AMBIENT AIR QUALITY ANALYSIS IN SHIMLA CITY:
A MODELLING APPROACH

A THESIS

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of

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to

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HIMACHAL PRADESH, INDIA

May- 2019

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitles "**Ambient Air Quality Analysis in Shimla City- A Modelling Approach"** submitted for partial fulfilment of the requirements for the Master of Technology in Civil Engineering (Environmental Engineering) at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Rajiv Ganguly.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"AMBIENT AIR QUALITY ANALYSIS OF SHIMLA CITY – A MODELLING APPROACH** "in the partial fulfilment of the requirements for the award of the degree of Masters of Technology in Civil Engineering (Environmental Engineering) submitted to the Department of Civil Engineering, **JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY, WAKNAGHAT** is an authentic record of work carried out by **Divyansh Sharma (172754)** during the period from August 2018 to May 2019 under the supervision of **Dr. Rajiv Ganguly**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

This study evaluated the existing ambient air quality of Shimla city for period of 2011-2017. The monitoring is conducted at two locations which are representative of two different conditions within city representing two distinct monitoring classifications- an urban and a background site. The assessment was based on several parameters. Short term variations in air quality was analysed by studying the change in concentrations of air pollutants for the festival of Diwali and compared with normal day concentration of pollutants. The higher levels of degradation was noted at monitoring site II i.e. the urban site where combined effect of vehicular emissions and firework activities affected the concentration of pollutants. It was observed that pyrotechnic activities had significant influence on concentrations of air pollutants especially RSPM. The results of short term analysis was validated by determination of Air Quality Index. Long term trends were analysed by studying the annual and seasonal variations in concentrations of air pollutants. The degree of pollution at two monitoring sites was observed using Annual Exceedance factor. The annual mean concentrations of NO_2 and SO_2 were found to be well within NAAQS standards, however annual average concentrations of RSPM crossed the standards several times. It was also noticed in seasonal analysis that concentrations of only particulate matter significantly varied during the seasons. Highest concentrations were observed during the summer season, with lowest levels of particulates were noted in rainy season. A regression analysis for determining the association of monitored air pollutants with meteorological parameters was conducted. Modelling studies revealed the use of STREET and CALINE 4 models for prediction of ambient air quality of Shimla city. Further, another focal point of research is absence of adequate monitoring stations and techniques and hence inability to represent the existing air quality of the entire city.

Keywords: Industrialization, Urbanization, Ambient Air, Atmospheric Pollutants, Meteorological Parameters.

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ABBREVIATIONS

ARAI: Automotive Research Association of India

AQI: Air Quality Index

BIS: Bureau of Indian Standards

CALINE: California Line Source Model

COPD: Chronic Obstructive Pulmonary Disease

CPCB: Central Pollution Control Board

DMRB: Design Manual for Roads and Bridges

EDX: Energy Dispersive X-Ray

GAM: Generalized Additive Model

GBD: Global Burden Disease

GDP: Gross Domestic Product

GoI: Government of India

HPSPCB: Himachal Pradesh State Pollution Control Board

IMD: Indian Meteorological Department

JNNURM: Jawaharlal Nehru National Urban Rejuvenation Mission

NAAQS: National Ambient Air Quality Standards

NAMP: National Air quality Monitoring Programme

NEDA: N-(1-naphthyl) - ethylenediamine di-hydrochloride

NEXUS: Near Road Exposures to Urban Air Pollution Study

NMSE: Normalized Mean Square Error

RDS: Respirable Dust Sampler

RSPM: Respirable Suspended Particulate Matter

SEM: Scanning Electron Microscope

SPM: Suspended Particulate Matter

TSPM: Total Suspended Particulate Matter

UFP: Ultra-Fine Particulate

VOC: Volatile Organic Carbon

WHO: World Health Organisation

CHAPTER 1

INTRODUCTION

1.1 Background

Air Quality can be described as the quality of air in our surroundings. With air being one of essentials of life, quality of air affects our breathing and ultimately our existence. Good air quality directly indicates the degree to which the air is clean i.e. pollution free or less polluted. Degradation of air quality damages most resources which combine to form the environment [1].

The air pollution is a result of large number of elements, predominantly by anthropogenic activities and some natural sources. Industrialization and globalization have helped in developing the economy of the countries. However, increasing population along with urbanization have led to an abrupt and unsystematic industrialization and vehicular sources. These factors have become the primary element of concern for developed as well as developing countries [3, 4]. In past, only domestic and industrial activities resulted in release of air pollutants especially SO_2 and TSP. High levels of smoke and SO_2 are outcomes of combustion of sulphur containing fossil fuels like coal. Moreover, rapid increase in population created the demand for meeting the transportation needs. The consequence was substantial increase in number of motor vehicles, which eventually led to degradation of air quality. Thus, air quality degradation in present state has been consequence of automobiles and industrial activities [5].

Air pollution has been repercussion of the anthropogenic activities like vehicles, industrial gaseous effluents, burning of fossil fuels, firecrackers and wood, construction activities etc. However, studies have shown influence of natural sources like volcanic eruptions, wildfires, dust emissions from windstorms and bio aerosols such as pollen grains and spores. The majorly concerned pollutants which are produced by these anthropogenic and natural sources are oxides of sulphur and nitrogen, particulates, carbon monoxide, ozone, heavy metals and other hazardous pollutants [5, 6, 7].

The composition and concentration of pollutants are affected by spatial factors like street distance, topography and influence of other pollutant sources. Meteorological parameters and traffic intensity are described as temporal factors which have influence on the air pollutant dispersion and its exposure to human being [34].

Prevailing meteorological conditions like wind speed, wind direction, ambient temperature, relative humidity etc. play an important part in improving or weakening the quality of air by affecting transportation and distribution of air pollutants [8]. Winds carry pollutants from their source causing them to disperse and thus, decreasing their concentration. However, stable conditions results in accumulation of pollutants near the source causing localized air pollution. One such episode of latter situation was Great Smog of London of 1952 where, little wind conditions and moist air formed fog. This fog in turn got mixed with the pollutants released from combustion of coal and formed the Great London Smog [9].

The effects of air quality degradation have been quantified and are well documented. They have been a subject of extensive research since past century [10, 11]. It has now been generally acknowledged and accepted that human health gets affected by the exposure of air pollution on a day to day basis. The consequences of degradation of air quality on human health are complicated because of contrast in sources and their varying individual effects [12]. Majority of the public health and environment concern has been linked with pollutants like particulate matter, oxides of nitrogen and sulphur and ozone. Concentration levels and time of exposure both are important parameters which decide the conditions affecting the human health [10]. During London Smog episode, the exacerbation of cardiovascular and respiratory systems were noted due to exposure to incomplete coal combustion and diesel emissions [9]. Figure 1.1 illustrated the impacts of air pollutants on various body parts of human body. Exposure of human beings especially vulnerable population namely infants, elder people to air pollution may result in several types of respiratory and cardio vascular disease and several types of cancers. Exposure of various air pollutants have been correlated with birth abnormalities and irregularities such as baby being born underweight, pre term births etc. [12].Various epidemiological research and site specific studies have also disclosed the adversities of degradation of air on potentially vulnerable population groups especially children and elderly people [13, 14]. With increase in mortality and morbidity rates results in massive burden on the existing public health system. This is turn also disturbs the efficiency of the skilled workforce sooner or later affects the productivity and economy of country [15].

.While long term trends being topic of research since quite long time, short-term episodes of degradation of air quality have caught eyes of scientific community considering the substantial effect on human health. Pyrotechnic display is an unconventional anthropogenic activity that creates short-term pollution and health threats all around the globe. The burning of firecrackers during celebrations and several cultural festivals around world emit gaseous pollutants, aerosols and trace elements into the atmosphere generating dense clouds of smoke. This can also stimulate several health effects like damaging of nervous system, haematological or carcinogenic effects on exposed population. Thus, the celebrations involving fireworks have direct repercussions on short and long term quality of air along with the public health and environment which shows necessity of extensive research in this area [16, 17].

