text{ } \mu\text{g m}^{-3}$ hourly PM_{10} sometimes reaching $600 \text{ } \mu\text{g m}^{-3}$) known as "episodes". High PM concentrations often occur during the nights.

¹ Heterogeneous traffic – Traffic comprising of motorized and non-motorized vehicles (two-wheelers and three-wheelers along with several other vehicles) with no-lane discipline is termed as heterogeneous traffic (Mallikarjuna and Rao, 2011).

Therefore, forecasting outdoor pollutant concentration, particularly, in traffic corridors has been of special interest to developing countries in light of the unpredictable growth of urban areas and heavy growth in traffic.

1.2 EPISODIC AIR QUALITY

The United States Environmental Protection Agency (USEPA) defines air pollution episode as a state of the ambient air environment in which the pollutant levels are elevated to or are in excess of NAAQS under certain meteorological conditions. The meteorological conditions play important role in determining the air quality and the variability observed in it. Therefore, air pollution episodes are caused by the sudden increase in pollutant levels as well as the unfavourable meteorological conditions, not facilitating transport, dilution and dispersion of the emissions. Certain meteorological conditions often trap the pollutants near the sources and generally responsible for occurrence of episodic air quality and, hence, only sudden increase in emissions are not the cause of air pollution episodes (Haagenson, 1979). It has also been found that the causes of air pollution episodes are difficult to understand and are strongly related to factors like emissions, meteorological condition, topography, atmospheric chemistry and solar radiation (Pohjola et al., 2004). These factors are influenced by the level of urbanization, the density of built environment, road network and the volume of traffic. The surface elements within diverse built environment also determine the distribution of pollutants within the urban boundary layer. Thus, these factors along with some meteorological conditions help form pockets of pollution within the urban areas. Such conditions may last for short time or extend over a few days and confine to certain locations, which, therefore may be regarded as air pollution episodes.

The management of episodic air quality is, therefore, a challenging task. Gokhale and Khare (2007, 2005) have developed a hybrid air quality model to forecast the extreme pollutant concentrations. However, the hybrid model represented short-term air quality only

at a specific location and considered only the traffic source of emission and meteorology. They proposed a theoretical framework for managing episodic urban air quality (Gokhale and Khare, 2007). There is a need for the development of a mathematical tool to identify and forecast episodic air quality for an effective management of air quality.

1.3 PROBLEM DEFINITION

People are often exposed to poor air quality in urban centres, which increases risk to health. Exposure of both short and long-term is important, depending upon the degree of air quality. A long-term exposure to sustained average air quality is equally a risk to health as a short-term exposure to the extreme air quality. In urban centres, traffic is the only or major source of poor air quality. Usually, people use urban centres for short-time as pedestrian to workplaces and other public utilities housed along the roads. Though, air quality is affected due to a regular traffic on roads, there are certain instances when traffic interruptions leading to traffic congestion and jam can suddenly increase pollutant concentration to high level. People exposed to pollutants during such conditions are prone to higher risks. Many times, calm and stagnant meteorological conditions are observed, which aggravate the episodic condition leading to extreme air pollutant concentrations and worst air quality. Further, to some extent urban sprawl may also contribute to such air pollution episodes.

Often in averaging air quality over the day, a conventional practice, such short-term episodes surpass unnoticed, which makes assessment of air quality inaccurate. Therefore, identification of episodic conditions in urban areas and development of a forecasting tool for its assessment is challenging to air quality scientists and researchers.

The effects of road traffic on air quality and health outcomes on human beings in urban environment are of major concerns (Aldrin et al., 2005; Zhang et al., 2010; Gokhale et al., 2005, Tomlin et al., 2009). The urban 'hot spots' (road junctions, the traffic intersections and the signalized roadways) are more prone to the severe vehicular pollution as vehicles

spend more time at these ‘spots’ and generate more pollutants (Kaur et al., 2005; Bowker et al., 2007; Pandien et al., 2009). In urban environments, air pollution ‘episodes’ can be defined as extreme situation, during which air pollutant concentrations exceed a specified threshold or NAAQS (European Commission, 2005; Stern et al., 2008; Shang et al., 2013; Muir et al., 2006). Urban air quality depends on various factors like urban sprawl, traffic characteristics, meteorology and urban boundary layer (De Ridder et al., 2008; Kumar et al., 2008; Kumar et al., 2009; Soulhac et al., 2009; Sarath et al. 2012; Cheng et al., 2012). CO is an important air pollutant from traffic as it has adverse health effects on humans even for short-term exposure (Li et al., 2015; Dai et al., 2015). Traffic source and idling status of the buses increases the levels of air pollutants (PM_{2.5} and CO) at extremely high levels and this short-term exposure has shown acute reduction effects on pulmonary function in young adults (Huang et al., 2016). Episodic air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs (Tao et al. 2011; Katsouyanni et al., 2011). So identification of the extreme or episodic urban air quality period is the most important step for further understanding of the episodic air quality. An aggregate index using five air pollutants (PM_{2.5}, PM₁₀, NO₂, O₃ and SO₂) was developed for European cities (Sicard et al., 2012). Air quality models are vital tools to assess the impact of air pollutants on human health and the urban environment. These models can be used to forecast the air pollutant concentrations in urban areas. Several dispersion models exist to evaluate and predict the pollutant dispersion in urban areas (Gibson et al., 2013; Wang et al., 2014; Abdul-Wahab, 2004).

The AMS/EPA Regulatory Model (AERMOD) is an air pollution dispersion model (Cimorelli et al., 2004). It is the latest model, widely used for predicting several types of air pollutants from a variety of sources. It characterizes the fundamental boundary layer parameters and vertical profile of the atmosphere along with an accurate representation of

plume buoyancy and urban nighttime boundary layer. It provides a variable urban treatment of vertical dispersion as a function of city population, and can selectively model sources as rural or urban. In a study, it was found that AERMOD (USEPA, 2004) was the most suitable for modelling the dispersion of airborne contaminants from area source². Only a few literature is available, which studied the suitability of the AERMOD for estimating concentrations associated with mobile source³ (Venkatram et al., 2009) emissions near roadways.

1.4 RESEARCH AIM

Episodic condition does not occur throughout the day. Since it depends on several factors related to road geometry, urban density, traffic and local meteorology, a method is needed that incorporates all these factors to identify the occurrence of the time of episodic conditions-time and intensity. The AERMOD model can provide a linkage between emissions from activity on roadways and resultant air concentrations during episodic conditions. Establishing such linkages is critical for developing mitigation strategies. The model can identify where air quality is most impacted along the traffic corridor and the population likely to experience elevated health risks due to episodic condition from air pollutant exposure occurring along roadways.

The aim of the proposed research was to develop a method to identify the episodic air quality, to determine the most episodic prone locations and health risks to sedentary workers in an urban traffic corridor caused by the key traffic originated pollutants CO, PM_{2.5} and black carbon (BC).

2 Area sources - Sources that generally have smaller emissions on an individual basis than major sources and are often too small or ubiquitous in nature to be inventoried as individual sources.

3 Mobile sources - Mobile sources includes on road vehicles (e.g., cars, trucks, buses) and off road sources (e.g, airplanes, boats, and off road equipment).

The following tasks have been carried out to achieve the research aim:

- i. Selection of urban traffic corridor and monitoring locations.
- ii. Field work to measure CO, PM_{2.5} and black carbon (BC) concentrations, meteorological parameters and traffic flow.
- iii. Estimation of emissions of CO, PM_{2.5} and BC.
- iv. Method to identify and find degree of episodic conditions.
- v. Identification of times and locations of episodic conditions because of CO and BC in the selected traffic corridor.
- vi. Identification of the influencing factors responsible for the episodic conditions.
- vii. Testing and validation of AERMOD dispersion model to identify times and locations of episodic conditions.
- viii. Application of the model to determine spatial concentrations in the selected urban traffic corridor.
- ix. Analysis of health risks (COPD, LC, IHD and Stroke) because of the PM_{2.5} episodic air quality using a health-based social survey and the exposure-response function models.

1.5 NOVELTY AND CONTRIBUTION OF THE RESEARCH

- A method has been developed to identify an episodic condition using pollutant emission, location geometry and the population in the study region without having the need of pollutant concentrations.
- The successful use of AERMOD dispersion model for temporal and spatial distribution of CO, BC and PM_{2.5} concentrations during episodic conditions including the magnitude of the degree of episodic condition.

- Estimation of health risks of the sedentary workers (shop salesmen and street vendors) due to exposure to PM_{2.5} near the episodic prone locations in the study domain.

1.6 OVERVIEW OF THESIS

This research is based on field monitoring data collected twice during 2014 and 2016. The first-time monitoring was done on March 2014 and second time on August, 2016. Field work of 2014 included data collection of CO concentration, meteorological parameters and traffic characteristics whereas field work of 2016, included all of the before mentioned (2014) parameters along with BC and PM_{2.5} concentrations. This thesis is composed of 8 chapters.

Chapter 1: Introduction — general information and overview regarding episodic condition in urban areas has been given in this chapter. It discusses episodic air quality and its characteristics with problems in conventional methods to identify episodic condition. It describes the main aim and detailed objectives to identify, and model episodic condition in urban areas. End of this chapter includes novelty of the research and overview of thesis.

Chapter 2: Literature review — this chapter starts with reviews about the episodic condition and its effects on human health with responsible factors to cause episodic condition. The review continues to the existing methods to identify episodic conditions and the gaps or problems of those methods. Further different category of models and its ability to forecast urban air quality was reviewed to get the idea about the suitable models for episodic air quality modelling.

Chapter 3: Research methodology — this chapter comprise of description of selected site with detailed methodology of data collection and brief description on data analysis. This chapter gives a brief idea about step by step methodology to achieve the all objectives mentioned in chapter 1.

Chapter 4: Data analysis and interpretation — in this chapter collected data was summarized by data analysis and it involves the interpretation of data to determine patterns, relationships

or trends of air quality with other parameters. Data analysis includes time series plots, statistical description of all the direct parameters (CO and BC concentrations, meteorological parameters) collected from field and analysed parameters (PM_{2.5} concentration, traffic speed and volume) collected from field data.

Chapter 5: Estimation of on-road emission — Emissions of the pollutants are important inputs for identification and modelling of episodic air quality. In this chapter, emissions of CO, BC and PM_{2.5} were estimated for 2014 and 2016 for both real and standard conditions. The real condition emissions were calculated using a semi-empirical model by relating the measured concentrations and the traffic flow while the standard condition emissions were calculated using the India NAAQS of 2009, assuming those the threshold concentrations for health risks.

Chapter 6: Method of identification and modelling of episodic conditions — encompasses identification of temporal and spatial episodic condition. The whole analysis was done for CO data collected in 2014 and method of temporal episode identification applied using data collected in 2016 for BC to check the suitability of above mentioned method for other pollutant.

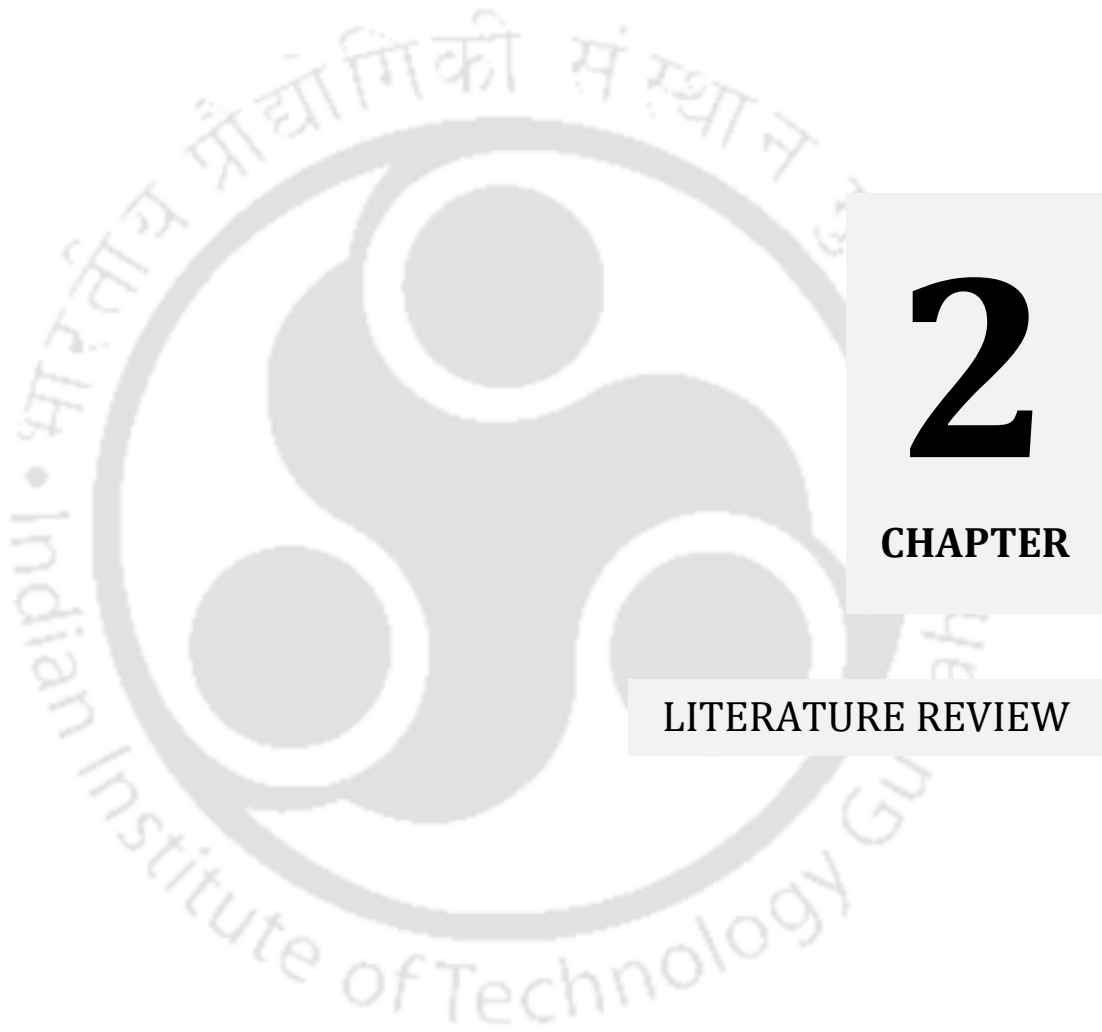
Chapter 7: Health risk of PM_{2.5} and episodic-prone locations using an Integrated Exposure-Response Function — includes identification of episode prone areas in terms of risk of some diseases of sedentary workers due to PM_{2.5} exposure. The distribution of health risk of chronic obstructive pulmonary disease (COPD), Lung cancer (LC), ischemic heart disease (IHD) and cerebrovascular disease (stroke) among the study area due to PM_{2.5} exposure, obtained using Integrated Exposure-Response (IER) function. In the health-based social survey the workers of the open shops (street vendors and workers of non-air conditioned shops openly facing to roadside emissions) and the workers of the air-conditioned shops were

Chapter 1

interviewed for demographic data and the history of COPD symptoms, and the lung function tests were performed on each participant.

Chapter 8: Conclusion, limitations and future scope — incorporates general conclusion of the total study and further this chapter points out the limitations of the study and the future scope of the study.





2

CHAPTER

LITERATURE REVIEW



CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The effects of vehicle traffic on air quality and health outcomes on human beings in urban environment are of major concerns. The urban ‘hotspots’ (road junctions, the traffic intersections and the signalized roadways) are more prone to the severe vehicular pollution as vehicles spend more time at these ‘spots’ and generate more pollutants. In urban environments, air pollution ‘episodes’ can be defined as extreme situation, during which air pollutant concentrations exceed a specified threshold (i.e. NAAQS) value. The vehicular exhaust in urban area (mainly at traffic intersections) can cause poor air quality and people are exposed to it due to their residences, work, shops, etc. in those areas. Urban air quality depends on various factors like urban sprawl, traffic characteristics, meteorology and urban boundary layer. CO is an important air pollutant from traffic as it has adverse health effects on human even for short-term exposure. Episodic air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs. So identification of the extreme or episodic urban air quality period is most important step for further understanding of the episodic air quality.

Air quality models are vital tools to assess the impact of air pollutants on human health and the urban environment. These models can be used to forecast the future air pollutant concentrations in urban areas. Several deterministic based models exist to evaluate and predict the pollutant dispersion in urban areas but majority of them are ‘causal’ in nature and fail to predict the extreme concentrations (Khare and Sharma, 2002; Jakeman et al., 1988). The statistical models that are ‘non-causal’ and based on the historical data, overcome the above

limitation and forecast the extreme concentrations with reasonable accuracy (Jakeman et al., 1988). Hybrid modelling is one of the techniques that estimate the entire range of the distribution of air pollutant concentrations by combining deterministic based models with suitable statistical distributional models. In developing countries, urban areas are very complex in nature so it is difficult to understand the urban system. So statistical models are generally more suitable for the description of complex site-specific relations between concentrations of air pollutants and potential predictors, and often have a higher accuracy, as compared to deterministic models (Zhang et al., 2012). The statistical models, which handle nonlinearity and interactive relationship are suitable to predict extreme air pollutant concentrations in urban areas.

2.2 URBAN AIR QUALITY

Air pollution is a serious public health problem which has been found in different cities of the world (Faiz and Sturm, 2000). Traffic is the most critical source of air pollution in most of the urban areas and the increasing severity and duration of traffic congestion have the potential to greatly increase pollutant emissions and to degrade air quality, particularly near large roadways. Unfavorable meteorological condition and uncertain large emissions sometime create pockets of air pollutants near road way with high concentration which can cause health damage to the exposed public (Zhang et al., 2013). Traffic congestion can increase risks for individuals driving on freeways and arterial roads, and for individuals living or working near roads. Air pollutants may cause injury to the respiratory tract that leads to risk of inflammation which can result cardiovascular disease in an individual. In many studies it has been found that short-term exposures to pollutants are thought to increase the risk of asthma symptoms in both children and adults (Seltzer et al., 1986; Meng et al., 2010; Mann et al., 2010). Acute health effects of air pollution within a few hours of exposure has been found in some recent studies (Bhaskaran et al., 2011; Kim et al., 2015a; Liu et al., 2018a). The problems are raising more

due to the rapid increase in vehicular emission from transport section combined with inadequate transport infrastructure, negligent environmental legislation and enforcement, lack of skilled manpower have resulted in poorly planned urban growth with severe air pollution problems (Faiz and Sturm, 2000).

2.3 CAUSATIVE FACTORS

Air pollution in cities is a serious environmental problem especially in the developing countries and air quality getting worse as the population, traffic, industrialisation and urbanisation. Pollutants levels in an urban environment depend on the intensity of the local emissions, the background concentrations of the pollutant, and the atmospheric ventilation and dispersion conditions. Available time series trend of air pollutants in cities may be too short or long. Emissions from motor traffic are a very important source group throughout the world. Motor vehicles emit large quantities of carbon monoxide (CO), hydrocarbons (HC) and fine particles (particulate matter, PM). PM from vehicle combustion is mostly carbonaceous material and this carbonaceous material consists mainly of elemental carbon (EC) in the form of black carbon (BC) and organic carbon (OC) (Sharma et al., 2005, Cadle et al., 1999). BC affects the radiation flux in the atmosphere due to sunlight absorption nature (Chung and Seinfeld, 2005) and also affects human health by damaging respiratory system.

2.3.1 Urban sprawl

Urban sprawl is altering the landscape, with current trends pointing to further changes in land use that will, in turn, lead to changes in population, energy consumption, atmospheric emissions and air quality. The main argument against the dispersed city or urban sprawl is that low densities result in a high dependence from motorized vehicles. But some authors claim that the environmental benefits resulting from urban compaction are doubtful and that higher densities can often result in greater traffic congestion leading to poor air quality. Ridder et al.

(2008) numerically simulated the effects of urban sprawl on road traffic, air quality and population exposure, for an air pollution episode. Vehicle travel and emissions, the spatial structure of metropolitan regions has been associated with meteorological phenomena that are important to regional air quality. Spatial structure plays a great role to trap or disperse the pollutants in street canyons. In street canyons, pollutant concentrations can be several times higher than in open area locations depending upon traffic characteristics, street canyon geometry, entrainment of emissions from adjacent streets and turbulence induced by prevailing winds, traffic and atmospheric stability (Kumar et al., 2008, 2009).

Street intersections within diverse built environments play an important role in the distribution of pollutants in the atmosphere. Pollutant dispersion depends on the different factor like road geometry, adjacent land use etc. Pollutant concentrations have found near road intersections of urban environment due to the traffic and road characteristics (Soulhac et al., 2009; Tomlin et al., 2009). A pollutant concentration fields developed at ground level adjacent to intersections is very complex in nature (Carpentieri et al., 2010; Soulhac et al., 2009). Baldauf et al. (2008) studied that the obstacles in adjacent land-use of road can cause higher pollutant concentrations. However, they reported lesser concentrations behind obstacles (noise barriers) as the pollutants were trapped in street canyon. Wind directionally, behind the barrier, pollutant concentration was more in case of open field (absence of barrier or obstacle). Xie et al. (2005) studied the influence of roof shape on streamlines in street canyon and concluded that the shapes of the building roofs in an urban environment are very significant factor for in-canyon vortex dynamics and pollutant concentration from street level emissions.

2.3.2 Traffic

Motor vehicle traffic is an important source of air pollution in cities of the developing world, where lack of effective transport management may result in harmful levels of air pollutants in the air. It has been estimated that 90% of urban air pollution in rapidly growing cities in

developing countries is attributable to motor vehicle emissions (UNEP, 2010). Many studies have discussed the impact of traffic on ambient air pollutant concentrations near major roads and highways (Kaur et al., 2005; Bowker et al., 2007). Vehicular exhaust emissions near traffic intersections are largely dependent on fleet speed, deceleration speed, and queuing time in idle mode with a red signal time, acceleration speed, queue length, traffic-flow rate, ambient conditions and vehicular composition (Pandien et al., 2009). Sharma et al., (2010) worked on impact of vehicular traffic emissions on black carbon aerosol mass concentration, trace gases and ground reaching solar radiation during strike and this study indicated that urban areas are greatly influenced by emissions from traffic which showed a higher pollutant concentration in pre and post-strike period. Strict enforcement of the maximum speed results free flowing traffic, which results in lower exhaust emissions of pollutant (Zhang et al., 2011). Traffic volumes are generally less on Saturdays and Sundays (non-working day) compared with average working days and it has been estimated that the effect of reduced traffic volume cause short term decrease of pollution concentration in urban environment (Angius, 1995; Tong et al., 2020). Keuken et al., (2012) found traffic volume, composition and congestion are important factors controlling pollutant emission and speed management can be an effective way to control the traffic emission for better air quality. It was also concluded that traffic volume can be the effective measure for reducing the health impact on the population living along inner-urban roads with intense traffic.

2.3.3 Meteorology

Meteorological parameters are significantly responsible for the transport and dispersion of the air pollutants from its source. These parameters include the dominant wind direction, wind velocity, relative humidity, and the atmospheric stability. Relations between concentrations of pollutants and meteorological characteristics has been identified in many studies like in Delhi (Guttikunda et al. 2012), Moscow (Kuznetsova et al. 2008), Cleveland (Pasch et al., 2011),

Philadelphia (Davis et al., 1968), Athens (Katsoulis et al., 1996) etc. Generally, increase of wind speed increases the turbulence which causes more rapid and complete dispersion of pollutants in the air. Study of wind direction gives idea in which direction the dispersion of pollutants occurring (Kumar et al., 2008). The relationship between air pollutants and relative humidity is different for different pollutants. Humidity increase in the atmosphere promotes the formation of particulate matter concentration and also effects on the size distributions (Pillai et al., 2002) but high humidity may also cause precipitation events accompanied by in-cloud scavenging of gas and aerosol. This results low concentrations of gas and aerosol (Elminir, 2005). Temperature inversion with low wind speed indicates stable boundary layer and limited vertical mixing. So stable atmospheric condition can cause accumulation of air pollutants in a region even there are low levels of emissions (Grange et al., 2013, Olcese et al., 1997). Yang et al. (2011) found meteorology contributed to at least a 16% reduction in PM_{2.5} levels in the roadside microenvironment.

2.3.4 Urban boundary layer

Air pollution is strongly associated with the boundary layer structure and wind field (land–sea circulation). It is very difficult to describe the complicated three-dimensional structure of urban boundary layer (Rotach et al., 2005) (Fig. 2.1). Atmospheric boundary layer is fundamental for atmospheric dispersion modelling and for investigating the processes frequently leading to high ground-level pollutant concentration. The meteorological part of the air pollution models are generally developed for surfaces of lesser roughness and do not take into account the dispersion conditions in the layer near the surface (Rotach, 2001). The structure of the Upper Boundary Layer (UBL) differs from rural to urban area because of the mechanical turbulence generated by the movement of air over the large roughness elements of the urban area and thermal turbulence resulting from heat produced in urban structures. Boundary layer plays a very important role for for the dispersion of pollutants in urban environment. Lowest boundary layer

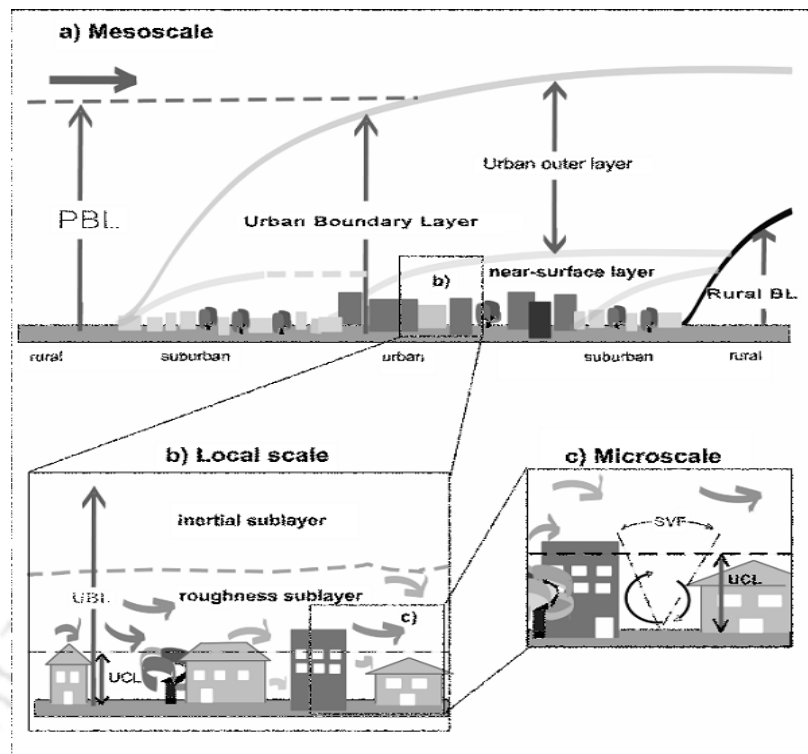


Fig. 2. 1 Urban boundary layer structure with various (sub) layers (adapted from Rotach et al., 2005) heights, temperature inversion and weakest wind speeds result in the highest pollutant concentration (Wang et al., 2019; Li et al., 2019).

2.4 AIR POLLUTION EPISODES

Air pollution episode is a state of the ambient air environment in which the accumulation of air pollutants is attaining or has attained levels which could, if such levels are sustained or exceeded (may be due to meteorology), lead to a substantial threat to the health of persons in the specific area affected. Air pollution episode can be for a specific, limited area affected by certain emissions (USEPA, 2002). According to Welsh Air Quality Forum “An air pollution episode is the term commonly used for a period of poor air quality, lasting up to several days, and often extending over a large geographical area. Concentrations of all the measured pollutants may increase at the same time, or only one species may be affected” (Welsh Air Quality Forum, 2003). The causes of air pollution episodes are complex and depend on various factors including emissions, meteorological parameters, topography, atmospheric chemical

processes and solar radiation. The relative importance of various factors depends on the climatic characteristics, the geographical region and the season of the year. The episodes have been categorized according to the scale of the main source areas, i.e. those originating from local emissions and those from regional and long-distance sources. “spring dust episodes” are the example of episodes from local emissions which may be caused by traffic emission. The larger scale episodes can be schematically classified as those involving photochemical pollution from both local, and regional and LRT sources, and the episodes caused by long range transported air masses (Valkama and Kukkonen, 2003).

2.5 METHODS OF IDENTIFICATION OF AIR POLLUTION EPISODES

An air quality episode can be defined as a situation, during which air pollutant concentrations exceed a specified threshold value. In Europe the hourly limit value for nitrogen oxides (NO_2) is $200 \mu\text{g m}^{-3}$, allowing 18 exceedings per calendar year; for ozone (O_3) the eight hourly average limit is $120 \mu\text{g m}^{-3}$, allowing 25 days averaged over three years and for CO the eight-hourly gliding average limit value is 10mg m^{-3} . For suspended particles (PM_{10}) the hourly limit value is $50 \mu\text{g m}^{-3}$ (allowing 35 exceeding per year) and $70 \mu\text{g m}^{-3}$ over 24 hours, allowing an exceeding once in a month (European Commission, 2011). If the air pollution concentration exceeds these standards at least for any of the pollutant concentration, the period is considered as episodic condition. Stern et al., (2008) identified episodic condition in Central Europe by following the air quality standard of European Commission. Earlier most of the articles discuss episodes as events of a sporadic or occasional nature, accidents but at present repeatedly high exposure of pollutants have been seen in urban areas (Shang, 2013). Muir et al., (2006) found elevated concentrations of PM_{10} at the Leeds Centre site during January 1997. In this study average urban PM_{10} concentration was considered as $20 \mu\text{g m}^{-3}$ and it was found the majority of cases when the disaggregated concentration of PM_{10} was $30 \mu\text{g m}^{-3}$ or higher than the

average. These time periods were identified as episodic condition (Fig. 2.2) and possible sources of emission was traffic and site vehicular activity.

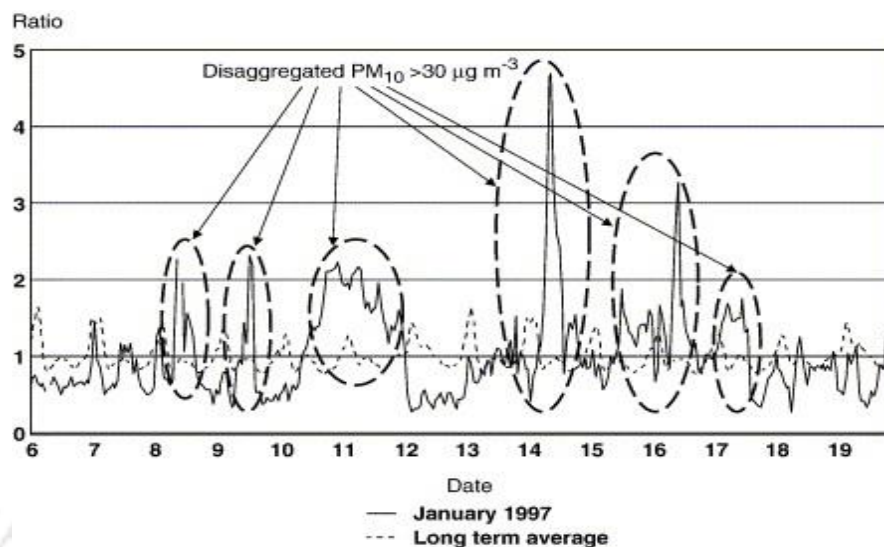


Fig. 2. 2 Hourly average ratios of concentrations of PM₁₀ to NO₂ at Leeds Centre, January 6–19, 1997 (adapted from Muir et al., 2006)

2.6 HEALTH IMPACTS OF CO, PM_{2.5} AND BC

CO is a colorless, odorless, tasteless, and toxic gas produced primarily during the incomplete combustion of carbonaceous fuels and substances. CO is a biological toxicant which can bind with haemoglobin in the lungs and forms carboxyhemoglobin (COHb). COHb decreases the oxygen-carrying capacity of the blood, tissue hypoxia reducing by reducing the availability of oxygen to body tissues (Raub et al., 2000). Inhalation of CO even at low concentration can cause acute lung injury (hyperoxia, ventilator-induced lung injury, and sepsis) in various animal models (Kanagawa et al., 2010; Nemzek et al., 2008). CO concentrations more than 1.5 ppm of 24-hour averaged exposure show significant increase in health risk though no exceedance case found for the threshold of CO but insignificant risk found below 1.5 mg m⁻³ of CO concentration. World Health Organization (WHO) Air Quality Guidelines suggest a limit of 10 mg m⁻³ for 8-hour average CO level (WHO, 2000) and according to CPCB the permissible limit for CO in 1- hour and 8- hour average is 4 mg m⁻³ and 2 mg m⁻³ (CPCB, 2012). Tao et al. (2011) worked on acute mortality effects of CO in cities of China and found

association between CO concentration changes with change in cardiovascular mortality. As traffic is a major source of CO in urban areas, control measures of the emissions from vehicle can reduce emissions of CO from traffic source.

All air pollutants cause harm to human health, but PM is the most harmful, which enters into the respiratory tract as it contains toxic substances (Guerreiro, 2013). Coarse PM is retained in the nasal cavities and upper airways, whereas fine and ultrafine PM may penetrate deeper into the lung alveoli and perhaps pass into the bloodstream (Brown et al., 2002). Meng et al. worked on association between size-fractionated particle number concentrations (PNCs) and daily mortality in Shenyang, China and stated that PM diameter smaller than $0.5 \mu\text{m}$ is most responsible pollutant to cause for adverse health effects and adverse health effects may increase with decreasing size of the particle (Meng et al., 2013). Kurt et al. (2016) reviewed 53 publications to understand the relationship of air pollution and its health impacts on asthma, chronic obstructive pulmonary disease (COPD), lung cancer and respiratory infection and these diseases worsened due to exposure to a variety of air pollutants with the greatest effects due to particulate matter (PM), ozone and nitrogen oxides. Black carbon is emitted from different combustion processes, mostly the incomplete combustion of fossil fuels, biofuels, and biomass (EPA, 2012). Black carbon (BC) is a significant component of fine particulate matter ($\text{PM}_{2.5}$) air pollution, which has been linked to a series of adverse health effects (Li et al., 2016; Goldberg et al., 2011; Janssen et al., 2011). Black carbon (BC) and $\text{PM}_{2.5}$ have been associated with deleterious effects on human health (Pope et al., 2002; Laden et al., 2006; McCracken et al., 2010; Beelen et al., 2007; Hua et al., 2014). Burnett et al. (2014) developed relative risk (RR) functions over the entire global exposure range for diseases: as ischemic heart disease (IHD), cerebrovascular disease (stroke), chronic obstructive pulmonary disease (COPD), and lung cancer (LC). In this study they used a methodology to estimate the population attributable fraction (PAF) from exposure to ambient $\text{PM}_{2.5}$ in the Global Burden of Diseases, Injuries, and

Risk Factors. Integrated exposure-response (IER) model was fitted with available RR and ambient air pollution data and found this model more suitable than previously used methods for disease burden assessment.

2.7 AIR QUALITY FORECASTING TOOLS

Ambient pollutant concentrations depend on precursor emissions and meteorological conditions. Under typical emission scenarios, it is local-scale circulations and diurnal variations of meteorological variables such as solar intensity, temperature, wind speed, and mixing height that determine the daily and seasonal variations of chemical concentrations. Compared with traditional air quality modelling for research forecasting model has its unique technical challenges and time requirements, and involves a number of real-time operational issues. Air quality forecasting can be made for the short- or long-term, depending on the objective of the applications (Dabberdt et al., 2006). The short-term forecasts (1-5 days) will predict concentrations of pollutants and can be used daily to aware general public about the possibly harmful conditions by which preventive actions can be taken to reduce exposures and emissions. The air quality models can be classified into major three types, viz. deterministic, statistical and hybrid models. The deterministic models are based on fundamental mathematical description of atmospheric processes and establish the cause and effect relationship between the output and the inputs. The statistical models, on the other hand, are based upon semi-empirical statistical relations among available data and measurements. The hybrid models are the combination of deterministic and statistical models.

2.7.1 Deterministic

All major meteorological, physical, and chemical processes which lead to the formation and accumulation of air pollutants by solution of the conservation equations for the mass of various species and transformation relationships among chemical species and physical states are

Deterministic models (Wayland et al., 2002). These models include chemical transport models (CTMs) or Air Quality models. Models-3 (CMAQ) simulates the PM_{10} and SO_2 concentrations in urban area (An et al., 2007). However, its performance decreases in winter time (Eder et al., 2006). Stern et al. (2008) compared the performance of five models for $PM_{2.5}$ and PM_{10} concentration. Four of the models (M-MUSCAT, CHIMERE, LOTOS-EUROS, REM-CALGRID) remaining EURAD underestimate PM_{10} and also the $PM_{2.5}$ components during the episodes of high-observed Concentrations. These models are not so much efficient to simulate the highest observed PM_{10} and $PM_{2.5}$. Reliable predictions were made by SKIRON/Eta-CAMx model for NO_2 , O_3 and PM_{10} concentrations but this model is not proved as a good real time forecasting model for mountainous urban area (Astitha et al., 2008). WRF/Chem-MADRID shows a good forecasting tool that is consistent with current RT-AQF models in urban area. The maximum 1-h and 8-h average forecasted O_3 mixing ratios are overpredicted and forecasted 24-h average $PM_{2.5}$ concentrations are underpredicted. The reason for overprediction and underprediction of O_3 and $PM_{2.5}$ may be due to uncertainties in emissions, inaccuracies in the predicted meteorological variables and uncertainties in lower boundary conditions (Chuang et al., 2011). Zhang et al. (2010) used model MOBILE6.2 for Vehicle emissions measurement and CALINE4 for pollutant dispersion. American Meteorological Society and U.S. Environmental Protection Agency Regulatory Model (AERMOD) is a steady-state Gaussian plume dispersion model which has been used by various researchers for point, line, area and volume sources (Cimorelli et al., 2003; Perry et al., 2005 ; Gibson et al., 2013). In the stable boundary layer (SBL), the concentration distribution is assumed to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function (p.d.f.) (Willis, and Deardorff, 1981; Briggs, 1993). AERMOD, in complex terrain performs well as it divides and streamlines plume flow over and around hills (Langner

and Klemm, 2011) and also due to the detailed inclusion of boundary layer vertical structure information, building downwash, plume rise and terrain treatment algorithms (Perry et al., 2005; Lakes Environmental, 2010). AERMOD can incorporate various complex algorithms and concepts, it has been applied to evaluate the dispersion of a number of pollutants, including PM₁₀, hydrogen cyanide (HCN), sulfur hexafluoride (SF₆), VOCs (Venkatram et al., 2001, 2004, 2009; Bhardwaj et al., 2005; Orloff et al., 2006; Zou et al., 2009, 2010). Besides these pollutants, the dispersion of heavy metals, such as hexavalent chromium and total gaseous mercury (TGM) can also be simulated with the AERMOD (Sax and Isakov, 2003; Mazur et al., 2009). This model is not suitable to account for the chemical reactivity of emissions. AERMOD has been used to study PM₁₀ dispersion over the city of Pune, India and found the comparison of observed and simulated concentrations of PM₁₀ shows that the model underestimates the concentrations over the city (Kesarkar et al., 2007). Chen et al. (2009) found that CALINE4 and CAL3QHC predictions of airborne particulate matter (PM) matched well with observations while AERMOD led to under-predictions at a near-road site. Claggett (2014) found that both CAL3QHCR and AERMOD under-predicted the observed PM_{2.5} concentration at a signalized intersection but CAL3QHCR had more data points within a factor of 2 of observations than AERMOD. The performance of AERMOD is sensitive to represent vehicular emissions. Hence, accurate emission input is very much important for AERMOD.