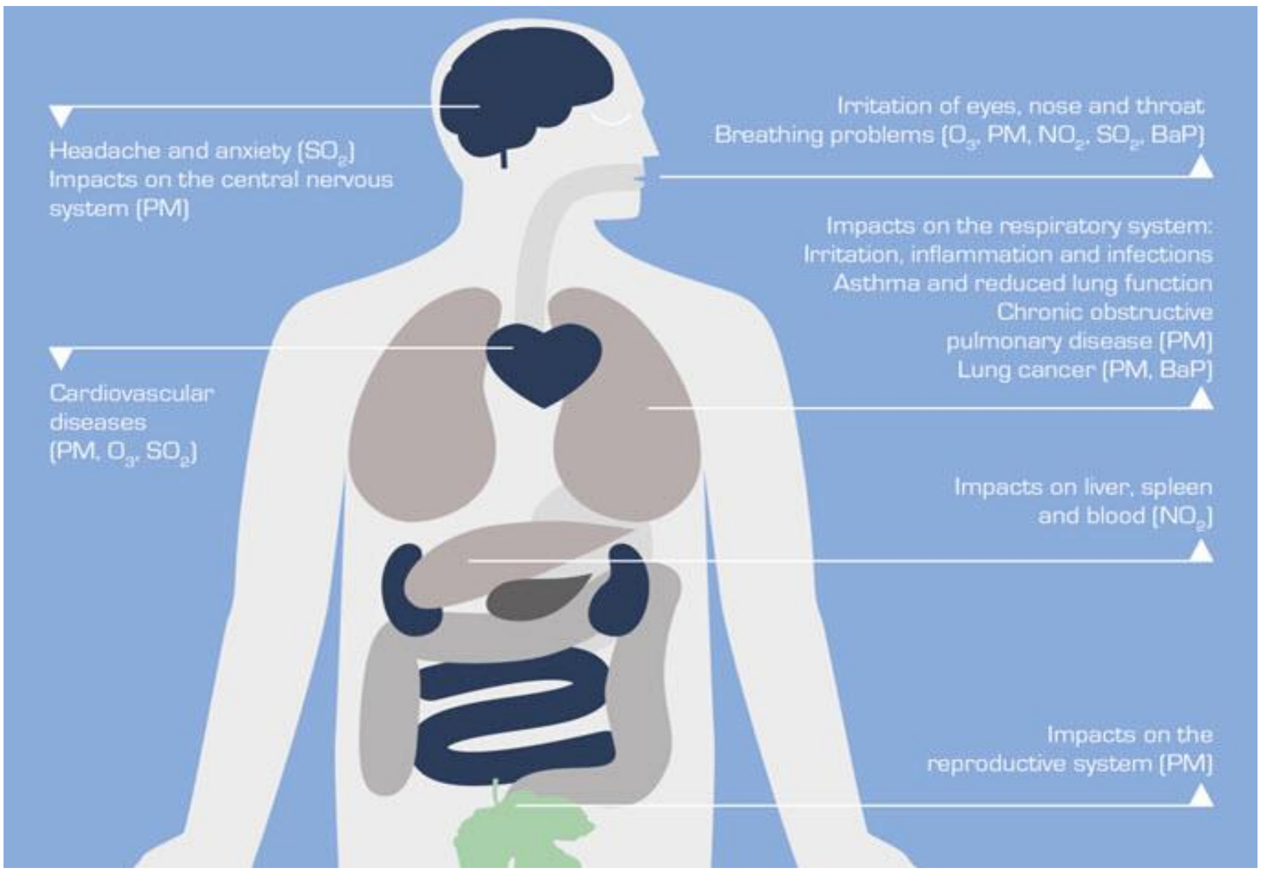


Figure 1.1: Impacts of Different Pollutants on Different Body parts [Source: http://www.airquality.dli.mlsi.gov.cy/health-effects]

1.2 Air Pollution in India: Current Scenario

Ambient air quality in urban areas of India has deteriorated particularly attributed to rapid urbanization and industrialization as well as rampant increase of vehicles. Several other anthropogenic activities like garbage burning, dearth of public awareness, wood and coal burning for domestic purposes and natural causes such as dust storms have also contributed in deteriorating the air quality [7, 18, 19].

Air pollution largely responsible for increased mortality and morbidity in India is yet become an electoral issue. The concerned regulatory bodies in central and state governments have intervened to reduced air pollution, however lack of rational policies and disorganized expansion of several sectors instrumental for economic growth of country like construction, industry etc. has proved to be barriers in the efforts. The absence of stringent air pollution regulations and policies and lack of adequate transportation system for public contribute further to the problem of local air pollution.

According to WHO data, there are fourteen cities from India placed among the world's 20 most polluted cities, worst being Uttar Pradesh's one of the largest cities, Kanpur having highest $PM_{2.5}$ levels in the world [20]. Fine particulate matter ($PM_{2.5}$) is one of the critical pollutants produced by intensive fuel burning, which can enter our body while inhaling and get trapped in the lungs, damaging the lungs and other body parts as well. On average, exposure to $PM_{2.5}$ concentrations of citizens in India is between 15 and 32 times the WHO air quality guidelines. The researchers and scientists have projected that India's $PM_{2.5}$ levels might get doubled by 2050 relative to 2015 levels.

The Lancet Commission on Pollution and Health 2015 has reported that pollution caused nine million deaths globally out of which highest deaths (2.51 million) were recorded only in India [21]. Poor air quality has created 1.09 million in our country. Moreover, household pollution has led to .97 million deaths. According to the GBD report, ambient air and household pollution have caused deaths of approximately 2 million preterm infants annually [29]. Thus, contribution of air pollution in aggravating the health conditions in the country is very large .Moreover, it can be placed above other elements like high blood pressure, smoking, child and maternal malnutrition which impact the human health [30]. Air pollution deaths have been a result of many non-communicable diseases such as cardiovascular diseases (heart stroke, lung cancer) and respiratory diseases [21].The present report of World Bank suggests that deaths due to air pollution account for 7.69 % of India's GDP [15].

Thus, potential impacts of the pollutants on human health and environment has created the urgency for analysis of ambient air quality. Assessment of air quality is generally done in two ways. First technique is large scale monitoring at varied sites. This approach is quite comprehensive and involves measurements of air pollutants and meteorological parameters. However, longer monitoring durations and cost involved are the disadvantages of this method. Second approach is development of an air quality model which are used to assess the present conditions and estimating the future concentrations of air pollutants. This way we can identify the troubled spots and ensure the steps for remediation for ensuring cleanest air possible [22].

1.3 Layout of Thesis

The report has been divided into six chapters:

Chapter One introduces the problem considered, its impact globally and in India. Brief about the air quality modelling has also been discussed.

Chapter Two reviews the available literature related to the analysis of ambient air quality of various locations w.r.t their long and short term impacts on human and environment. Literature relevant to various modelling techniques has also been discussed. Objectives that were established after literature review has also been listed in the same chapter.

Chapter Three provides the background of the city. The insight of complications faced by city and their association with the air pollution has also been discussed It also highlights the methodology of the research.

Chapter Four presents the discussion and graphical analysis of ambient air quality of Shimla city depicting the short term and long term trends of air pollutants in the city. The AQI has also been calculated to confirm the changing trends of air quality in Shimla city.

Chapter Five outlines the results of modelling of PM_{10} concentrations using the STREET and CALINE4 dispersion models. Statistical analysis has been used to find the suitability of models. Limitations and obstructions involved in use of model for predicting the pollutant concentration for city has also been discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Characterization and quantification of air pollution sources

2.1.1 Chin T.H.A (1995), "Containing Air Pollution and Traffic Congestion: Transport Policy and the Environment in Singapore" [5].

This paper analysed the policies related to transportation and measures which are instrumental in curbing the air pollution in Singapore. Large scale noise and air pollution is caused by increase in number of vehicles at any urban location. There is a significant relation between traffic density and air and noise pollution levels. Author has analysed the effectiveness of road pricing and Vehicle Quota System (VQS), which assist in controlling traffic congestions and ownership of automobiles in Singapore.

2.1.2 Almeida S. M., Pio C. A., Freitas M. C., Reis M. A. and Trancoso M. A. (2005), "Source Apportionment of Fine and Coarse Particulate Matter in a Sub-Urban Area at the Western European Coast" [6].

Possible sources of particulate matter in city of Lisbon were determined using Principal Component Analysis (PCA) and Multilinear Regression Analysis (MLRA). After indentification, sources were clustered togethor to form seven major groups which were soil, sea, road traffic, secondary aerosols, petroleum combustion, burning of coal and biomass and a Se/Hg emission source. Secondary aerosols and vehicle exhaust were the major contributors of $PM_{2.5}$ however, marine and mineral aerosols were predominant in coarse franction. This research article concluded that identification and characterization of sources helps in formulation of abatment strategies to improve air quality.

2.1.3 Limbeck A. and Puls C. (2010), "Particulate Emissions from On-Road Vehicles" [64].

This paper compared the outcomes obtained from various tunnel studies performed at varying sites around the world by quantifying the emission rates generated by vehicles in road tunnels. Tunnel studies can be used as a technique for indirect measurement of vehicular emissions. Vehicle fleet composition effects the on road concentrations of particulates. Majority of particles included soluble ions like ammonium, sulphates and mineral components like silicon, iron, aluminium, magnesium and calcium. Particulate emissions were attributed to tailpipe exhaust fraction as well as non-tailpipe sources. PM_{10} emissions were influence by resuspended matter and brake wear however, fine particles mainly originated from combustion processes. Authors have highlighted that real time emission rates of motor vehicles can be quantified in road tunnels.

2.1.4 Pachauri T., Singla V., Satsangi A., Lakhani A. and Kumari K.M. (2013), "Characterization of major pollution events (dust, haze, and two festival events) at Agra, India" [65].

Particulates sample were collected during events which have the potential to alter the air quality of Agra city. The events for which studies were carried included dust storms and festivals of Diwali and Holi. Measurements of concentrations pollutants: NO_2, SO_2 and O_3 were also performed along with the meteorological parameters. Burning of biomass during the night prior to Holi festival and pyrotechnic display during the festival of Diwali elevated the aerosol load in the atmosphere. Since, these festivals are celebrated in winter months, so stable conditions justify the intensification of air pollutant concentrations during the festivals. Highest levels of TSP were observed during Haze episodes and other episodes exhibited a decreasing order of Holi > DEs > Diwali.