Some researchers found higher concentration of pollutant due to consideration of source type (Claggett, 2014 and Askariyeh et al., 2017) so consideration of different model configuration (emission inventory, source type etc.) is very important for accurate prediction of pollutant concentrations.

2.7.2 Statistical

The association between specific meteorological parameters and air quality can be quantified using a variety of statistical methods. Statistical techniques, unlike deterministic models, do

not aim to describe the formation and accumulation of air pollutants in the chemical, physical and meteorological details. Instead statistical models directly adapt to the patterns that arise from the observed data. Statistical models use different functions to predict the air quality by depending upon different external conditions.

Burrows et al. (1995) used non parametric data driven tree based analysis method known as classification and regression trees (CART). By this study, it was found that, this method is computationally fast and good O₃ predictor at a specific site. But it was not able to predict the extreme air pollution condition accurately as regression based air quality forecast models have a tendency to under predict the high pollutant concentrations. ARIMAX (Multivariate time series model) model is simple and easily implementable and in this model the concentration of the pollutant is expressed as the function of previous physical variables (Finz et al., 1982). This model widely used for air quality forecasting in urban areas, but shows a linear representation of the variables where the system is non-linear (Goyal et al., 2006). Cobourn et al (1999) gave more importance to nonlinear regression model formulation to minimize this potential problem by appropriate selection and transformation of the predictor variables. By combining standard I and Hi-lo regression model, hybrid model formed which showed significantly more accurate results than the original Standard I model for predicting 1-h maximum daily ozone but this model performed well when the forecasts were next day forecasts. Otherwise it performed poorly if forecasting were made two or three days out may be due to uncertainty in meteorology. Models which can model non-linear relationships well are artificial neural networks (ANN)() and generalized additive model (GAM) (Ahmad et al., 2019; Borge et al., 2019). Schlink et al. (2006) compared the performance of 15 types of statistical models for the forecasting of ozone concentration and found best results in GAM and ANN. Artificial neural network models perform better when combined with nearest neighbor method technique to predict the PM₁₀ concentration in an urban area especially for

episodic condition. ANN can perform well as daily maximum of 8-h average of pollutant concentration than 1-h average concentration (Perez, 2012). Aldrin et al. (2005) preferred to use generalized additive model (GAM) to predict the concentration of PM_{10} and $PM_{10}-PM_{2.5}$ and for NO_x in urban environment and found traffic volume and wind as a good predictor variable. The logarithm of hourly concentration of an air pollutant was modelled as sum of non-linear functions of traffic volume and meteorological variables. The logarithmic transformation of the variables done to achieve more homoscedasticity and to make sure that all predicted values are positive on the original scale. GAM on log-scale can be transformed back again to a model with multiplicative effects on the original scale.

Zhang et al. (2010) used Motor Vehicle Emissions Factor Model version 6.2 (MOBILE6.2)/CALINE4 and generalized additive models to predict the short term $PM_{2.5}$ and CO concentration near traffic intersection. GAM was found more efficient to predict the CO concentration in all the seasons than MOBILE6.2/CALINE4. GAM performance might be improved by ways like (i) incorporating other traffic information (heavy duty diesel vehicles proportion and average fleet speed), (ii) using different expressions for independent variables for example, absolute humidity, (iii) considering the discontinuities in wind direction and time (Zhang et al., 2010), (iv) using potential interactions of variables like interaction between wind direction and wind speed as it shows combined effect to dispersion (Aldrin et al., 2005, Currie et al., 2004).

2.7.3 Hybrid

Hybrid models are the combination of Statistical and Deterministic models. This combination has shown better accuracy than single type of model to forecast air pollutant concentration as per different literature reports. The hybrid modelling approach consists of a hybrid of deterministic and stochastic components. So the performance of the model depends on the combination of the stochastic component with the deterministic component of the system.

GFLSM–LLD hybrid model (general finite line source model (GFLSM) as deterministic and log logistic distribution (LLD) model as statistical components) is capable to simulate the CO concentration in urban traffic intersection (Gokhale et al., 2005). Sharma et al. (2013) predicted hourly ground level ozone (GLO) by using a combination of dispersion (CMAQ) and statistical modelling. The model was able to predict the entire range (middle, lower and upper extremes) of concentration distribution. The CMAQ shows satisfactory performance in predicting the hourly O₃ concentration in the middle ranges but the hybrid model shows improved performance over the CMAQ. Konovalov et al. (2009) combined deterministic and statistical approaches for PM₁₀ forecast in Europe. Statistical post-processing of forecasts from a chemical transport model (i.e., CHIMERE) was formulated for PM₁₀. This approach found significantly improved the deterministic PM₁₀ forecasts where RMSE maximum reduction was 50%, and the maximum increase of the coefficient of determination (r^2) of more than 85%.

2.8 SUMMARY

A plethora of literature establish the fact that urban areas are facing air pollution problems all over the world mainly from traffic. Together with meteorology, it is likely to cause episodic air quality. Several air quality models are available for forecasting urban air quality. Most of the models are inadequate in forecasting short-term air quality, or extreme pollutant concentration or episodic air quality. Amongst, however, statistical hybrid models are known for forecasting short-term pollutant concentrations but not all forecast the episodic conditions satisfactorily. These models also do not give the spatial distribution of concentrations within the study area whereas deterministic models, simulate spatial distribution of various pollutants during extreme condition. A steady–state Gaussian plume dispersion model, AERMOD has been less explored in case of traffic source. Thus, more studies are needed to improve the performance of AERMOD for near-road predictions by altering different model configurations.



3

CHAPTER

RESEARCH METHODOLOGY



CHAPTER 3

RESEARCH METHODOLOGY

3.1 GENERAL

This chapter includes the selection of the urban traffic corridor in the downtown of Guwahati (the fastest growing city of north-east India), study domain with the methods of data collection and data analysis. The data includes the measurements and collection of CO, BC, PM_{2.5} concentrations, traffic count, traffic speed, meteorological parameters such as wind speed, wind direction, temperature, relative humidity, solar radiation and atmospheric pressure. It further includes the research methods.

3.2 SELECTION OF URBAN TRAFFIC CORRIDOR AND MONITORING LOCATIONS

A traffic corridor, two-way road of about 300 m long in the dense urban area, located in the Lachit Nagar of Guwahati, was selected. It is highly trafficked. It houses several public and governmental offices, commercial and shopping complexes. The proximity, where traffic jams and higher pedestrian population are likely to occur, three monitoring locations were selected based on the local meteorology and other practical considerations. Figure 3.1 shows the study area and the monitoring locations with details of the urban traffic corridor with dimensions. Three monitoring stations at different locations were chosen for investigating the most likely times as well as important locations of the episodic condition because as the urban characteristics are not uniform throughout the corridor and traffic flow and meteorology are not constant throughout the day then it may show effect on pollutant concentrations.

3.3 FIELD WORK

Field work was done to collect the pollutant concentrations (CO, BC and PM_{2.5}), meteorology, traffic volume and speed, population and other data. The details of the field work have been shown in Table 3.1.

3.3.1 Ambient air quality

The CO concentrations were measured by a CO analyzer (make: Delta OHM, model: HD37ABI7D). This instrument measures CO by an electrochemical cell method (sensor) with two electrodes indicating the presence of CO in the ambient air. The monitoring was carried out for a period of one month (March 2014) continuously to determine representative air

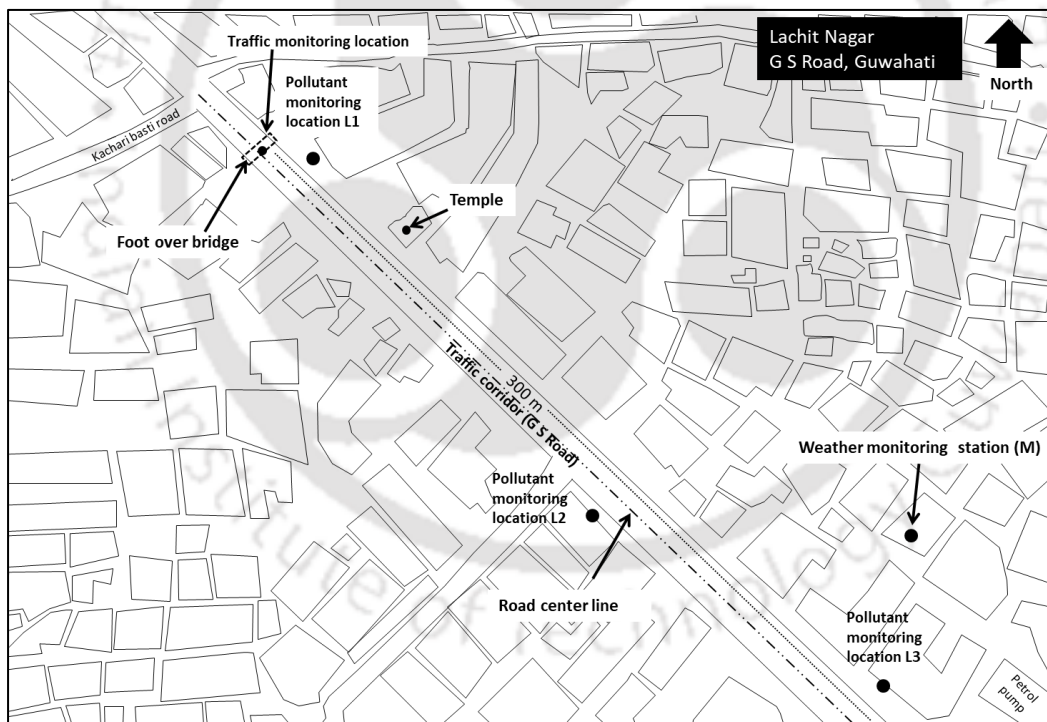


Fig. 3. 1 Traffic corridor (two-way and two-lane) and the monitoring locations (L1, L2 and L3 are CO monitoring locations and M is meteorological station location)

quality in terms of CO. It covered all the working days and non-working days. The CO concentrations were recorded every 3 second continuously at daytime. The instrument was placed as per the standard guidelines of ambient air quality monitoring given by Central

Pollution Control Board (CPCB), at 1.5 m from the ground level and at 1 to 1.5 m distance from the curb of the road as the pedestrians and street vendors get exposed to this distance. Plate 1 shows the measurement campaigns at L1, L2 and L3. At each location, CO concentrations were measured for a period of one week covering weekdays and weekend days. CO concentration was again measured at L3 for one week (working days) during last week of August 2016. The methodology adopted for CO has been also applied to BC and PM_{2.5} concentration at one location (M) in the corridor for examining its suitability to other types of pollutants at height 15m.

Table 3. 1: The details of the field work

Year	Month	Data	Location	Frequency	Duration
2014	March	CO	L1, L2 and L3	Hourly	3 weeks
		Meteorology	M		
		Traffic	Traffic corridor	Hourly	1 week
		Pedestrian count	Traffic corridor		
		Others	Study domain	NA	NA
2016	August	CO	L3	Hourly	1 week
		BC	M	Hourly	
		PM _{2.5}	M	8-hourly	
		Meteorology	M	Hourly	
		Traffic	Traffic corridor	Hourly	

BC concentrations were measured with Aethalometer (Magee Scientific – AE 33). The PM_{2.5} concentrations were measured as 8-hour average with the OMNI™ FT Ambient Air Sampler (by Mesa Labs). The PM_{2.5} samples from ambient air were collected using filter paper (Nylon filter paper, pore size 0.8 µm, diameter 47mm).

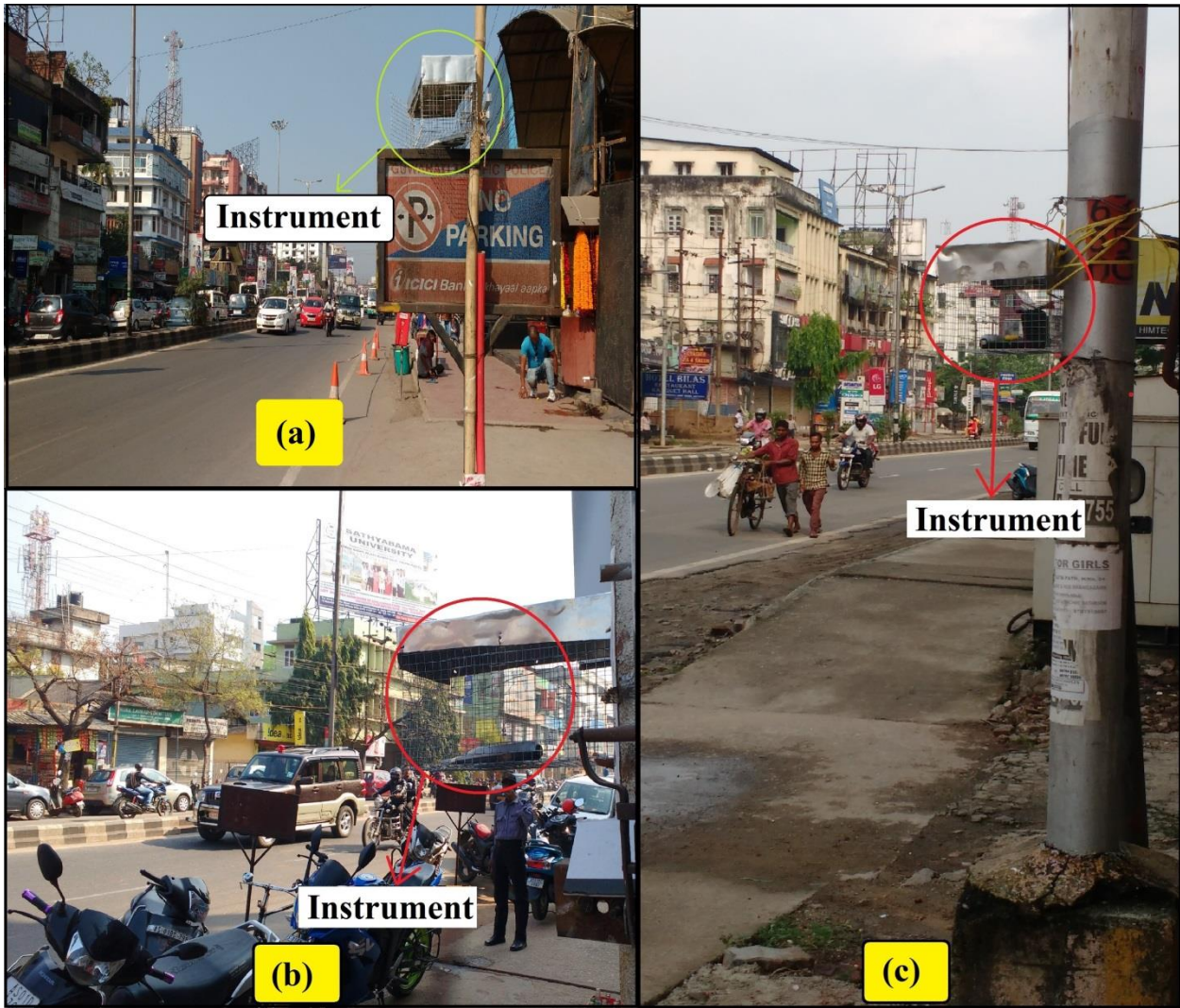


Plate 1: Measurement campaign at a) L1, b) L2 and c) L3 with surrounding

3.3.2 Collection of traffic data

Traffic count data were done by videotapes. The camera was installed on a pedestrian bridge in Lachit Nagar, which covered both lanes of the traffic corridors. The traffic counts were carried out at day time for one-week simultaneously with the air quality measurement campaign. The video tapes were analyzed for every minute to obtain various traffic characteristics.

3.3.3 Measurement of meteorological data

The meteorological data were collected by a weather station (6152 Wireless Vantage Pro2). It was installed on the rooftop of a building (15m from ground level) located within the traffic

corridor as per the standard guidelines (e.g. any obstacle or barrier within 30 m. that may interfere with the meteorological parameters) as shown in figure 3.1(b). The weather station has two parts – an integrated sensor suite (ISS) and anemometer and the wind vane. It records wind speed, wind direction, ambient temperature, solar radiation, humidity, and station pressure every 1 min. The meteorological monitoring was carried out in parallel with the ambient air quality monitoring for the same period.

3.3.4 Collection of population data

The pollutant exposure is more for pedestrians and cyclists and the potential further increases during episodic conditions. Therefore, pedestrian population count was also done by using the same videotapes used for traffic counts (Appendix-I). The population count was also carried out for the same time period.

3.3.5 Collection of other relevant data

The other relevant data on building density, mean building height, engineering dimensions of the roadway etc. were collected.

3.4 DATA ANALYSIS AND INTERPRETATION

The data have been analysed and interpreted to determine patterns, relationships of air quality with the influencing parameters, and the trends. This has been done by studying the time series, statistical relationships between the CO, PM_{2.5} and BC concentrations and the meteorological parameters, traffic speed and traffic volume.

The CO and BC concentrations along with traffic parameters (number and speed), meteorological parameters [temperature, humidity, wind speed (WS), wind direction (WD) solar radiation (SR) and atmospheric pressure (AP)], and population were organized and synchronized for 1 hour averages. The data were put to statistical tests for assuring quality. PM_{2.5} concentrations was analyzed as 8-hour average.

3.4.1 Pollutant concentrations

The CO concentration were collected at three sites (Location 1: L1, Location 2: L2 and Location 3: L3) in the selected traffic corridor. The instrument recorded the concentration every 3 sec, which was averaged for 1hour interval. The data sets were analyzed separately for weekdays (Monday-Friday) and weekend days (Saturday-Sunday). The data analysis included the time series, patterns, and descriptive statistics.

3.4.2 Traffic characteristics

Video tapes were analyzed to determine volume of traffic in 1hour interval for a period from morning 7:00 hours to 18:00 hours, which was further used to determine the composition of traffic. The traffic count was classified into four compositions, i.e. (i) two-wheelers – motorcycle, moped and scooter, (ii) three-wheelers - auto rickshaw, (iii) passenger cars and medium utility vehicles (PC-MUV) - car, van, and jeep and (iv) light and heavy commercial vehicles (LHCV) - minibus, truck (Mishra et al., 2013; Gokhale, 2011; Mallikarjuna et al., 2009). For traffic analysis, data were separated as weekdays (Monday-Friday) and weekend days (Saturday-Sunday).

3.4.3 Meteorological characteristics

The meteorological parameters such as wind speed, ambient air temperature, wind direction, relative humidity, solar radiation and air atmospheric pressure were measured on weekdays and weekend days at 15m height at the station M near L3 shown in figure 3.1. The data were put to statistical tests for assuring quality. The wind incident angle, which is the angle of wind towards the road, was calculated. This data also was analysed separately for weekdays (Monday-Friday) and weekend days (Saturday-Sunday). The data analysis included the time series, patterns, descriptive statistics, wind rose of meteorological data to get an idea about prevalent wind direction.

3.4.4 Population

The video tapes were analysed to determine the pedestrian count and the time variations to determine which time more pedestrians were exposed from traffic emission.

3.5 ESTIMATION OF ON-ROAD EMISSIONS

CO and PM_{2.5} are the most major pollutants emitted from transport sector. Diesel is used in public passenger and cargo vehicles, while private two wheelers, light motor vehicles (passenger), car and jeeps use gasoline. It is assumed that, diesel is used as fuel in buses, omni-buses, taxi, trucks, lorries, light motor vehicles (goods), trailers and tractors, while two wheelers, light motor vehicles (passenger), car and jeeps use gasoline. Traffic emission was calculated by multiplying the traffic count in each composition to the respective emission rates taken from the Automotive Research Association of India (ARAI).

Emissions of CO, BC and PM_{2.5} were estimated for 2014 and 2016 for both real and standard conditions, the temporal difference between them provides time when episodic condition may occur and of what magnitude. The real condition emissions were calculated using a semi-empirical model by relating the measured concentrations and the traffic flow while the standard condition emissions were calculated using the India NAAQS of 2009, assuming those the threshold concentrations for health risks. The detailed methodology with results has been presented in Chapter 5.

3.6 METHOD OF IDENTIFICATION AND MODELLING OF EPISODIC CONDITIONS

This chapter encompasses a method developed for identification of temporal and spatial episodic conditions and its application. The indicator (Lepicier et al., 2013) of the chronic health impact of pollutant emission (referred as ICHIPE) was employed for the acute health impact of pollutant emission (referred as “*I*”) using the relevant short-term parameters. Two indicators for every hour (short-term) from 7:00 to 18:00 hours have been calculated for real

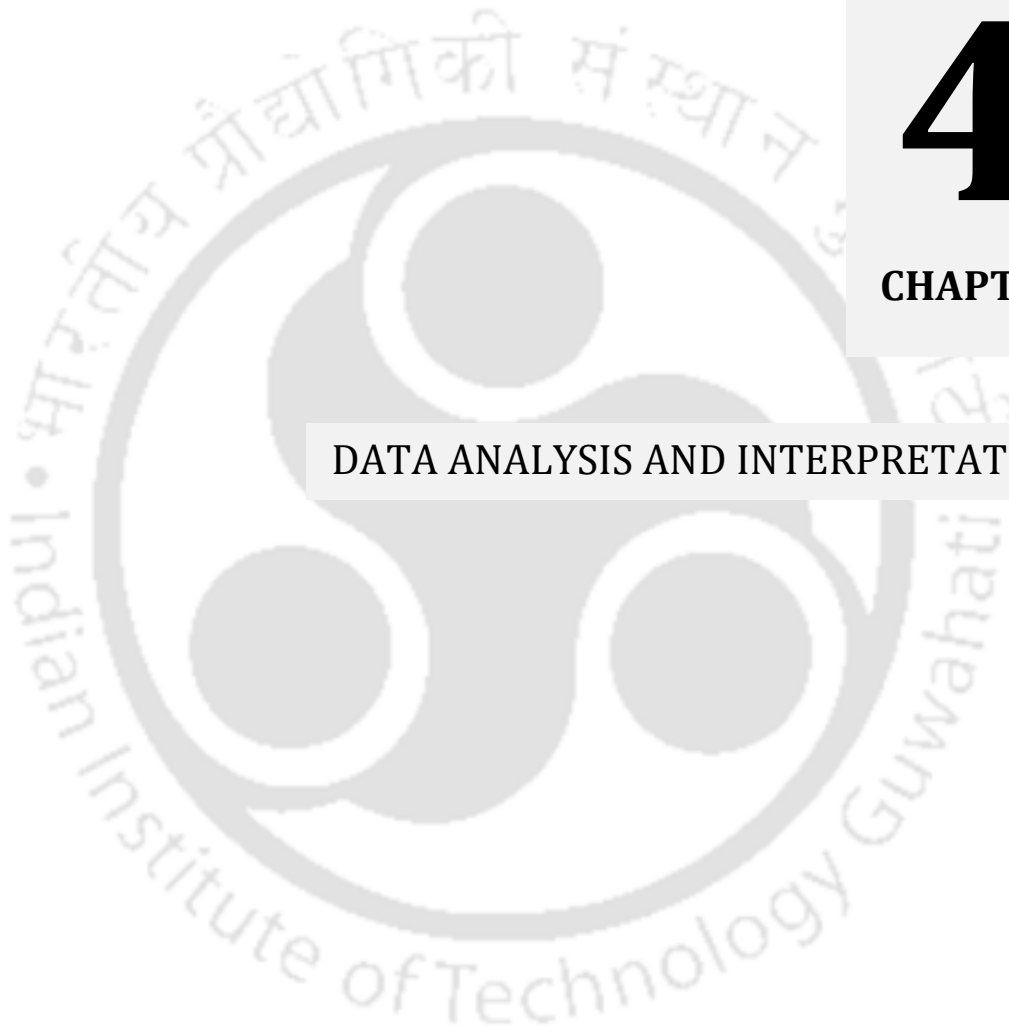
condition⁴ (I_r) and for the standard condition⁵ (I_s) and compared to identify the exceedances. The episodic conditions were identified using the indicators for 2014. The most influencing factors to the episodic conditions have been identified using statistical correlation analysis. AERMOD was applied to simulate the measured concentrations of CO at the selected monitoring locations within the traffic corridor. Further validation of the method was done for using the same method for BC data collected on 2016. The detailed methodology with results has been presented in Chapter 6.

3.7 HEALTH RISK OF PM_{2.5} AND EPISODIC-PRONE LOCATIONS USING AN INTEGRATED EXPOSURE-RESPONSE FUNCTION

To determine health risks due to PM_{2.5}, episode-prone areas in terms of the risks of four common diseases which occur upon exposure to PM_{2.5} have been found out. The distribution of health risks of chronic obstructive pulmonary disease (COPD), Lung cancer (LC), ischemic heart disease (IHD) and cerebrovascular disease (stroke) due to exposure to higher PM_{2.5} concentrations have been obtained using Integrated Exposure-Response (IER) function. AERMOD was used to predict PM_{2.5} concentrations from line source emissions in the study domain. Model performance was analysed using statistical analysis. A social questionnaire survey was also carried out in the traffic corridor on the participants who are sedentary workers in the shops located along the roadside. In the health-based social survey, the workers of the open shops (street vendors and workers of non-air conditioned shops openly facing to roadside emissions) and the workers of the air-conditioned shops were interviewed for demographic data and the history of COPD symptoms, and the lung function tests were performed on each participant. The detailed methodology and results has been presented in Chapter 7.

⁴ Indicator for real condition is the indicator, which represents that the humans are exposed to the air pollutant levels resulting from the real-time emissions caused by the actual traffic flow on the road.

⁵ Indicator for standard condition represents safe level considering health impacts of air pollutants on humans.



4

CHAPTER

DATA ANALYSIS AND INTERPRETATION



DATA ANALYSIS AND INTERPRETATION

4.1 GENERAL

Collection and interpretation near-road air quality measurements needs evidence on source characteristics as well as the resulting air pollutant concentrations. In this study, CO, PM_{2.5} and BC were chosen as these pollutants are the major traffic related air pollutants and its ability of causing public health issues. In this chapter, the data have been analysed and interpreted to determine patterns, relationships of air quality with the influencing parameters, and the trends. This has been done by studying the time series, statistical relationships between the CO, PM_{2.5} and BC concentrations and the meteorological parameters, traffic speed and traffic volume.

4.2 TRAFFIC CHARACTERISTICS

4.2.1 Traffic volume

Videotapes were analysed to determine volume of traffic in different composition (vehicle types) every hour from 7:00 AM to 6:00 PM. Fig. 4.1 and 4.2 presents the traffic volume observed on week days and weekend days of the year 2014 and Fig. 4.3 shows the traffic on the weekdays of the year 2016 for the four categories of vehicles and the total traffic. The maximum volume of traffic was observed to be between 10:00 AM and 12:00 noon on both week and weekend days of the year 2014 and on weekdays of 2016, two peaks were found, first, between 10:00 AM and 12:00 noon and second, from 5:00 PM onwards. The peaks observed in the morning and evening match the busy activities of the city due to commercial business, offices, colleges and schools. Similar trend was found by Wang et al. (2015) and Yi

et al. (2018). In comparison to 2014, the traffic volume was found increased in 2016 particularly two-wheeler (51%), which may have affected several relevant characteristics.

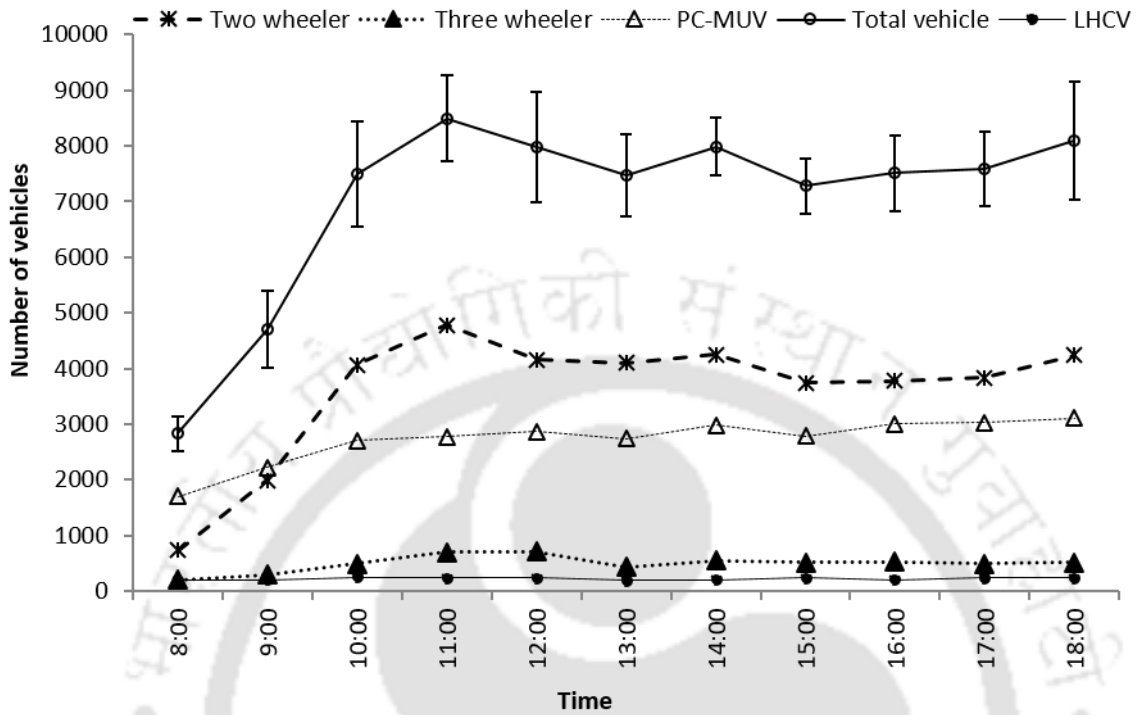


Fig. 4. 1 Temporal variation of traffic volume during the weekdays of data collected in 2014

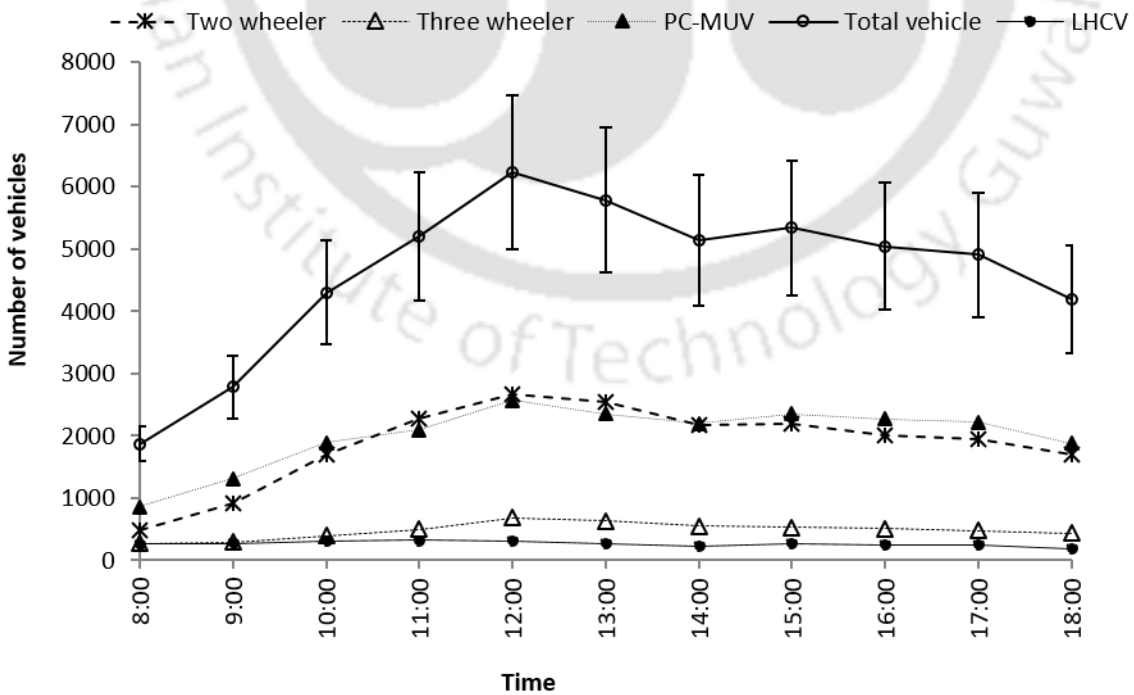


Fig. 4. 2 Temporal variation of traffic volume during the weekends of data collected in 2014

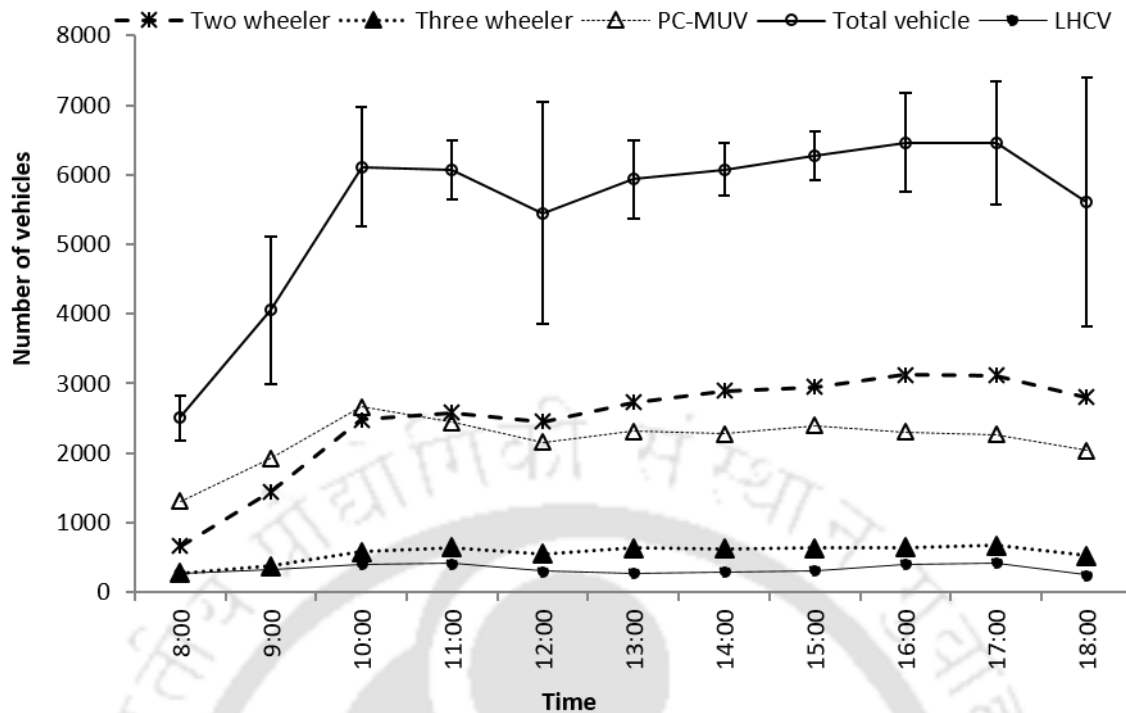


Fig. 4.3 Temporal variation of traffic volume during the weekdays of data collected in 2016

4.2.2 Traffic Composition

Fig. 4.4 shows the traffic composition (vehicles of different types) observed at the GS road of Guwahati. It is observed that the composition of traffic is different on week days (Fig. 4.4 (a)) and weekend days (Fig. 4.4 (b)). On weekend days, the share of PC-MUV increased from 36 to 39%, and of two-wheelers reduced from 44 to 41% as compared to weekdays. The percentage share of LHCV and three-wheeler on weekdays and weekend days of 2014 remains same. The study region is the central and main shopping hub in Guwahati and people gather for shopping on weekend days. So, this might be the reason for the increase in the share of PC-MUV in weekend days. In 2016 the weekday traffic composition 4.4 (c) has shown rise in PC-MUV share by 3% and two-wheeler share by 7% whereas share of three-wheeler and LHCV decreased by 3% and 7% from 2014 observation.

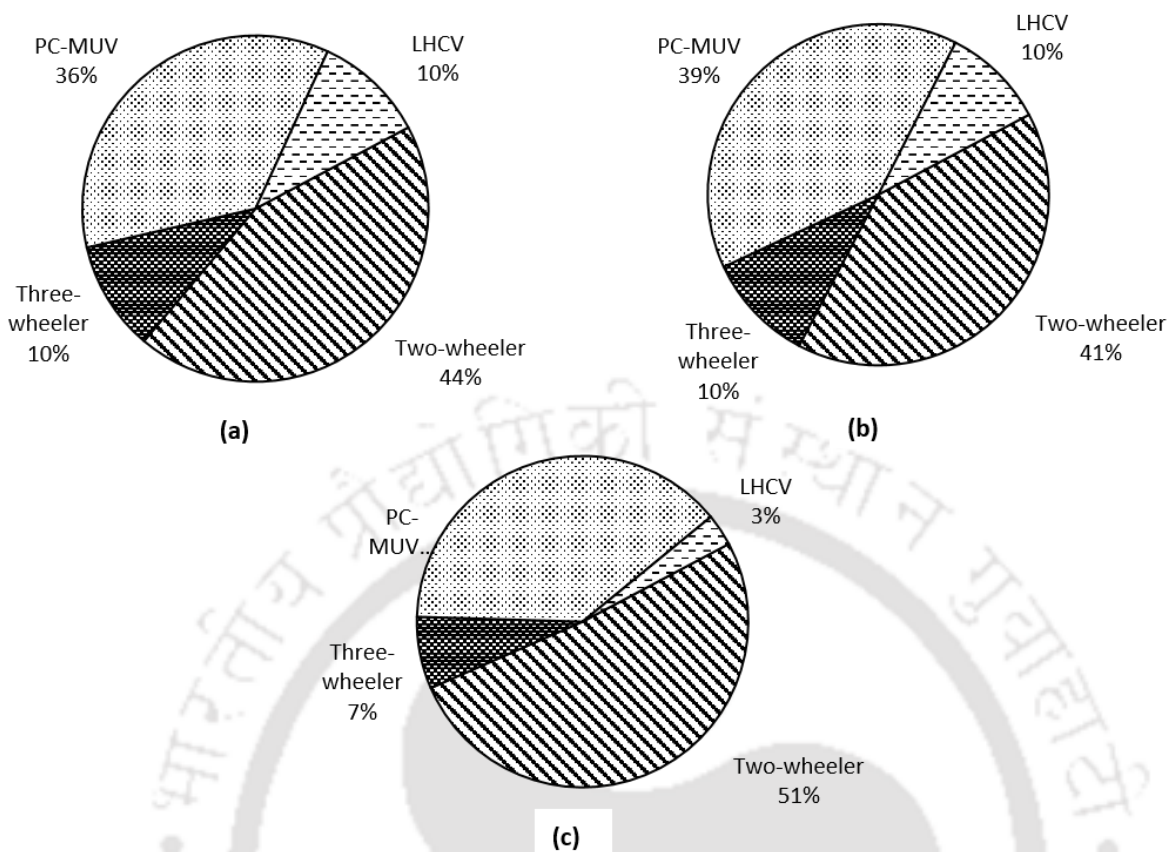


Fig. 4.4 Traffic composition on (a) weekdays (2014), (b) weekend days (2014) and (c) weekdays (2016)

4.2.3 Traffic speed

Hourly averaged traffic speed (kmph) was analysed for weekdays. The speed is the average velocity of all categories of vehicles in each hour. Fig 4.5 shows the variations of the traffic

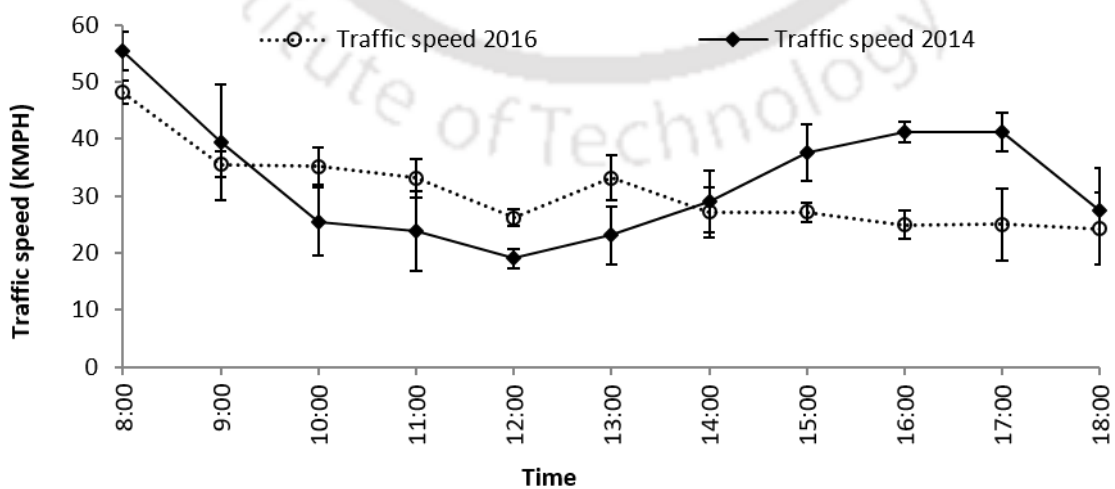


Fig. 4.5 Temporal variation of traffic speed in the traffic corridor-data collected for weekdays on 2014 and 2016

speed on weekdays of 2014 and 2016. On weekdays between 10:00 AM and 12:00 noon, the traffic speed has reduced to 18.9 kmph from 25.5 kmph and 26.1 kmph from 35.1 kmph in case of 2014 and 2016 respectively. The lowest speed was observed to be at 12:00 noon and then at 6:00 PM for both years.

4.3 CO, PM_{2.5} AND BC CONCENTRATION

The CO concentrations were collected at three sites (Location 1: L1, Location 2: L2 and Location 3: L3) in the selected traffic corridor. The instrument recorded the concentration every 3 sec, which was analysed to determine 1-h average (Fig. 4.6). The CO concentration was high at L1 in comparison to L2 and L3 with the mean concentrations of 1.112 ppm on weekdays and 0.386 ppm on weekend days of 2014. In 2016, the CO concentration at L3 was found to be higher as compared to 2014. On weekdays (Fig. 4.6 a), the CO concentrations ranged from 0.497-1.606 ppm at L1, 0.136-0.582 ppm at L2, and 0.156-1.123 ppm at L3. The results show that throughout the corridor pollutant concentration is not uniform indicating the importance of various local factors, in particular the non-uniformity of the roadside built-up, on the dispersion of traffic emission. Further, it may also be due to the spatial variation in the dynamic traffic flow pattern within the corridor. On weekend days (Fig 4.6 b), the CO concentration at L1 was more from 10:00 AM to 1:00 PM whereas from 11:00 AM to 2:00 PM, concentration was more at L3. The high concentration at L2 was observed at 2:00 PM. This might be due to the sudden traffic congestion that may be occurring around this time at L2 due to the several eating outlets and restaurants. The BC concentration and PM_{2.5} were also measured at location M at a height of 15 m from the ground. BC and PM_{2.5} were collected for a week in 2016. The BC concentrations were averaged and analysed for every hour and the PM_{2.5} concentrations for 8 hourly from 9:00 AM to 12:00 midnight (Fig. 4.7 and 4.8).

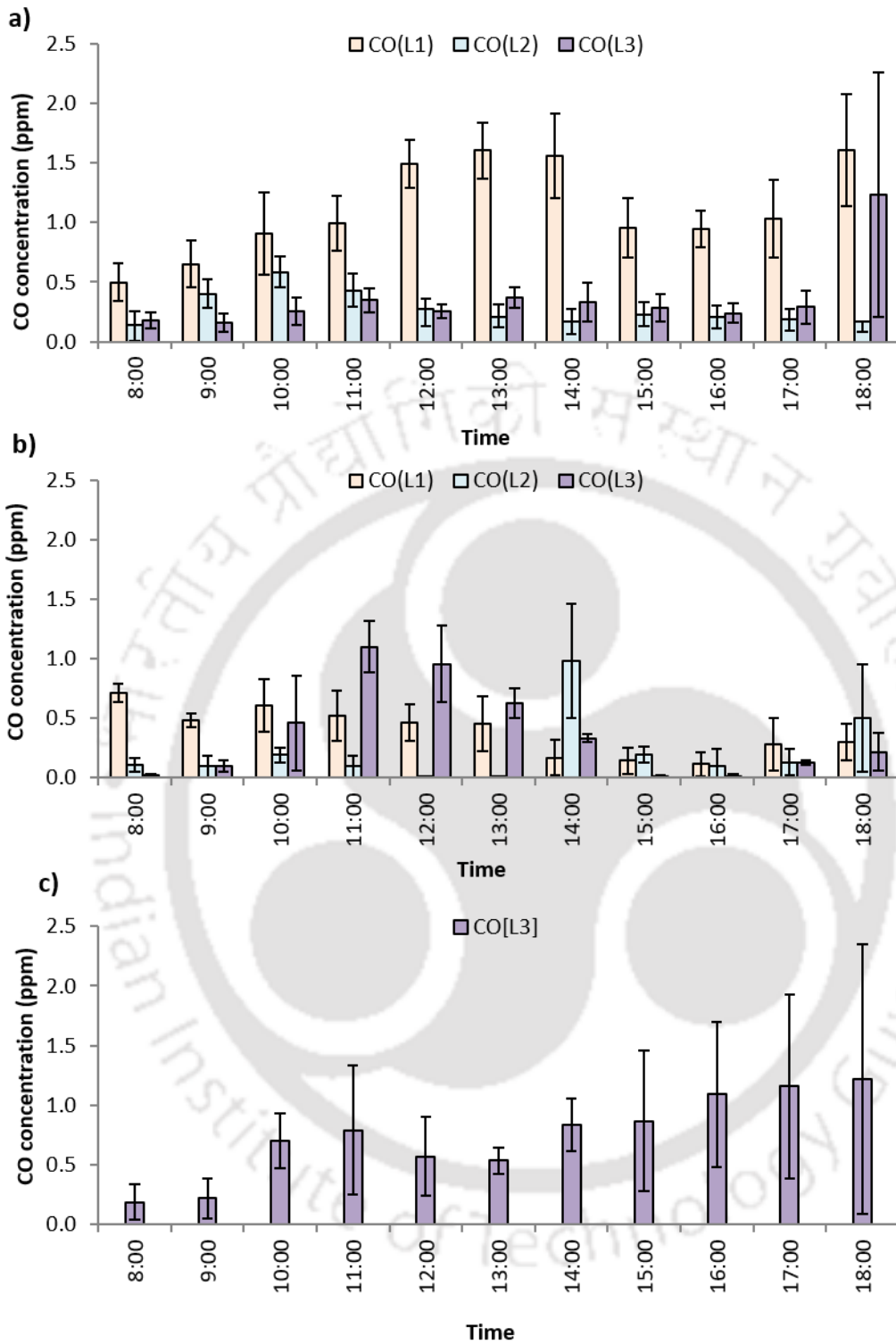


Fig. 4. 6 Hourly variation of CO concentration observed at the monitoring sites (L1, L2 and L3) during a) weekdays (2014), b) weekend days (2014) and c) weekdays (2016)

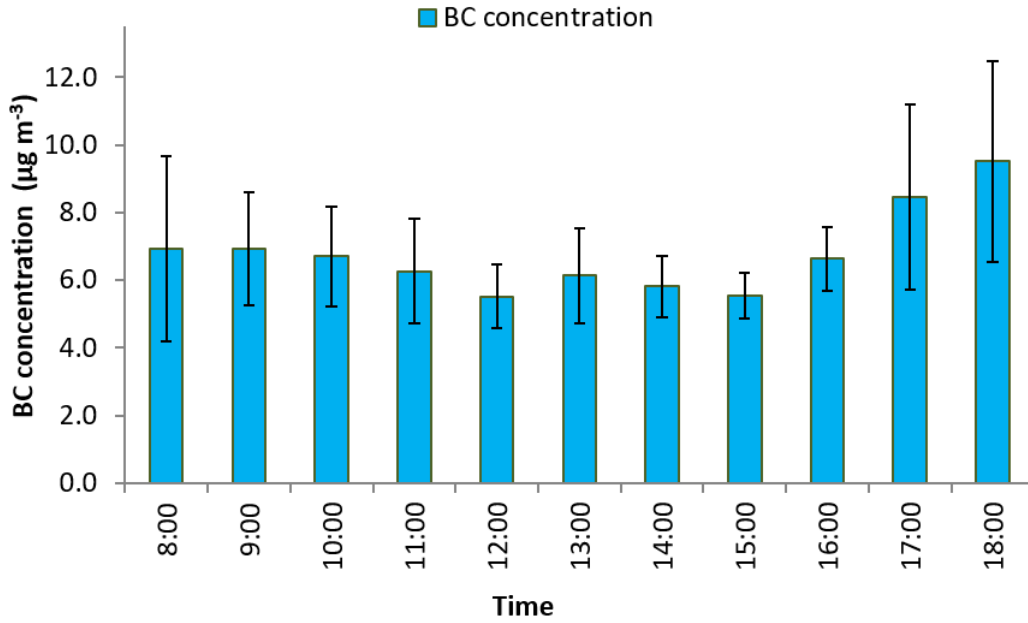


Fig. 4. 7 Hourly variation of CO concentration observed at location M

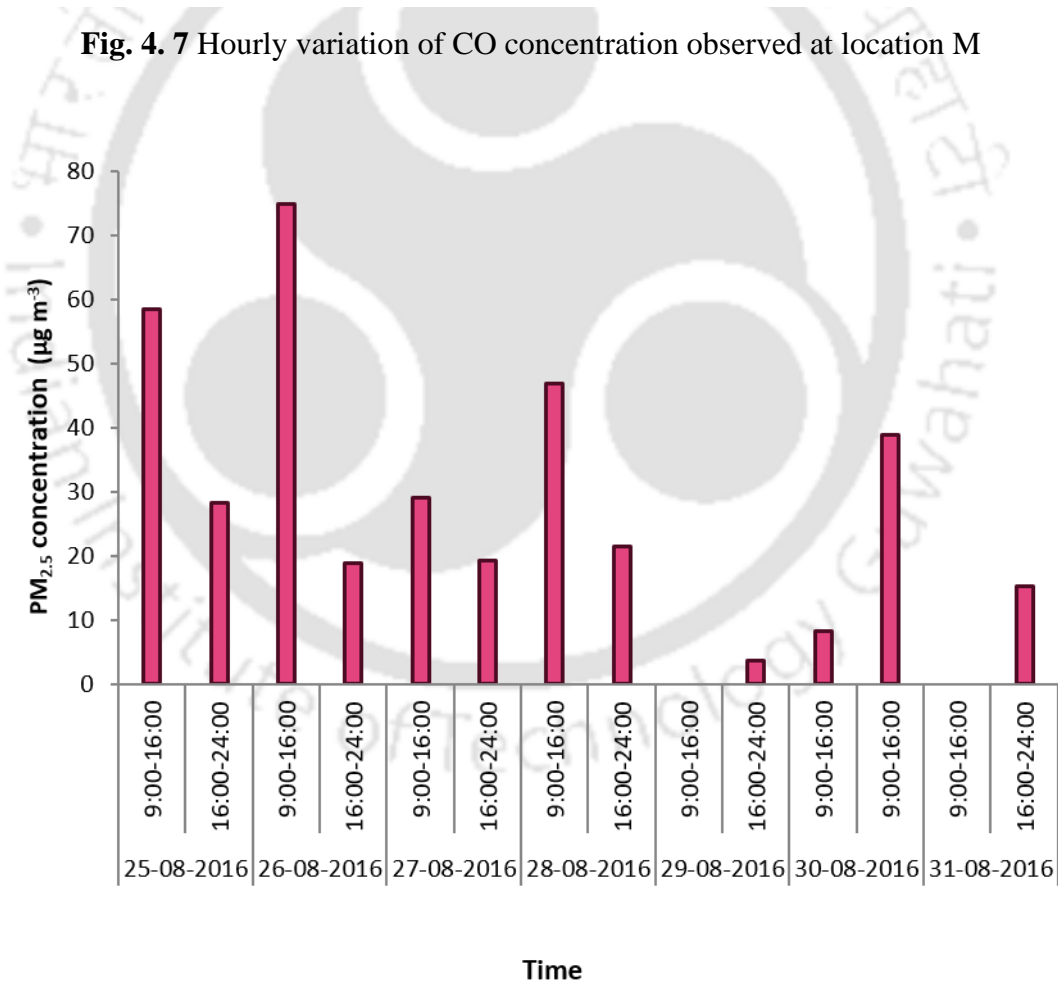


Fig. 4. 8 Hourly variation of PM_{2.5} concentration observed at location M

4.4 METEOROLOGY

Fig. 4.9 and Fig. 4.10 shows the meteorological parameters such as wind speed, ambient air temperature, wind direction, relative humidity, solar radiation and air atmospheric pressure

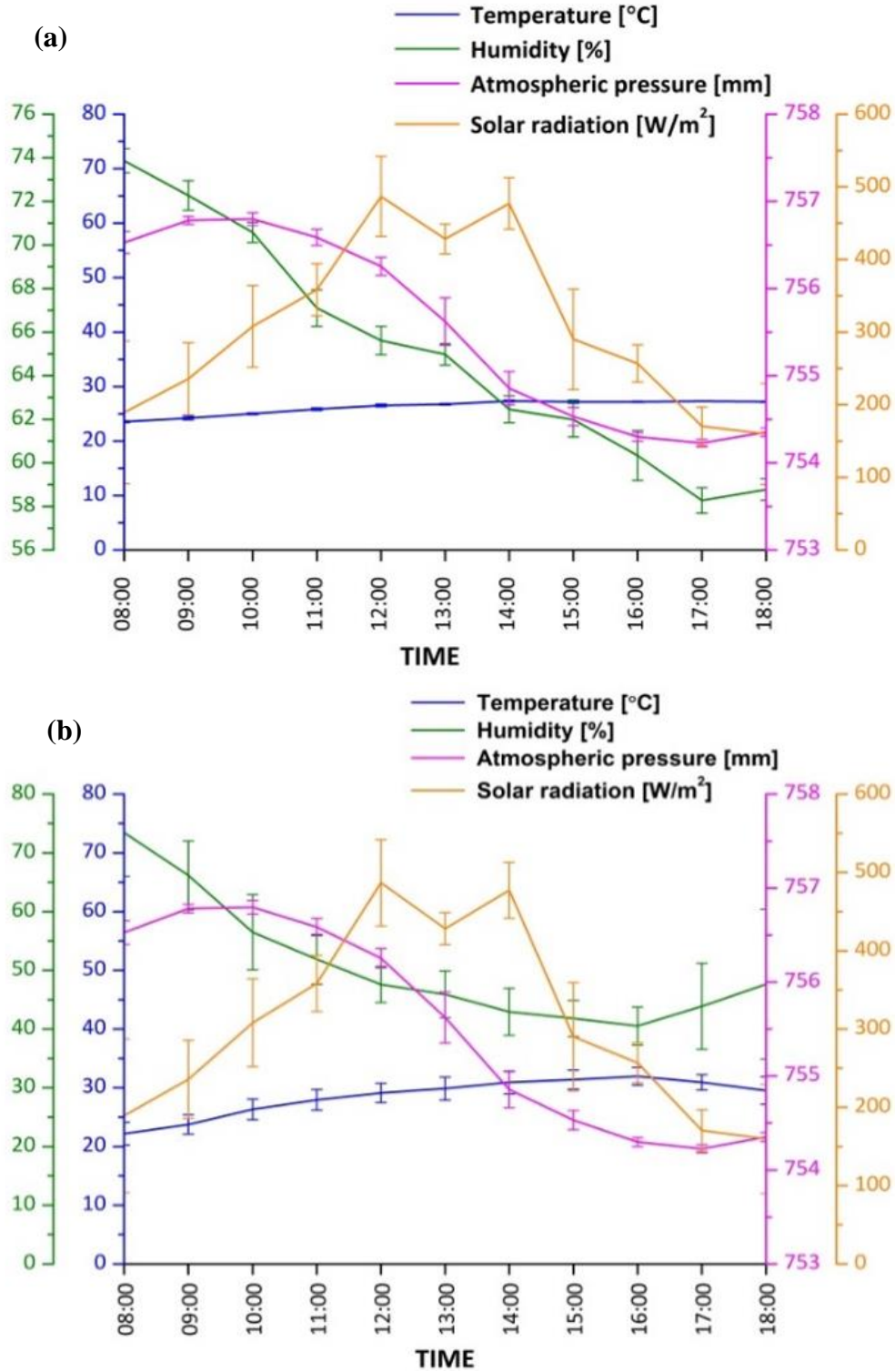


Fig. 4. 9 Hourly averaged ambient temperature, humidity, atmospheric pressure and solar radiation during CO monitoring at a) L1 and b) L2

which were measured at the station during the CO measurements. The variations in relative humidity, temperature, atmospheric pressure and solar radiation during monitoring at L1 and L2 are shown in Fig. 4.9 and for L3 shown in Fig. 4.10 for weekdays. It has been observed as expected that as the temperature increases relative humidity decreases and vice versa. The inverse relationship between temperature and humidity was also found by different researchers (Akinbode et al., 2008; Peng et al., 2020; Hassan et al., 2020). The difference in the temperature measured at 15 m height was not significant during monitoring of all the three locations whereas the variation in relative humidity was, however, different and noticeable. The intensity of solar radiation and atmospheric pressure for all the locations was more or less same.

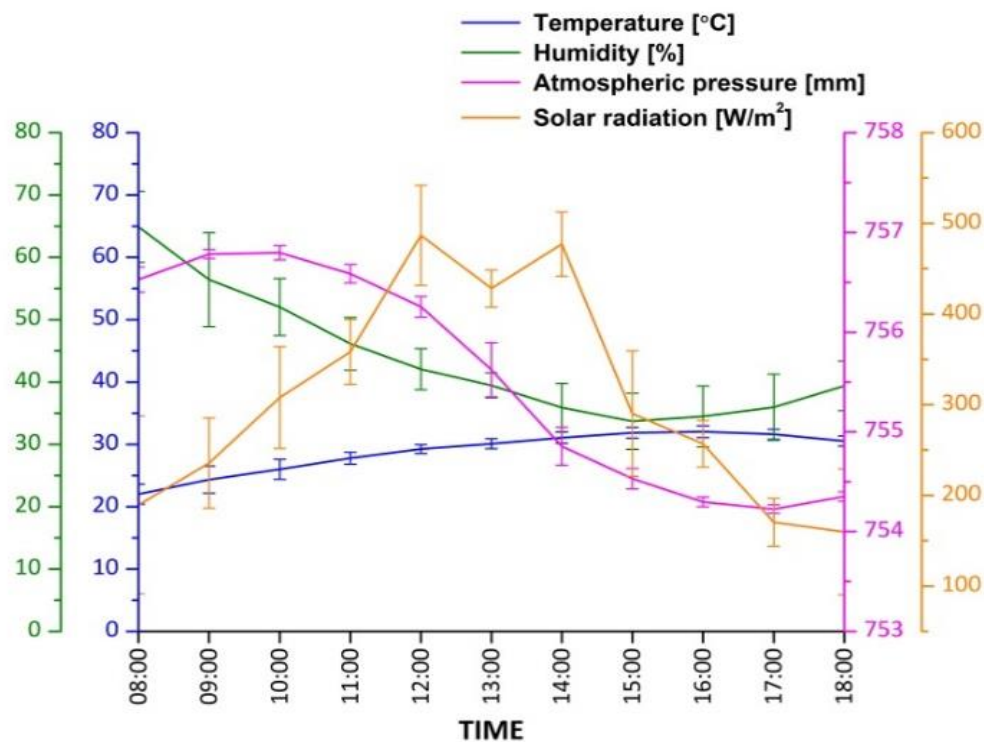


Fig. 4. 10 Hourly averaged ambient temperature, humidity, atmospheric pressure and solar radiation during CO monitoring at L3

The wind rose diagram shows useful information on the prevailing wind direction and different wind speeds. It is constructed using the wind velocity and direction data measured in the selected corridor at 15 m height on the G S road, Guwahati, as shown in Fig. 4.11. The

prevailing wind direction (blowing from) for location L1, L2 and L3 was East, North East and South East, respectively. Wind speed was highest at location L1 and lowest at L2. Wind speed less than level 0.5 m s^{-1} (calm condition) occurred during monitoring at L1, L2 and L3 with frequencies 6.7%, 37.5% and 29.2%, respectively.

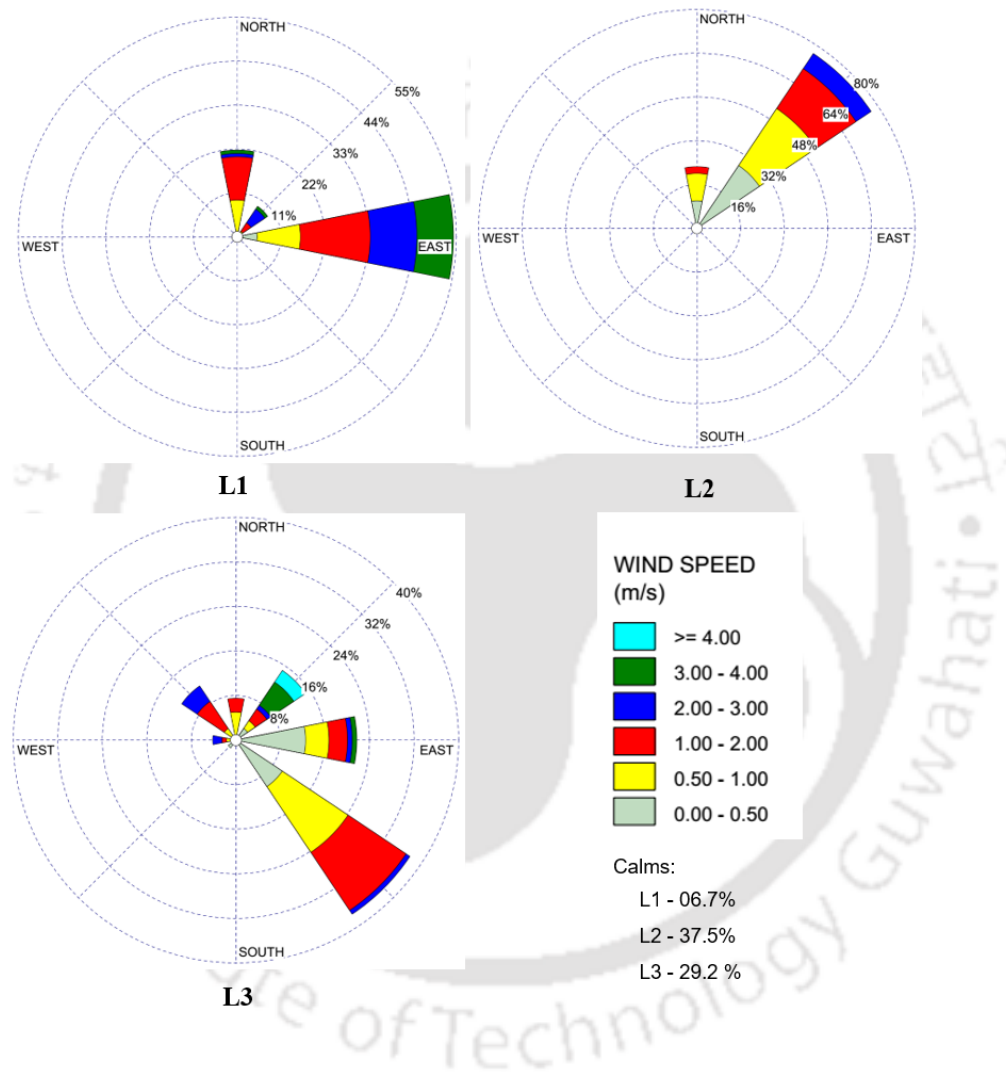


Fig. 4. 11 Wind rose diagram for three locations during the study period (working days) during CO monitoring at L1, L2 and L3

4.5 STATISTICAL DESCRIPTION OF DATA

Table 4.1 and 4.2 show the descriptive statistics of CO concentrations of the three sites on weekdays and weekend days, respectively. The mean concentration at L1 and L2 was more on weekdays, whereas at L3 it was observed to be more or less same on weekdays and

Table 4. 1: Summary statistics of hourly CO concentration during weekdays (2014)

Monitoring locations	Range	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation (ppm)	K-S test	p (K-S)	S-W test	p (S-W)
L1	1.11	0.50	1.60	1.11	0.39	0.22	0.15	0.89	0.13
L2	0.45	0.14	0.58	0.28	0.14	0.26	0.04	0.84	0.03
L3	1.08	0.16	1.23	0.36	0.30	0.40	0.00	0.56	0.00

Table 4. 2: Summary statistics of hourly CO concentration during weekend days (2014)

Monitoring locations	Range	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation (ppm)	K-S test	p (K-S)	S-W test	p (S-W)
L1	0.60	0.12	0.71	0.39	0.20	0.18	0.20	0.95	0.61
L2	0.98	0.01	0.99	0.22	0.29	0.35	0.00	0.69	0.00
L3	1.10	0.00	1.10	0.35	0.39	0.19	0.20	0.85	0.04

Note: a) K-S test is test statistics for Kolmogorov –Smirnov test, b) p(K-S) is probability value for K-S test, c) S-W test is test statistics for Shapiro-Wilk test and d) p(S-W) is probability value for Shapiro-Wilk test.

weekend days with the marginal difference. The range of CO concentrations was 0.136 – 1.606 on weekdays at L1 and L3, but at L2, weekend days' range of CO concentrations was 0 – 1.099. Even the difference in the standard deviations was found to be marginal among the locations on both weekdays and weekend days. Table 4.3 and 4.4 shows the descriptive statistics of traffic count and traffic speed on weekdays and weekend days, respectively. The main difference on weekdays and weekend days' traffic count was in the number of two-wheelers. The mean number of two-wheelers was more on weekdays. Other types of vehicles were also more on weekdays but the difference was less. For meteorology (Table 4.5 and 4.6), no such important difference was found either on weekdays or weekend days.

Tests for normality (Shapiro-Wilk test and Kolmogorov-Smirnov test) calculate the probability that the sample is drawn from a normal population. The hypotheses used were:

H_0 : The sample data not significantly different than a normal population.

H_a : The sample data significantly different than a normal population.

The probabilities for normality test are given as (i) Probabilities > 0.05 for the data to be normal; and (ii) Probabilities < 0.05 for the data to be not normal.

High probabilities indicate that data are normally distributed. The results of the K-S and S-W tests are shown in Table 4.1 to 4.6. The observed CO, traffic and meteorological data showed higher probability values (p) both on weekdays and weekend days for most of the parameters. The probability values indicated that the data are normally distributed on weekdays and weekend days.

Table 4. 3: Summary statistics of hourly traffic compositions on weekdays (2014)

Traffic composition	Range	Minimum	Maximum	Mean	Std. Deviation	K-S test	p (K-S)	S-W test	p(S-W)
Two-wheeler	2645	622	3267	2372	823	0.24	0.03	0.85	0.02
Three-wheeler	443	261	704	564	151	0.25	0.02	0.78	0.00
PC-MUV	1456	1253	2709	2236	429	0.27	0.01	0.85	0.02
LHCV	334	272	606	376	93	0.15	0.20	0.89	0.09
total traffic	4349	2409	6758	5550	1386	0.34	0.00	0.74	0.00
Traffic speed (kmph)	36	19	55	33	10	0.23	0.04	0.92	0.23

Table 4. 4: Summary statistics of hourly traffic compositions on weekend days (2014)

Traffic composition	Range	Minimum	Maximum	Mean	Std. Deviation	K-S test	p (K-S)	S-W test	p(S-W)
Two-wheeler	2184	479	2664	1871	661	0.21	0.18	0.90	0.17
Three-wheeler	410	272	682	480	125	0.14	0.20	0.97	0.83
PC-MUV	1719	855	2575	2001	506	0.23	0.13	0.85	0.05
LHCV	138	186	325	267	39	0.17	0.20	0.94	0.53
total traffic	4367	1867	6235	4620	1288	0.23	0.13	0.89	0.14
Traffic speed (kmph)	34	25	60	40	10	0.14	0.20	0.96	0.77

Note: a) K-S test is test statistics for Kolmogorov –Smirnov test, b) p(K-S) is probability value for K-S test, c) S-W test is test statistics for Shapiro-Wilk test and d) p(S-W) is probability value for Shapiro-Wilk test

Table 4. 5: Summary statistics of hourly meteorological parameters during weekdays of the year 2014

Parameters	Location	Range	Minimum	Maximum	Mean	Std. Deviation	K-S test	p (K-S)	S-W test	p(S-W)
Ground temperature (°C)	L1	12.95	24.63	37.57	31.58	4.11	0.03	0.66	-0.66	1.28
	L2	10.57	25.74	36.31	32.52	2.92	-1.11	0.66	2.03	1.28
	L3	11.97	25.65	37.61	31.81	3.89	0.07	0.66	-1.12	1.28
Temperature (°C)	L1	3.0	24.0	27.0	26.2	1.3	0.38	0.00	0.68	0.00
	L2	10.0	22.0	32.0	28.8	3.5	0.19	0.20	0.87	0.07
	L3	10.0	22.0	32.0	28.5	3.2	0.22	0.15	0.87	0.08
Humidity (%)	L1	16.0	58.0	74.0	65.1	5.5	0.17	0.20	0.94	0.51
	L2	31.0	34.0	65.0	43.5	10.2	0.22	0.15	0.87	0.07
	L3	32.0	41.0	73.0	50.8	10.4	0.24	0.07	0.85	0.04
Wind Direction (°)	L1	302.0	24.0	326.0	157.0	123.4	0.22	0.13	0.85	0.04
	L2	177.3	84.7	262.0	198.4	70.2	0.24	0.07	0.82	0.02
	L3	67.5	0.0	67.5	57.3	21.0	0.41	0.00	0.57	0.00
Wind speed (m s ⁻¹)	L1	1.7	1.5	3.2	2.2	0.6	0.23	0.11	0.91	0.26
	L2	1.6	0.2	1.8	1.0	0.6	0.22	0.13	0.87	0.09
	L3	2.4	0.3	2.6	1.4	0.7	0.17	0.20	0.96	0.82
Atmospheric pressure (mm)	L1	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
	L2	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
	L3	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
Solar radiation (W m ⁻²)	L1	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33
	L2	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33
	L3	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33

Table 4. 6: Summary statistics of hourly meteorological parameters during weekend days of the 2014

Parameters	Location	Range	Minimum	Maximum	Mean	Std. Deviation	K-S test	p (K-S)	S-W test	p(S-W)
Ground temperature (°C)	L1	12.95	24.63	37.57	31.58	4.11	0.03	0.66	-0.66	1.28
	L2	10.57	25.74	36.31	32.52	2.92	-1.11	0.66	2.03	1.28
	L3	11.97	25.65	37.61	31.81	3.89	0.07	0.66	-1.12	1.28
Temperature (°C)	L1	3.0	24.0	27.0	26.2	1.3	0.38	0.00	0.68	0.00
	L2	10.0	22.0	32.0	28.8	3.5	0.19	0.20	0.87	0.07
	L3	10.0	22.0	32.0	28.5	3.2	0.22	0.15	0.87	0.08
Humidity (%)	L1	16.0	58.0	74.0	65.1	5.5	0.17	0.20	0.94	0.51
	L2	31.0	34.0	65.0	43.5	10.2	0.22	0.15	0.87	0.07
	L3	32.0	41.0	73.0	50.8	10.4	0.24	0.07	0.85	0.04
Wind Direction (°)	L1	302.0	24.0	326.0	157.0	123.4	0.22	0.13	0.85	0.04
	L2	177.3	84.7	262.0	198.4	70.2	0.24	0.07	0.82	0.02
	L3	67.5	0.0	67.5	57.3	21.0	0.41	0.00	0.57	0.00
Wind speed (m s ⁻¹)	L1	2.4	0.3	2.6	1.4	0.7	0.17	0.20	0.96	0.82
	L2	1.6	0.2	1.8	1.0	0.6	0.22	0.13	0.87	0.09
	L3	1.7	1.5	3.2	2.2	0.6	0.23	0.11	0.91	0.26
Atmospheric pressure (mm)	L1	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
	L2	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
	L3	3.0	754.0	757.0	755.6	1.3	0.22	0.15	0.83	0.02
Solar radiation (W m ⁻²)	L1	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33
	L2	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33
	L3	327.0	160.0	487.0	305.5	118.6	0.13	0.20	0.92	0.33

Table 4. 7: Summary statistics of hourly meteorological parameters during weekdays of the year 2016

Parameters	Range	Minimum	Maximum	Mean	Std. Deviation	K-S test	p (K-S)	S-W test	p(S-W)
CO	1.00	0.20	1.20	0.70	0.30	0.12	0.20	0.94	0.60
PM _{2.5}	358.10	220.00	578.10	410.30	140.20	0.15	0.20	0.90	0.20
BC	2.60	5.50	8.00	6.80	0.80	0.13	0.20	0.95	0.70
Temperature (°C)	4.20	29.60	33.80	32.10	1.40	0.18	0.20	0.93	0.40
Humidity (%)	14.30	66.90	81.10	72.10	4.80	0.17	0.20	0.90	0.20
Wind Direction (°)	0.90	0.70	1.60	1.20	0.30	0.18	0.20	0.91	0.30
Wind speed (m s ⁻¹)	80.00	194.00	274.00	244.10	28.10	0.21	0.20	0.88	0.10
Atmospheric pressure (mm)	4.90	1000.40	1005.30	1002.80	2.00	0.19	0.20	0.85	0.00
Solar radiation (W m ⁻²)	564.50	20.20	584.70	366.00	193.90	0.16	0.20	0.92	0.30
Two-wheeler	4054	728	4782	3606	1180	0.36	0	0.74	0
Three-wheeler	510	204	714	495	148	0.22	0.14	0.92	0.3
PC-MUV	1404	1704	3108	2719	413	0.3	0.01	0.79	0.01
LHCV	55	191	246	220	21	0.29	0.01	0.84	0.03
Total traffic	5663	2827	8490	7039	1707	0.37	0	0.7	0
Traffic speed (kmph)	24	24	48	31	7	0.24	0.06	0.83	0.02

4.6 CO VS TRAFFIC COMPOSITION

The relationship between CO and traffic composition was studied to understand the influence of traffic characteristics on pollutant concentration. Fig. 4.12 shows the variation of traffic characteristics with CO concentration at locations L1, L2 and L3 during 2014 and 4.13 shows the same at location L3 during 2016. The trend of CO of all sites was different than the trend of total volume of traffic. This may be due to the variation of the meteorological parameters (Ginzburg et al., 2015). Whereas the trend of CO at L3 on 2016 showed a similar trend with total traffic volume.