2.1.5 Guttikunda S.K. And Goel R. (2014), "Nature of air pollution, emission sources, and management in the Indian cities." [7]

In this paper, authors have highlighted the sources of emission and techniques to control them which are required to deal with the degrading air quality in Indian cities with a particular focussing on several domains namely, public transportation, travel demand management, industrial emission standards, road dust management etc. Commonly identified contributors resulting in lowering of air quality include manufacturing of vehicles and electricity generation industries, construction activities, combustion of petroleum products and biomass in industries and households, road dust waste burning and marine/ sea salt. Contributions of varying sources on air pollution has been reported for major urban cities of India. It concluded that ground measurements, computational and satellite studies have pointed towards changing pollution trends in India.

2.1.6 Tripathi S.K. (2016), "Evaluation of Ambient Air Pollution: A case study of Varanasi, U.P." [46].

Study was carried out in 5 major circles of Varanasi for analysis of NO_x, SO_2, and SPM by BIS methods. The results showed higher value of all parameters i.e. NO_x, SO_2, and SPM beyond CPCB limit. The city is facing severe air pollution due to rapid urban development, numerous construction projects sanctioned from government and aggressive growth in the vehicular usage and fuel consumption.

Higher concentrations of oxides of nitrogen persisting in the ambient air drastically impact both humans and ecosystem and also play a decisive role in tropospheric chemistry. Average Concentration of NO_x ranged between 76 ±12.33 μg/m^3 at Lanka to 151.27±15.45 μg/m^3 at Cantt. Station. NO_x concentrations at one station near to and was above the CPCB standards (80μg/$m^{3)}$ for other four stations. Anthropogenic combustion from industries, vehicles and household industries resulted in peaking of NO_x emissions. Average Concentration of SO_2 was observed highest at Cantt. Station (224.4 ±26.1 μg/m3) and lowest at the Lanka (114.6±12.28 μg/m^3). Average Concentration at all stations was above the CPCB standard (80 μg/$m^{3)}$. This high concentration of SO_2 can be attributed to increased vehicular load. Value of SPM concentrations were 8 to 35 times higher than the average concentration for SPM set by CPCB (100 μg/m^3). Heavy vehicles use in transport system and construction activities in urban areas contributed to large concentrations of SPM in air.

2.1.7 Sharma S. and Sharma K. (2016), "Ambient Air Quality Status of Jaipur City, Rajasthan, India" [18].

Pollutants like PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO were studied along with the several meteorological parameters for a duration of one year in the city of Jaipur. AQI was calculated for the monitored pollutants on the basis of monthly average concentrations. Concentrations during winter season was observed to be higher as compared to summer or monsoon seasons. Analysis of AQI revealed the influence of particulates in degradation of ambient air of Jaipur. Particulate concentration seems to be aggravated in the city due to heavy transport activities and industrial emissions. Several other factors like burning of garbage in open areas and use of conventional fuels and biomass for cooking and other domestic purposes.

2.1.8 He J., Chen K. and Xu J. (2017), "Urban Air Pollution and Control" [28].

The authors writes about the degradation of air quality of urban areas in currently developing countries like China, India and countries in Southeast Asia. Growing population and unplanned urbanization have enhanced the emissions and concentrations of air pollutants. Air Pollutants like

PM, SO_x, NO_x and VoCs are considered to be posing threat to human health, vegetation, global atmospheric environment and human property. Majority of air pollutants are emitted through stationary sources like industrial facilities and mobile sources which include road transportation. This article has also documented some major of prevention as well as end-of-pipe treatments of primary air pollutants.

2.1.9 Khanum F., Chaudhary M.N. and Kumar P. (2017), "Characterization of five-year observation data of fine particulate matter in the metropolitan area of Lahore." [2]

This study analysed the long term trends of fine particulate matter at two sites (one being commercial area-town hall and other being residential cum industrial-township) in Lahore city for the period of 2007-2011. Seasonal variations-winter, summer, pre monsoon and post monsoon analysis was conducted. Annual mean concentrations during weekends and weekdays were also analysed. Mainly industrial activities and increased vehicular movements were the reason of increasing concentration at township site.

Correlation $PM_{2.5}$ was developed with SO_2, NO_2, CO, O_3 and with meteorological parameters as well. Annual Exceedance factor and percentage increase in $PM_{2.5}$ was also calculated to understand the Exceedance over regulatory limits. Levels of $PM_{2.5}$ were high during winters as compared to other seasons and during weekends (approximately 4% higher) compare to weekdays.

2.2 Association of health impacts and air pollution

2.2.1 Pope C.A. and Dockrey D.W. (2006), "Health Effects of Fine Particulate Air Pollution: Lines that Connect" [10].

Authors have reviewed the work on acute and chronic effects produced on human health by particulate exposure. Short term exposures were analysed by studying the association of mortality with particulates using GAM models and generalized linear models. Strongest association amongst all particulate matter with morbidity was found with $PM_{2.5}$.

It was concluded that quantity and length of exposure of particulates have a direct and significant effect on the human health. Also it was observed that, degree of association of lengthy exposure of particulates with mortality was considerably better than those from the daily time series.

2.2.2 Samoli E., Nastos P.T., Paliatsos A.G., Katsouyanni, K. and Priftis K.N. (2011) "Acute effects of air pollution on pediatric asthma exacerbation: Evidence of association and effect modification" [13].

This was an epdemiological research involving investigation of impacts of short term exposure of air pollutants like RSPM, SO_2, NO_2 and O_3 on pediatric asthma cases in the city of Athens (Greece). Daily time series data was collected from pediatric centres and hospitals and fixed monitoring stations. Poisson's regression models were used to assess the interrelation of pollutants also taking into consideration the seasonality, weather conditions and effects of weekdays and weekends. There was 2.54% increase in admittance of pediatric asthma with 10 $\mu g/m^3$ increase in PM_{10} concentrations. This association was observed to be stronger during the desert dust days and was much more evident during winter months. However, same increase in SO_2 resulted in 5.98% increase in asthma exacerbations among children. The study showed limited evidence in association of NO_2 and asthma problem.

2.2.3 Beverland I., Cohen G., Heal M., Carder M., Yap C., Robertson C., Hart C., and Agius R. (2012), "A Comparison of Short-term and Long-term Air Pollution Exposure Associations with Mortality in Two Cohorts in Scotland" [11].

Lengthy and brief exposures of black smoke were associated with mortality and compared with each other. Time series study analysis revealed the better association of Short-term exposure–mortality in cohort participants than in general public. However, magnitude of association of long term exposure and mortality was greater than the temporary exposure–mortality associations reason being the possibility of effects generated the longer persistence of pollutants in atmosphere. The association of prolonged pollution – mortality was observed to be influenced by the intra-urban fluctuations. Thus, geographical differences in pollution climate can be used to determine the long term exposures and their impact on public health.

2.2.4 Zhang K. and Batterman S. (2013), "Air pollution and health risks due to vehicle traffic" [69].

The study demonstrated a method for identification of risks pertaining to people residing in vicinity of roads particularly by using modelling techniques to determine the on and near road concentrations of NO_2 and epidemiological risks attributable to traffic for different traffic volumes during peak periods. Incremental analysis was used for estimation of impacts of pollution and characterisation of health risks caused due to congestion.

The modelling analysis showed that risks determined for a freeway had a “U” shaped pattern with elevated traffic density for on road populations and remained flat at lower volumes of vehicles for near road populations. However, increase in risks was tremendous and sharp for both on and near road populations for an arterial road with increased traffic. These variations were result from stringent emission factors, long rush hour periods for near road populations, change in relationship of NO_2 and NO_x emissions and travel lags for the on-road population. It also highlighted potential threat of traffic congestions to human health and additional traffic that could significantly increase the risks.

2.2.5 Batterman S., Ganguly R.,Isakov V., Burke J., Arunachalam S., Synder M., Robins T. and Lewis T. (2014), “Dispersion Modelling of Traffic-Related Air Pollutant Exposures and Health Effects Among Children with Asthma in Detroit, Michigan” [51].

This paper discussed an epidemiological study focussing on the use of the modelling system to determine the vulnerability of people getting exposed to air pollutants near the streets. NEXUS investigated the impacts of exposure of air pollutants on asthmatic children residing adjacent to major roads in Detroit. Various dispersion models like RLINE, CMAQ and RLINE were employed to determine the air pollutant emissions generating from mobile and stationary sources.

The modelling system used in NEXUS provided advanced information (e.g. dramatic spatio-temporal variations of pollutant concentrations related to traffic emissions) regarding exposure to air pollutants generated via traffic movement which cannot be captured by simple parameters like traffic density and distance to roads. The paper also highlights the use of modelling system and NEXUS for designing and determining the buffers required between highways and sensitive areas like hospitals, schools and houses.

2.2.6 Miranda A., Valente J., Costa A., Lopes M. and Borrego C. (2014), “Air Pollution and Health Effects” [72].

Authors have addressed the progress in research related to determination of the inter relation between air pollutants and human beings. They have reviewed the current methods and techniques used in examining the impacts of air pollution on well beings of human. Concentration and properties of pollutants determine their impact on human health. Several other factors like the age and state of health an individual, exposure time, weather conditions and the distance from the sources of emissions also have impact the association between pollutant and its effects on humans. Children falls in sensitive groups that are vulnerable to the exposure of air pollutants. Thus, degradation in air quality at schools and residents of children can affect the growth and health of children. Multi-pollution is an important issue which should be considered while assessing the impact of air quality on human health. Better understanding of vulnerable section of population can facilitate in policy making and risk assessment.

2.2.7 Ghosh D. and Parida P. (2015), "Air Pollution and India: Current Scenario" [19].

This research paper highlighted the condition of the capital city, New Delhi with prime focus on the impact of particulate concentrations on human health and environment. Air pollution is worsening in New Delhi, particularly concentrations of PM have been enhanced due to ever increasing automobile emissions and increase in coal fuelled factories. Authors have also outlined the professionals who are more prone and vulnerable to the exposure of air pollutant. It includes traffic cops, hawkers, vehicle drivers, roadside shopkeepers and residents of house located on busy roads.

2.2.8 Prasad D. and Sanyal S. (2016), "Air Quality and its effect on health: A Geographical Perspective of Lucknow City" [12].

This was a health oriented paper in which authors have tried to relate impact of air pollution in Lucknow city on human health. The key air pollutants (NOx, SO_2, RSPM and SPM) and their concentration were identified with focus of the study on determining the impact of these pollutants on health on people in study area. Perception study used to assess the opinions of residents of city revealed that 52% of respondents marked automobiles as the major source of air pollution followed by industries (30.5%) and domestic pollutants (15%). Study considered pre and post monsoonal change in concentration of pollutants for the period of 2008-2011. The air monitoring data collected was the correlated with the health problems and revealed the association of poor health with low air quality. Regression analysis confirmed the linear dependency of airborne diseases with respect to increase in particulate matters. It also concluded that pervasiveness of airborne diseases varies according to the age of people along with their professions and occupations in which they are engaged.

2.2.9 Baccini M., Mattei A., Mealli F., Bertazzi P.A.and Carugno M. (2017), "Assessing the short term impacts of air pollution on mortality: a matching approach" [73].

The research involved determining the impact of exposure to elevated average PM_{10} concentrations on mortality in the Milan (Italy), during the period 2003–2006. Propensity score was used to estimate the rates of mortality in the city. Thus, impacts of PM_{10} were measured in terms of attributable deaths through a direct comparison of daily potential outcomes, depending on the propensity scores. This approach proved to be quite relevant in assessing the impacts of past events in this field.

2.2.10 Gordon T., Balakrishnan K., Dey S., Rajagopalan S., Thornburg J., Thurston G., Agrawal A., Collman G., Guleria R., Limaye S., Salvi S., Kilaru S., Nadadur S. (2018),"Air pollution health research priorities for India: Perspectives of the Indo-U.S. Communities of Researchers" [30].

This paper has discussed the bilateral dialog between scientists and academicians from U.S. and India who came together to develop strategies for mitigation of air pollution and promotion of collaborative research in this field. The abrupt growth in the power, industrial, and transportation sector along with surge in urbanization, have worsened the ambient air quality of cities in India. Main causes of household air pollution in India consists use of traditional stoves and extensive biomass burning which generates heterogeneous chemical substances resulting from incomplete combustion. Emission sources in India are region specific and their contribution in degradation of air quality vary from place to place. This study also highlighted the major gaps in India regarding association of air pollutants and health including mortality and morbidity in India.

2.3 Inter-relationship of air pollution and meteorology

2.3.1 Crawford T.V. (1969), "Air Pollution and Meteorology" [74].

Wind speed and atmospheric stability have been mentioned as the prime meteorological parameters which effect the atmospheric dispersion of pollutants. Concentrations at downwind from a continuously emitting source is inversely proportional to wind speed. However, pollutant concentrations are greater during stable conditions in atmosphere due to reduction of vertical diffusion rate. Thus, calm conditions and stronger temperature inversions are conducive to limited atmospheric dispersion.

2.3.2 Elminir H.K. (2005), "Dependence of urban air pollutants on meteorology" [8].

This study was carried out in city of Cairo (Egypt) in 2002. Dispersion of air pollutants in atmosphere is altered by the varying velocity of wind and its direction. Calm conditions are known to elevate the ambient concentrations of pollutants. However, higher wind speeds, entrainment of aerosol particles from the surrounding desert can contribute to the ambient particulate matter levels. Strong vertical mixing occurs at low relative humidity which can result in high NO_2 and O_3 concentrations. High relative humidity can uplift the quantities of CO, SO_2 and PM_{10} in atmosphere.

2.3.3 Prakash D., Payra S., Verma S. and Soni M. (2013), "Aerosol particle behaviour during Dust Storm and Diwali over an urban location in north western India" [47].

Study was conducted in city of Jaipur for the behaviour of aerosol over the two events namely Dust storm and Diwali festival from May to December 2011. Aerosol Number Concentration and size distribution of particles were calculated using the aerosol spectrometer. Lower ANC were observed during the dust storms due to dispersion effect while very high concentrations were found during Diwali due to calm wind conditions. These results highlighted the urge of periodic monitoring of aerosols to guide authorities and for changing perception of general public about the use firecrackers and pollution episodes.

2.3.4 Saha U., Talukdar S., Jana S. and Maitra A. (2014), "Effects of air pollution on meteorological parameters during Deepawali festival over an Indian urban metropolis" [16].

Air quality trends during the festival of Diwali were assessed by analysing criteria pollutants and their association with meteorological parameters over the Kolkata city. Short term basis included studies like "pre Diwali, Diwali and post Diwali day(s)"-one and seven day analysis for the period 2011, 2012, 2013. While long term trends included study of change in concentrations of air pollutants during the festival of Diwali. These concentrations were then also compared with normal day concentrations. Concentrations of air pollutants intensified due to prevailing stable atmospheric conditions during the festival. Due to burning of firecrackers, visibility got reduced, lapse rate changed and relative humidity got lowered as well.

2.4 Long term and Short term trends of Air Pollution

2.4.1 Ravindra K., Mor S. and Kaushik C. (2003), "Short-term variation in air quality associated with firework event: A case study" [55].

Temporary variations in air quality due to extensive use of fireworks were assessed from concentrations of SO_2, NO_2, PM_{10} and TSP during Diwali festival in Hissar city in November 1999. Few sites observed 10 folds increase in Sulphur dioxide levels but remained below the prescribed limits. Concentrations of NO_2 increased 2 to 3 times but remained below prescribed limit while PM_{10} and TSP were way above their prescribed limits. Short lived air pollution and exposure of its pollutants above allowable limits is likely to increase the acute health effects.

2.4.2 Vecchia R., Bernardonia V., Cricchioa D., D'Alessandroa A., Fermob P., Lucarellic F., Navad S., Piazzalungab A. and Vallia G. (2008),"The impact of fireworks on airborne particles" [67].

This study was conducted on night of 9th and 10th of July 2006 in Milan, on the eve of celebration of winning of FIFA World Cup by Italian team. The deterioration in air quality was noted due to pyrotechnic displays as well as due to vehicular emissions. Chemical and physical properties of airborne particles were studied using the samples which were collected during the fireworks episode.

Contribution of fireworks to the change in chemical profile and concentration of particulates were quantified using Positive Matrix Factorisation and Multiple Linear Regression. Chemically characterisation of samples allowed the characterization of aerosols and gaseous emissions released during the firework displays in the city. Results highlighted the increase in fine fraction of metals especially Sr, while coarse fraction concentrations no significant change. The chemical profiling of firework sources and its contribution to local environment provides a better intuition about the aerosol characteristics its association with the pyrotechnic displays.

2.4.3 Singh D., Gadi R., Mandal T., Dixit C., Singh K., Saud T., Singh N. and Gupta P. (2009), "Study of temporal variation in ambient air quality during Diwali festival in India" [54].

Ambient concentrations of primary criteria air pollutants were employed to study the change in air quality during the days of Deepawali festival in Delhi from 2002 to 2007. Extensive use of fireworks caused short term fluctuations in the air quality. Concentrations of PM_{10}, SO_2, and NO_2

increased two to six times during the festival. Adverse meteorological conditions like decrease in temperature, lower wind flow, reduction mixing height intensified the concentrations of pollutants on Diwali days. Trend analysis showed that with increased firework activities escalated the concentrations of pollutants reaching their maximum value on the day of celebration of festival.

2.4.4 Agrawal A., Upadhyay V.K. and Sachdeva K. (2011), "Study of aerosol behaviour on the basis of morphological characteristics during festival events in India" [61].

Impacts of emissions during two important festival viz. Diwali and Holi on atmosphere were studied by understanding settling and time of emissions of aerosols. This research was conducted in the city of Delhi in October 2009 (Diwali) and February-March 2010 (Holi). EDX and SEM studies were employed to determine settling velocity by studying the morphology and composition of the aerosols.

Results showed that aerosols emitted during Diwali were spherical in shape with particle diameter ranging between 9.5 to 15μm. While, aerosol diameter on the day of Holi festival was 46μm in morning and diameter of afternoon sample was 13μm. It was also noted that meteorological visibility reduced in a much more significant manner during Diwali as compared to Holi festival reason being much high concentrations of aerosols get emitted during Diwali due to intensive burning of fire crackers.

2.4.5 Nishanth T., Praseed K.M., Rathnakaran K., Kumar M.K.S., Krishna R.R. and Valsaraj K.T. (2012), "Atmospheric pollution in a semi-urban, coastal region in India following festival seasons" [66].