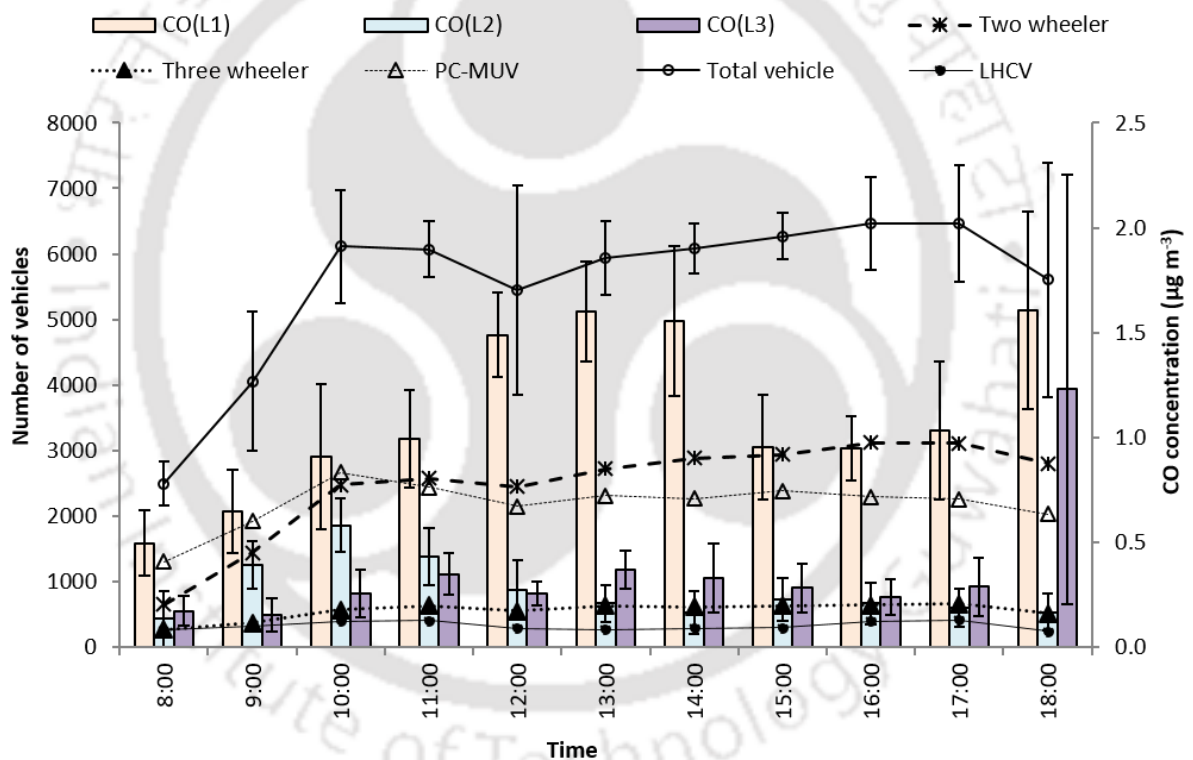


Fig. 4. 12 Variation of pollutant concentrations and traffic volumes on weekdays of 2014

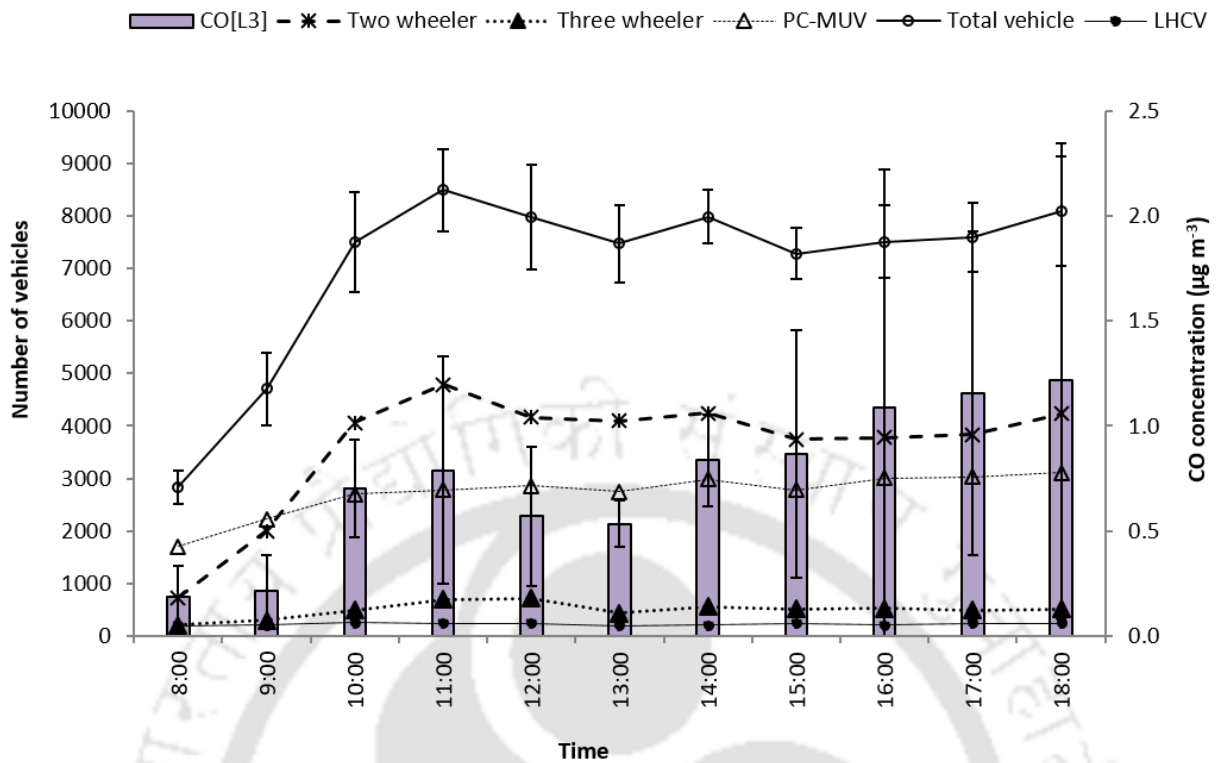


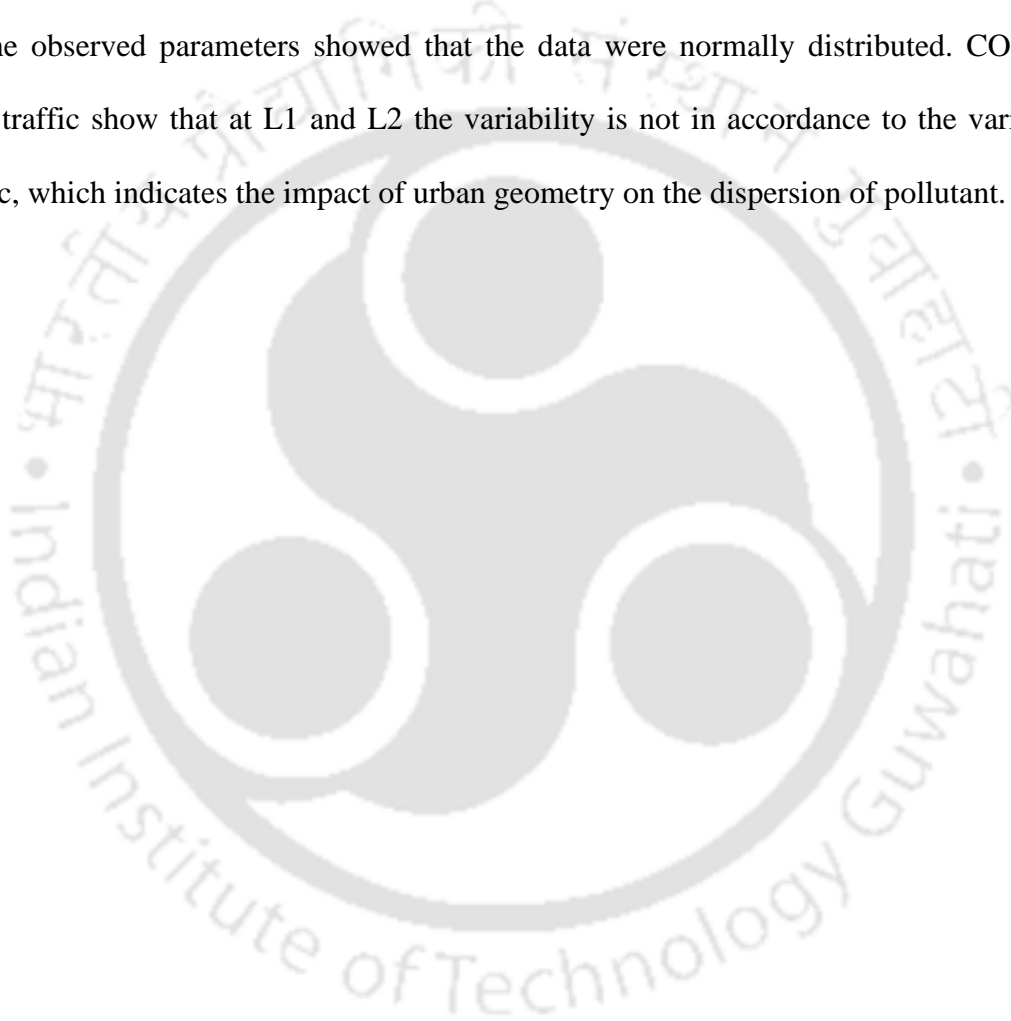
Fig. 4.13 Variation of pollutant concentrations and traffic volumes on weekdays of 2016

4.7 SUMMARY

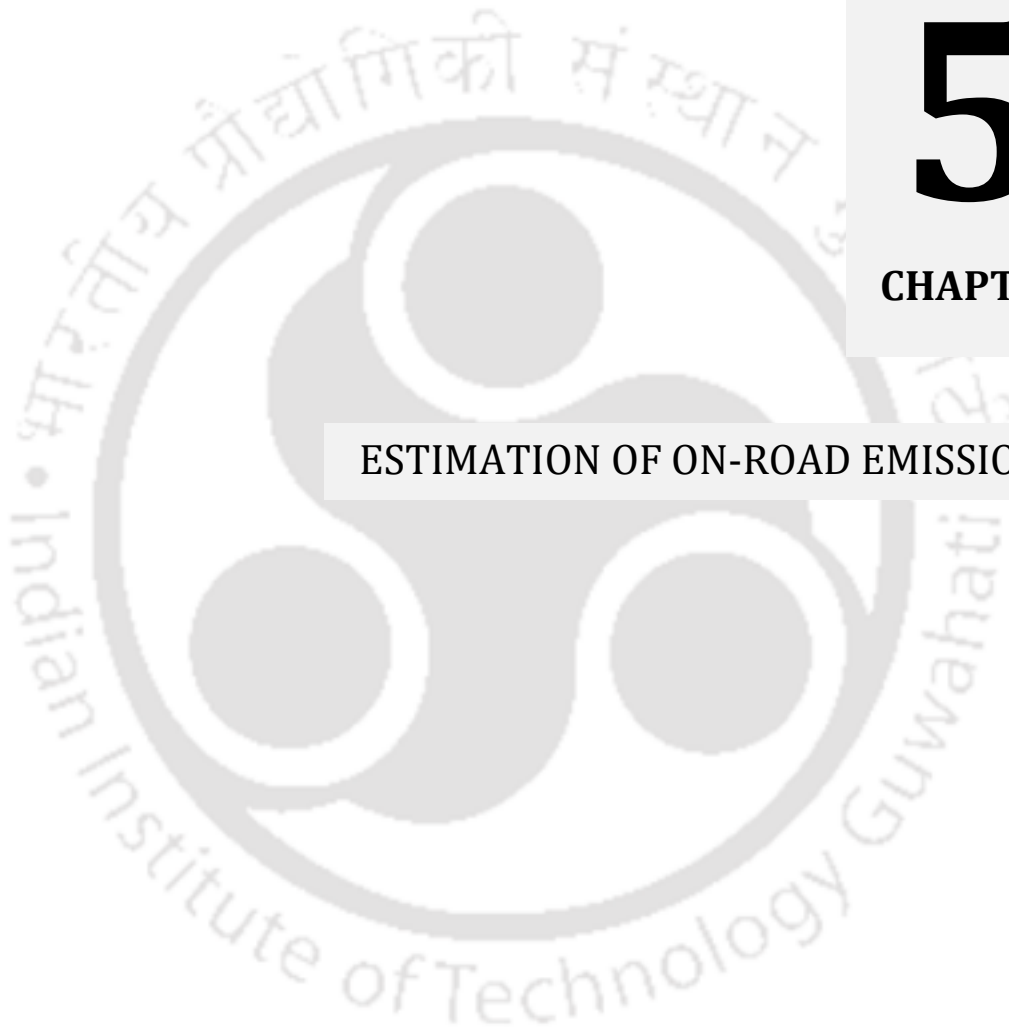
The temporal variation of traffic volume shows the expected pattern with two peaks due to office hours and a significant increase (24%) of traffic from 2014 to 2016 is seen. Traffic composition is dominated by two-wheelers on both weekdays and weekend days and is the major mode of transport for office goers. PC-MUV is increasing during the weekends, showing the typical urban lifestyle, due to increased leisure activities. Traffic speed acts as an indicator of congestion. It has been observed that whenever traffic volume increased, traffic speed drops significantly. CO concentrations vary randomly throughout the traffic corridor indicating the presence of factors (related to the heterogeneous built-up surrounding the roadway within the corridor) interfering with the dispersion of traffic emission. Higher CO concentration is observed in the vicinity of commercial complexes especially during the weekend. Further temporal as well as spatial variations were observed in relative humidity within the corridor, it is relatively different at three locations. Wind direction was

predominantly from the eastern side (of the monitoring stations) and also for a short time from north-east to south-east.

Statistical analysis of the data revealed that the weekday's range for CO is higher than weekend, however, the standard deviations were found to be marginal among the locations on both weekdays and weekend days. In case of traffic, two-wheeler was a dominant category and showed a significant difference during weekdays and weekends. Probability analysis of all the observed parameters showed that the data were normally distributed. CO variation with traffic show that at L1 and L2 the variability is not in accordance to the variability of traffic, which indicates the impact of urban geometry on the dispersion of pollutant.







5

CHAPTER

ESTIMATION OF ON-ROAD EMISSIONS



ESTIMATION OF ON-ROAD EMISSIONS

5.1 METHODOLOGY

On-road vehicle increase in emissions has significantly deteriorated the urban air quality, which adversely affects human health. Motor vehicles emit large quantities of CO, HC and PM. Automotive Research Association of India (ARAI) have developed vehicular exhaust emission standards (ARAI, 2007). In this chapter emission has been calculated using the above mentioned emission factors and the traffic counts. Two kinds of emissions were calculated. First calculated emission was for real condition (Q_R) from traffic which has been calculated by using ARAI emission factors and other is for standard condition (Q_S) from traffic. Here emission for standard condition is assumed to be the maximum emission on the selected traffic corridor, which will cause no health impact on the pedestrians.

5.1.1 Estimation of emission for real condition

To estimate emissions for the real condition traffic volume data were collected in March, 2014. The emissions of CO, PM_{2.5} and BC were calculated hourly for weekdays and weekend days separately from 7:00 AM to 6:00 PM. Emissions were calculated by using the traffic volume data and the ARAI emission factors of CO and PM_{2.5}. The vehicles were classified into 7 categories (Two-wheeler, Three-wheeler [Petrol], Three-wheeler [Diesel], Car, Multi utility vehicle [MUV], Light commercial vehicle [LCV] and Heavy-duty vehicle [HDV]) as shown in Table 5.2. Average vehicle counts of weekdays (2014 and 2016) was taken for calculation. BC fractions of PM_{2.5} emissions from each category of vehicles was taken from the guide book of emission calculation (EMEP/EEA air pollutant emission inventory guidebook, 2016).

Table 5. 1: Emission factors according to ARAI (2007)

Vehicle type	Sub-category	EF of CO (g/km)	EF of PM _{2.5} (g/km)
2W	>200 cc	0.72	0.013
3W (Petrol)	<200 cc	2.29	0.015
3W (Diesel)	<500 cc	0.41	0.091
Car	<1600 cc	0.06	0.015
MUV	<3000 cc	0.25	0.096
LCV	6-seater or more (Reference mass <1700)	3.20	0.017
HDV	>6000 cc	3.92	0.300

5.1.2 Estimation of emission for standard condition

Standard emission was assumed as the maximum emission on the selected traffic corridor, which will cause no health impact on the pedestrians or the user of the corridor. To calculate this emission, it is assumed that the pollutant concentration of the corridor is always within the standard limit. The box modelling approach has been used to calculate emission rate Q_s (g/hour). For Q_s , a semi-empirical model (Dirks et al., 2003) has been used to estimate emission rates, ' Q ' (mg/hour), at the concentrations equal to the ambient air quality standards. The safe levels for PM_{2.5} was 0.06 mg m⁻³, for BC was 0.02 mg m⁻³ and for CO it was 2 mg m⁻³. Hourly average levels of Central Pollution Control Board (CPCB) - NAAQS of CO is 4 mg m⁻³ which suggests more than 4 mg m⁻³ concentration is harmful to public health and the environment. Tao et al. (2011) observed significant association with total and cardiovascular mortality in urban areas due to exposure of CO less than 2 mg m⁻³. So in this study the considered safe level of CO was taken as 2 mg m⁻³. The semi-empirical model is given by equation 5.1 (Dirks et al., 2002)

$$C = \frac{Q}{u \cdot \Delta z \cdot \sin(\theta)} + C_b \quad (5.1)$$

where, C_b is the background concentration (mg m^{-3}); Δz , the box height which refers to the height up to which emission rises and disperses (Gokhale and Pandian, 2007), has been calculated by putting the observed pollutant concentrations related to other parameters (Appendix-II); u (m s^{-1}), the horizontal wind speed which is assumed to be uniform at an angle (θ) (degree) to the road.

In this study, C_b is assumed to be zero, which means that the traffic emission is the only source of the three pollutants in the traffic corridor. So equation 5.1 can be rewritten as given by equation 5.2. The emission rate Q_s was converted from $\text{mg m}^{-1} \text{s}^{-1}$ to mg using length and width of the roadway in the corridor.

$$Q_s = C \cdot u \cdot \Delta z \cdot \text{Sin}(\theta) \tag{5.2}$$

5.2 RESULTS AND DISCUSSION

Peak of Q_R was observed at 5:00 PM (Fig 5.1) in case of CO collected in 2014, whereas Q_R on 2016 showed highest emission at morning 11:00 AM. Liu et al. (2018b) found peak period at morning (7:00-9:00 AM) and evening (17:00-18:00). Total emission (g) for standard

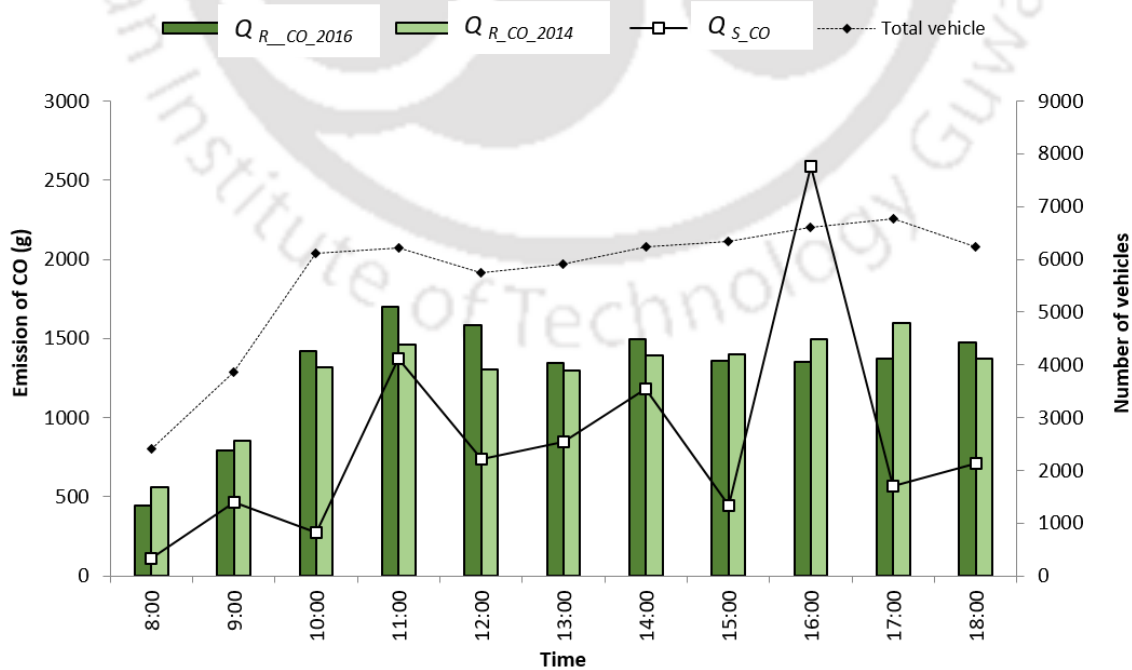


Fig. 5. 1 Temporal variation of emissions on weekdays for CO

condition (Q_S) was also calculated. Figure 5.1 indicates that Q_S was lower during morning time (8:00 AM to 10:00 AM). The trend of $PM_{2.5}$ and BC emission are similar, as BC is the fraction of $PM_{2.5}$ (Fig. 5.2) (Taheri et al., 2019). Two peaks were found for both the pollutants at morning and evening time. The evening peak was higher than morning peak. The trend of Q_R of $PM_{2.5}$ and BC are reverse in comparison to their respective Q_S . This phenomenon indicates the exceedance of safe level traffic emission at the traffic corridor.

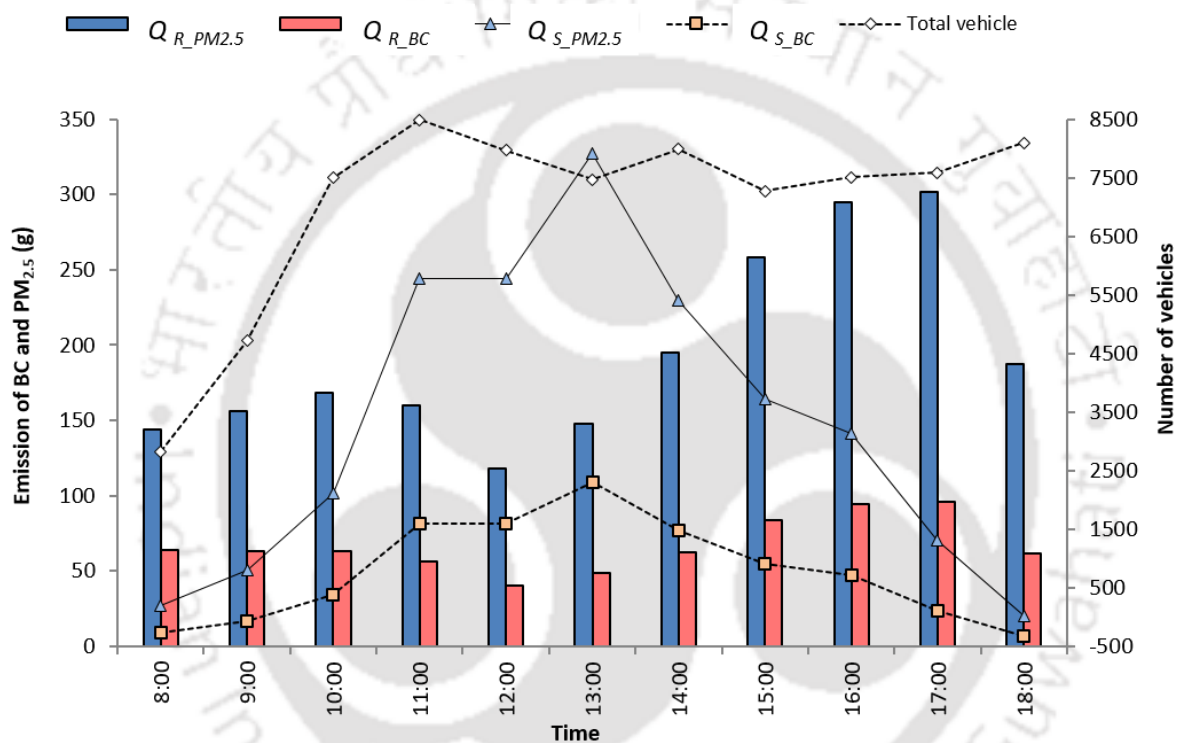


Fig. 5. 2 Temporal variation of emissions on weekdays for $PM_{2.5}$ and BC

5.3 SUMMARY

The results show that exceedance of safe level emission can occur during peak hour and non-peak hour of traffic. This finding suggests that to maintain the standard concentration at the time and location of the exceedance, the emission should be low. Whereas in real condition, during that time, emission is high specially in case of BC and $PM_{2.5}$. These estimated emissions have been used to calculate the indicators for real and standard condition in forthcoming chapter (Chapter 6).

6

CHAPTER

METHOD OF IDENTIFICATION AND MODELLING OF EPISODIC CONDITION



CHAPTER 6

METHOD OF IDENTIFICATION AND MODELLING OF EPISODIC CONDITION

6.1 GENERAL

An emission-based indicator for chronic health impact on humans is used by Lepicier et al. (2013) for comparison between different urban scenarios. It, however, does not include about safe levels for humans or the magnitude of the health impact. In the present study, this indicator has been used for a short term effect by incorporating short-term emissions of CO and population exposure for real-world condition and the reference standard condition to identify air pollution episodes. The difference between the two indicators has been considered as the degree of episodic condition. Further, multi-collinearity analysis and backward regression method have been used to identify the influencing parameters on the air pollution episodes. AERMOD was used to identify the episode prone spots at the study area. Along with temporal identification of episode, spatial episode prone zones have also been identified by finding the spatial distribution of CO concentrations using AERMOD, a globally used steady-state dispersion model. The frame work of this chapter has been given in Fig. 6.1.

6.2 METHODOLOGY

6.2.1 Identification of episodic condition due to CO

The step-by-step method is presented as flowchart in Fig. 6.2.

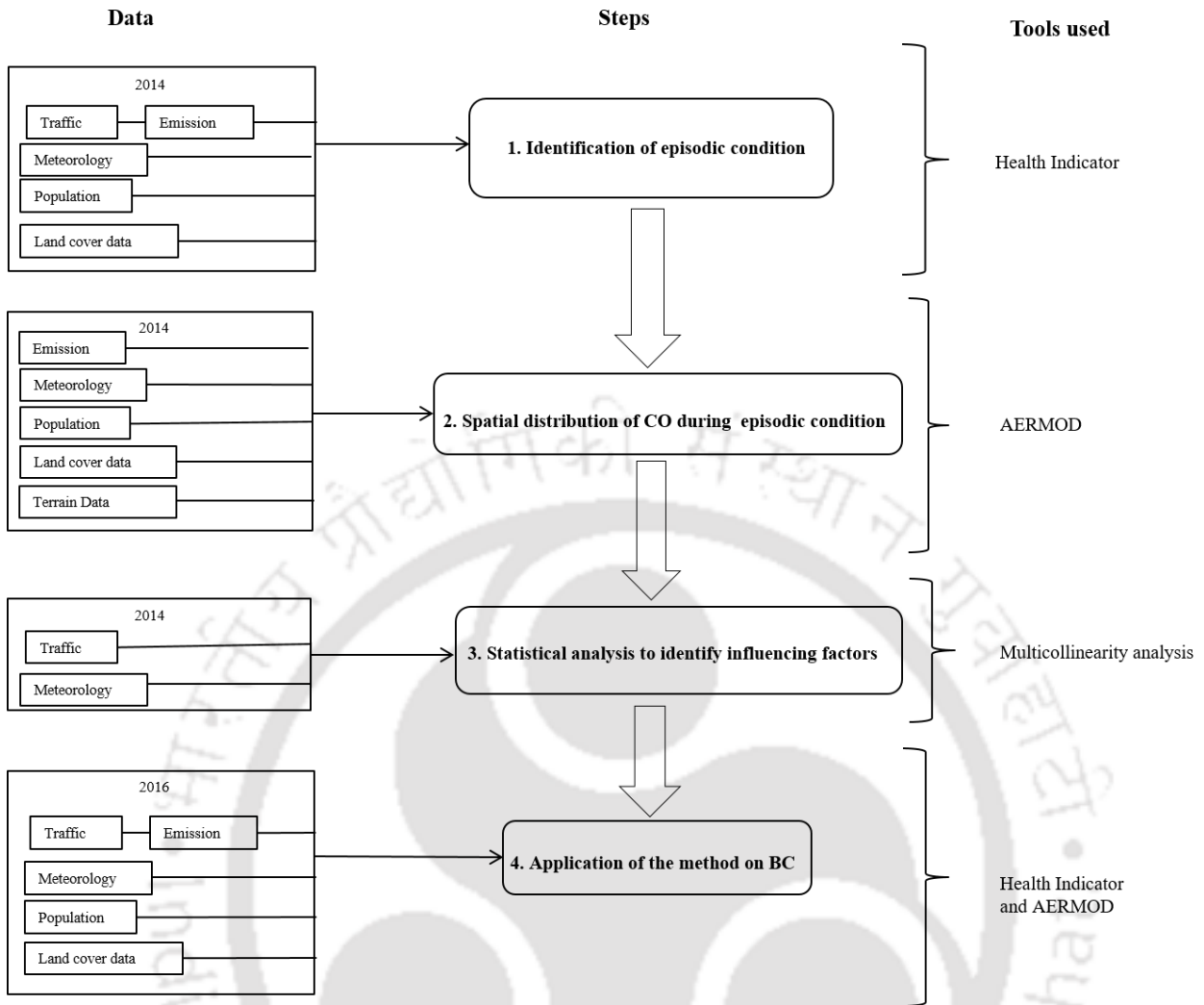


Fig. 6. 1 Flow chart of the methodology for identification and modelling of episodic condition

6.2.1.1 Study site and field work

A traffic corridor, two-way road of about 300 m long in the dense urban area, located in the Lachit Nagar of Guwahati, was selected. It is a highly trafficked corridor and houses many important government and public buildings. The monitoring locations were selected in the proximity of regular traffic jams and high pedestrian population. Fig 3.1 shows the study area and the monitoring locations with same important features of the urban traffic corridor. The details of CO monitoring have been given in section 3.2.1. Traffic and meteorological data collection methods are discussed in section 3.2.2.

The exposure of pedestrian and cyclist is more along the traffic corridor, which increases further during episodic conditions. Therefore, pedestrian population count was also done by using the same videotapes used for the traffic counts. The population count was also carried out for the same time period. The other relevant data on building density, mean building height, and the engineering dimensions of the roadway were collected.

6.2.1.2 Emission modelling

Emission was calculated for real and standard conditions for the calculation of indicators. The methods are described below:

Emission for real condition

Traffic emission (g) for real condition was calculated by multiplying the traffic count in each composition to the respective emission rates taken from the Automotive Research Association of India (ARAI). The estimated hourly total emission (g) has been discussed in the previous chapter, section 5.1.1.

Emission for standard condition

The empirical box modelling was used to calculate the emission for standard condition using the safe level, assuming those the threshold concentrations of health risks. The estimated emission for standard condition has been discussed in the previous chapter, section 5.1.2.

6.2.1.3 Identification of episodic condition due to CO

Most researchers considered episodic condition when air pollutant concentrations exceeded its national standard level (Hien et al., 2011; Oanh et al., 2005). In this study, an indicator developed by Lepicier et al. (2013) for the chronic health impact of pollutant emission has been used for the short-term impact of pollutant emission caused by the traffic in the selected traffic corridor. The indicator (I) was calculated by equation 6.1 (Lepicier et al., 2013) as the product of a long-term emission, exposure factor and toxicity factor of the pollutants under study.

$$I = Q_i \cdot F_{Exp} \cdot F_{Tox} \quad (6.1)$$

where, F_{Exp} is the population exposure component (person m⁻³), F_{Tox} the toxicity factor (m³ mg⁻¹) and Q_i is the emission of pollutant i (mg).

To forecast episodic condition along a roadway in the traffic corridor due to CO two hourly-indicators from 8:00 to 18:00 hours have been calculated, for real condition (I_r) and for standard condition (I_s). The I_s is the indicator, which represents safe level considering health impacts of air pollutants on humans. It assumes that the pollutant concentration has no health impacts on humans if exposed for a period of 1-h anytime during the day. The I_r is the indicator, which represents that the humans are exposed to the air pollutant levels resulting from the real-time emissions caused by the actual traffic flow on the road, population exposed and the local meteorology. The indicators for real and standard conditions were calculated by equations 6.2 and 6.3, respectively. The Q_R and Q_S were estimated using a semi-empirical model (Dirks et al., 2003; Gokhale and Pandian, 2007).

$$I_r = Q_R \cdot F_{Exp} \cdot F_{Tox} \quad (6.2)$$

$$I_s = Q_S \cdot F_{Exp} \cdot F_{Tox} \quad (6.3)$$

where, F_{Exp} is the population exposure (person m⁻³), F_{Tox} , the toxicity factor (m³ mg⁻¹) and Q_R and Q_S are the total emissions of CO (mg) for real and standard conditions, respectively.

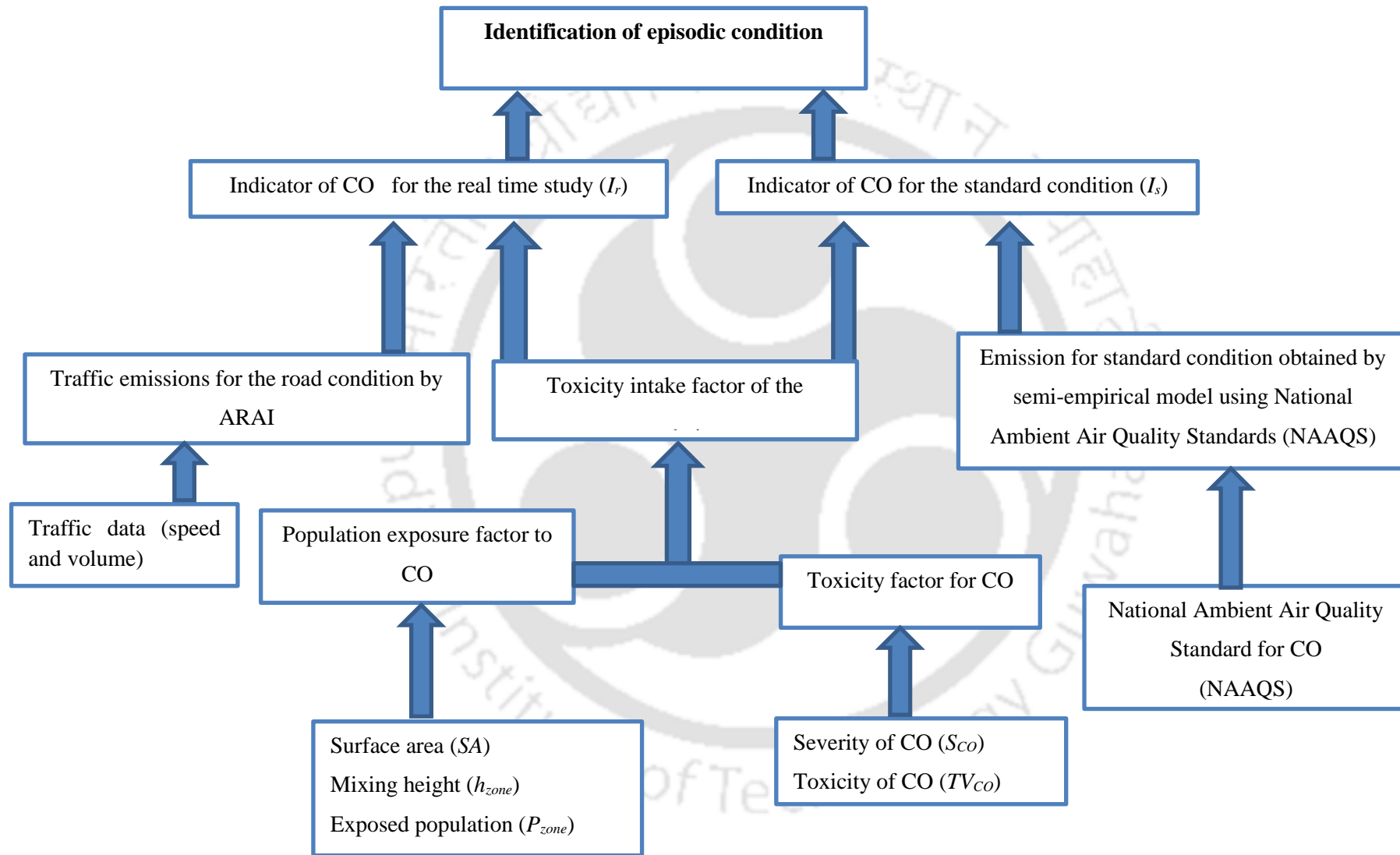


Fig. 6. 2 Methodology for the development of Indicator for the Health Impact of Pollutant Emissions (I)

Population Exposure factor

The population exposure factor represents the exposure of population using the corridor within which the pollutants are dispersed under different meteorological conditions at different times of the day. The exposure factor is given by equation 6.4 (Lepicier et al., 2013).

$$F_{Exp} = \frac{P_{zone}}{SA \cdot h_{zone}} \quad (6.4)$$

where, P_{zone} is the number of pedestrian in the zone; SA the zone surface (m^2); and h_{zone} is the mixing height in the zone (m), which was calculated by using equation 6.5 (Lepicier et al., 2013).

$$h_{zone} = (0.38) \cdot \{(0.45) \cdot H \cdot d\}^{0.2} \cdot (SA_{zone})^{0.4} \quad (6.5)$$

where, H is the mean height of the buildings in the region (m), and d is the building density (m^2 of buildings area m^2).

Toxicity factor

Toxicity factor, which is used to calculate indicator, has two components - the potential for toxicity and the severity of a pollutant. The toxicity factor uses the threshold value of a pollutant which can cause health effect, and the severity as a criterion for applying different weighting to different pollutants, according to their magnitudes of causing the health impact on human health. Selection of a type of reference effect for exposure to the pollutant and decision on a severity value for each effect is a vital task (Lepicier et al., 2013). The toxicity factor is expressed by equation 6.6.

$$F_{T_i} = \frac{S_i}{TV_i} \quad (6.6)$$

where, S_i (severity of pollutant) is a constant value (1, 0.4 and 0.4 for CO, PM_{2.5} and

BC, respectively) and TV_i is the toxicity value (threshold value of 2, 0.06 and 0.02 for CO, $PM_{2.5}$ and BC, respectively) of pollutant ($mg\ m^{-3}$).

Both indicators, real and standard conditions for each pollutant, were compared on the same time scale to examine when the I_r exceeds the I_s . This exceedance event indicated the episodic condition occurring at that time. Further, the combine effect of the three pollutants was studied. The indicators and the difference between them provided the magnitude of episodic event caused due to the compound effect of pollutants under a certain meteorological condition and population exposure.

6.2.2 Spatial distribution of CO during episodic condition

6.2.2.1 AERMOD

AERMOD is a USEPA recommended, steady-state Gaussian air quality dispersion model, which is often used to assess pollutant concentrations from traffic source (Venkatram et al., 2009; Gibson et al., 2013). It predicts mostly the criteria pollutants such as SO_2 , CO, NO_2 , lead (Pb) and $PM_{2.5}$ emitted from several sources. It incorporates the effects of vertical variations in the planetary boundary layer (PBL) for the dispersion of air pollutants. AERMOD incorporates AERMET (meteorological preprocessor) to describe the characteristics of planetary boundary layer and AERMAP (terrain preprocessor) to describe plume flow in complex terrain (i.e. hill). The AERMET requires hourly data on cloud cover, surface meteorology, such as wind speed and direction, temperature, dew point, humidity and sea level pressure and twice-a-day upper air soundings. The AERMAP uses gridded terrain data (digital elevation model data) to calculate a representative terrain-influence height, which is uniquely defined for each receptor location to calculate the plume height. The input data used in this study have been described in model application section. The AERMOD model algorithms have been specified for convective and stable conditions.

The AERMOD concentration prediction algorithm in the stable boundary layer (i.e., stable and neutral stratifications) has been explained by equation 6.7.

$$(C_s)\{z_r, y_r, z\} = \frac{Q}{\sqrt{2\pi} u \sigma_{zs}} F_y \times \sum_{m=-\infty}^{\infty} \left\{ \exp \left[-\frac{(z - h_{es} - 2mz_{ieff})^2}{2\sigma_{zs}^2} \right] + \exp \left[-\frac{(z + h_{es} + 2mz_{ieff})^2}{2\sigma_{zs}^2} \right] \right\} \quad (6.7)$$

where z_{ieff} is the effective mechanical mixing height; σ_{zs} the total vertical dispersion; h_{es} the plume height; F_y the lateral distribution functions; σ_{zs} the vertical dispersion; m the number of image sources and u is the wind velocity.

The AERMOD concentration prediction algorithm for the convective boundary layer is different from stable conditions. For buoyant releases, AERMOD addresses distance dependent plume rise. A “direct” source is defined to treat that portion of the plume’s mass that is transported directly to the ground, plus all subsequent reflections of this direct mass. For plume segments initially rising in updrafts, an “indirect” or modified-image source is included to address the initial reflection at z_i and all subsequent reflections at $z = 0$ and z_i of this indirect mass. A plume-rise component is added to delay the downward dispersion of the indirect source material from the CBL top; this mimics the tendency of buoyant plumes to remain temporarily near z_i and resist downward mixing. Additionally, a “penetrated” source (above the CBL top) is included to account for material that initially penetrates the elevated inversion while allowing for it to subsequently reentrain into the growing CBL. The total concentration (C_c) in the CBL is found by summing the contribution from the three sources as for the horizontal plume state shown by equation 6.8.

$$C_c\{z_r, y_r, z_r\} = C_d\{z_r, y_r, z_r\} + C_r\{z_r, y_r, z_r\} + C_p\{z_r, y_r, z_r\} \quad (6.8)$$

where, C_d , C_r and C_p are the contributions from the direct, indirect, and penetrated sources, respectively as shown by equation 6.9, 6.10 and 6.11. This three-plume concept is shown schematically in Figure 6.3.