Variations in air pollutants namely oxides of nitrogen, RSPM and ozone were determined to assess the impact of fireworks on ambient air quality during celebration of Vishu festival in Kannur, Kerala. Significant change in quantities of concentrations of air pollutants was observed when the firecrackers were set off. Organic analysis of particulate samples collected on the day of festival constituted a variety of hazardous organic compounds. Exposure to increased levels of air pollutants for short duration pose a potential threat on a regional to humans especially residing in a densely populated area.

2.4.6 Chatterjee A., Sarkar C., Adak A., Mukherjee U., Ghosh S. and Raha S. (2013), "Ambient Air Quality during Diwali Festival over Kolkata – A Mega City in India" [50].

Change in air quality was estimated by assessing the variations in the ambient concentrations of aerosols and gaseous pollutants during the festival of Diwali. Diurnal variation studies observed that concentrations were elevated on Diwali night indicating maximum intensity of pyrotechnic activities during that period. Particulates and several other major ions followed similar course of trend for the festival days which can be described as: Diwali night conc.> Post Diwali night conc.>Post Diwali day conc.> Pre Diwali night conc.> Diwali day conc.>Pre Diwali day conc.

2.4.7 Verma C. and Deshmukh D. (2014), "The ambient air and noise quality in India during Diwali festival: A Review" [49].

The study compared effects of fireworks on air quality of different cities of India during the festival of Diwali. Air pollutants assessed included SO_2, NO_2, PM_{10} and $PM_{2.5}$. Concentrations of these pollutants were found about 2-6 times higher during the day of festival. Cities which were compared included Nagpur, Lucknow, Rajnandgaon, Hyderabad, Kolkata, Hissar, Delhi and Rajim. Noise levels on the day of Diwali were also measured which were found to high in during the night time. The deterioration of ambient air quality due to the pyrotechnic display in megacities of India has a considerable amount of impact on human health on a regional scale.

2.4.8 Baldwin N., Gilani O., Raja S., Batterman S., Ganguly R., Hopke P., Berrocal V., Robins T., Hoogterp S. (2015), "Factors affecting pollutant concentrations in the near-road Environment" [52].

For this study, a mobile air pollutant laboratory was employed for measurement of concentrations of air pollutants like black carbon, nitrogen oxides, sulphur dioxide, and particulate matter ($PM_{2.5}$ and PM_{10}) at major roadways in the city of Detroit, Michigan during a winter period .This study examined the space variations of pollutants related to traffic and demonstrated a technique for assessment of air quality near roads. The concentration gradients were estimated using the parameters like traffic volume, wind speed and direction and background concentrations. Along with the above said parameters, concentration gradients are also dependent on the road geometry and slope, distance of receptor from the road traffic volume, and most importantly time of the day.

2.4.9 Baranyai E., Simon E., Braun M., Tóthmérész B., Posta J. and Fábián I. (2015),"The effect of a fireworks event on the amount and elemental concentration of deposited dust collected in the city of Debrecen, Hungary" [62].

Variation in concentrations of deposited dust during pyrotechnic display was assessed in Debrecen, Hungary. Silver Linden leaves were used for biomonitoring studies of the dust and trace elements generated from fireworks. Samples were collected from individual selected species two days before and two days after the festival. It was noted that overall quantity of foliage dust was significantly higher after burning of firecrackers when, compared to the dust load collected on a normal day. Concentration of calcium, magnesium and strontium was reported in the airborne dust.

2.4.10 Batterman S., Ganguly R. and Harbin P. (2015), "High Resolution Spatial and Temporal Mapping of Traffic-Related Air Pollutants" [48].

This study used a dispersion model (RLINE) to forecast the concentrations of fine particulates and oxides of nitrogen in an urban area at exclusively sharp spatial resolution. Hourly to annual averaging periods and resolutions as fine as 10 m were included in analysis. The pollutant data produced is useful in identifying air pollution hotspots and can also be used for epidemiology studies as well.

2.4.11 Goel R. And Guttikunda S.K. (2015), "Evolution of on-road vehicle exhaust emissions in Delhi" [58].

On-road vehicle exhaust emissions for a 40-year horizon (1990-2030) were evaluated, retrospectively and prospectively, for Delhi region. According to the study, PM, SO_2, CO and VOCs reached their maximum concentrations during late 1990s and have reduced significantly through year 2012. However, NO_x and CO have shown an increasing trend. Emission reductions have been attributed to implementation of vehicular emission standards, reduction of sulphur content and removal of lead from fuel, mandatory retirement of old vehicles etc. Smog in the region has been a result ground-level ozone formed from mixing of oxides of nitrogen along with VOCs. This study also emphasized on the possibility of shift from individual vehicles to public transport which will help in bringing down the number of vehicles on road ultimately reducing the vehicular emissions.

2.4.12 Pathak C.Y., Mandalia H.C., Roy D. and Jadeja R.B. (2015), "Comparative Study of Ambient Air Quality Status of Ahmedabad and Gandhinagar City in Gujarat, India" [57].

Ambient air quality of two cities of Gujarat were analysed. The monitoring stations set up at two cities covered residential, industrial, commercial and other sensitive areas. RSPM, SPM, NO_2 and SO_2 were the pollutants measured and compared with the NAAQS standards. Study concluded that rapid increase in population has resulted in elevated vehicular movements in both the cities which are prime cause of air pollution. Rapid growth and establishment of industries, mostly in Ahmedabad have also contributed in deterioration of air quality.

2.4.13 Ganguly R. and Thapa S. (2016), "An assessment of ambient air quality in Shimla city" [27].

Variations in air quality of Shimla was analysed using the monthly average concentrations of air pollutants over a period of 10 years. Long term trends analysis revealed that annual average concentrations of NO_2 and SO_2 are complies with the NAAQS standards, while RSPM concentrations exceeded the annual acceptable limits. RSPM concentrations were primarily elevated due to large fleet of vehicles, traffic gridlocks and congestion and increased tyre wear and dust load due to poor maintenance of roads. However, absence of any significant industries have resulted in lower SO_2 levels in the city. The concentrations of monitored air pollutants were observed to highest during spring season reason being, increased tourist influx and pollen dispersion. Also, a screening model -DMRB was used for prediction of NO_x and RSPM concentrations.

2.5 Air Pollution Modelling

2.5.1 Johnson W.B., Ludwig F.L., Dabberdt W.F. and Allen R.J. (1973), "An Urban Diffusion Simulation Model for Carbon Monoxide" [38].

The objective of this research was to develop an approach or numerical model for prediction of vehicle generated emissions as a function of local meteorology and traffic distribution. A simple Gaussian dispersion model was formulated for calculation of concentrations of Carbon Dioxide as a function of local weather and traffic conditions in street of an urban locality. Input variables involved in the formulation model are traffic data, wind speed and direction, mixing depth and atmospheric stability category. Results obtained in study emphasized the fact that local air quality varies drastically even for short distance from monitoring location for a pollutant near the surface.

2.5.2 Mensink C. and Lewyckvj N. (2001), "A simple model for the assessment of air quality in streets" [75].

An analytical model was formulated for calculation of concentration of air pollutants in an urban street. The model is dependent on wind direction, however recirculation of flow in street canyon has not been assumed. The model was tested on streets of Antwerp (Belgium) and Hannover (Germany). It was assumed that distribution of concentration of pollutants over the street is uniform. The calculated concentrations showed reasonably closeness to measured concentrations, on condition of using the observed vehicle numbers and correct background concentrations and meteorological conditions.

2.5.3 Chen H., Bai S., Eisinger D., Niemier D. and Clagget M. (2009), "Predicting Near Road $PM_{2.5}$ concentrations- Comparative Assessment of CALINE4, CAL3QHC and AERMOD" [76].

This study compared of three dispersion models in predicting near road concentrations of $PM_{2.5}$. The analysis included studying the effectiveness of these models and distinguishing them with respect to methodology and data requirements. A road in London and an intersection in Sacramento were selected as sample sites for evaluation of the models. The statistical analysis and screen plots revealed that CALINE4 and CAL3QHC performed well at Sacramento site, however AERMOD had under predicted the concentrations of $PM_{2.5.}$ The analysis of models CALINE4 and CAL3QHC as the London site resulted in over predictions during low on-road emissions, while the models under predicted when on road emissions were high. The study highlighted that the effect of street canyon and receptor location at London site resulted in relatively low efficiency of the models.

2.5.4 Ganguly R. and Broderick B.M. (2010), "Estimation of CO concentrations for an urban street canyon in Ireland" [24].

The air quality in an urban street in Dublin, Ireland was evaluated using two street canyon models: STREET and OSPM. It was evident from the statistical analysis that models performed reasonably well in predicting the mean long term concentrations. However, results for OSPM were much better as compared to STREET thus, displaying the better performance of OSPM. This paper also highlighted the suitability of STREET model for prediction of CO concentrations in an urban street despite being a simplistic model. Also, availability of good traffic data and background concentrations is necessary for better working of these models.

2.5.5 Dhyani R., Sharma N. and Gulia S. (2013), "Performance evaluation of CALINE4 model in hilly terrain- A case study of highway corridors in Himachal Pradesh" [77].

Performance of CALINE4 was evaluated on mountainous terrain considering the Indian scenario of meteorology and traffic conditions. The analysis was performed along two busy roadways in Solan district of Himachal Pradesh representing both flat and hilly terrains. Concentrations of flat and hilly terrain that were obtained from the models were then compared using statistical model performance indicators.

This study revealed the satisfactory working of model in flat terrain, however the model was not able to explain complexity of terrain and did not perform satisfactorily in hilly terrain conditions. Diesel powered vehicles had discernible contributions in CO and NO_x concentrations at both the locations. Authors have suggested the applicability of CALINE4 model in assessing and managing the traffic related pollution along the urban corridors in India.

2.5.6 Sharma N., Gulia S., Dhyani R. and Singh A. (2013), "Performance evaluation of CALINE4 dispersion model for an urban highway corridor in Delhi" [78].

This paper focused on evaluation of efficiency of CALINE 4 dispersion model in forecasting the concentrations of CO along a highway going through the city of Delhi. Two different sets of vehicle emission factors described by ARAI and CPCB were used for modelling purpose.

Concentrations of predicted using ARAI emission factors were 12% higher as compared to the concentrations estimated by CPCB emission factors. However, statistical analysis revealed that model had under predicted the concentrations of CO for both the emission factors.

Authors have questioned the use of CALINE 4 in conditions where air quality on roadside in urban locality is influenced by other emission sources (e.g. industries etc.).

2.6 Objectives of Research:

After assessing and reviewing the available literature, primary criteria pollutants namely NO_2, SO_2 and RSPM were selected for the research and pertinent objectives were carefully selected which are described as follows:

1. To study of existing ambient air quality in Shimla for the period for (2011-2017): Short term and Long term trends.

   Short term trends describe the temporary variations in concentrations of pollutants which can result in degradation of air quality. Natural sources like dust storms and anthropogenic activities like pyrotechnic displays during the celebration of festivals and ceremonies analysed in short term trends. While, the long term analysis of air pollutants involves studying the annual seasonal variations.
2. To investigate the effect of meteorological parameters on pollutant concentrations and deriving relation between these parameters and concentrations.
3. To examine the suitability of relevant air quality models for prediction of pollutant concentrations.

CHAPTER 3
METHODOLOGY

3.1 City Overview

Shimla or Simla, the capital city of H.P., India is situated at 2130 m above m.s.l. in 'mid Himalayas' and is situated in zone 43 R with UTM coordinates 707282.29Easting and 3443249.65Northing. It was discovered by the British in 1819. Since then, the city has evolved from a small hill town to one of the prominent tourist haven. With fragile ecosystem around, Shimla has characterised by difficult topography having steep slopes, rugged mountains and deep valleys [26].

Figure 3.1: Map of Shimla (Source: Google maps)

The city falls in 'humid subtropical' climate zone as per Köppen climate classification system with severe and long winters from October to February. The temperature varies between 0 - 13^{o}C during winters. The city encounters severe cold spells during the months of December and January in which snowfall occurs as well. The summers (March – June) experience moderately varying temperature that range between 20- 30ºC. The monsoon period lasts for about three months from July to September and records moderate rainfall. As per Census (2011), total population of the city stands out to be around 1, 69,758 [26].

There are several factors which can be associated to the expansion and growth of the city, first and foremost being the seat of state administration and other main government offices. Shimla used to be summer capital of British Empire and since then it has been a prominent tourist spot. Thus, there has been growth in tourism in Shimla because of its easy accessibility and easy terrain compared to other hill stations. Shimla has also developed as educational and academic centre since last decade, thus migration of people to the city has increased. Floating Population comprise of tourists as well as people in service sector which constitutes a sizable proportion in Shimla City. Table 3.1 shows the growth of population in Shimla calculated by Municipal Corporation of Shimla [26].

Table 3.1: Population Growth of Shimla

Year	2011	2021	2031
Resident Population	1,69,758	2,56,883	3,49,361
Floating Population	76,000	1,00,000	1,25,000

3.2 Justification of the Project

Majority of Tier I cities and metropolitans in India like Mumbai, Delhi, Kolkata etc. are already experiencing degraded air quality with vehicular and industrial pollution as major contributors and thus, lag behind in complying with the health-based standards. In this context, detailed studies and numerous scientific literatures are available detailing the sources, impacts and possible health exposures impacts on the residents living in such cities. However, reported literatures on other category of cities in India are almost non-existent and hence the impacts of increased air pollution often go unnoticed for such cities while drafting an implementation of policy decisions [27].

Substantial increase in number of vehicles has strained the congested streets of the Shimla city. Space constraints has made widening of roads impossible in the city. Private vehicle ownership in Shimla has increased from 48,000 in 2011 to 71,781 in 2013 and to about 83000 in 2015. The city currently has 308 buses for population of 0.17 million, but the public transport ridership has reduced to 45% due to inconvenient public transport facility and lack of proper pedestrian infrastructure [32]. The number of tourists visiting the city are increasing at very fast rate since past few years. Tourist influx causes increased traffic density, imposing burden on the already congested and narrow streets of Shimla. Thus, due to Poor Street spacing, increase in number of vehicles and inadequate parking facility, Shimla faces problems of traffic congestions and unregulated movements of vehicles on day to day basis.

Earlier, development projects were implemented in city under JNNURM scheme which included projects like construction of roads, tunnels, parking spaces etc. Recently, Shimla has been selected by Ministry of Urban Development for development of city as “Smart City.” Sustainable environment is one of the core infrastructure elements of this mission. Moreover, air quality has been a characteristic used in measurement of Smart City Index [31]. The fragile ecosystem in hill city has to be taken into consideration which could pose a challenge to urban development. Thus, environmental factors and changing climate conditions has to be addressed and taken into consideration for urban planning and development of the city [32].

Figure 3.2: Traffic Jam in Shimla, near Old Bus Stand

3.3 Monitoring Stations

HPSPCB monitors air quality in Shimla city at two stations. The pollutants which are observed by HPSPCB are SO_2, NO_2 and PM_{10}. Therefore, these pollutants have been taken into consideration for the analysis of ambient air quality of the city.

3.3.1 Station I- Tekka Bench (Background Site)

Monitoring Station I has been established at the ridge, the main attraction of the Shimla city. This place exhibits the natural air quality of Shimla city as it experiences least vehicular pollution due to restriction on entry of vehicles on ridge road. Thus, the station has been described as the

‘Background site.’ This station has been temporarily closed since March, 2017 due to inadequacy of space for instruments as a result of renovation works carried out by Municipal Corporation Shimla [27].

Figure 3.3: Monitoring Site I (Background Site)

3.3.2 Station II- Bus Stand (Urban Site)

Monitoring Station II is located at the bus stand where the vehicular pollution can be exemplified in its best form. This location gets severely congested during the morning hour rush and weekends during large tourist influx. Traffic jam can be even experienced in off-peak hours with unregulated moving patterns of vehicles due to poor street spacing. This has been referred as ‘Urban Site’ falling in residential cum commercial area zone [27,71].

Figure 3.4: Monitoring Site II (Urban Site)

Figure 3.5: Traffic Jam at Bus Stand

3.4 Monitoring Methods

The monitoring of air pollutants at both the stations is carried out conforming to the guidelines as prescribed by CPCB. The Sulphur dioxide concentrations are determined by modified West and Gaeke method. SO_2 is absorbed from a certain controlled volume of air into sodium tetrachloromercurate solution. The absorbed SO_2 then reacts with solution in impinger to form a stable sodium tetrachloromercurate. The SO_2 reacts with sodium tetrachloromercurate to produce dichlorosulphitomercurate which is also a stable compound. This compound then reacts with formaldehyde soultion producing a colour spectra which is determined using spectrophotometer to determine SO_2 concentrations.

The concentrations of oxides of nitrogen are estimated by the modified Jacobs and Hochheiser technique. The sample of ambient Nitrogen Dioxide gas is sucked into the impinger which contain a blended solution of sodium hydroxide and sodium arsenite. NO^{2-} ions are generated in the above process, which is then reacted with phosphoric acid, sulphanilamide and NEDA to generate a stable highly coloured dye whose absorbance is measured using spectrophotometer.

Measuring of PM_{10} concentrations involve use of a RDS sampler with a cyclonic connector having the air suction rate of 1.1 m^3/min. The particulate matter is collected on a glass fibre filter paper and the mass of particulate matter retained is determined in laboratory which is divided by sample air volume and is reported in ppm units [33].

Meteorological data like wind speed and its direction, surface air temperature, RH etc. was obtained from I MD, Shimla.

3.5 Annual Exceedance

Annual Exceedance, also called Exceedance Factor is the ratio of annual mean concentration of a pollutant to its standard value. It represented as follows:

$$Exceedance\ Factor = \frac{Observed\ annual\ mean\ concentration\ of\ criteria\ pollutant}{Annual\ Standard\ for\ respective\ pollutant\ and\ area\ class}$$

Air quality has been classified into four categories based on Exceedance Factor:

a) EF > 1.5 – Critical Pollution

b) 1.0<EF<1.5 – High Pollution

c) .5<EF<1.0 – Moderate Pollution

d) EF<.5 – Low Pollution

First two categories (Critical and High Pollution) depicts that present air pollutants does not meet the prescribed pollutant standards. The third category (moderate pollution) signifies that prescribed standards are met however, may exceed in future if concentrations of air pollutants are allowed to increase and remains unabated. The last category (low pollution) suggests that concentrations of air pollutants are well within the prescribed standards either due to lack of anthropogenic activities or strict regulations and policies [2].