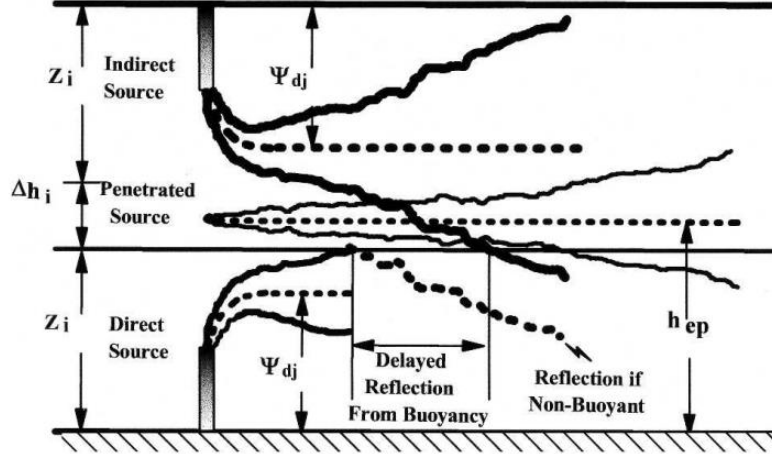


Fig. 6.3 AERMOD's source contributions (source: Cimorelli et al., 2005)

$$(C_d)\{z_r, y_r, z\} = \frac{Q f_p}{\sqrt{2 \pi u}} F_y \times \sum_{j=1}^2 \sum_{m=0}^{\infty} \frac{\lambda_j}{\sigma_{zj}} \times \left\{ \exp \left[-\frac{(z - \Psi_{dj} - 2mz_i)^2}{2\sigma_{zj}^2} \right] + \exp \left[-\frac{(z + \Psi_{dj} + 2mz_i)^2}{2\sigma_{zj}^2} \right] \right\} \quad (6.9)$$

$$(C_r)\{z_r, y_r, z\} = \frac{Q f_p}{\sqrt{2 \pi u}} F_y \times \sum_{j=1}^2 \sum_{m=1}^{\infty} \frac{\lambda_j}{\sigma_{zj}} \times \left\{ \exp \left[-\frac{(z + \Psi_{rj} - 2mz_i)^2}{2\sigma_{zj}^2} \right] + \exp \left[-\frac{(z - \Psi_{rj} + 2mz_i)^2}{2\sigma_{zj}^2} \right] \right\} \quad (6.10)$$

$$(C_p)\{z_r, y_r, z\} = \frac{Q(1 - f_p)}{\sqrt{2 \pi u} \sigma_{zp}} F_y \times \sum_{m=-\infty}^{\infty} \left\{ \exp \left[-\frac{(z - h_{ep} - 2mz_{ieff})^2}{2\sigma_{zp}^2} \right] + \exp \left[-\frac{(z + h_{ep} + 2mz_{ieff})^2}{2\sigma_{zp}^2} \right] \right\} \quad (6.11)$$

where, f_p is the fraction of the source material that does not penetrate; z_i and z_{ieff} the effective mechanical mixing height; σ_{zj} and σ_{zp} the total vertical dispersion; Ψ_{dj} , Ψ_{rj} and h_{ep} the plume

height for direct, indirect, and penetrated sources; F_y the lateral distribution functions; m the number of image sources and u is the wind velocity. A flowchart of AERMOD modelling system has been shown in Fig. 6.4.

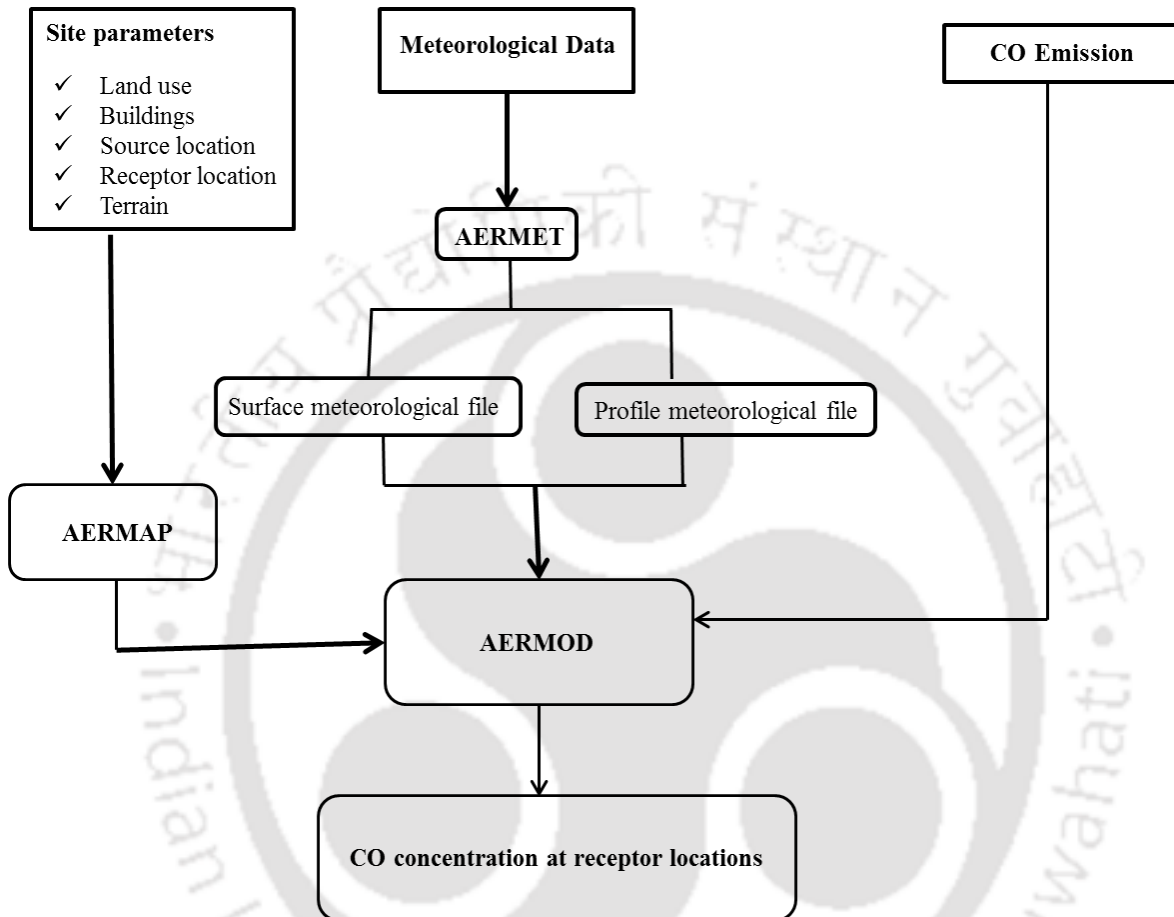


Fig. 6. 4 Flow chart of spatial modelling of CO

6.2.2.2 Model application

The AERMOD model has been applied for the study period of March, 2014. The model has been set up by using two possible sources such as traffic, and area source. Area source covers the small bus stop where buses are stopping throughout the day and causing emissions. The site is shown in Figure 3.1. The hourly aggregated emission rates have been calculated by using ARAI emission factors. All the line sources are located at a height of 0.375 m (Liu et al., 2011). The AERMET requires classification of the modelling domain into different ‘sectors’ depending on land use. A single sector with ‘urban’ land use type is specified. AERMET

outputs two files that contain processed meteorological data ready for input into AERMOD. Building data was obtained by doing survey on field. For each buildings floor height was counted and height calculated by multiplying with 3.3 as it is the average floor height in Guwahati. Total 444 pollutant concentration receptors were specified in a 21 x 21 grid matrix over the study network to capture the spatial distribution of concentration for the entire domain. The modeled concentrations obtained at the location where the CO and CO₂ analyzer were used for making comparisons to the measured values. Figure 3.1 shows the emission source specification (roadway) in the site. After that observed and modelled concentration was compared to validate the model. After comparison the highest concentrations of each receptor was segregated which fall in episodic period. So after this contour plot was made to identify the locations which are prone to episode of CO during episodic period.

6.2.3 Factors causing episodic condition

The higher value of the degree of episodic condition indicates health risk in respect of the three pollutants. The relationship, therefore, between the degree of episodic condition and other parameters (meteorological and traffic) has been analyzed to identify the key parameters responsible for the development of episodic condition in the traffic corridor. Multiple regression has been carried out for identifying the influencing parameters on the episodic conditions. For developing a multiple regression model, to select the most appropriate parameters for the indicator, multi-collinearity and backward elimination methods have been used. After multi-collinearity analysis, the backward elimination regression analysis has been done by removing the variables one by one having the coefficients of low level of significance (t-test). The final model has been proposed, thus, developed to identify the variables causing episodic condition. The coefficients of variables of the final model (Model 3) were used for the purpose of validation of the model. The SPSS 20.0 software was used for the statistical analysis

to obtain relationship between the indicator and other independent variables. The frame work for this analysis is shown in Figure 6.5.

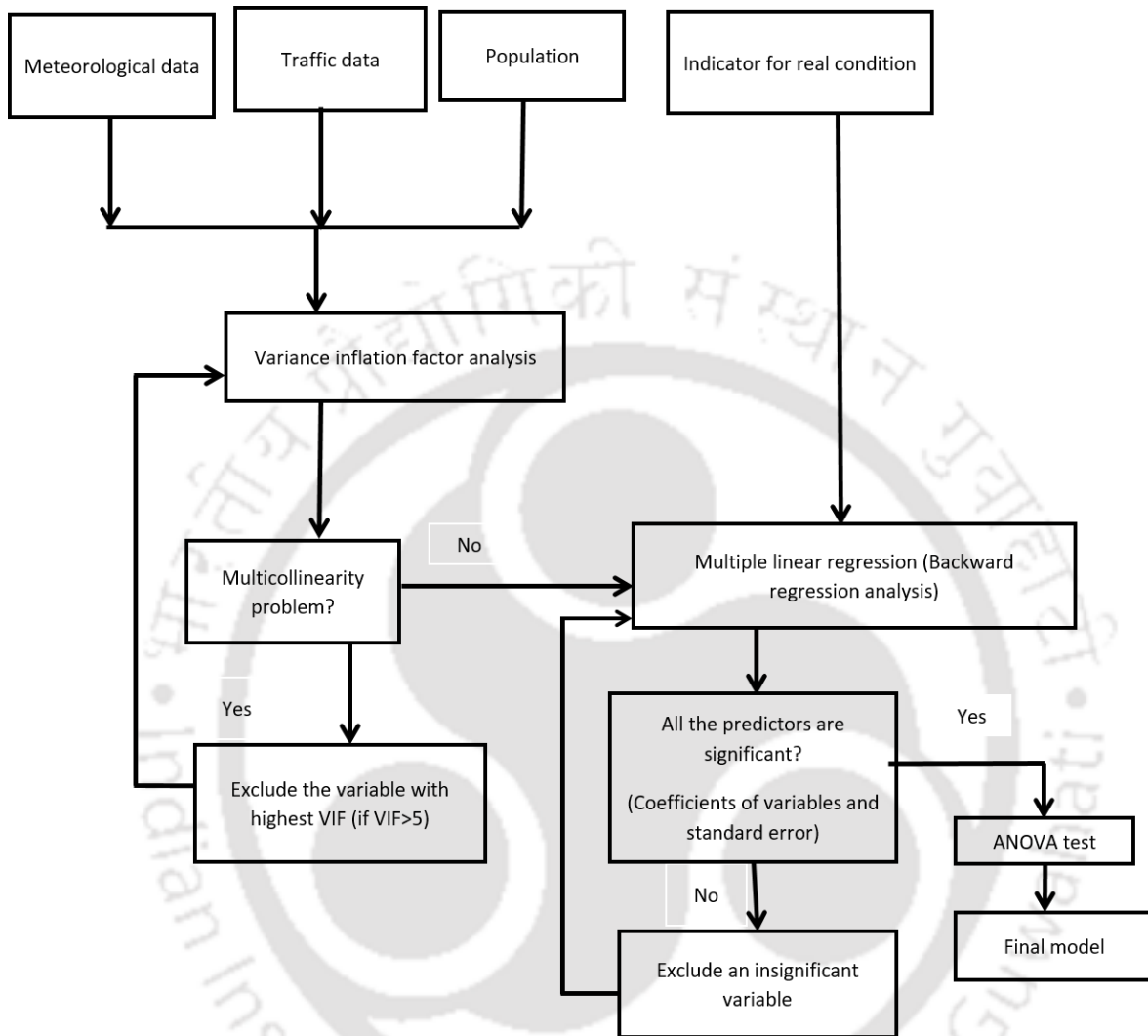


Fig. 6. 5 Multiple regression modelling to identify the variables causing episodic condition

6.3 RESULTS AND DISCUSSION

6.3.1 Identification of episodic condition due to CO

Figure 6.6 show the comparisons of the indicators at real and standard conditions on the same time scale for CO. The results showed that (Fig. 6.6 a) the I_r exceeds the I_s at morning between 10:00 - 14:00 hours and at evening on 16:00 hours at location L1. L2 showed (Fig. 6.6 b) different pattern as exceedance observed at morning between 8:00 – 11:00 hours and there was

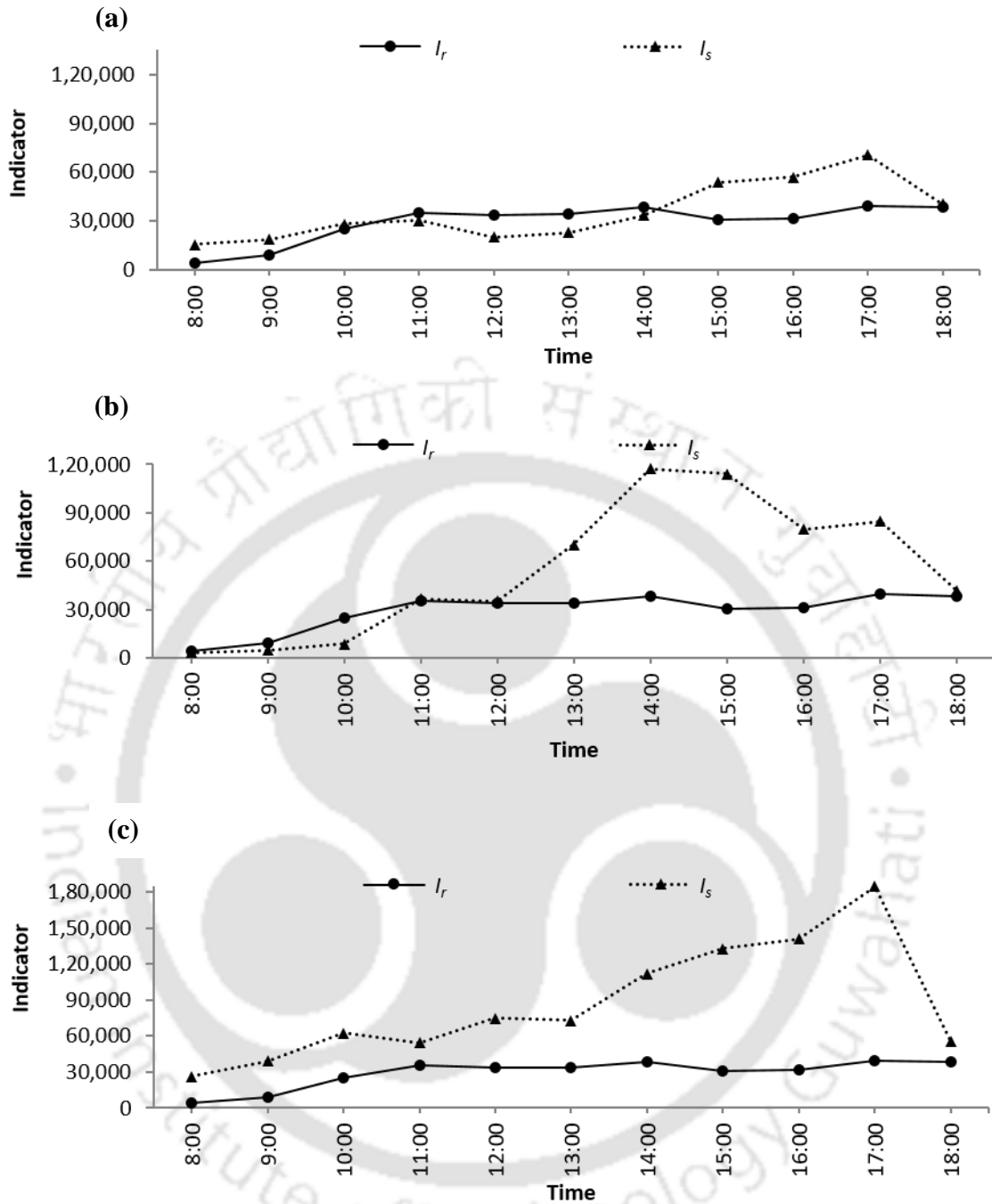


Fig. 6. 6 Variation of Indicator values observed at (a) L1 and (b) L2 and (c) L3

no exceedance observed for L3 (Fig. 6.6 c). This indicates that even with same traffic emission the chances of episode due to CO may differ with different location and meteorology. To get the actual exceedance time and magnitude of the episodic condition, the difference between the I_r and I_s values were calculated and plotted against the time, as shown in Fig. 6.7. The episodic condition was observed at different time at L1 and L2 and showed difference in the

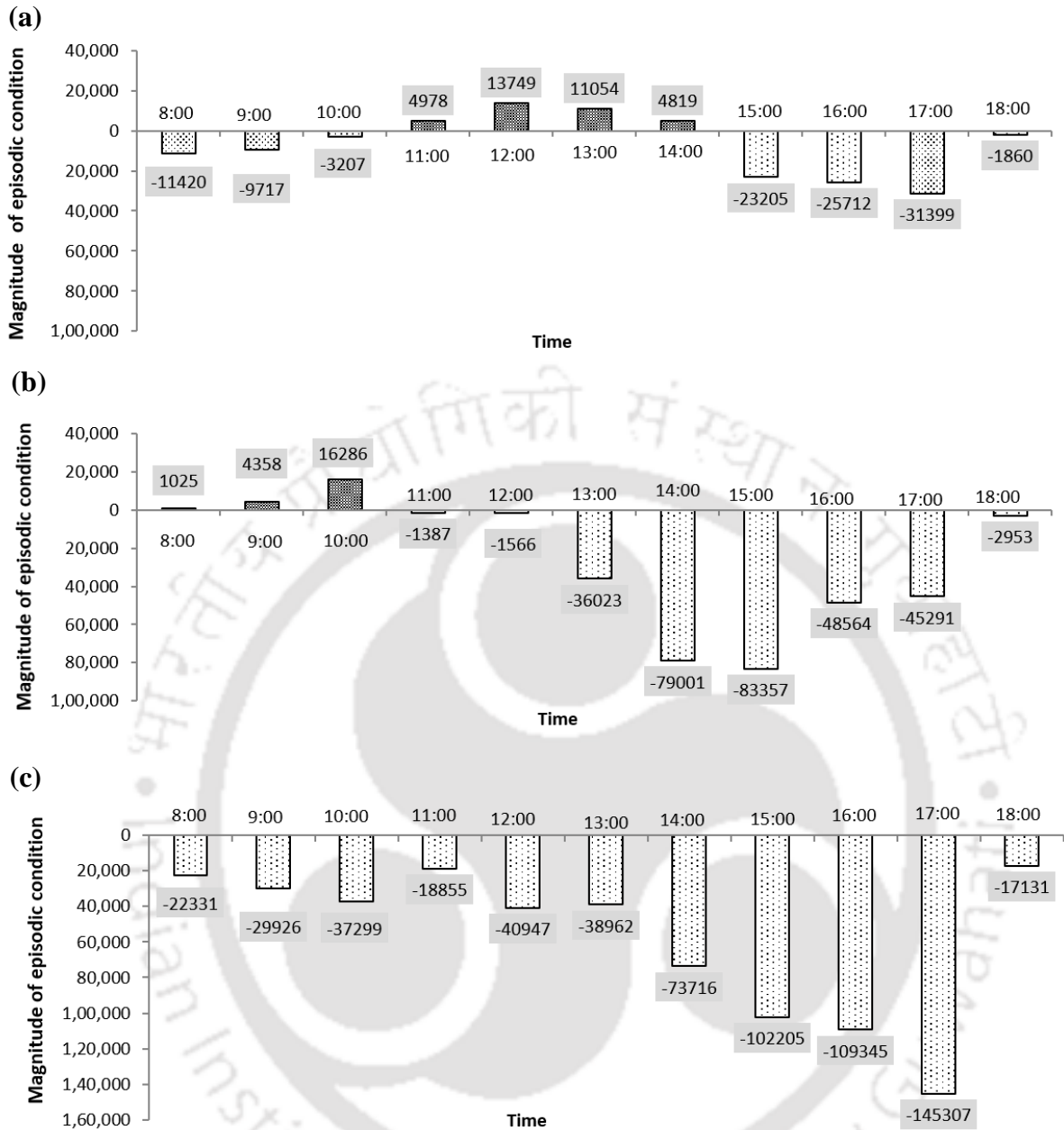


Fig. 6. 7 Magnitudes of episodic conditions at (a) L1, (b) L2, and (c) L3

degree of episodic condition too. This may be due to the combined effect of low wind and high emissions from traffic. The highest magnitude of episodic condition was observed at 12:00 noon at L1 and 10:00 hours at L2. It is also essential for this reason to determine the factors that are causing variations in degree of episodic condition. The ratio of I_r and I_s (Fig. 6.8 a) was used to get the frequency of exceedance or episode in each location with clear observation

of degree of the episodic condition. If I_r and I_s is equal or I_r is less than I_s the ratio will be 1 or less than 1. The ratio value 1 is the threshold value for episode which has been shown as red dot line in Fig. 6.8 a. Episodic condition observed 4 times in L1 and 3 times in L2 but the magnitude was quite high at L2. Fig 6.8 b suggests that percentage of duration of episodic condition was 36% and 27% for L1 and L2. Therefore, after studying the temporal variation of episodic conditions in the traffic corridor the study of spatial distribution is important to identify the most episodic-prone zones.

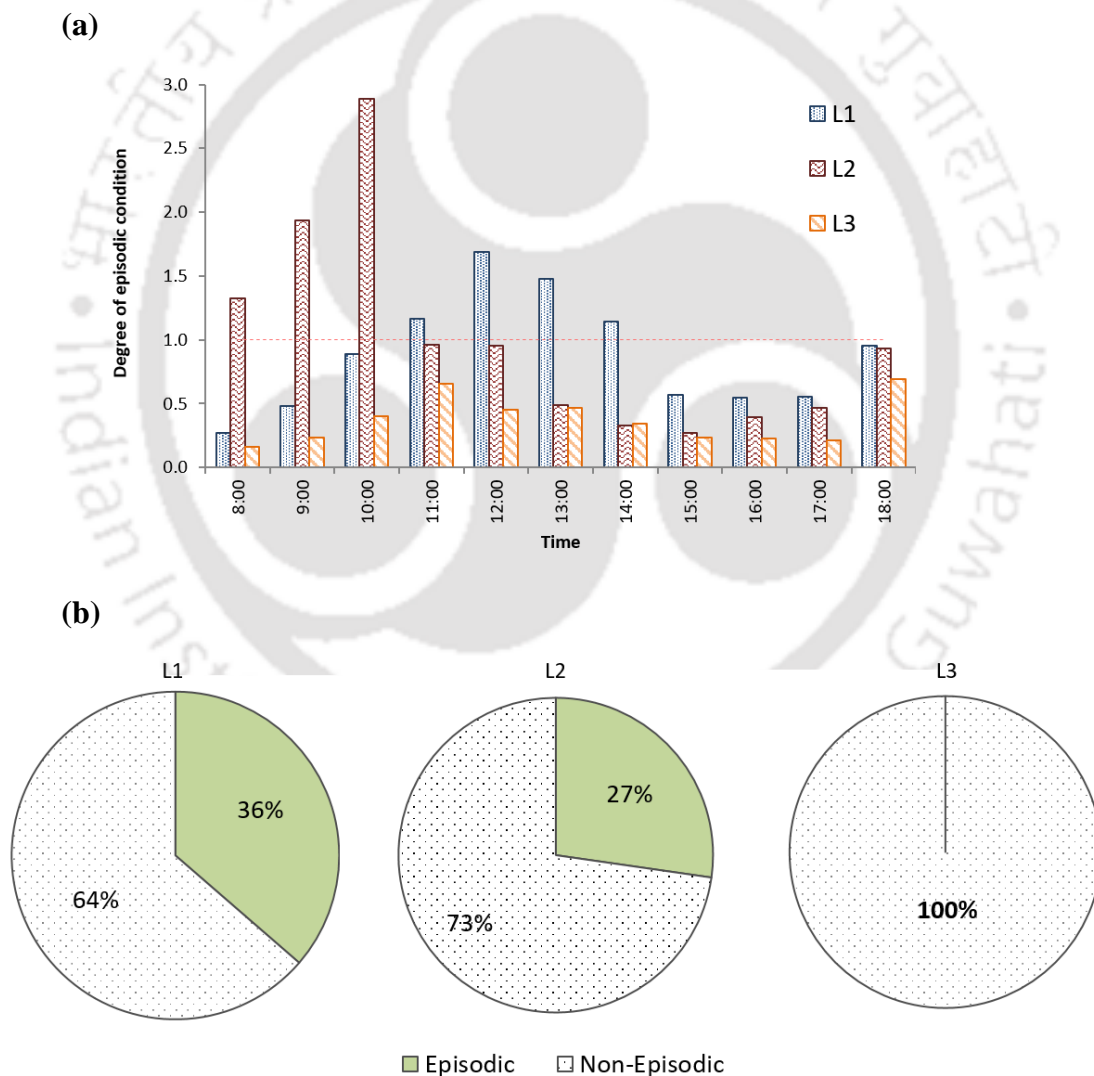


Fig. 6.8 (a) Degree of episodic condition (b) Percentage of duration of episodic condition

6.3.2. Spatial distribution of CO during episodic condition

The upper air estimator, in the AERMET based on the well referred algorithms (Thomson et al., 1992) has been used to estimate the mixing height using surface meteorological data (Jesse et al., 2011). The spatial distribution of CO during the highest concentration at all the locations shown in Fig. 6.9 to 6.11. The 1st highest maximum modelled concentration at L1 and L2 was found at 18:00 hours whereas at L3 the highest concentration was found at 11:00 hours. The highest concentration was found at L1 and lowest was at L3 (Fig. 6.9 and Fig. 6.11). This is an hourly average maximum CO concentration modeled for March, 2014 at 1.5 m height. Highest

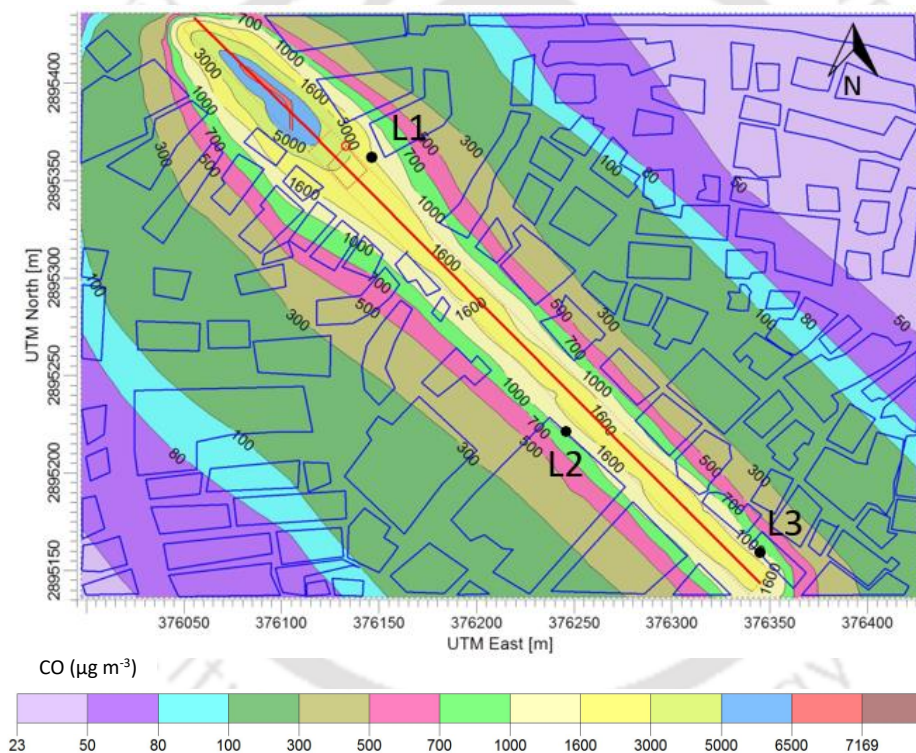


Fig. 6. 9 Spatial distribution of the modelled CO ($\mu\text{g m}^{-3}$) in the study region (21 X 21 grid matrix*) during monitoring at L1 (Time - 18:00 hours, Max. concentration - 1623 $\mu\text{g m}^{-3}$)

concentration was found to be about 1623 $\mu\text{g m}^{-3}$ at L1, 1528 $\mu\text{g m}^{-3}$ at L2 and 720 $\mu\text{g m}^{-3}$ at L3. This prediction has been validated by comparing the modelled concentration and the observed concentration at the same time.

* Total 441 pollutant concentration receptors were specified in a 21 x 21 grid matrix over the study network to capture the spatial distribution of concentration for the entire domain.

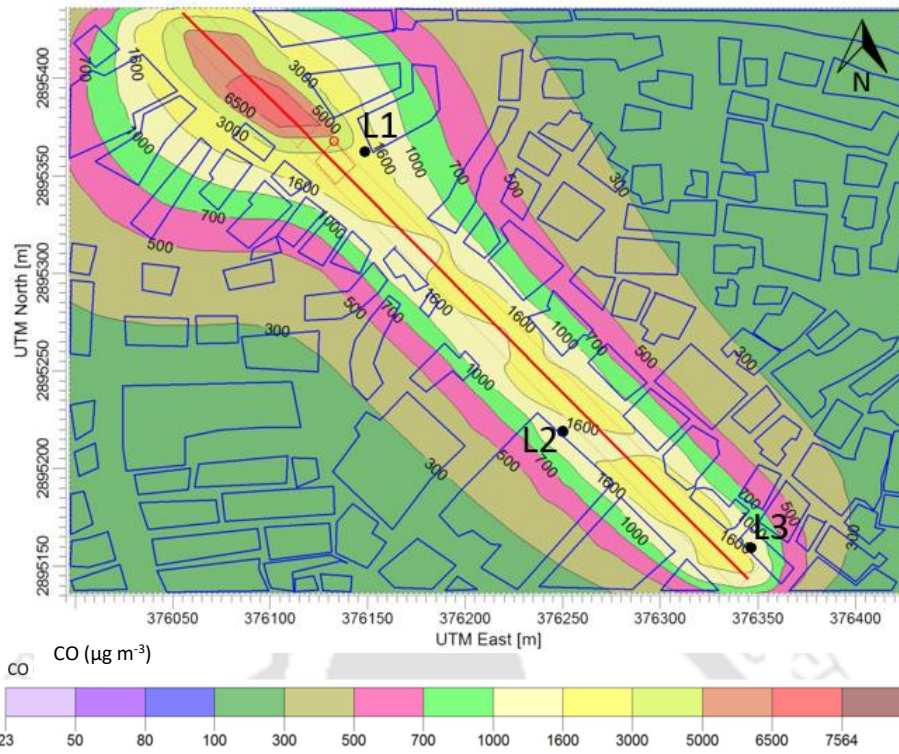


Fig. 6. 10 Spatial distribution of the modelled CO ($\mu\text{g m}^{-3}$) in the study region during monitoring at L2 (Time - 18:00 hours, Max. concentration - 1528 $\mu\text{g m}^{-3}$)

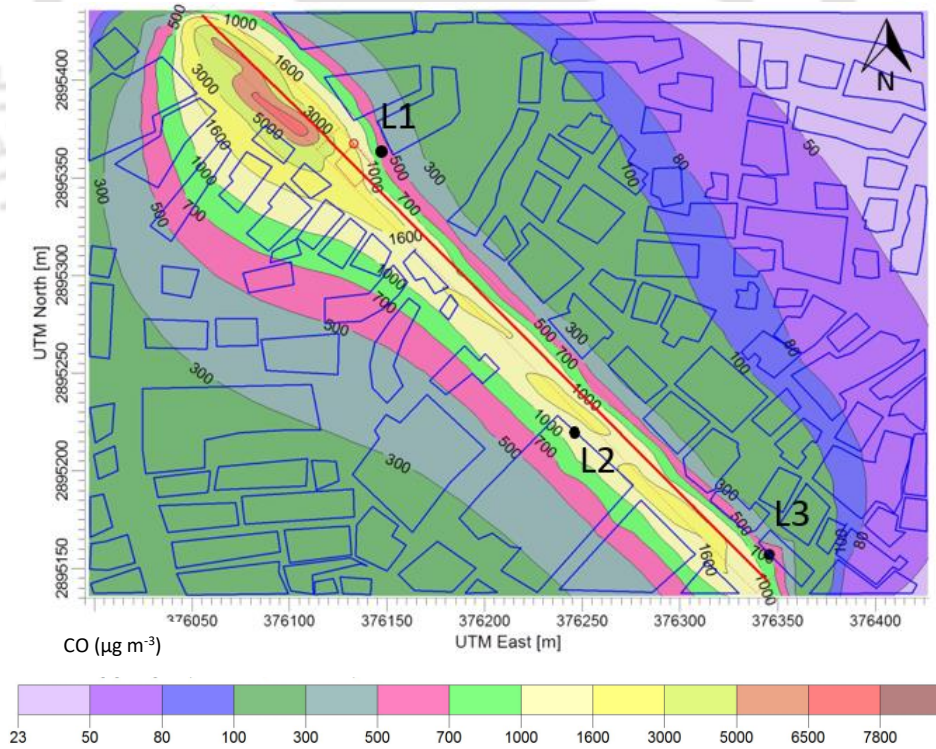


Fig. 6. 11 Spatial distribution of the modelled CO ($\mu\text{g m}^{-3}$) in the study region during monitoring at L3 (Time - 11:00 hours, Max. concentration - 720 $\mu\text{g m}^{-3}$)

The modelling results showed that the highest concentrations occur during the episodic condition. It is also a peak hour for traffic. Fig. 6.12 shows the modelled CO concentrations

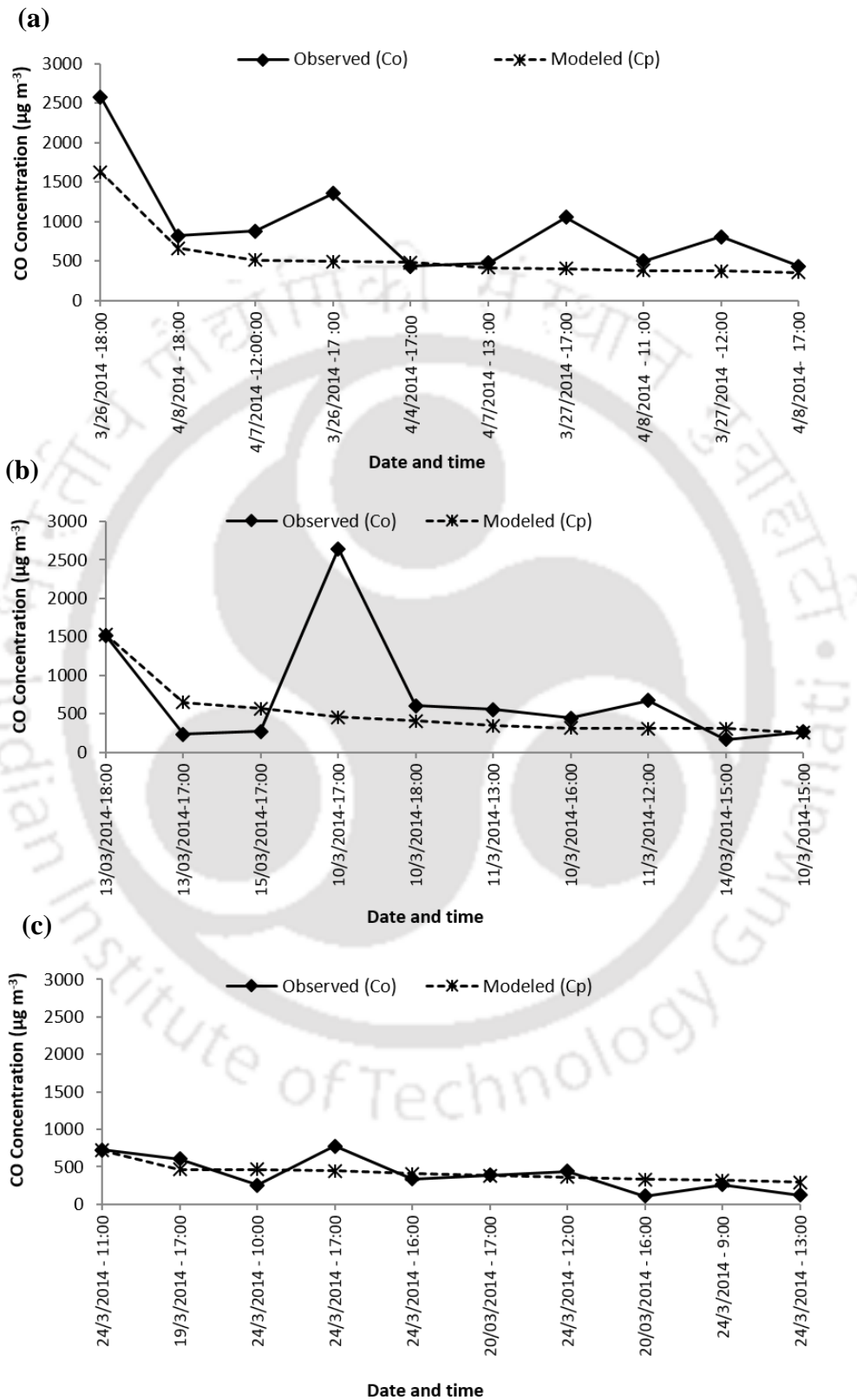


Fig. 6. 12 Observed and modelled hourly (1st to 10th maximum) concentration of CO at a) L1, b) L2 and c) L3

and comparison with observed concentration at the three sites (L1, L2 and L3). Performance evaluation was done by using statistical parameters (FB, MG, NMSE, VG, R and FAC2). An accurate model would have MG, VG, R, and FAC2 1.0; and FB and NMSE 0.0 (Chang and Hanna, 2004). Overall, the values of FB indicate that at L1 and L2 under predicts by a moderate amount (about 35 to 48%), while at L3 it over predicts by about 4% (Table 6.1). The fraction

Table 6. 1: Air quality modelling results and the performance evaluation at L1, L2 and L3

Location	Mean Observed Hourly Concentration ($\mu\text{g m}^{-3}$)	Mean Modelled Hourly Concentration ($\mu\text{g m}^{-3}$)	FB	MG	NMSE	VG	R	FAC2
L1	932.88	570.62	0.48	1.56	0.46	1.38	0.81	0.80
L2	736.69	512.72	0.36	1.15	1.40	1.86	0.33	0.70
L3	402.55	420.04	-0.04	0.82	0.16	1.32	0.64	0.80

of predictions within FAC2, is slightly high for L1 and L3 (0.8) than L2 (0.7). NMSE value are less than 0 for L1 and L3 but at L2 the value is 1.40 which indicates that the magnitude of the scatter is more than the mean concentration which can be seen in Fig. 6.13.

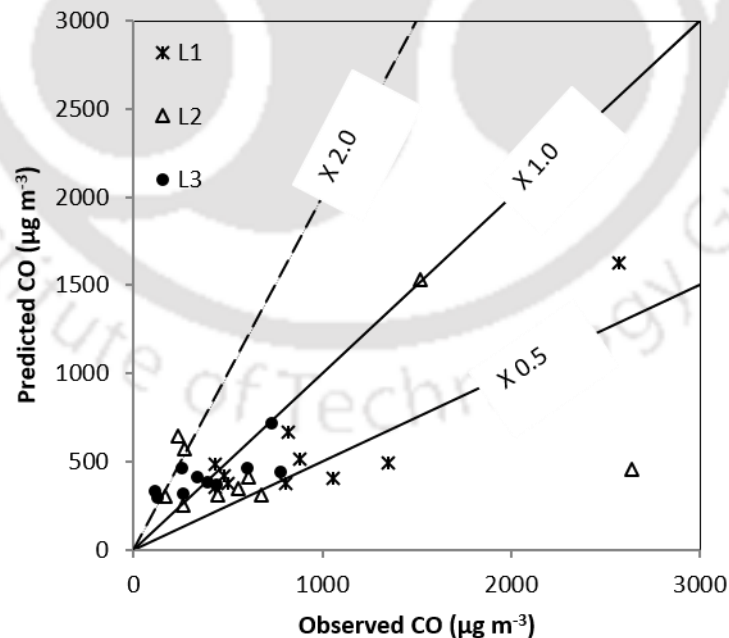


Fig. 6. 13 Observed vs. modelled hourly (1st to 10th maximum) concentration of CO at L1, L2 and L3 with FAC2 upper and lower limit boundaries

It was seen that concentrations were modelled well at L3 and whereas at L1 prediction was well but the MG and R values were slightly high due to under prediction. Whereas, at L2 the NMSE and VG values were high, which may be due to outlier as was observed in Fig. 6.12 b, at 4th highest prediction. So episodic condition was seen near road during episodic period as contour plot is showing high concentrations adjacent to the road. The concentrations at roadside are not uniform. The adjacent area to L1 location is more prone to episode.

6.3.3 Factors causing episodic condition

The type of variables, referred as direct (Set-1), includes the traffic parameters i.e., traffic speed (TS) and Total vehicle (TV) and meteorological variables, i.e. wind speed (WS), wind direction (WD), relative humidity (RH) and temperature (Temp) for multi-collinearity analysis. These parameters were used to achieve the relationship between these independent and dependent (degree of episodic condition) variables. The analysis was done on variables of Set-1 first. The results (Table 6.2) showed that the variance inflation factor (VIF) was more than 5 for Temp and RH, thus, there exist a collinearity. Hence, 'RH' was removed (due to VIF more than 5) and reanalyzed. It has been observed that in Set-2 for all the parameters, the VIF value was less than 5, which depicts the absence of multi-collinearity between the independent variables.

Backward elimination analysis (Table 6.3) was started with Model-1 (parameters of Set-1). For Model-1, WD and TV showed p -value of more than 0.05. In the next step, i.e. for Model-2, TV was removed and p -value for WD was found to be 0.073, which is not significant. For the Model-3, WD was removed and reanalyzed. So the process was stopped at Model-3, when p -value was found to be less than 0.05 (0.000 for Temp, 0.010 for WS and 0.000 for TS) for the predictor variables of Temp, WS and TS. In several studies, it is found that Temp and WS are the major meteorological factors for causing higher air pollution (Xu et al., 2011; Zhang et al., 2015 and Csavina et al., 2014). The present study also confirmed the similar results. The

RH is also an important variable, but, since it is directly related to Temp, it was eliminated in the multi-collinearity analysis. The ANOVA (Table 6.4) of all the models highlighted the fact that the variation explained by the model was not due to chance (at a significance level $p < 0.05$). The coefficients and standard error of the all 4 models are shown in Table 6.5- 6.7.

From this analysis, traffic speed, temperature and wind speed were identified as the major factors which caused episodic condition in the traffic corridor.

Table 6. 2: Results obtained using multi-collinearity analysis for CO

Variable name	Variance inflation factor (VIF) of the predictors in different datasets	
	Set- 1	Set-2
Temperature	10.99	2.61
Humidity	6.79	Removed
Wind Direction	1.35	1.61
Wind speed	1.85	1.54
Traffic Speed	1.55	2.91
Total vehicle	3.13	2.61

Table 6. 3: Results obtained using backward regression analysis to eliminate statistically insignificant variables for CO

Variable name	Significance level of the independent variables (p -value of the coefficients) in different models		
	Model-1	Model-2	Model-3
Temperature	0.000	0.000	0.000
Wind speed	0.100	0.079	0.010
Traffic Speed	0.000	0.000	0.000
Wind Direction	0.060	0.073	Removed
Total vehicle	0.394	Removed	Removed

Table 6. 4: Stepwise linear regression ANOVA results

Model	Predictors	Sources of Variation	Sum of Squares	df	Mean Square	F	Sig.	R ²
Model-1	Temperature, Wind Direction Wind speed Traffic Speed Total vehicle	Regression	35210226581	5	7042045316	14.6	0.00	0.73
		Residual	12981844185	27	480809044			
		Total	48192070766	32				
Model-2	Temperature Wind Direction Wind speed Traffic Speed	Regression	34849736010	4	8712434002	18.3	0.00	0.72
		Residual	13342334756	28	476511956			
		Total	48192070766	32				
Model-3	Temperature Wind speed Traffic Speed	Regression	33193657570	3	11064552523	21.4	0.00	0.69
		Residual	14998413196	29	517186662			
		Total	48192070766	32				

Table 6. 5: Coefficients and standard error of Model 1

Model-1	Coefficients		
	B	Std. Error	t-ratio
Constant	309803.86	47015.53	6.59
Temperature	-8501.38	2093.43	-4.06
Wind Direction	87.88	44.84	1.96
Wind speed	-10404.26	6102.87	-1.71
Traffic Speed	-2174.57	457.33	-4.76
Total vehicle	-4.87	5.62	-0.87

Table 6. 6: Coefficients and standard error of Model 2

Model-2	Coefficients		
	B	Std. Error	t-ratio
Constant	306803.71	46677.69	6.57
Temperature	-9542.97	1705.63	-5.59
Wind Direction	82.37	44.19	1.86
Wind speed	-10997.69	6037.10	-1.82
Traffic Speed	-1971.32	390.74	-5.05

Table 6. 7: Coefficients and standard error of Model 3

Model 3	Coefficients		
	B	Std. Error	t-ratio
Constant	282954.53	46767.08	6.05
Temperature	-8128.99	1591.58	-5.11
Wind speed	-15688.55	5717.16	-2.74
Traffic Speed	-1875.29	403.52	-4.65

6.4 VALIDATION AND APPLICATION OF THE METHOD TO BC

Identification of episodic condition was done in case of CO and the method was repeated by applying emission data of BC. The method was applied to BC to validate the time and spatial locations of the episodic condition caused by CO. This signifies that it may be useful method to forecast future episodic events in urban traffic corridors but only in case of CO whereas BC from traffic which is the fraction of PM_{2.5} is also an important pollutant in respect of human health. The details of the method of data collection has been given in chapter 3. The emission of BC was calculated using traffic data collected in 2016. The spatial distribution of BC was also analysed like CO using AERMOD. The model was evaluated for BC using some statistical parameters (FB, MG, NMSE, VG, R and FAC2). The frame work of the method has been given in Fig. 6.14.

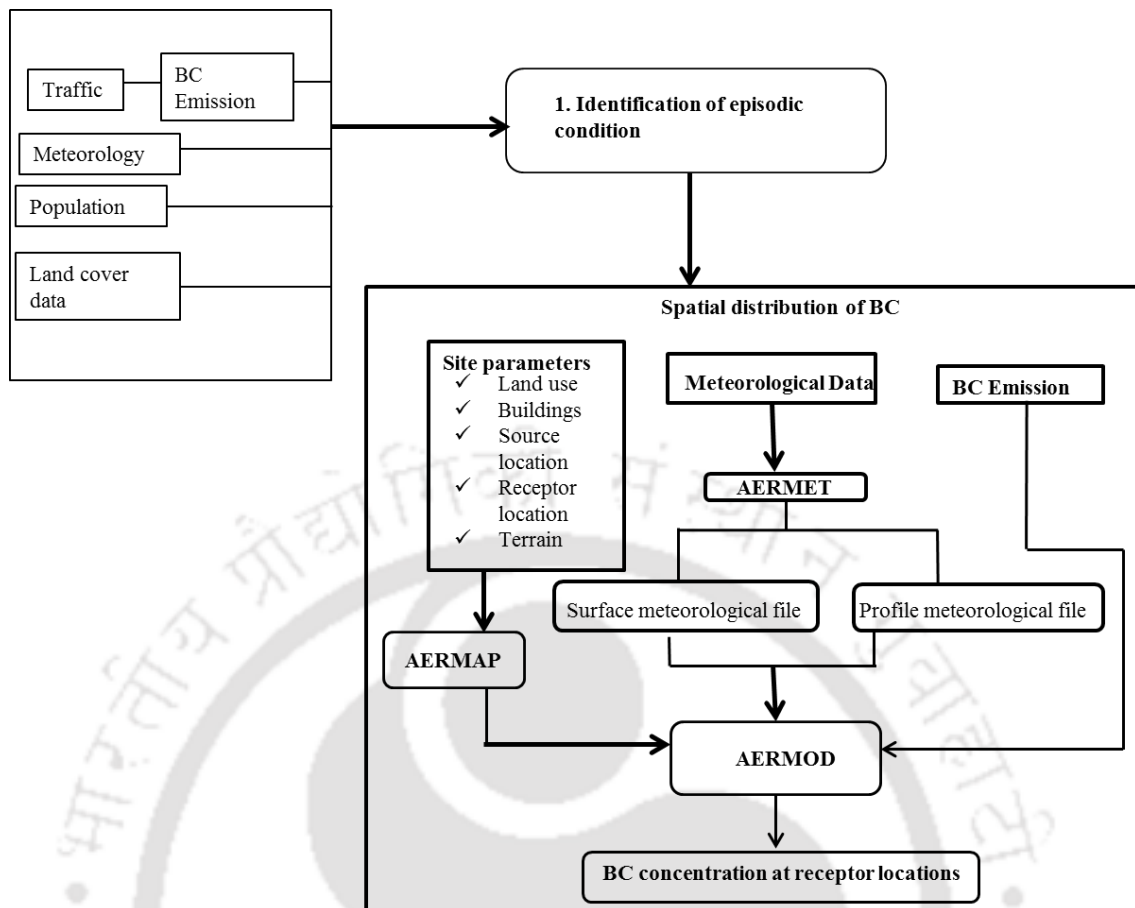


Fig. 6. 14 Flow chart of the method for validation and application of the method to BC

6.4.1 Results and discussion

Fig. 6.15 shows the comparisons of the indicators at real and standard conditions on the same time scale for BC. The results showed that (Fig. 6.15) the I_r exceeds the I_s between 8:00 - 10:00 and 15:00 to 18:00 hours. at location M. To get the actual exceedance time and magnitude of the episodic condition, the difference between the I_r and I_s values were calculated and plotted against the time, as shown in Fig. 6.16. The highest degree of episodic condition was observed at morning 8:00 and 16:00 hours. The ratio of I_r the I_s (Fig. 6.17 a) was used to get the frequency of exceedance or episode condition observed 3 times in morning and 4 times in afternoon to evening. Fig 6.17 (b) suggests that percentage of duration of episodic condition was 64% at location M. Like CO, spatial distribution is also important to identify the most episode prone zones so AERMOD was used to check the episodic prone areas are same as CO

or different. in location M with clear observation of magnitude of the episodic condition. Fig. 6.18 shows the spatial distribution of BC.

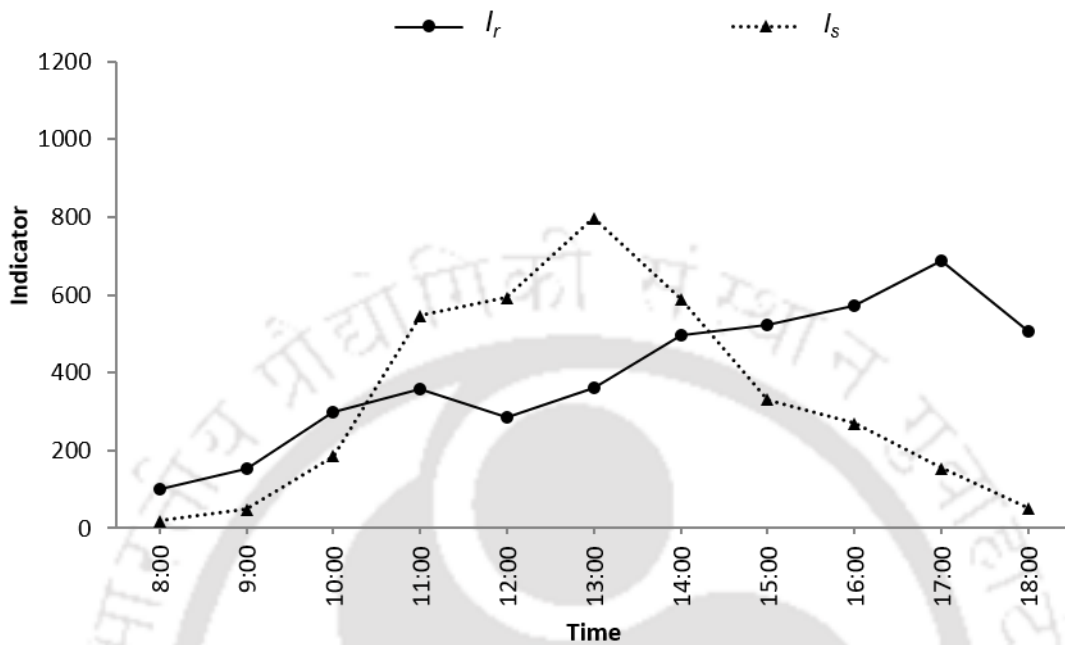


Fig. 6.15 Temporal variation of Indicator values at location M due to BC

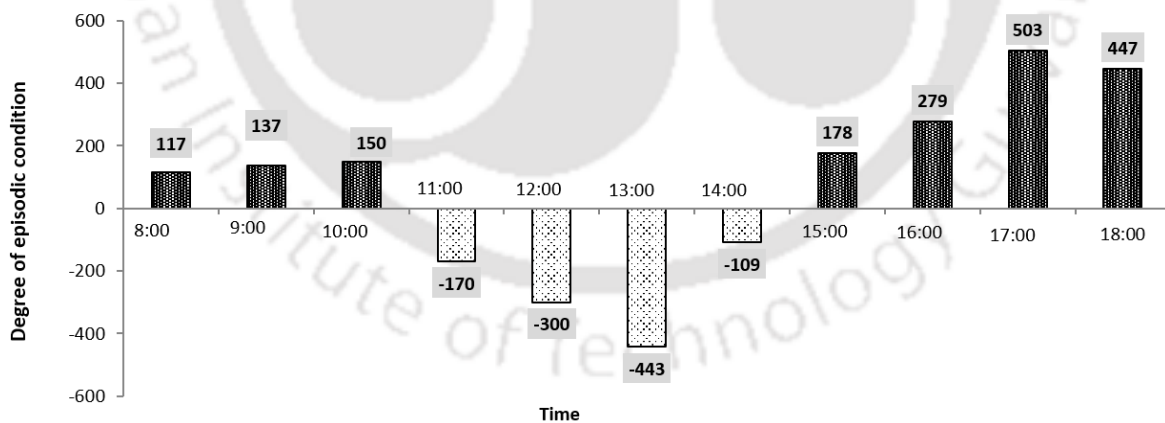


Fig. 6.16 Degree of episodic condition at location M due to BC

The modelling results showed that the highest concentrations occur during the episodic condition. The predicted BC concentrations at site M have been modelled and compared with observed concentration as shown in Fig. 6.19. Performance evaluation was done by using statistical parameters (FB, MG, NMSE, VG, R and FAC2) (Table 6.8). Overall, the values of

FB at M depicts that it under predicts by about 7%. The fraction of predictions within FAC2, is high (1.0) at this location M for BC. NMSE value are near to 0 which indicates that the magnitude of the scatter is less than the mean concentration which can be seen in Fig. 6.20.

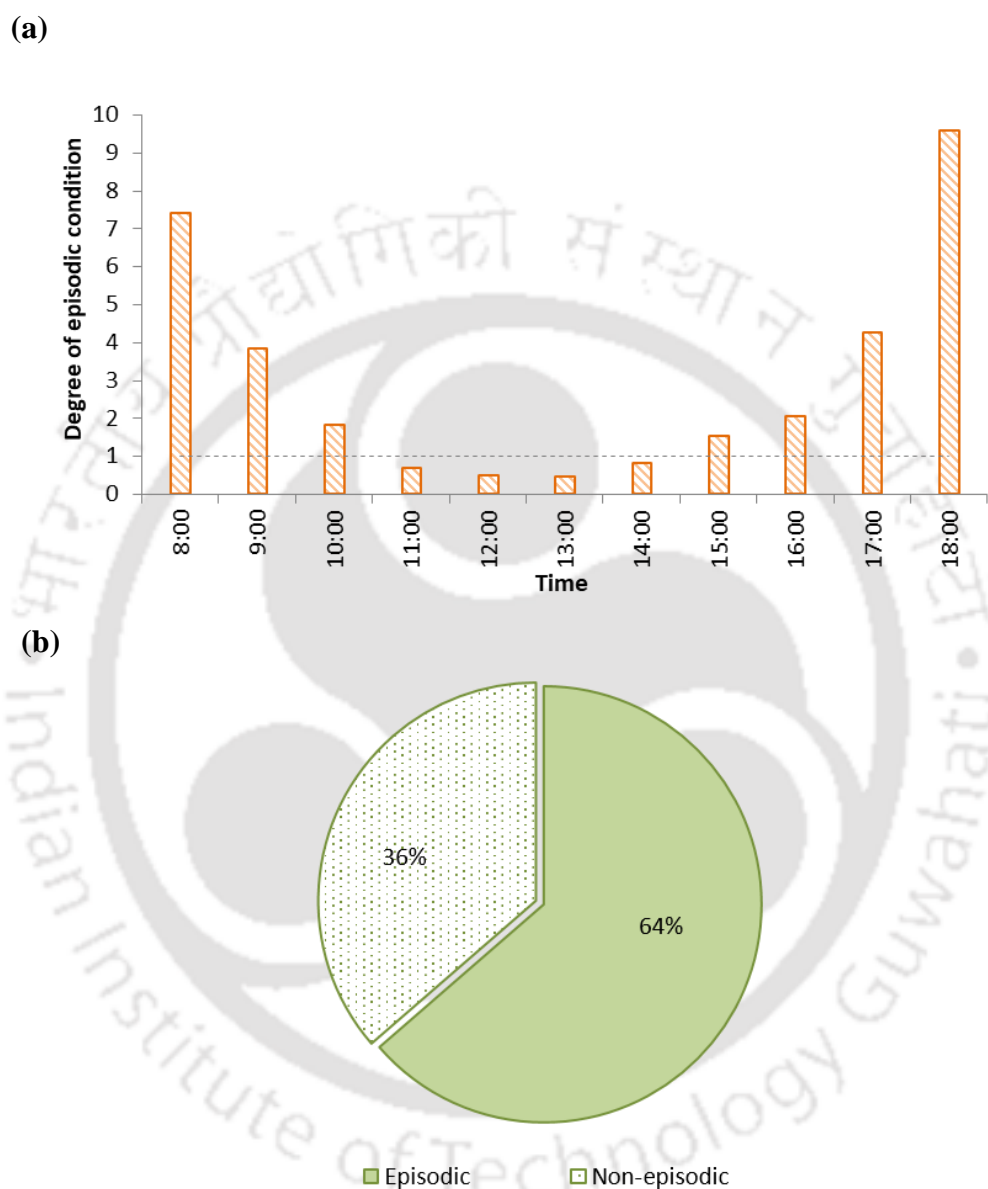


Fig. 6. 17 a) Magnitude of episodic condition b) Percentage of duration of episodic condition at location M due to BC

In case of BC, episodic condition is seen near road during episodic period as contour plot is showing high concentrations adjacent to the road. The concentrations at roadside are not uniform like CO but spatial distribution of BC concentration is different than CO. The adjacent area to L3 and opposite side of the road from L2 location is more prone to episode.

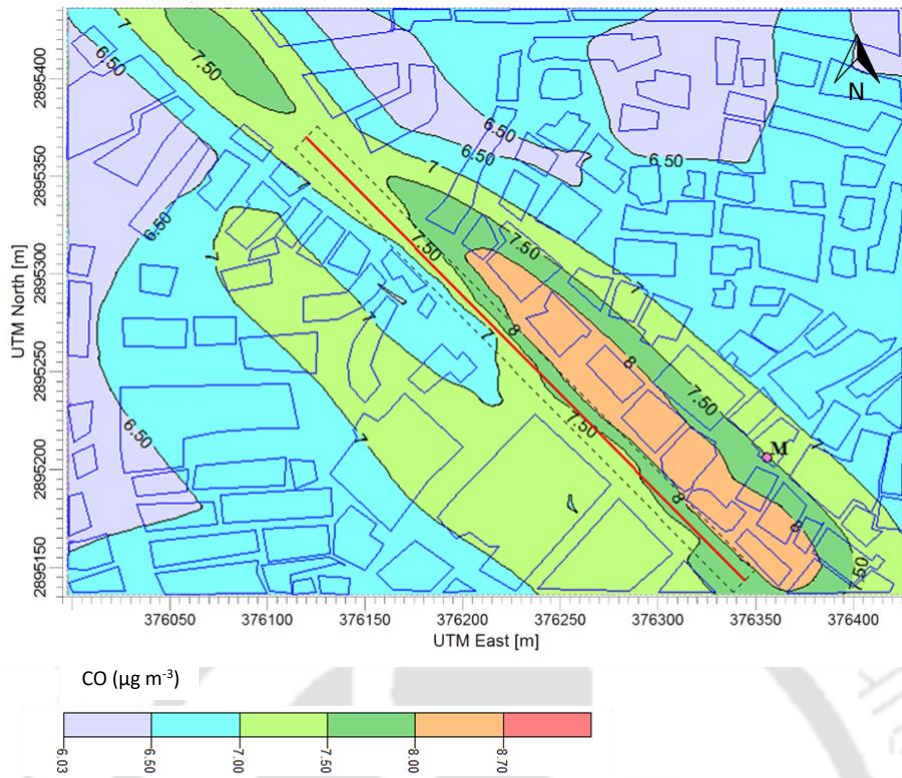


Fig. 6. 18 Spatial distribution of the modelled BC ($\mu\text{g m}^{-3}$) in the study region during monitoring at M (Time - 8:00 hours, Max. concentration – 7.51 $\mu\text{g m}^{-3}$)

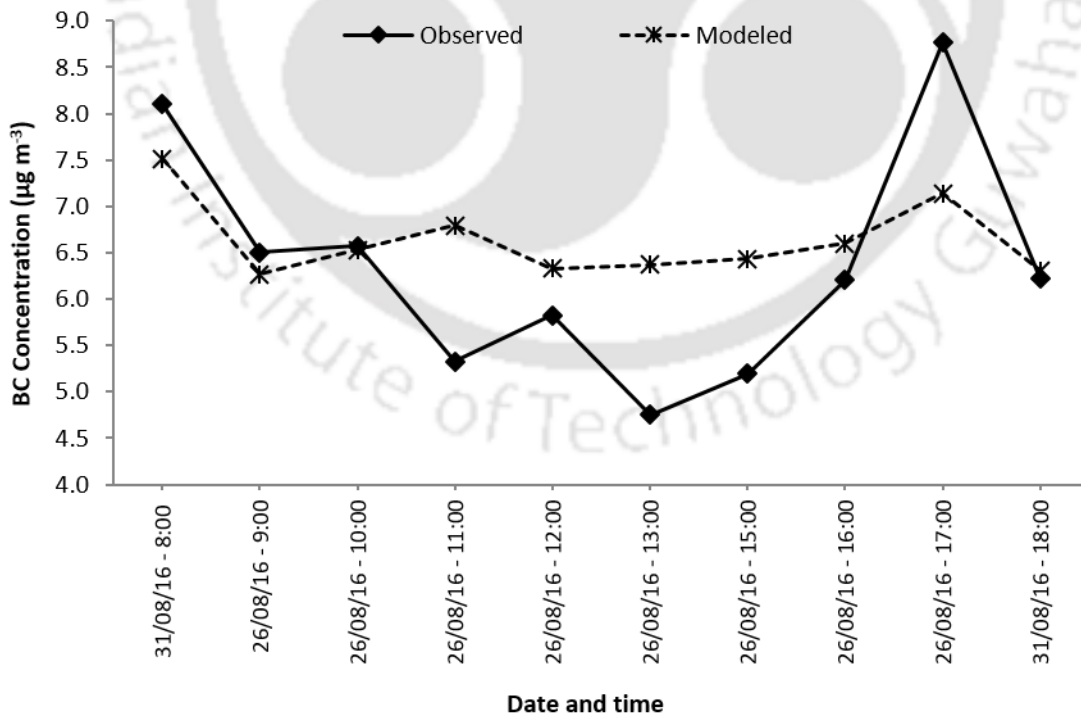


Fig. 6. 19 Comparison of the observed and modelled (26thAugust-2nd September, 2016) BC concentration at location M

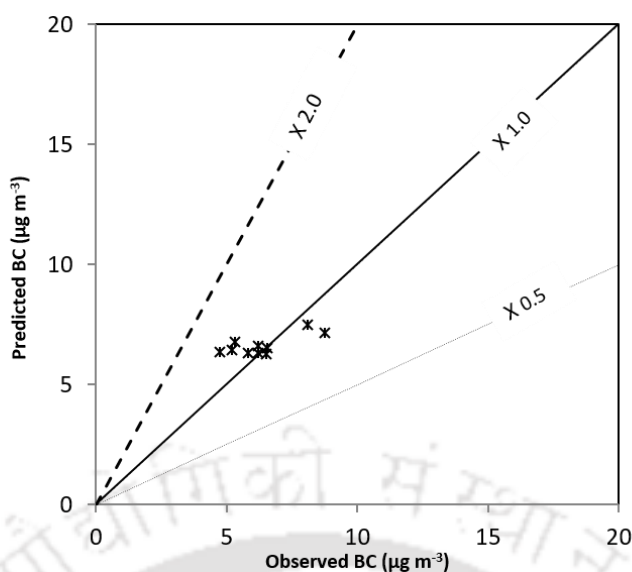


Fig. 6. 20 Observed vs modelled hourly (1st to 10th maximum) concentration of BC at location M with FAC2 upper and lower limit boundaries

Table 6. 8: Air quality modelling results and the performance evaluation at location M for BC

Location	Mean Observed Hourly Conc. ($\mu\text{g m}^{-3}$)	Mean Modelled Hourly Conc. ($\mu\text{g m}^{-3}$)	FB	MG	NMSE	VG	R	FAC2
M	6.35	6.63	-0.04	0.94	0.02	1.03	0.66	1

6.5 SUMMARY

Mean degree of episodic condition in case of CO was 1.66 ± 0.61 and in case of BC was 4.35 ± 3.07 . Episodic condition may occur same time (8:00 AM to 10 AM) for both gaseous (CO) and particulate pollutant (BC) but depending upon the characteristics may last for different durations (3 to 4 hours for CO and 7 hours for BC). AERMOD modelled the concentrations of CO and BC satisfactory (FB = -0.04 and -0.04; NMSE = 0.16 and 0.02; R = 0.64 and 0.65; and FAC2 = 0.80 and 1 respectively) during episodic conditions. The temporal variation of the BC episode was different than CO. The percentage of duration of episodic condition was 64% which is very higher and worse than CO in all the locations. Spatial distribution is also different than CO, which indicates that the pollutant characteristics also an important factor for the nature of distribution of pollutants within an area.



7

CHAPTER

HEALTH RISK OF PM_{2.5} AND EPISODIC-PRONE LOCATIONS USING AN INTEGRATED EXPOSURE-RESPONSE FUNCTION



CHAPTER 7

HEALTH RISK OF PM_{2.5} AND EPISODIC-PRONE LOCATIONS USING AN INTEGRATED EXPOSURE-RESPONSE FUNCTION

7.1 GENERAL

Particulate matter (PM) is a mixture of microscopic solids and liquid particles suspended in air. Majority of Indian population exposed to ambient levels of PM is much higher than WHO guidelines (Dey et al., 2012). Global Burden of Diseases (GBD) study of 2015 ranks the pollution due to PM_{2.5} the sixth amongst the risk factors for global premature mortalities and disability-adjusted life-years (DALYs) (Forouzanfar et al., 2016). Chronic obstructive pulmonary disease (COPD) is the disease of the lungs, which causes difficulty in breathing. The symptoms of COPD are ongoing cough, shortness of breath, wheezing, and chest tightness, which restrict affected people from performing daily life activities, like washing, cleaning (Roche et al., 2013). COPD is not a single disease, but several lung diseases combined (WHO, 2019). Spirometry is the most useful option to make the diagnosis of COPD (Spyratos et al., 2012). Lung function test evaluates forced expiration after complete inhalation, determine forced vital capacity (FVC) and the forced expired volume during the first second (FEV1) (Ranu et al., 2011). Peak expiratory flow (PEF) measurement also is a useful tool for assessing airway obstruction (Marinho and Custovic, 2008). COPD management and treatment should consider both disease impact assessment and future risk of exacerbations by assessment of symptoms with activity limitations and airflow limitation or exacerbation history (GOLD, 2017). The COPD Assessment Test (CAT) is a short, eight-item health status questionnaire developed to provide a simple tool for quantifying the

symptoms and impacts of COPD (Jones et al., 2009). Fig. 7.1 shows the research method for the risk function.

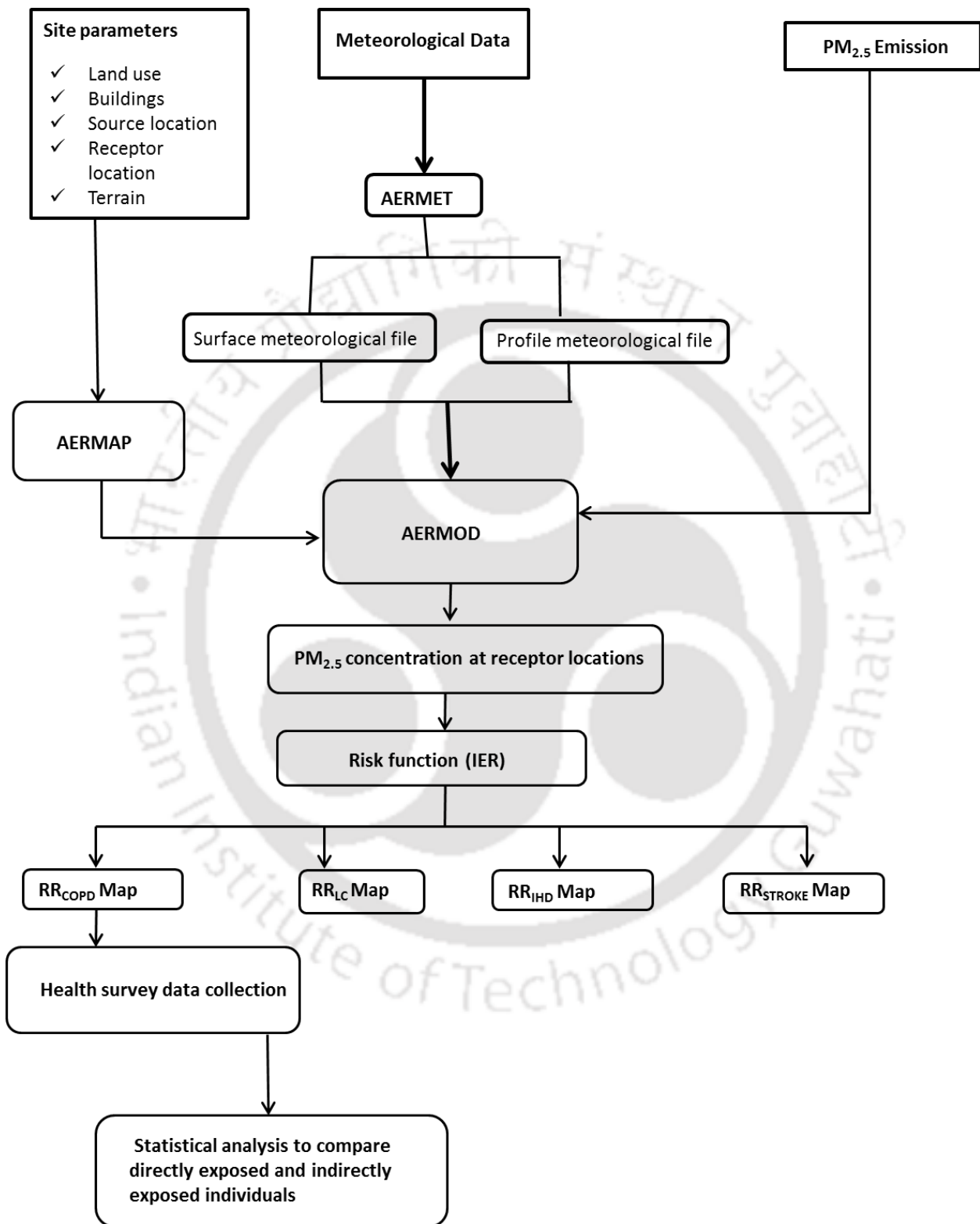


Fig. 7. 1 Flow chart for estimation of health risk due to PM_{2.5} and identification of episodic-prone locations

7.2 RESEARCH METHOD

7.2.1 Field monitoring

The PM_{2.5} samples were collected at location 'M' (Fig. 3.1) at 1.5 m above the ground by an OMNI™ FT Ambient Air Sampler (by Mesa Labs) from ambient air every hour from 7:00 AM to 18:00 PM for one week in August, 2016. For sampling, nylon filter paper of pore size 0.8 µm and 47 mm diameter was used. The samples were then analysed with the gravimetric method, and using flow rate and the run time, ambient concentrations of PM_{2.5} were calculated.

Along with the PM_{2.5} sampling, monitoring of meteorological parameters was carried out with weather station (6152 Wireless Vantage Pro2).

7.2.2 PM_{2.5} emission

ARAI emission factors were used to estimate PM_{2.5} emissions. Chapter 5 shows the method.

7.2.3 Spatial distribution of PM_{2.5} during episodic condition

AERMOD was used to estimate the PM_{2.5} concentrations from traffic source and determined its distribution within the study area (as used for CO and BC). The details of the model have been described in Chapter 6. The inputs were same as given for CO except the emissions and meteorology.

7.2.4 Relative risk analysis

Integrated exposure response (IER) function is an integrated risk function using Relative Risk (RR) from epidemiological studies for exposure from ambient air pollution (AAP), secondhand tobacco smoke (SHS), active smoking (AS) and household air pollution (HAP) developed by Burnett et al. (2014). The risk estimate for AAP was obtained from the cohort studies conducted across the globe, SHS and AS risk estimates were obtained from the study of Pope et al. (2011) and risk estimates for HAP were obtained from the study of Smith et al.

(2014). Since the estimates from different exposures are different, a common metric was used (Pope III, et al., 2009; Pope et al., 2011). Single cigarette is equivalent they used to exposure to a daily ambient PM_{2.5} concentrations of 667 µg m⁻³ and the same information of cigarettes smoked was converted into daily ambient PM_{2.5} concentrations.

The function (equation 7.1 and 7.2) shows that risk estimates because of cardiovascular diseases in the beginning increases and flattens out then at higher PM_{2.5} concentration (Pope et al., 2009), while in case of lung cancer the risk estimates increases monotonically with increase in PM_{2.5} concentration (Pope et al., 2011).

For $c < c_{cf}$

$$RR_{IER}(c) = 1 \quad (7.1)$$

For $c \geq c_{cf}$

$$RR_{IER}(z) = 1 + \alpha \{1 - \exp[-\gamma(c - c_{cf})^\delta]\} \quad (7.2)$$

where, 'c' is the exposure to PM_{2.5} in µg m⁻³, 'c_{cf}' the concentration below which the risk is zero, and the unknown parameters (α , γ , δ) are obtained by nonlinear regression methods.

The PM_{2.5} concentrations modelled by AERMOD were used as the modelled exposure to PM_{2.5} at each receptor point to calculate the relative risk (RR).

7.2.5 Respiratory health analysis of sedentary workers

Open shops located along roadside are the most susceptible population subgroup, at risk to higher exposures and adverse respiratory health risks than close shops as the concentration of air pollutants at the roadside may be significantly higher than inside the shops (Jones et al., 2008). 50 and 48 shop assistants working in air-conditioned (14 shops) and open (25 shops) shops, respectively in the selected study area of Lachit Nagar, Guwahati participated in this study. COPD was defined by lung function according to the Global Initiative for Chronic Obstructive Lung Disease criteria (GOLD, 2017) and the questionnaire used for this study

involved questions of COPD Assessment Test (CAT) from the article of Jones et al., 2009. The shop assistants of close air-conditioned shops had indirect exposure, while those of non-air conditioned shops had direct exposure to traffic air pollutants. All the persons agreed to participate in the health survey were aware of ill health effects of air pollution. Of 48, 41 persons were non-smokers (open shops) and 7 were casual smokers. For close shops, out of 50, 48 persons were non-smokers and 2 were casual smokers. The questionnaires were collected by interviewing each of the participants. It included demographic information such as gender, age, duration (months/years), and working hours per day. It also included for each participant a Lung functions tests, i.e. FEV₁ (l), PEF (l/s), FVC (l) and FEV₁/FVC (%) and respiratory symptoms. These were incorporated in the COPD assessment. The symptoms covered in the study were cough, phlegm, chest tightness, comfort to walk uphill or stairs, limitation in doing daily activity, confidence in leaving home with lung condition, sleep quality and low energy feeling. These symptoms were rated on a scale of 0 to 5 according to the magnitude of occurrence of the symptoms. Where, 0 means individual do not suffer with the symptoms and 5 means individual suffers severely. The post-bronchodilator, FEV₁/FVC < 0.70 confirms the persistent airflow limitation or COPD. The lung function tests were conducted by using Contec Spirometer SP-10 (CONTEC™).

Chi-square analysis was done to compare gender distribution and respiratory symptoms between the two groups (open shop and air conditioned shop assistants). The comparison between the two groups was done on the basis of the demographic data and the lung function test results using one-way ANOVA in the SPSS version 20. The *p*-value of < 0.05 was used as the level of statistical significance.