3.6 Air Quality Index

It is a comprehensive tool used for intimation of information regarding the status of air quality of surroundings in which people are residing. It helps in understanding the quality of air by awarding a definite number to express the measured air quality in respect of its repercussions on health of human [44]. Formula used for estimating the AQI is based on the concept of 'liner segmented principle' [45].

$$I_p = \left[\frac{I_{HI} - I_{LO}}{C_{HI} - C_{LO}}\right]\left(C_p - C_{LO}\right) + I_{LO}$$

Where,

I_p = AQI of pollutant 'p'

C_p = Monitored concentration of pollutant

C_{HI} = Breakpoint concentration (mentioned in Table 1 of Appendix A) $\geq C_p$

C_{LO} = Breakpoint concentration (mentioned in Table 1 of Appendix A) $\leq C_p$

I_{HI} = Sub index value corresponding to C_{HI}

I_{LO} = Sub index value corresponding to C_{LO}

3.7 Air Quality Modelling

It is an indispensable tool for studying the air pollution and its effect on ambient air quality. It can be used to establish emission control legislations, evaluating and planning the control of air pollution and further helps in selection of sites of future sources of pollutants [22, 23]. Dependency of environmental protection agencies and authorities on these models has increased particularly in policy and decision making regarding the management and control of air quality, traffic and public health. The impact of air pollution in urban areas primarily caused by emissions from vehicles and industries has become an area of extensive research. This has led to formulation of numerous models related to the influence of urban complexities on pollutant accumulation and distribution patterns.

There are evidences of urban air pollution cause by substantial increase in motor vehicles hence, assessment of impacts of road traffic on air quality becomes considerably essential [24]. Dispersion models are generally used for retrospective and prospective assessment of air quality on roadside. They provide theoretical estimates for present and future concentrations of air pollutant as well as determining spatial and temporal variations [25].

The model predictions are function of traffic emissions, meteorological conditions, road geometry and receptor location. These predicted traffic concentrations are then summed with local background concentrations which give total concentrations of any air pollutant at specific location [24, 25]. The distinctiveness and quantity of traffic fleet directly accounts for the rate of release of emissions in the street. Thus, measurement of emission factors is an important component of air quality model as it relates traffic and dispersion of pollutants which can have effect the accuracy of predictions.

3.7.1 Street Canyon Modelling

An urban street canyon is nothing but a continuous narrow street confined between buildings on both sides. However, lanes which are not flanked continuously by buildings are also involved in the definition of urban street canyon [35]. The dimensions of the canyon namely height of building and width of canyon are expressed in the ratio which is referred as the aspect ratio. Classification of Street canyons is on the basis of aspect ratio as follows:

- Deep Canyon : $\frac{H}{W} = 2$
- Regular Canyon : $\frac{H}{W} = 1$ and no major openings on walls
- Avenue Canyon : $\frac{H}{W} < .5$

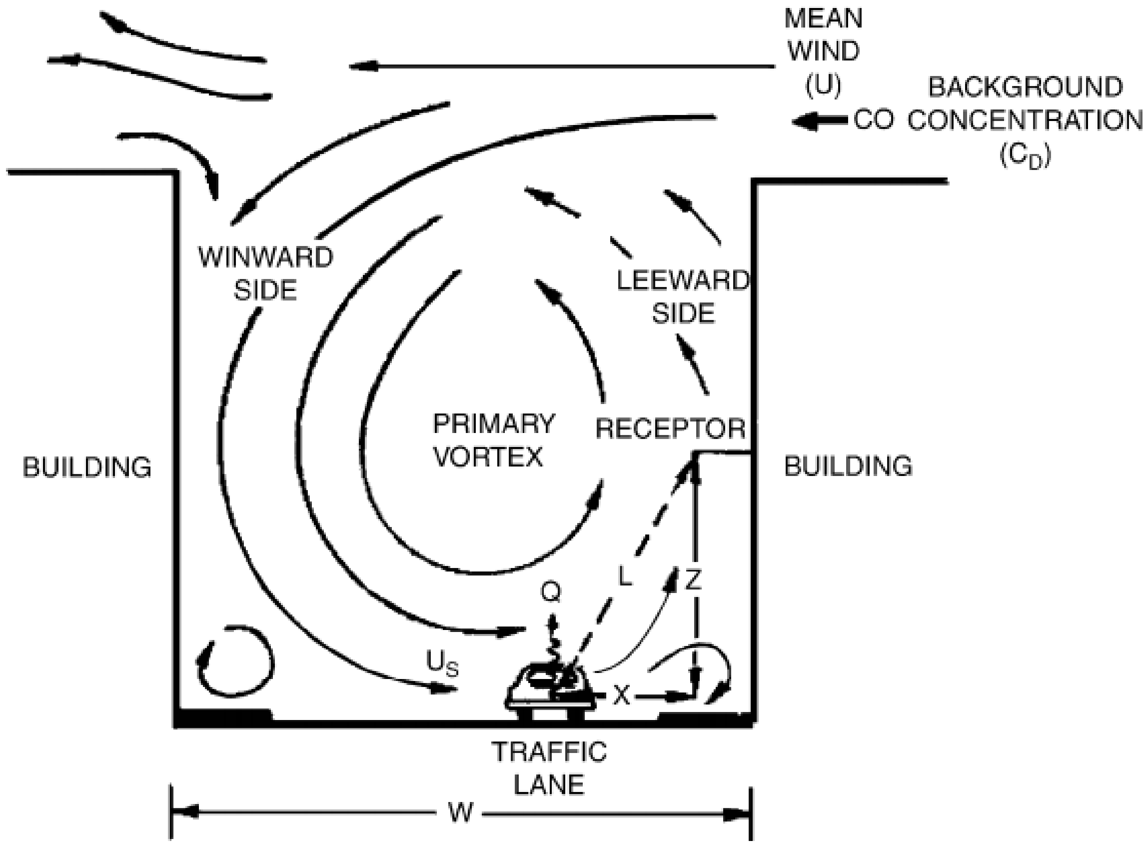


Figure 3.6: Dispersion of pollutant in a street canyon illustrating the formation of vortex

The up wind side i.e. the direction from where wind is blowing is known as Leeward side whilst, the downwind side is called Windward side. Vortices formation occurs inside the canyon when winds roof top level blow in direction opposite to that of street level winds. This leads to intensification of pollutants on the street towards the leeward side [35, 36].

There are number of dispersion models developed for prediction of concentrations of pollutants in street canyons. They are convenient in management of ambient air conditions and traffic, future planning and forecasting, exposure studies etc. CALINE4, STREET, OSPM CPBM are a few examples of Gaussian plume models which can be used for urban street canyon modelling [35].

3.7.2 Description of air quality models

Gaussian model in its elementary form are used to measure the field concentrations originating from point sources. The point source emissions are presumed to be directly proportional to rate of emissions, and inversely to the wind velocities. Thus, the obtained horizontal and vertical average concentrations of pollutants are described by bell shaped curve as in Gaussian distribution. However, Gaussian models can be modified to forecast the concentrations of pollutants for street canyons and line sources i.e. vehicular pollution.

Two Gaussian plume models viz. STREET and CALINE4 have been used for analysing the ambient air quality of the city. They use modified equations of Gaussian distribution in forecasting the pollutant concentrations.

3.7.2.1 STREET

It is one of the earliest and simplistic models which can be used to derive the concentrations of pollutants in street canyons. The prediction of pollutant concentration is based on the assumption that, two components exits in a roadside pollutant namely, concentrations generated due to vehicular emissions (C_s) and the background concentrations in the urban locality (C_b) [24, 35].

$$C = C_s + C_b$$

The C_s consists further two components comprising of leeward and windward side components. The former depicts the build-up and intensification of pollutant and latter represents the pollutant concentration developed from recirculation [24]. Pollutant concentration on leeward side of street is given by the following expression:

$$C_S^L = \frac{KQ}{(U + U_s)(\sqrt{x^2 + z^2} + h_o)}$$

Where,

K- Empirical constant parameter (normal values 6,7,8)

Q- Rate of emission discharge in street

U- Roof level wind speed

U_s- Constant accounting for additional movement of air induced by movement of traffic (empirical value .5 m/s)

x- Horizontal distance of receptor from centre of traffic lane

z- Receptor height

h_o- Constant which represents initial pollutant dispersion height (empirical value- 2m)

It has been reported that concentrations on windward side of street decreases due to entrainment of fresh air from the roof top into the street canyon. Thus, original equation has been modified to calculate the windward side concentrations [36].

$$C_S^W = \frac{KQ}{W(U+U_s)}\left(\frac{H-z}{H}\right)$$

Where, H and W represents the height and width of the canyon.

Relationship has been derived for calculation the roof level wind speed (U) which uses the airport wind speed [36].

$$U\ (m/s) = .33U_a + 1$$

3.7.2.2 CALINE 4

It is latest and final version of the line source emission models drafted by the California transport department. The model uses modified version of Gaussian dispersion equation and concept of 'mixing zone' to forecast the dispersion of line source emissions in proximity of street. Mixing zone is the region which lies directly above the road which is assumed to have turbulence and uniform rate of emissions. This model has the ability perform within the distance 500m of receptor from roadway and predict the concentrations of pollutant with great efficiency [40]. It can be employed to predict the concentrations of particulates and gases like CO and NO_2 [40, 41].