7.3 RESULTS AND DISCUSSION

7.3.1 Spatial distribution of PM_{2.5}

The 1st highest 8-hourly modelled concentration at the location M was found between 8:00 and 16:00 hours. Fig. 7.2 shows the spatial distribution of 8-hourly PM_{2.5} concentrations modelled for August, 2016 at 15 m height. The highest 8-hourly average concentration was 101 $\mu\text{g m}^{-3}$. This value was validated by comparing with the observed concentration of the same time at the location. The modeling results showed that the highest concentrations occur

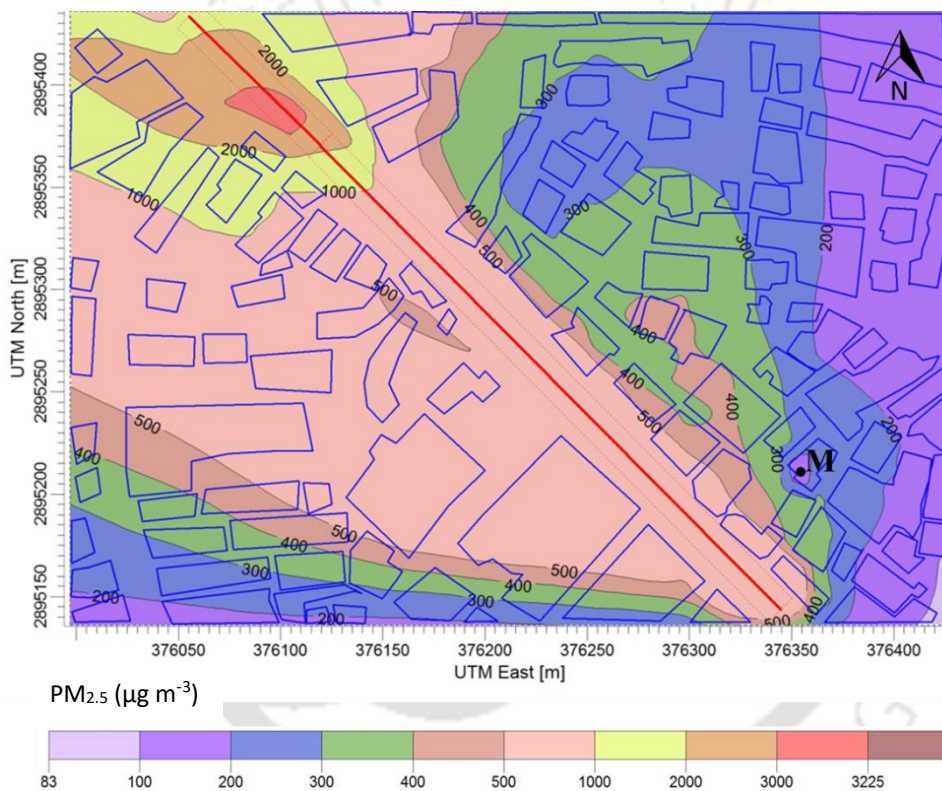


Fig. 7. 2 Spatial distribution of the modelled PM_{2.5} ($\mu\text{g m}^{-3}$) in the study region during monitoring at M (Time – 8:00 -16:00 hours, Max. concentration – 100 $\mu\text{g m}^{-3}$)

during the day time which includes two traffic peak hours. Fig. 7.3 and 7.4 show the comparison of the modelled and observed PM_{2.5} concentrations. The performance was evaluated using statistical indicators such as FB, MG, NMSE, VG, R and FAC2. Accurate comparison would have the MG, VG, R, and FAC2 values to be near 1.0 and FB and NMSE

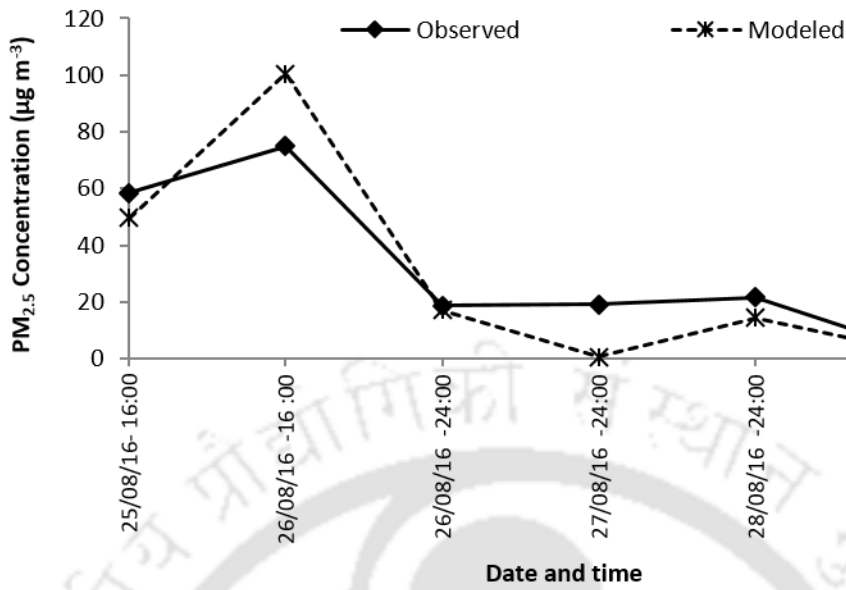


Fig. 7. 3 The comparison of the observed and modelled 8-hour average (1st to 10th maximum) PM_{2.5} concentrations

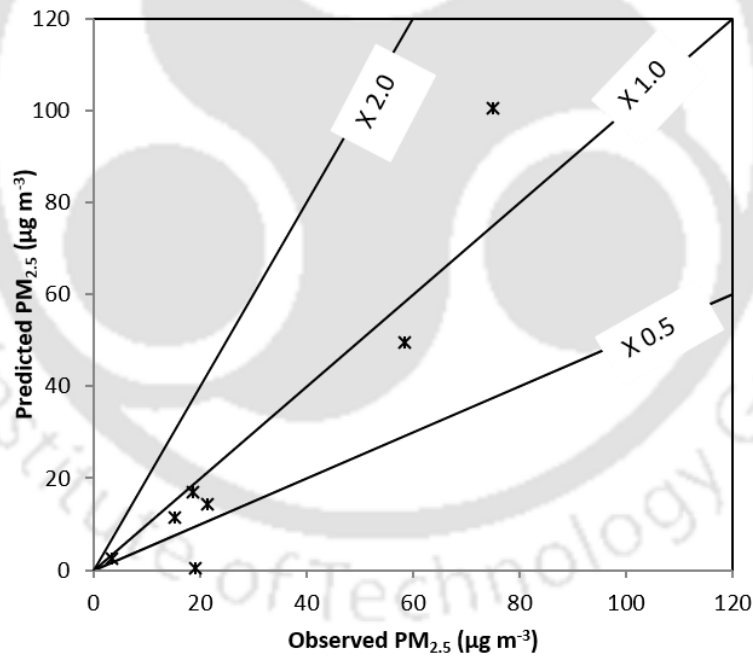


Fig. 7. 4 Observed vs modelled 8-hour average (1st to 10th maximum) PM_{2.5} concentrations

near 0.0 (Chang and Hanna, 2004). From Table 7.1, it has been observed that the modelled concentrations were under predicted, i.e. about 7.7% when FB were compared, while, the predictions within the factor of two, i.e. FAC2 was high (0.86). The NMSE value was < 0

showing the data scattered. Like CO and BC, the episodic condition because of PM_{2.5} was near the road as observed from the contours of high concentrations next to the road.

Table 7. 1: Air quality modelled results and the performance evaluation at location M for PM_{2.5}

Location	Observed 8-hour average mean concentration ($\mu\text{g m}^{-3}$)	Modelled 8-hour average mean concentration ($\mu\text{g m}^{-3}$)	FB	MG	NMSE	VG	R	FAC2
M	30.2	28.0	0.08	0.48	0.19	6.70	0.82	0.86

7.3.2 Relative-Risk analysis

The RRs were calculated for each receptor points for the highest modelled concentration (Appendix-III). They were 1.32–4.59 for COPD, 1.46–8.13 for LC, 1.37–1.99 for IHD, and 2.02 – 2.19 for stroke (Fig. 7.5 – 7.8). Among the four diseases, the LC had the highest RR while the stroke had the lowest RR. The spatial distributions of RRs for the four diseases were

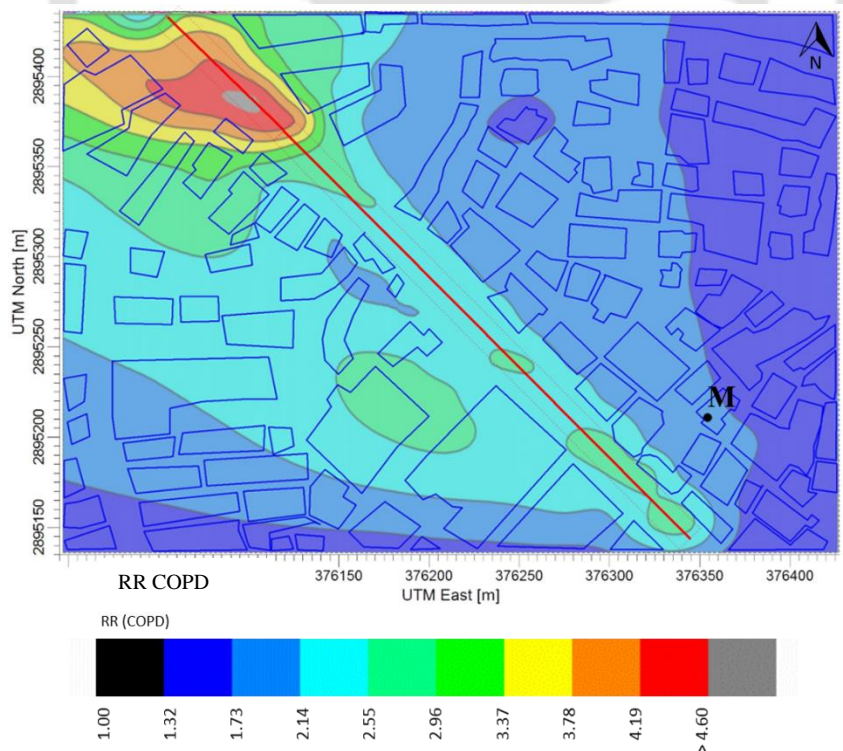


Fig. 7. 5 Spatial distribution of the COPD relative risk (RR) in the study area

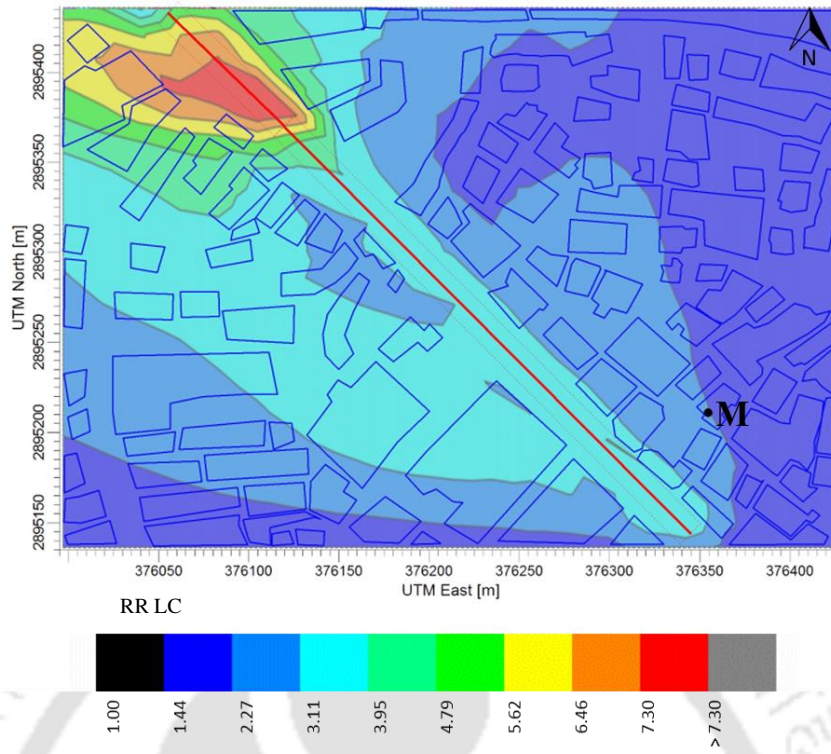


Fig. 7. 6 Spatial distribution of the LC relative risk (RR) in the study area

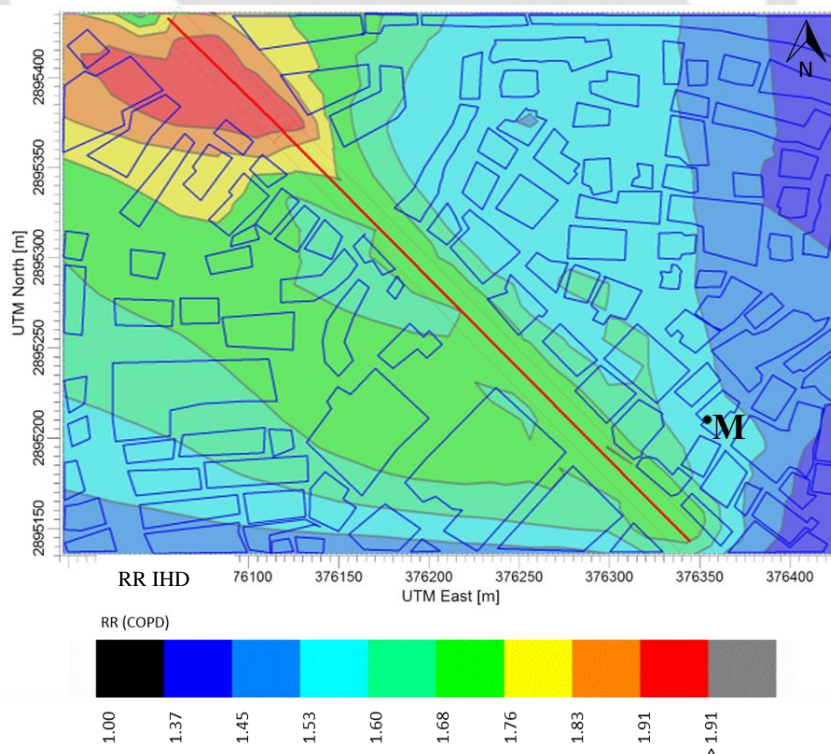


Fig. 7. 7 Spatial distribution of the IHD relative risk (RR) in the study area

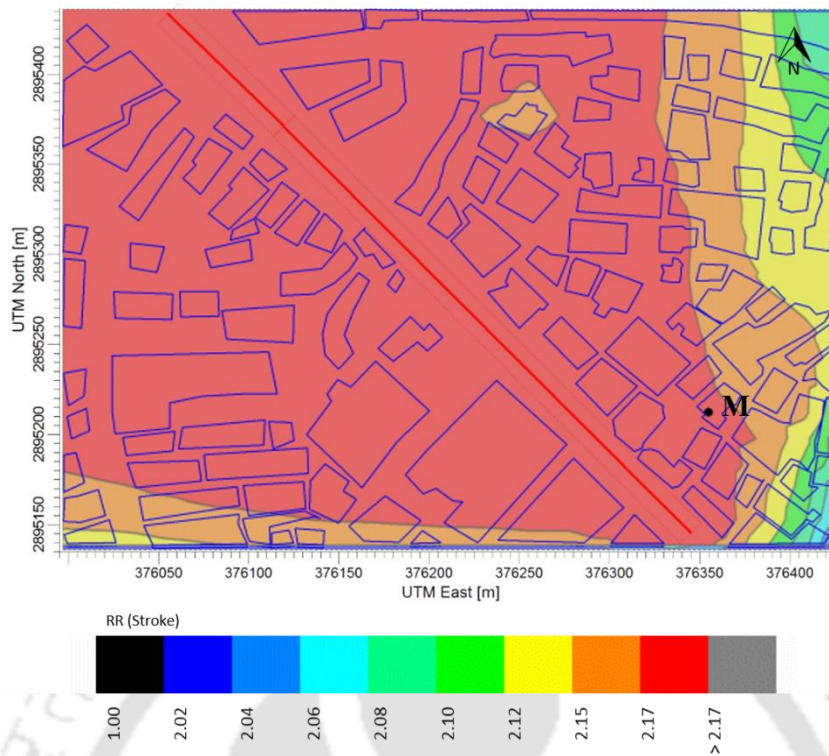


Fig. 7. 8 Spatial distribution of the stroke relative risk (RR) in the study area

not same. The nonlinear relationship between RR and $PM_{2.5}$ exposures was evident as in the IER model.

7.3.3 Health survey data analysis

Total 89 participants (41 open shops and 48 air-conditioned shop assistants) were interviewed and lung function test performed to get the evidence of the IER model output of RR in case of COPD (Appendix-IV). It was a great challenge to convince the participants who were busy in their work and most of them were not aware of the air pollution health effects. It took one month to complete the questionnaire by interviews. Only the participants who were not suffering from any known respiratory disease and non-smokers, interviewed.

The two groups were compared in case of gender distribution, demographic data, lung function test data and COPD symptoms. Chi-square test (Table 7.2) p -value (>0.05) suggests that gender distribution amongst the two groups were different by accepting the null

Table 7. 2: Demographic data of open shop and air conditioned shop assistants

	Number of female	DS	Age (year)	Height (cm)	Weight (kg)	Years of work (year)	working hours (hour)
Open shops (N=41)	8 (19.5%)	Min	18	147	50	1	6
		Max	66	187	79	45	14
		Mean	32.98	163	61.95	10.22	9.63
		Std. Dev.	10.29	8	8.55	10.23	1.87
Air conditioned shops (N=48)	16 (33.3%)	Min.	20	148	42	0.5	9.0
		Max	42	190	75	6.0	9
		Mean	25.17	162	54.92	2.10	9.00
		Std. Dev.	4.14	8	7.49	1.66	0.00
P value for comparison	0.143	NA	0.00	0.71	0.00	0.00	0.02

NA – Not applicable

DS – Descriptive statistics

hypothesis. Socio-demographic characteristics such as age, weight, years of work and working hours were significantly different between both the groups of study population. The distribution of height was similar across both groups. Whereas ANOVA *p*-value in case of age, weight, years of work and working hours for the two groups are not similar but in case of height it is similar. FEV1 and FVC of the two groups were similar but PEF and FEV1/FVC (%) differed (Table 7.3). This result is due to the effect of traffic related air pollution on open

Table 7. 3: Lung function test results of open shop and air conditioned shop assistants

	DS	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)
Open shops (N=41)	Min	1.0	1.0	1.0	57
	Max	3.0	10.0	4.0	100
	Mean	1.90	4.88	2.13	89.43
	Std. Dev.	0.59	2.38	0.72	11.78
Air conditioned shops (N=48)	Min	0.9	1.0	0.9	58
	Max	3.1	10.3	3.5	100
	Mean	1.88	6.56	1.92	98.19
	Std. Dev.	0.54	1.95	0.56	6.24
p-value for comparison	NA	0.89	0	0.15	0

NA – Not applicable

DS – Descriptive statistics

shop assistants. The comparison of COPD related symptoms also supports this event as open shop assistants shows (Table 7.4 and Fig. 7.9) more percentage of people who are suffering with the symptoms. Kongtip et al. (2006) found with increase of pollutant concentration, street vendor's symptoms increased. Air conditioned shop assistants are the workers who were working in air condition for at least 9 hours a day which may be the cause of cough, low

Table 7. 4: COPD related symptoms of open shop and air conditioned shop assistants

Symptoms	Open shops (%)	Air conditioned shops (%)	P value for comparison
Cough	29.3	14.6	0.28
Phlegm	9.8	8.3	0.19
Chest tightness	39.0	4.2	0.01
Breathless towards uphill	41.5	4.2	0.001
Limitation in daily activity	14.6	2.1	0.134
Problem in leaving home with respiratory health	14.6	0.0	0.057
Sound sleep	17.1	0.0	0.064
Energy low	31.7	10.4	0.053

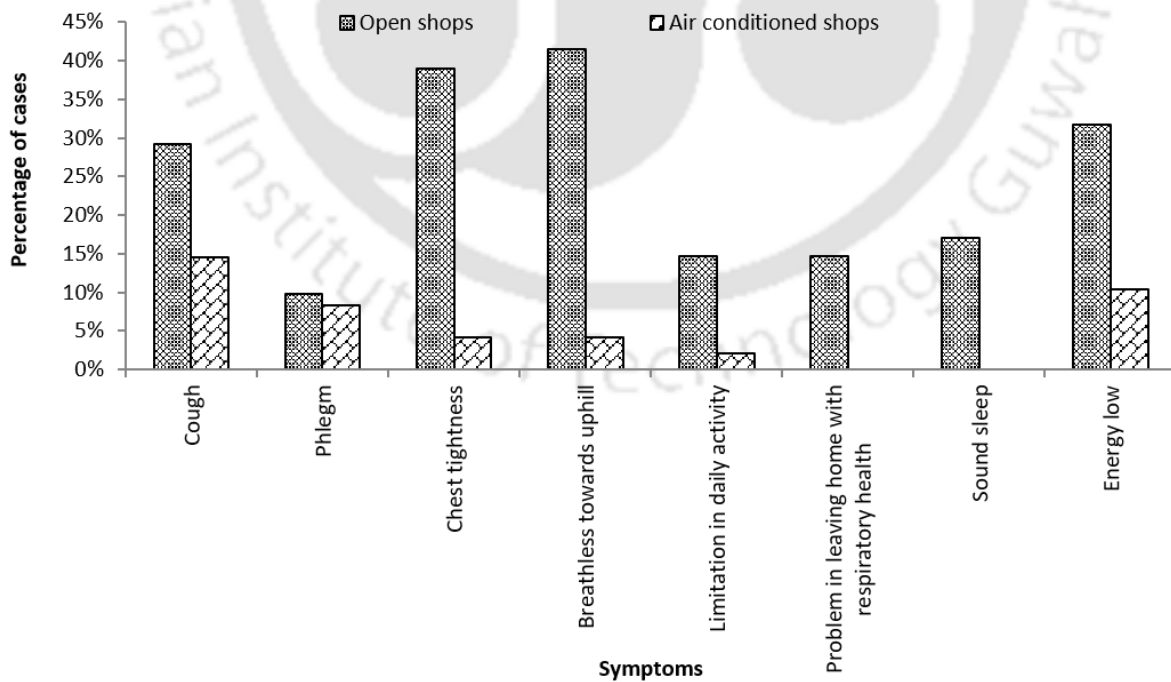


Fig. 7. 9 Comparison of percentage of cases for each symptom between open shop and air conditioned shop assistants

energy feeling and phlegm because if it was the effect of air pollution then chest tightness and breathless problem should also had been observed as found by Jones et al., 2008.

GOLD (2017) recommended a CAT score ≥ 10 as equivalent symptom cut-points for categorizing patients into low- or high-symptom groups. CAT score of the two groups were compared in case of each symptom and activity limitations which included in the questionnaire (Fig. 7.10). The mean CAT score for entire population (N = 89) was 2.6 ± 4.9 [for affected population (N = 31) 7.52 ± 5.68], ranging from 0 to 21 (for affected population 1 to 21) in this study. The mean CAT score for open shop assistants (N = 41) was 4.68 ± 6.30 [for affected population (N = 23) 8.34 ± 6.28] ranging from 0 to 21 (for affected population 4 to 21) whereas for air conditioned shop assistants (N = 48) mean score was 0.85 ± 2.10 [for affected population (N = 8) 5.13 ± 1.96] and ranged from 0 to 10 (for affected population 1

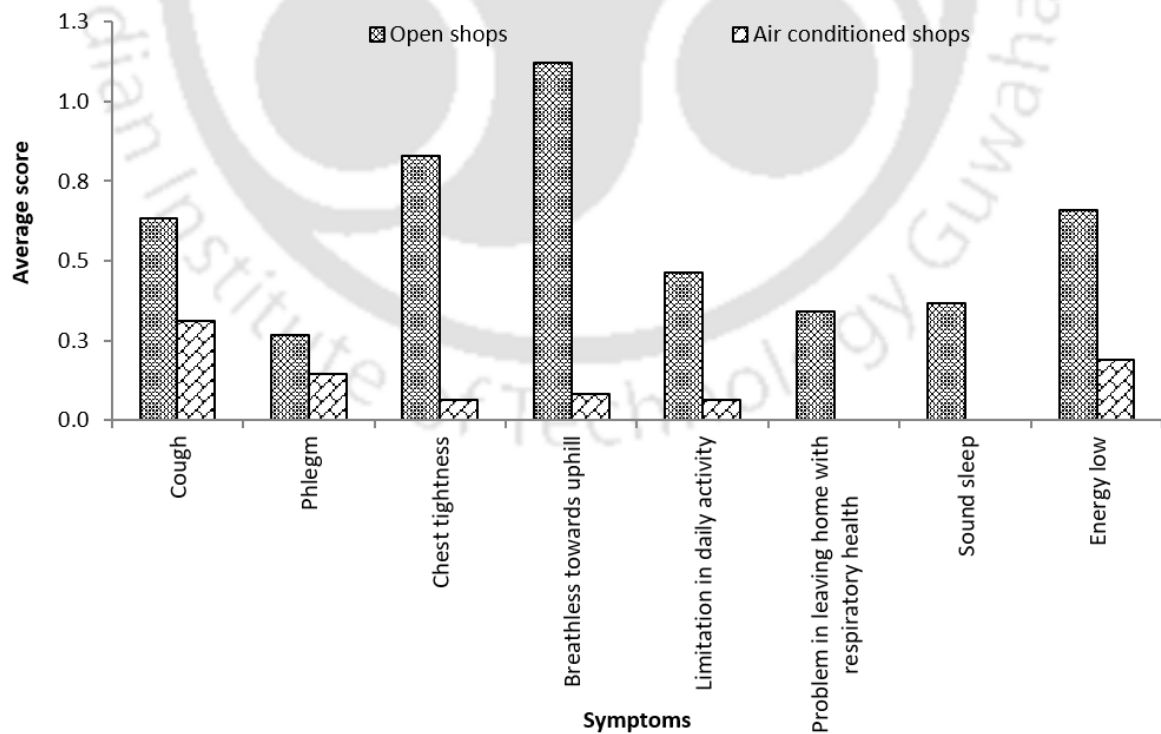
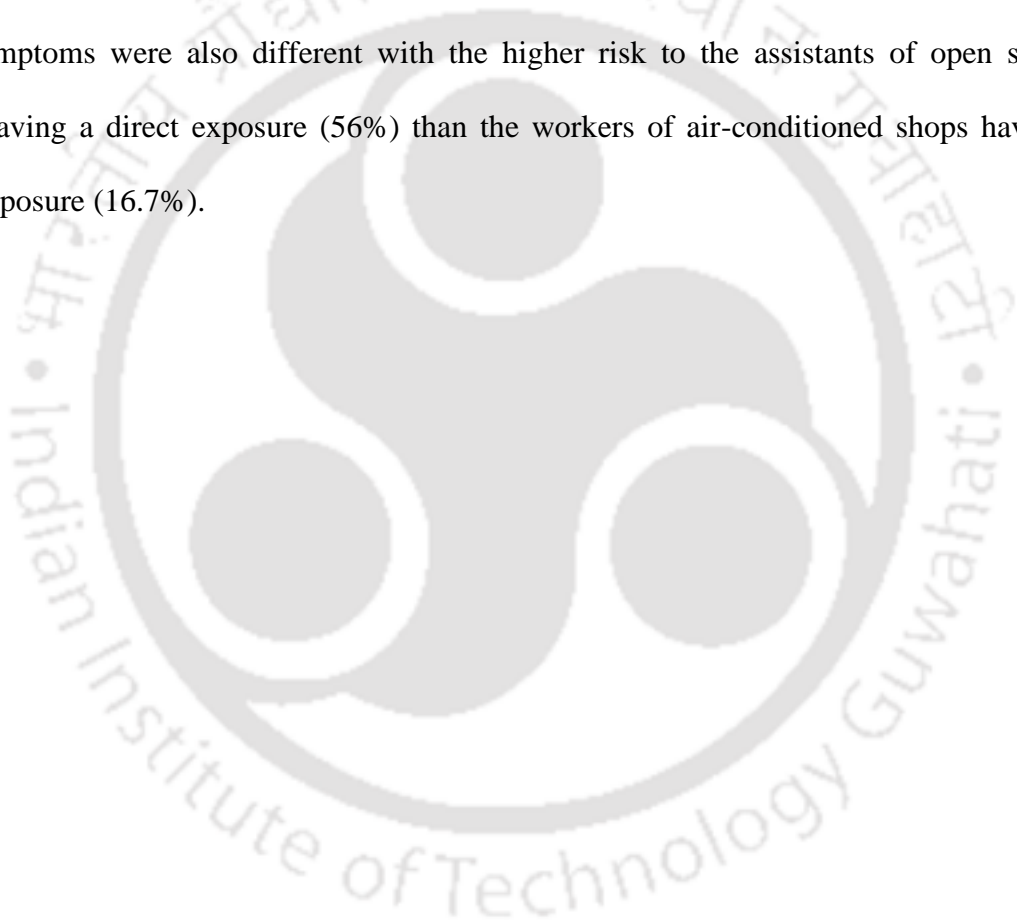


Fig. 7. 10 Comparison CAT score for each symptom between open shop and air conditioned shop assistants

to 10). From Fig. 7.10, it can be observed that the magnitude of symptoms and activity limitations were also more in open shop assistants in comparison to air conditioned shop assistants.

7.4 SUMMARY

The analysis of RR identified the roadside area as the most COPD risk prone area. Health relative risks show that both the groups of shop assistants are exposed to $PM_{2.5}$ and are affected. But as the level of exposure ($PM_{2.5}$) in both groups was different, the resulting COPD symptoms were also different with the higher risk to the assistants of open shop workers having a direct exposure (56%) than the workers of air-conditioned shops having indirect exposure (16.7%).





8

CHAPTER

CONCLUSION



CHAPTER 8

CONCLUSION

8.1 GENERAL CONCLUSION

The method developed for prediction of episodic condition and its magnitude may help to forecast future episodic events in urban traffic corridors to ensure appropriate measures for managing air quality. This method can be used for the same site for different time period by using traffic emission of that particular time as the method was validated by the same. This method may be also useful to forecast episodes related to other pollutants like BC. The pattern of the episodic condition due to BC was worse than CO, which indicates the importance of traffic causing episodes in urban areas of Guwahati. Spatial distribution of pollutants is not similar, which indicates that also the pollutant characteristics an important factor for the nature of distribution of pollutants within an area.

8.2 KEY CONCLUSIONS

- A simple method based on the health-based indicators to identify episodic condition for gaseous (CO) and particulate (BC) pollutants developed, applied and validated (Mean degree of episodic condition for CO and BC were 1.66 ± 0.61 and 4.35 ± 3.07 , respectively).
- Episodic condition may occur same time (8:00 AM to 10 AM) for both gaseous (CO) and particulate pollutant (BC) but depending upon the characteristics may last for different durations (3 to 4 hours for CO and 7 hours for BC).
- The line source AERMOD could model the concentrations of CO, BC and $PM_{2.5}$ reasonably well (FB = -0.04, -0.04 and 0.07; NMSE = 0.16, 0.02 and 0.143; R = 0.64, 0.65 and 0.816; and FAC2 = 0.80, 1 and 0.86, respectively) during episodic conditions in the microenvironment of urban traffic corridor.

- Health relative risks show that both the street vendors and shop salesmen are exposed to PM_{2.5} and are affected. But as the level of exposure (PM_{2.5}) in both groups was different, the resulting COPD symptoms were also different with the higher risk to the workers having a direct exposure (56%) than the workers of air-conditioned shops having indirect exposure (16.7%).
- The temporal variations of pollutant concentrations were not in accordance to the variability of traffic flow, showing that the local geometry and meteorology affects the dispersion of pollutant.
- This method does not require real-time concentration measurement to identify episodic condition which other methods demands and this can be a useful tool for researchers with instrument limitation problem.

8.3 LIMITATIONS

- The study assumed that traffic was the only source of CO, BC and PM_{2.5} in the selected traffic corridor while there may be a contribution from a few other minor local or airborne sources.
- It was assumed that salesmen of non-air conditioned shops and street vendors exposed to the same level of pollutant concentrations.
- Health risk study could be done only for PM_{2.5} due to non-availability of risk factors for CO and BC.

8.4 FUTURE SCOPE

- CO and BC although much less but also contributed by biomass burning, which could be included in estimating the episodic conditions.
- Measurement of pollutant concentrations in the indoor of the air-conditioned shops could be studied and included to improve the health risk estimates.
- Probability of COPD symptoms for different groups could be estimated.

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APPENDIX

APPENDIX – I

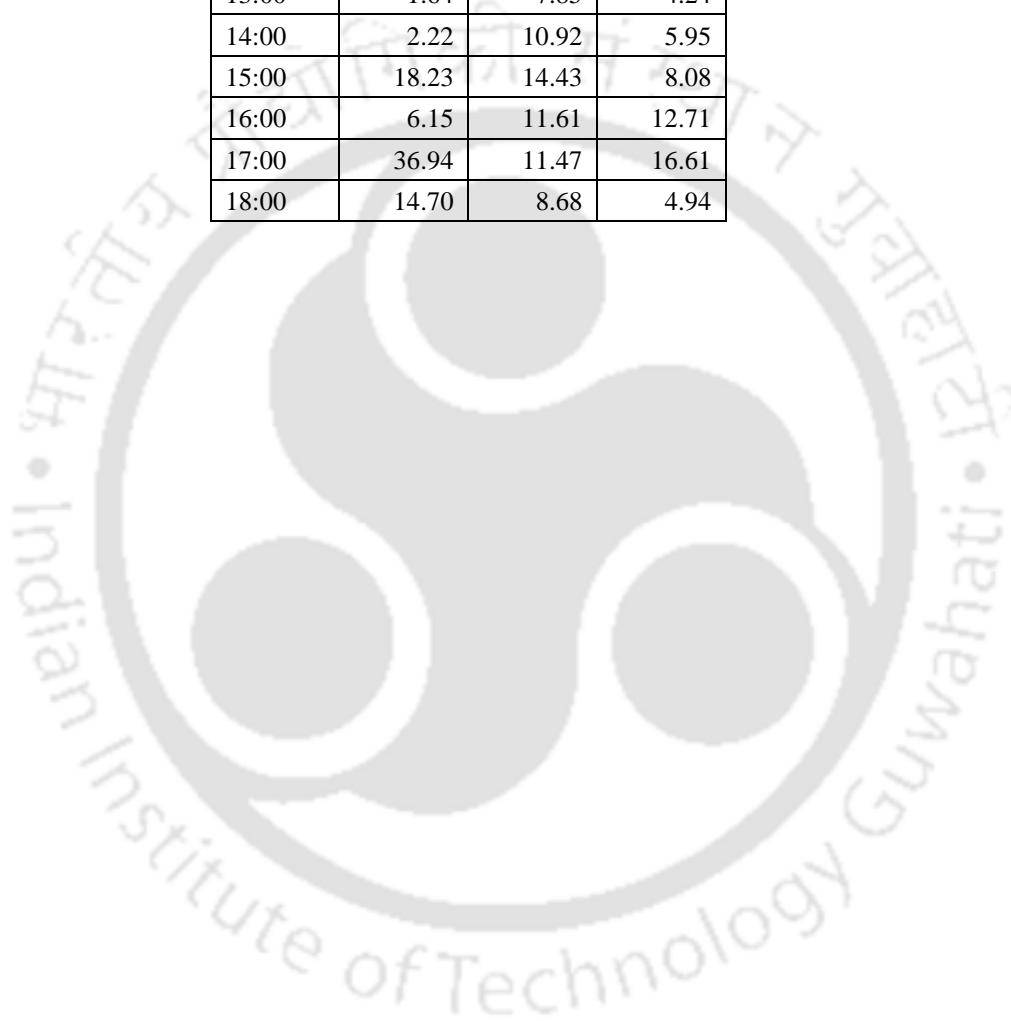
Pedestrian population counts

Weekdays (2014)					
Time	Moving	Cyclist	Stationary	Total	Standard Deviation
8:00	628	94	55	776	112
9:00	863	142	84	1088	85
10:00	1647	163	144	1954	247
11:00	2191	170	126	2487	119
12:00	2379	174	123	2675	157
13:00	2387	201	126	2713	141
14:00	2542	180	106	2829	180
15:00	1983	162	101	2245	88
16:00	1920	139	99	2158	143
17:00	2289	128	120	2537	160
18:00	2581	160	149	2890	89

Weekend (2014)					
Time	Moving	Cyclist	Stationary	Total	Standard Deviation
8:00	272	80	80	431	61
9:00	499	127	127	752	82
10:00	554	150	150	853	100
11:00	1007	127	127	1260	201
12:00	1352	114	114	1580	184
13:00	1785	157	157	2098	131
14:00	1471	124	124	1719	269
15:00	1313	83	83	1478	137
16:00	1297	97	97	1491	91
17:00	1594	94	94	1782	165
18:00	2581	93	93	2767	152

APPENDIX – IICalculated Δz on weekdays (2014)

Time	L1	L2	L3
8:00	12.16	12.15	7.82
9:00	10.74	11.74	8.62
10:00	11.74	11.63	7.15
11:00	3.69	9.17	8.20
12:00	1.58	7.19	4.35
13:00	1.64	7.85	4.24
14:00	2.22	10.92	5.95
15:00	18.23	14.43	8.08
16:00	6.15	11.61	12.71
17:00	36.94	11.47	16.61
18:00	14.70	8.68	4.94



APPENDIX – III

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
1	375997	2895140	1.50	1.76	1.46	2.14
2	376019	2895140	1.51	1.76	1.46	2.14
3	376040	2895140	1.51	1.78	1.46	2.14
4	376062	2895140	1.53	1.80	1.47	2.15
5	376083	2895140	1.54	1.82	1.47	2.15
6	376105	2895140	1.55	1.84	1.48	2.15
7	376126	2895140	1.55	1.84	1.48	2.15
8	376148	2895140	1.55	1.83	1.48	2.15
9	376169	2895140	1.55	1.83	1.48	2.15
10	376191	2895140	1.57	1.86	1.48	2.15
11	376212	2895140	1.58	1.89	1.49	2.15
12	376234	2895140	1.60	1.91	1.49	2.16
13	376255	2895140	1.62	1.94	1.50	2.16
14	376277	2895140	1.61	1.94	1.50	2.16
15	376298	2895140	1.68	2.05	1.52	2.17
16	376320	2895140	1.95	2.52	1.60	2.18
17	376341	2895140	2.02	2.65	1.62	2.18
18	376363	2895140	1.68	2.04	1.52	2.17
19	376384	2895140	1.48	1.72	1.45	2.13
20	376406	2895140	1.38	1.56	1.41	2.09
21	376427	2895140	1.32	1.46	1.38	2.03
22	375997	2895150	1.59	1.90	1.49	2.16
23	376019	2895150	1.60	1.92	1.50	2.16
24	376040	2895150	1.62	1.95	1.50	2.16
25	376062	2895150	1.65	1.99	1.51	2.16
26	376083	2895150	1.68	2.04	1.52	2.17
27	376105	2895150	1.70	2.08	1.53	2.17
28	376126	2895150	1.73	2.13	1.54	2.17
29	376148	2895150	1.75	2.17	1.54	2.17
30	376169	2895150	1.77	2.21	1.55	2.17
31	376191	2895150	1.81	2.27	1.56	2.17
32	376212	2895150	1.85	2.35	1.57	2.18
33	376234	2895150	1.88	2.39	1.58	2.18
34	376255	2895150	1.93	2.48	1.59	2.18
35	376277	2895150	1.97	2.56	1.61	2.18
36	376298	2895150	2.01	2.63	1.62	2.18
37	376320	2895150	2.51	3.56	1.72	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
38	376341	2895150	2.67	3.89	1.76	2.19
39	376363	2895150	1.91	2.44	1.59	2.18
40	376384	2895150	1.55	1.83	1.47	2.15
41	376406	2895150	1.42	1.61	1.42	2.11
42	376427	2895150	1.34	1.49	1.39	2.05
43	375997	2895170	1.67	2.04	1.52	2.17
44	376019	2895170	1.70	2.08	1.53	2.17
45	376040	2895170	1.73	2.13	1.54	2.17
46	376062	2895170	1.76	2.19	1.55	2.17
47	376083	2895170	1.81	2.27	1.56	2.17
48	376105	2895170	1.86	2.35	1.57	2.18
49	376126	2895170	1.90	2.44	1.59	2.18
50	376148	2895170	1.97	2.55	1.60	2.18
51	376169	2895170	2.02	2.66	1.62	2.18
52	376191	2895170	2.08	2.75	1.63	2.18
53	376212	2895170	2.13	2.84	1.64	2.18
54	376234	2895170	2.16	2.89	1.65	2.18
55	376255	2895170	2.20	2.98	1.66	2.18
56	376277	2895170	2.28	3.12	1.68	2.18
57	376298	2895170	2.22	3.02	1.67	2.18
58	376320	2895170	2.52	3.59	1.73	2.18
59	376341	2895170	2.44	3.42	1.71	2.18
60	376363	2895170	1.86	2.35	1.57	2.18
61	376384	2895170	1.56	1.85	1.48	2.15
62	376406	2895170	1.43	1.64	1.43	2.12
63	376427	2895170	1.35	1.50	1.39	2.06
64	375997	2895180	1.75	2.16	1.54	2.17
65	376019	2895180	1.77	2.21	1.55	2.17
66	376040	2895180	1.81	2.28	1.56	2.17
67	376062	2895180	1.87	2.38	1.58	2.18
68	376083	2895180	1.93	2.49	1.60	2.18
69	376105	2895180	2.00	2.62	1.61	2.18
70	376126	2895180	2.08	2.76	1.63	2.18
71	376148	2895180	2.18	2.94	1.66	2.18
72	376169	2895180	2.27	3.11	1.68	2.18
73	376191	2895180	2.35	3.26	1.69	2.18
74	376212	2895180	2.40	3.35	1.70	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
75	376234	2895180	2.37	3.31	1.70	2.18
76	376255	2895180	2.35	3.25	1.69	2.18
77	376277	2895180	2.30	3.17	1.68	2.18
78	376298	2895180	2.57	3.68	1.74	2.18
79	376320	2895180	2.70	3.95	1.76	2.19
80	376341	2895180	2.00	2.60	1.61	2.18
81	376363	2895180	1.88	2.39	1.58	2.18
82	376384	2895180	1.64	1.99	1.51	2.16
83	376406	2895180	1.45	1.66	1.44	2.12
84	376427	2895180	1.38	1.55	1.41	2.09
85	375997	2895200	1.80	2.25	1.56	2.17
86	376019	2895200	1.84	2.33	1.57	2.18
87	376040	2895200	1.89	2.42	1.58	2.18
88	376062	2895200	1.96	2.53	1.60	2.18
89	376083	2895200	2.04	2.68	1.62	2.18
90	376105	2895200	2.13	2.85	1.65	2.18
91	376126	2895200	2.24	3.05	1.67	2.18
92	376148	2895200	2.36	3.27	1.69	2.18
93	376169	2895200	2.47	3.49	1.72	2.18
94	376191	2895200	2.56	3.67	1.73	2.18
95	376212	2895200	2.59	3.71	1.74	2.18
96	376234	2895200	2.47	3.49	1.72	2.18
97	376255	2895200	2.33	3.21	1.69	2.18
98	376277	2895200	2.58	3.70	1.74	2.18
99	376298	2895200	2.71	3.97	1.76	2.19
100	376320	2895200	2.14	2.86	1.65	2.18
101	376341	2895200	1.96	2.55	1.60	2.18
102	376363	2895200	1.81	2.28	1.56	2.17
103	376384	2895200	1.72	2.11	1.53	2.17
104	376406	2895200	1.49	1.74	1.45	2.13
105	376427	2895200	1.38	1.55	1.41	2.09
106	375997	2895210	1.89	2.41	1.58	2.18
107	376019	2895210	1.94	2.50	1.60	2.18
108	376040	2895210	1.99	2.60	1.61	2.18
109	376062	2895210	2.06	2.71	1.63	2.18
110	376083	2895210	2.14	2.87	1.65	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
111	376105	2895210	2.24	3.05	1.67	2.18
112	376126	2895210	2.34	3.25	1.69	2.18
113	376148	2895210	2.47	3.50	1.72	2.18
114	376169	2895210	2.60	3.74	1.74	2.18
115	376191	2895210	2.65	3.85	1.75	2.19
116	376212	2895210	2.65	3.85	1.75	2.19
117	376234	2895210	2.45	3.45	1.71	2.18
118	376255	2895210	2.27	3.11	1.68	2.18
119	376277	2895210	2.48	3.50	1.72	2.18
120	376298	2895210	2.33	3.23	1.69	2.18
121	376320	2895210	2.02	2.65	1.62	2.18
122	376341	2895210	1.91	2.44	1.59	2.18
123	376363	2895210	1.75	2.18	1.54	2.17
124	376384	2895210	1.69	2.06	1.52	2.17
125	376406	2895210	1.58	1.89	1.49	2.15
126	376427	2895210	1.41	1.59	1.42	2.11
127	375997	2895230	1.98	2.58	1.61	2.18
128	376019	2895230	2.03	2.66	1.62	2.18
129	376040	2895230	2.08	2.75	1.63	2.18
130	376062	2895230	2.15	2.88	1.65	2.18
131	376083	2895230	2.23	3.04	1.67	2.18
132	376105	2895230	2.32	3.19	1.69	2.18
133	376126	2895230	2.41	3.37	1.70	2.18
134	376148	2895230	2.54	3.62	1.73	2.18
135	376169	2895230	2.65	3.84	1.75	2.19
136	376191	2895230	2.66	3.86	1.75	2.19
137	376212	2895230	2.59	3.73	1.74	2.18
138	376234	2895230	2.25	3.07	1.67	2.18
139	376255	2895230	2.36	3.27	1.69	2.18
140	376277	2895230	2.52	3.60	1.73	2.18
141	376298	2895230	1.99	2.60	1.61	2.18
142	376320	2895230	2.00	2.61	1.61	2.18
143	376341	2895230	1.87	2.38	1.58	2.18
144	376363	2895230	1.70	2.09	1.53	2.17
145	376384	2895230	1.65	2.00	1.51	2.16
146	376406	2895230	1.60	1.91	1.49	2.16
147	376427	2895230	1.50	1.74	1.46	2.14

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
148	375997	2895240	2.06	2.72	1.63	2.18
149	376019	2895240	2.11	2.81	1.64	2.18
150	376040	2895240	2.17	2.91	1.65	2.18
151	376062	2895240	2.23	3.02	1.67	2.18
152	376083	2895240	2.30	3.16	1.68	2.18
153	376105	2895240	2.36	3.29	1.70	2.18
154	376126	2895240	2.46	3.46	1.71	2.18
155	376148	2895240	2.54	3.63	1.73	2.18
156	376169	2895240	2.60	3.74	1.74	2.18
157	376191	2895240	2.57	3.69	1.74	2.18
158	376212	2895240	2.40	3.34	1.70	2.18
159	376234	2895240	2.55	3.65	1.73	2.18
160	376255	2895240	2.61	3.77	1.74	2.18
161	376277	2895240	2.09	2.77	1.64	2.18
162	376298	2895240	1.93	2.49	1.60	2.18
163	376320	2895240	1.98	2.57	1.61	2.18
164	376341	2895240	1.84	2.32	1.57	2.18
165	376363	2895240	1.66	2.02	1.52	2.16
166	376384	2895240	1.62	1.95	1.50	2.16
167	376406	2895240	1.58	1.88	1.49	2.15
168	376427	2895240	1.53	1.80	1.47	2.14
169	375997	2895260	2.14	2.86	1.65	2.18
170	376019	2895260	2.19	2.95	1.66	2.18
171	376040	2895260	2.24	3.06	1.67	2.18
172	376062	2895260	2.29	3.15	1.68	2.18
173	376083	2895260	2.36	3.28	1.70	2.18
174	376105	2895260	2.41	3.36	1.70	2.18
175	376126	2895260	2.45	3.45	1.71	2.18
176	376148	2895260	2.48	3.51	1.72	2.18
177	376169	2895260	2.47	3.49	1.72	2.18
178	376191	2895260	2.37	3.30	1.70	2.18
179	376212	2895260	2.33	3.22	1.69	2.18
180	376234	2895260	2.51	3.56	1.72	2.18
181	376255	2895260	2.27	3.10	1.67	2.18
182	376277	2895260	1.93	2.49	1.60	2.18
183	376298	2895260	1.98	2.58	1.61	2.18
184	376320	2895260	1.98	2.57	1.61	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
185	376341	2895260	1.83	2.30	1.57	2.18
186	376363	2895260	1.62	1.96	1.50	2.16
187	376384	2895260	1.59	1.90	1.49	2.16
188	376406	2895260	1.56	1.85	1.48	2.15
189	376427	2895260	1.53	1.80	1.47	2.15
190	375997	2895270	2.21	2.99	1.66	2.18
191	376019	2895270	2.27	3.11	1.68	2.18
192	376040	2895270	2.32	3.21	1.69	2.18
193	376062	2895270	2.37	3.30	1.70	2.18
194	376083	2895270	2.42	3.39	1.71	2.18
195	376105	2895270	2.41	3.37	1.70	2.18
196	376126	2895270	2.40	3.35	1.70	2.18
197	376148	2895270	2.35	3.26	1.69	2.18
198	376169	2895270	2.23	3.03	1.67	2.18
199	376191	2895270	2.10	2.79	1.64	2.18
200	376212	2895270	2.26	3.09	1.67	2.18
201	376234	2895270	2.47	3.48	1.72	2.18
202	376255	2895270	1.95	2.51	1.60	2.18
203	376277	2895270	1.91	2.44	1.59	2.18
204	376298	2895270	1.97	2.56	1.61	2.18
205	376320	2895270	1.93	2.49	1.60	2.18
206	376341	2895270	1.78	2.23	1.55	2.17
207	376363	2895270	1.59	1.90	1.49	2.16
208	376384	2895270	1.57	1.86	1.48	2.15
209	376406	2895270	1.54	1.81	1.47	2.15
210	376427	2895270	1.52	1.78	1.46	2.14
211	375997	2895290	2.26	3.08	1.67	2.18
212	376019	2895290	2.34	3.23	1.69	2.18
213	376040	2895290	2.39	3.33	1.70	2.18
214	376062	2895290	2.44	3.42	1.71	2.18
215	376083	2895290	2.47	3.49	1.72	2.18
216	376105	2895290	2.41	3.37	1.70	2.18
217	376126	2895290	2.31	3.17	1.68	2.18
218	376148	2895290	2.18	2.93	1.66	2.18
219	376169	2895290	1.99	2.60	1.61	2.18
220	376191	2895290	2.41	3.37	1.70	2.18
221	376212	2895290	2.57	3.68	1.74	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
222	376234	2895290	2.08	2.74	1.63	2.18
223	376255	2895290	1.91	2.45	1.59	2.18
224	376277	2895290	2.00	2.61	1.61	2.18
225	376298	2895290	1.98	2.57	1.61	2.18
226	376320	2895290	1.88	2.40	1.58	2.18
227	376341	2895290	1.75	2.16	1.54	2.17
228	376363	2895290	1.58	1.89	1.49	2.15
229	376384	2895290	1.54	1.82	1.47	2.15
230	376406	2895290	1.52	1.79	1.47	2.14
231	376427	2895290	1.50	1.76	1.46	2.14
232	375997	2895300	2.31	3.19	1.68	2.18
233	376019	2895300	2.40	3.34	1.70	2.18
234	376040	2895300	2.48	3.50	1.72	2.18
235	376062	2895300	2.52	3.60	1.73	2.18
236	376083	2895300	2.55	3.64	1.73	2.18
237	376105	2895300	2.47	3.50	1.72	2.18
238	376126	2895300	2.33	3.23	1.69	2.18
239	376148	2895300	2.11	2.80	1.64	2.18
240	376169	2895300	2.33	3.22	1.69	2.18
241	376191	2895300	2.48	3.51	1.72	2.18
242	376212	2895300	2.22	3.01	1.66	2.18
243	376234	2895300	1.87	2.38	1.58	2.18
244	376255	2895300	1.89	2.42	1.58	2.18
245	376277	2895300	1.96	2.53	1.60	2.18
246	376298	2895300	1.96	2.54	1.60	2.18
247	376320	2895300	1.86	2.37	1.58	2.18
248	376341	2895300	1.75	2.17	1.54	2.17
249	376363	2895300	1.60	1.91	1.49	2.16
250	376384	2895300	1.52	1.79	1.47	2.14
251	376406	2895300	1.50	1.76	1.46	2.14
252	376427	2895300	1.49	1.73	1.45	2.13
253	375997	2895320	2.36	3.27	1.69	2.18
254	376019	2895320	2.46	3.48	1.72	2.18
255	376040	2895320	2.55	3.65	1.73	2.18
256	376062	2895320	2.64	3.82	1.75	2.19
257	376083	2895320	2.67	3.89	1.76	2.19
258	376105	2895320	2.52	3.58	1.73	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
259	376126	2895320	2.33	3.23	1.69	2.18
260	376148	2895320	2.15	2.88	1.65	2.18
261	376169	2895320	2.30	3.17	1.68	2.18
262	376191	2895320	2.40	3.35	1.70	2.18
263	376212	2895320	1.96	2.53	1.60	2.18
264	376234	2895320	1.81	2.27	1.56	2.17
265	376255	2895320	1.88	2.40	1.58	2.18
266	376277	2895320	1.93	2.49	1.59	2.18
267	376298	2895320	1.92	2.46	1.59	2.18
268	376320	2895320	1.84	2.32	1.57	2.18
269	376341	2895320	1.75	2.17	1.54	2.17
270	376363	2895320	1.61	1.93	1.50	2.16
271	376384	2895320	1.50	1.76	1.46	2.14
272	376406	2895320	1.49	1.73	1.45	2.13
273	376427	2895320	1.47	1.71	1.45	2.13
274	375997	2895330	2.43	3.41	1.71	2.18
275	376019	2895330	2.55	3.65	1.73	2.18
276	376040	2895330	2.65	3.84	1.75	2.19
277	376062	2895330	2.77	4.08	1.77	2.19
278	376083	2895330	2.81	4.16	1.78	2.19
279	376105	2895330	2.58	3.71	1.74	2.18
280	376126	2895330	2.22	3.02	1.67	2.18
281	376148	2895330	2.43	3.41	1.71	2.18
282	376169	2895330	2.60	3.75	1.74	2.18
283	376191	2895330	2.10	2.78	1.64	2.18
284	376212	2895330	1.82	2.29	1.56	2.18
285	376234	2895330	1.78	2.22	1.55	2.17
286	376255	2895330	1.83	2.31	1.57	2.18
287	376277	2895330	1.88	2.39	1.58	2.18
288	376298	2895330	1.87	2.39	1.58	2.18
289	376320	2895330	1.81	2.28	1.56	2.17
290	376341	2895330	1.73	2.14	1.54	2.17
291	376363	2895330	1.62	1.94	1.50	2.16
292	376384	2895330	1.49	1.73	1.45	2.13
293	376406	2895330	1.48	1.71	1.45	2.13
294	376427	2895330	1.46	1.68	1.44	2.13
295	375997	2895350	2.56	3.67	1.73	2.18

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
296	376019	2895350	2.68	3.90	1.76	2.19
297	376040	2895350	2.80	4.14	1.78	2.19
298	376062	2895350	2.90	4.33	1.79	2.19
299	376083	2895350	3.01	4.56	1.81	2.19
300	376105	2895350	2.67	3.90	1.76	2.19
301	376126	2895350	2.64	3.82	1.75	2.19
302	376148	2895350	2.73	4.00	1.76	2.19
303	376169	2895350	2.30	3.17	1.68	2.18
304	376191	2895350	1.94	2.50	1.60	2.18
305	376212	2895350	1.78	2.22	1.55	2.17
306	376234	2895350	1.77	2.21	1.55	2.17
307	376255	2895350	1.78	2.22	1.55	2.17
308	376277	2895350	1.82	2.30	1.56	2.18
309	376298	2895350	1.83	2.31	1.57	2.18
310	376320	2895350	1.79	2.24	1.55	2.17
311	376341	2895350	1.73	2.13	1.54	2.17
312	376363	2895350	1.62	1.95	1.50	2.16
313	376384	2895350	1.48	1.71	1.45	2.13
314	376406	2895350	1.46	1.69	1.44	2.13
315	376427	2895350	1.45	1.66	1.44	2.12
316	375997	2895360	2.78	4.11	1.77	2.19
317	376019	2895360	2.97	4.48	1.80	2.19
318	376040	2895360	3.10	4.76	1.82	2.19
319	376062	2895360	3.23	5.03	1.84	2.19
320	376083	2895360	3.30	5.19	1.85	2.19
321	376105	2895360	3.49	5.61	1.88	2.19
322	376126	2895360	3.10	4.76	1.82	2.19
323	376148	2895360	2.69	3.93	1.76	2.19
324	376169	2895360	2.12	2.84	1.64	2.18
325	376191	2895360	1.85	2.34	1.57	2.18
326	376212	2895360	1.78	2.23	1.55	2.17
327	376234	2895360	1.75	2.17	1.54	2.17
328	376255	2895360	1.75	2.16	1.54	2.17
329	376277	2895360	1.79	2.24	1.56	2.17
330	376298	2895360	1.79	2.24	1.56	2.17
331	376320	2895360	1.76	2.19	1.55	2.17
332	376341	2895360	1.71	2.09	1.53	2.17

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
333	376363	2895360	1.62	1.96	1.50	2.16
334	376384	2895360	1.50	1.75	1.46	2.14
335	376406	2895360	1.45	1.67	1.44	2.13
336	376427	2895360	1.44	1.65	1.43	2.12
337	375997	2895380	3.14	4.85	1.83	2.19
338	376019	2895380	3.36	5.31	1.86	2.19
339	376040	2895380	3.65	5.96	1.90	2.19
340	376062	2895380	3.94	6.61	1.93	2.19
341	376083	2895380	4.03	6.82	1.94	2.19
342	376105	2895380	4.45	7.79	1.98	2.19
343	376126	2895380	4.26	7.34	1.96	2.19
344	376148	2895380	2.54	3.63	1.73	2.18
345	376169	2895380	2.05	2.70	1.63	2.18
346	376191	2895380	1.86	2.35	1.57	2.18
347	376212	2895380	1.78	2.23	1.55	2.17
348	376234	2895380	1.72	2.12	1.54	2.17
349	376255	2895380	1.70	2.08	1.53	2.17
350	376277	2895380	1.75	2.16	1.54	2.17
351	376298	2895380	1.75	2.18	1.54	2.17
352	376320	2895380	1.74	2.15	1.54	2.17
353	376341	2895380	1.70	2.08	1.53	2.17
354	376363	2895380	1.62	1.96	1.50	2.16
355	376384	2895380	1.51	1.76	1.46	2.14
356	376406	2895380	1.44	1.65	1.43	2.12
357	376427	2895380	1.43	1.63	1.43	2.12
358	375997	2895390	3.46	5.55	1.87	2.19
359	376019	2895390	3.71	6.09	1.90	2.19
360	376040	2895390	4.12	7.00	1.95	2.19
361	376062	2895390	4.34	7.51	1.97	2.19
362	376083	2895390	4.59	8.12	1.99	2.19
363	376105	2895390	4.59	8.13	1.99	2.19
364	376126	2895390	3.29	5.17	1.85	2.19
365	376148	2895390	2.50	3.54	1.72	2.18
366	376169	2895390	2.16	2.90	1.65	2.18
367	376191	2895390	1.93	2.49	1.60	2.18
368	376212	2895390	1.85	2.34	1.57	2.18
369	376234	2895390	1.77	2.20	1.55	2.17

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
370	376255	2895390	1.73	2.13	1.54	2.17
371	376277	2895390	1.77	2.21	1.55	2.17
372	376298	2895390	1.78	2.22	1.55	2.17
373	376320	2895390	1.75	2.17	1.54	2.17
374	376341	2895390	1.69	2.07	1.53	2.17
375	376363	2895390	1.62	1.95	1.50	2.16
376	376384	2895390	1.51	1.76	1.46	2.14
377	376406	2895390	1.43	1.63	1.43	2.11
378	376427	2895390	1.42	1.61	1.42	2.11
379	375997	2895410	3.72	6.11	1.90	2.19
380	376019	2895410	3.90	6.52	1.92	2.19
381	376040	2895410	4.15	7.08	1.95	2.19
382	376062	2895410	4.00	6.74	1.93	2.19
383	376083	2895410	4.30	7.43	1.96	2.19
384	376105	2895410	3.63	5.92	1.89	2.19
385	376126	2895410	2.81	4.17	1.78	2.19
386	376148	2895410	2.64	3.83	1.75	2.19
387	376169	2895410	2.10	2.79	1.64	2.18
388	376191	2895410	1.97	2.55	1.61	2.18
389	376212	2895410	1.89	2.41	1.58	2.18
390	376234	2895410	1.81	2.27	1.56	2.17
391	376255	2895410	1.77	2.21	1.55	2.17
392	376277	2895410	1.80	2.26	1.56	2.17
393	376298	2895410	1.79	2.23	1.55	2.17
394	376320	2895410	1.75	2.18	1.55	2.17
395	376341	2895410	1.70	2.08	1.53	2.17
396	376363	2895410	1.61	1.93	1.50	2.16
397	376384	2895410	1.50	1.76	1.46	2.14
398	376406	2895410	1.41	1.61	1.42	2.11
399	376427	2895410	1.40	1.59	1.42	2.10
400	375997	2895420	3.74	6.15	1.90	2.19
401	376019	2895420	3.74	6.17	1.91	2.19
402	376040	2895420	3.44	5.49	1.87	2.19
403	376062	2895420	3.86	6.44	1.92	2.19
404	376083	2895420	3.96	6.65	1.93	2.19
405	376105	2895420	3.10	4.76	1.82	2.19

APPENDIX – III (Continued)

Calculated relative risk (RR)

Receptors	UTM (East)	UTM (North)	RR (COPD)	RR (LC)	RR (IHD)	RR (Stroke)
406	376126	2895420	2.76	4.06	1.77	2.19
407	376148	2895420	2.59	3.73	1.74	2.18
408	376169	2895420	2.33	3.23	1.69	2.18
409	376191	2895420	2.01	2.63	1.62	2.18
410	376212	2895420	1.92	2.46	1.59	2.18
411	376234	2895420	1.85	2.33	1.57	2.18
412	376255	2895420	1.80	2.26	1.56	2.17
413	376277	2895420	1.83	2.30	1.57	2.18
414	376298	2895420	1.81	2.27	1.56	2.17
415	376320	2895420	1.76	2.19	1.55	2.17
416	376341	2895420	1.69	2.07	1.53	2.17
417	376363	2895420	1.61	1.93	1.50	2.16
418	376384	2895420	1.50	1.75	1.46	2.14
419	376406	2895420	1.40	1.59	1.42	2.10
420	376427	2895420	1.39	1.58	1.41	2.10
421	375997	2895440	3.29	5.17	1.85	2.19
422	376019	2895440	3.07	4.71	1.82	2.19
423	376040	2895440	2.15	2.88	1.65	2.18
424	376062	2895440	3.29	5.16	1.85	2.19
425	376083	2895440	3.13	4.83	1.83	2.19
426	376105	2895440	2.98	4.51	1.80	2.19
427	376126	2895440	2.65	3.85	1.75	2.19
428	376148	2895440	2.52	3.59	1.73	2.18
429	376169	2895440	2.39	3.33	1.70	2.18
430	376191	2895440	2.12	2.82	1.64	2.18
431	376212	2895440	1.96	2.54	1.60	2.18
432	376234	2895440	1.88	2.40	1.58	2.18
433	376255	2895440	1.85	2.34	1.57	2.18
434	376277	2895440	1.85	2.35	1.57	2.18
435	376298	2895440	1.83	2.31	1.57	2.18
436	376320	2895440	1.78	2.22	1.55	2.17
437	376341	2895440	1.70	2.08	1.53	2.17
438	376363	2895440	1.61	1.92	1.50	2.16
439	376384	2895440	1.49	1.74	1.46	2.14
440	376406	2895440	1.39	1.57	1.41	2.10
441	376427	2895440	1.39	1.56	1.41	2.09

APPENDIX – IV

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score	
1	Open shops	Worker - 1	M	18	147	50	SA*	NO	1	10	NO	1.96	3.14	2.25	87	3	0	2	1	0	0	0	0	6	
2		Worker - 2	M	20	170	52	SA	NO	3	7	NO	2.52	7.9	2.52	100	0	0	1	0	0	0	0	0	0	1
3		Worker - 3	F	21	152	50	SA	NO	4	10	NO	2.35	4.81	2.47	95	0	0		0	0	0	0	0	0	0
4		Worker - 4	M	23	160	54	SEC†	NO	4	8	NO	0.67	1.32	1.08	62	3	0	3	4	0	0	0	0	0	10
5		Worker - 5	M	23	162	58	SA	NO	1	8	NO	1.86	6.71	1.86	100	0	0	0	0	0	0	0	0	0	0
6		Worker - 6	M	24	162	51	SEC	NO	3.5	10	NO	2.43	5.11	3.21	76	4	3	0	0	0	0	0	0	0	7
7		Worker - 7	M	26	165	72	SA	NO	4	10	NO	2.67	10.3	2.8	95	0	0	0	0	0	0	0	0	0	0
8		Worker - 8	M	26	165	58	SV	NO	3	8	NO	2.5	7.32	2.61	96	2	0	4	3	3	1	4	4	4	21
9		Worker - 9	M	26	158	63	SA	NO	6	9	NO	2.21	6.53	2.34	94	0	0	0	0	0	0	0	0	0	0
10		Worker - 10	F	27	152	50	SA	NO	2	10	YES	1.56	4.28	1.92	81	2	0	2	3	4	4	3	3	3	21
11		Worker - 11	M	27	162	75	SA	NO	5	9	NO	1.7	5.58	1.72	99	0	0	0	0	0	0	0	0	0	0
12		Worker - 12	F	29	157	62	SV‡	NO	10	10	NO	1.22	1.47	1.49	82	2	0	0	4	4	3	2	4	4	19
13		Worker - 13	M	29	165	75	SA	NO	5	9	YES	2.64	3.11	3.34	79	0	0	4	4	0	0	0	0	0	8
14		Worker - 14	M	30	178	60	SA	NO	4	6	NO	2.78	5.7	2.85	98	0	0	0	0	0	0	1	1	1	2

* Shop assistant

† Security

‡ Street vendor

APPENDIX – IV (Continued)

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score	
15	Open shops	Worker - 15	M	32	175	65	SA	NO	12	9	NO	2.45	3.12	2.82	87	0	0	0	3	3	0	0	0	6	
16		Worker - 16	M	33	162	55	SA	NO	13	10	NO	2.36	6.85	4	59	0	1	3	4	0	0	0	0	2	10
17		Worker - 17	M	34	162	53	SV	NO	20	12	NO	2.36	5.21	3.02	78	0	0	2	1	0	0	0	0	1	4
18		Worker - 18	M	34	162	69	SA	NO	7	10	NO	2.14	10.45	2.14	100	0	0	0	0	0	0	0	0	0	0
19		Worker - 19	M	35	165	57	SA	NO	11	9	NO	1.22	1.47	1.49	82	0	0	0	0	0	0	0	0	0	0
20		Worker - 20	M	37	165	65	SA	NO	10	10	NO	1.22	3.81	1.26	97	0	0	0	0	0	0	0	0	0	0
21		Worker - 21	M	37	162	50	SA	NO	20	8	YES	1.46	5.65	1.46	100	0	0	0	0	0	0	0	0	0	0
22		Worker - 22	F	40	152	50	SA	NO	18	8	NO	1.74	2.95	1.79	97	0	0	0	0	0	0	0	0	0	0
23		Worker - 23	M	42	163	55	SV	NO	4	8	NO	2.39	2.96	2.96	81	1	0	1	1	0	1	2	1	7	
24		Worker - 24	M	43	160	67	SEC	NO	5	8	NO	1.29	3.48	1.32	98	0	0	0	0	0	0	0	0	0	0
25		Worker - 25	M	48	152	56	SA	NO	30	12	NO	1.64	2.37	2.14	77	1	0	2	3	0	0	0	0	2	8
26		Worker - 26	M	48	165	79	SA	NO	15	10	NO	1.31	4.26	1.35	97	2	0	0	0	0	0	0	0	0	2
27		Worker - 27	M	66	187	78	SV	NO	45	14	NO	1.88	5.91	2	94	0	0	1	0	0	0	1	0	2	
28		Worker - 28	M	18	173	65	SA	NO	2	12	NO	2.31	6.75	2.31	100	0	0	0	0	0	0	0	0	0	0
29		Worker - 29	M	29	173	68	SA	NO	10	14	NO	2.31	3.9	2.43	95	0	0	0	0	0	0	0	0	0	0
30		Worker - 30	M	32	167	77	SA	NO	10	8	NO	1.79	5.33	1.83	98	0	0	0	0	0	0	0	0	0	0
31		Worker - 31	M	32	170	72	SV	NO	20	13	NO	2.77	4.54	2.79	99	0	0	0	0	0	0	0	0	0	0

APPENDIX – IV (Continued)

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score
32	Open shops	Worker - 32	F	34	157	60	SA	NO	1	8	NO	2	6.23	2.11	95	0	0	0	0	0	0	0	0	0
33		Worker - 33	F	35	152	63	SA	NO	17	10	YES	0.67	0.69	1.17	57	4	4	4	4	0	1	0	2	19
34		Worker - 34	F	63	160	62	SA	NO	45	12	YES	1.32	2.78	1.53	86	0	0	0	4	4	4	2	2	16
35		Worker - 35	M	34	162	69	SA	NO	10	12	NO	2.14	10.45	2.14	100	0	0	2	3	1	0	0	0	6
36		Worker - 36	M	42	162	55	SV	NO	10	12	NO	1.79	5.7	1.79	100	0	0	0	0	0	0	0	0	0
37		Worker - 37	M	25	164	60	SA	NO	6	8	NO	1.79	3.39	1.9	94	0	0	0	0	0	0	0	0	0
38		Worker - 38	M	28	162	68	SA	NO	5	9	NO	1.64	2.51	2.04	80	1	0	1	1	0	0	0	3	6
39		Worker - 39	M	38	166	59	SV	NO	7	8	NO	1.52	2.22	1.72	88	0	3	0	1	0	0	0	0	4
40		Worker - 40	M	33	170	65	SV	NO	6	9	NO	1.38	4.22	1.78	78	1	0	2	2	0	0	0	1	6
41		Worker - 41	F	31	162	68	SA	NO	4	8	NO	1.9	7.16	1.95	98	0	0	0	0	0	0	0	1	1

APPENDIX – IV (Continued)

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score		
42	Air conditioned shops	Worker - 42	M	20	152	48	SA	NO	2	9	NO	1.99	7.43	1.99	100	1	0	0	0	0	0	0	2	3		
43		Worker - 43	M	20	160	55	SA	NO	2	9	NO	2.21	7.47	2.21	100	0	0	0	0	0	0	0	0	0	0	
44		Worker - 44	F	20	168	47	SA	NO	1	9	NO	1.56	4.12	1.56	100	0	0	0	0	0	0	0	0	0	0	
45		Worker - 45	F	20	157	47	SA	NO	1	9	NO	2.25	5.91	2.25	100	0	0	0	0	0	0	0	0	0	0	
46		Worker - 46	M	21	167	60	SA	NO	1	9	NO	2.39	7.6	2.4	99	0	0	0	0	0	0	0	0	0	0	
47		Worker - 47	M	21	168	65	SA	NO	1	9	NO	2.29	10.22	2.29	100	0	0	0	0	0	0	0	0	0	0	0
48		Worker - 48	M	21	160	55	SA	NO	1	9	NO	1.6	7.06	1.6	100	0	0	0	0	0	0	0	0	0	0	0
49		Worker - 49	M	21	167.64	50	SA	NO	1	9	NO	1.45	7.35	1.45	100	0	0	0	0	0	0	0	0	0	0	0
50		Worker - 50	M	21	160	55	SA	NO	1	9	NO	2.27	9.27	2.27	100	1	1	1	1	0	0	0	0	1	5	
51		Worker - 51	M	22	170	64	SA	NO	2	9	NO	2.09	10.3	2.09	100	0	0	0	0	0	0	0	0	0	0	0
52		Worker - 52	F	22	162.56	52	SA	NO	1	9	NO	1.38	5.72	1.38	100	0	0	0	0	0	0	0	0	0	0	0
53		Worker - 53	F	22	162.56	52	SA	NO	1	9	NO	1.81	3.96	1.86	97	0	0	0	0	0	0	0	0	0	0	0
54		Worker - 54	M	23	164	61	SA	NO	1	9	NO	1.71	7.68	1.71	100	3	2	0	0	0	0	0	0	0	5	
55		Worker - 55	M	23	174	57	SA	NO	1	9	NO	2.65	8.32	2.7	99	0	0	0	0	0	0	0	0	0	0	0
56		Worker - 56	M	23	156	56	SA	NO	6	9	NO	2.57	9.52	2.59	99	0	0	0	0	0	0	0	0	0	0	0
57		Worker - 57	M	23	164	63	SA	NO	5	9	NO	2.56	6.23	2.6	98	0	0	0	0	0	0	0	0	0	0	0
58		Worker - 58	M	24	170	60	SA	NO	1	9	NO	0.86	5.79	0.86	100	0	0	0	0	0	0	0	0	0	0	0
59		Worker - 59	M	24	170	60	SA	NO	2	9	NO	2.02	6.5	2.06	98	0	0	0	0	0	0	0	0	0	0	0

APPENDIX – IV (Continued)

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score		
60	Air conditioned shops	Worker - 60	M	24	173	60	SA	NO	1	9	NO	3.1	8.53	3.22	96	0	0	0	0	0	0	0	0	0	0	
61		Worker - 61	F	24	148	52	SA	NO	1.5	9	NO	2	5.72	2	100	0	0	0	0	0	0	0	0	0	0	0
62		Worker - 62	F	24	154.94	50	SA	NO	4	9	NO	1.52	6.75	1.52	100	0	0	0	0	0	0	0	0	0	0	0
63		Worker - 63	F	24	152	48	SA	NO	1	9	NO	2.34	4.48	2.34	100	0	0	0	0	0	0	0	0	0	0	0
64		Worker - 64	M	25	177	54	SA	NO	2	9	NO	1.74	6.81	1.75	99	3	2	0	0	0	0	0	0	0	0	5
65		Worker - 65	M	25	153	47	SA	NO	0.5	9	NO	1.01	5.13	1.01	100	0	0	0	0	0	0	0	0	0	0	0
66		Worker - 66	F	25	160	49	SA	NO	0.5	9	NO	1.11	4.21	1.11	100	0	0	0	0	0	0	0	0	0	0	0
67		Worker - 67	F	25	152	46	SA	NO	1.5	9	NO	1.72	5.35	1.72	100	0	0	0	0	0	0	0	0	0	0	0
68		Worker - 68	M	25	169	55	SA	NO	4	9	NO	2.56	9.21	2.56	100	0	0	0	0	0	0	0	0	0	0	0
69		Worker - 69	F	25	155	42	SA	NO	0.5	9	NO	1.11	3.23	1.13	98	0	0	0	0	0	0	0	0	0	0	0
70		Worker - 70	F	25	160	47	SA	NO	1.5	9	NO	1.52	6.68	1.52	100	0	0	0	0	0	0	0	0	0	0	0
71		Worker - 71	M	25	169	62	SA	NO	1.5	9	NO	1.88	7.81	1.88	100	0	0	0	0	0	0	0	0	0	0	0
72		Worker - 72	M	25	160	55	SA	NO	2	9	NO	1.64	4.89	1.75	94	0	0	2	0	3	0	0	0	0	5	
73		Worker - 73	F	25	162	57	SA	NO	3	9	NO	2.15	4.36	2.54	92	2	0	0	0	0	0	0	0	2	4	
74		Worker - 74	M	26	167	51	SA	NO	2	9	NO	2.1	7.51	2.1	100	0	0	0	0	0	0	0	0	0	0	0
75		Worker - 75	M	26	170	75	SA	NO	1	9	NO	2.43	10.3	2.43	100	0	0	0	0	0	0	0	0	0	0	0
76		Worker - 76	M	26	160	65	SA	NO	1.5	9	NO	2.4	7.94	2.43	100	0	0	0	0	0	0	0	0	0	0	0
77	Worker - 77	M	26	170	64	SA	NO	2	9	NO	1.57	5.52	1.57	99	0	0	0	0	0	0	0	0	0	0	0	

APPENDIX – IV (Continued)

Health survey data

Serial No.	Shop category	Name	Sex	Age (Y)	Height (cm)	Weight (Kg)	Occupation	Smoker	Years worked	Hours in a day spends	Occupational and residential address same	FEV1 (l)	PEF (l/s)	FVC (l)	FEV1/FVC (%)	Cough	Phlegm	Chest tight	Breathless towards uphill	Daily activity limitation	Confidence in leaving home	Sound sleep	Energy	CAT score			
78	Air conditioned shops	Worker - 78	F	26	152.4	48	SA	NO	6	9	NO	0.97	3.9	0.99	99	0	0	0	0	0	0	0	0	0	0		
79		Worker - 79	F	27	152	49	SA	NO	3	9	NO	1.86	6.1	1.86	100	0	0	0	0	0	0	0	0	0	0	0	
80		Worker - 80	M	28	162	54	SA	NO	0.5	9	NO	1.75	7.47	1.75	100	0	0	0	0	0	0	0	0	0	0	0	
81		Worker - 81	M	28	190	65	SA	NO	1	9	NO	1.92	6.38	1.93	100	0	0	0	0	0	0	0	0	0	0	0	
82		Worker - 82	M	28	162	50	SA	NO	1	9	NO	3.13	6.07	3.5	89	2	0	0	0	0	0	0	0	2	4	4	
83		Worker - 83	F	30	164	45	SA	NO	5	9	NO	1.5	5.67	1.5	100	0	0	0	0	0	0	0	0	0	0	0	0
84		Worker - 84	M	30	164	70	SA	NO	4	9	NO	1.67	6.95	1.67	100	0	0	0	0	0	0	0	0	0	0	0	0
85		Worker - 85	M	30	164	67	SA	NO	5.5	9	NO	2.07	9.27	2.07	100	0	0	0	0	0	0	0	0	0	0	0	0
86		Worker - 86	M	32	156	57	SA	NO	1	9	NO	0.95	0.98	1.65	58	3	2	0	3	0	0	0	0	2	10	10	
87		Worker - 87	M	32	152	45	SA	NO	6	9	NO	1	5.45	1	100	0	0	0	0	0	0	0	0	0	0	0	0
88		Worker - 88	M	34	164	55	SA	NO	5	9	NO	2.49	7.16	2.49	100	0	0	0	0	0	0	0	0	0	0	0	0
89		Worker - 89	F	42	152	45	SA	NO	1	9	NO	1.52	4.74	1.53	99	0	0	0	0	0	0	0	0	0	0	0	0