CALINE 4 predicts the concentrations of pollutant for a particular receptor by dividing roadway into a series of segments and calculating the individual concentrations of these segments using Gaussian dispersion equation [42]. The following equation is used to estimate the concentrations of any pollutant at any point (x,y,z).

$$C = \frac{q}{2\pi u\sigma_y\sigma_z}\left\{\exp\left[\frac{-(z-H)^2}{2{\sigma_z}^2}\right] + \exp\left[\frac{-(z+H)^2}{2{\sigma_z}^2}\right]\right\}\int_{y1}^{y2}\exp\left(\frac{-y^2}{2{\sigma_y}^2}\right)$$

Where,

q- Line source strength

U-wind speed

σ_z and σ_y are vertical and horizontal Gaussian dispersion parameters which are functions of x, not y

H- Height of source

3.8 Performance Evaluations

The working efficiency of models were evaluated by comparative analysis of predicted concentrations with respect to the monitored concentrations using relevant statistical measures. Seven statistical parameters were used for performance evaluation of models. Mean is indicative of the central tendency of a large set of data, while standard deviation signifies the dispersion of any data from the point of central tendency. The index of agreement (IA) indicates the degree of similarity or correctness between predicted and monitored concentrations. NMSE highlights the scattering in data set. Pearson's Coefficient 'R' is measure of degree of dependency between two variables. Fractional bias is a dimensionless number used as a measure of symmetry between mean concentrations indicating the overestimation or underestimation. Factor of two is indicative of degree of prediction of the model [24, 43]. The formulae of the above said statistical indicators with respect to predicted (C_{pred}) and monitored (C_{obs}) concentrations have been described below:

i) The Standard Deviation (SD):

$$S.D. = \sqrt{\frac{1}{n}\sum_{i-1}^{i=n}(C_i - \bar{C})^2}$$

Where,

n- Total number of observations,

C_i- Concentration of ith observation

$\bar{C}$ – Mean concentrations of n observations

ii) Index of Agreement (I.A.)

$$\text{I.A.} = 1 - \frac{\overline{(C_{pred} - c_{obs})^2}}{\overline{\left(|C_{pred} - \overline{C_{obs}}| + |C_{obs} - \overline{C_{obs}}|\right)^2}}$$

I.A. = 1-perfect agreement between measured and modelled concentration

I.A. = 0- complete disagreement

iii) Normalized Mean Square Error (NMSE):

$$NMSE = \frac{\overline{(C_{obs} - C_{obs})^2}}{\overline{C_{obs}C_{pred}}}$$

iv) Pearson's Coefficient of Regression (R)

$$R = \frac{\overline{(C_{obs} - \overline{C_{obs}})\,(C_{pred} - \overline{C_{pred}})}}{\sigma_{pred}\sigma_{obs}}$$

Where, σ_{pred} *and* σ_{obs} are standard deviations of predicted and monitored data. Value of R ranges between 0 to 1.

v) Fractional Bias (FB)

$$FB = \frac{2\left(\overline{C_{pred}} - \overline{C_{obs}}\right)}{\overline{C_{pred}} + \overline{C_{obs}}}$$

Value of FB ranges between -2 to 2. FB equal to -2 implies extreme over prediction while, value of FB equal to 2 indicates extreme under prediction

vi) Factor of two (F_2)

$$F_2 = 0.5 < \frac{C_{pred}}{C_{obs}} < 2$$

CHAPTER 4

AMBIENT AIR QUALITY ANALYSIS- TREND ANALYSIS

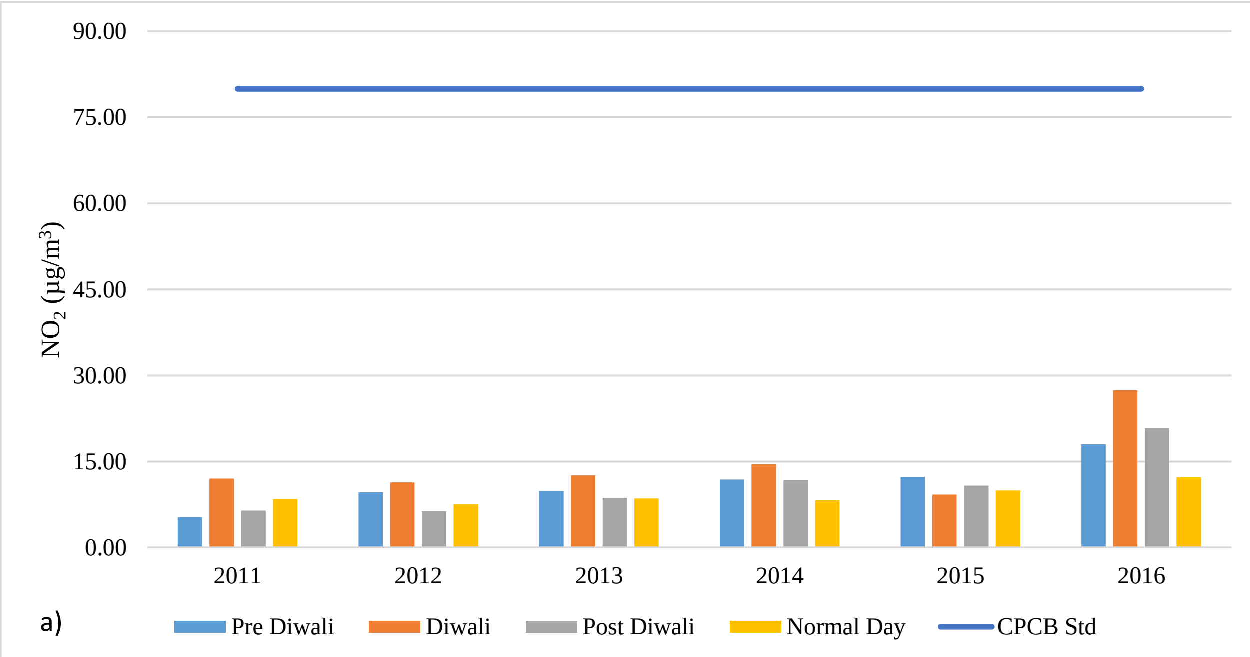
This chapter includes results and inferences drawn from the evaluation of spatio-temporal variations in the Shimla City. Ambient air quality of Shimla city was analysed for the period of 2011 to 2017. Short term analysis include assessment of air quality during the Diwali festival. While, the long term trends have been investigated by examining the change in annual and seasonal concentrations of pollutants.

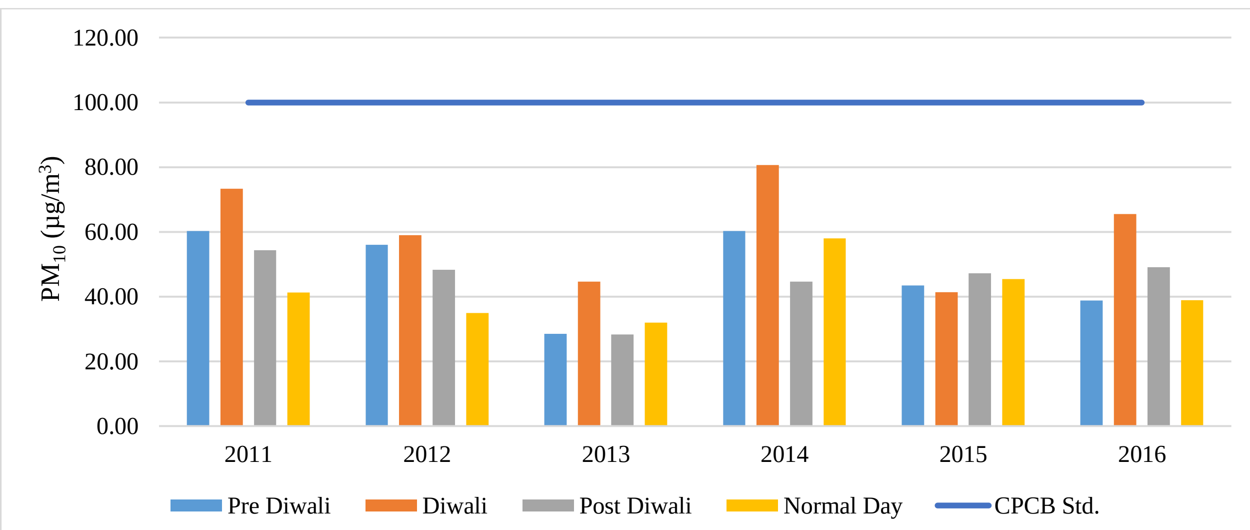
It was observed in preliminary studies that annual mean concentrations of Sulphur dioxide in Shimla have been below 5 µg/m^3 for entire study period, which are well within the defined standards of 50 µg/m^3. Thus, effect of SO_2 pollutant on Shimla city is minimal. Major reason of such low levels of SO_2 is due to absence of any major industry and manufacturing unit in vicinity of the Shimla city. Steady rate of SO_2 has been maintained in city which can be a result of several preventive measures like limiting sulphur content in diesel, substitution of conventional domestic fuels with unconventional ones like LPG and use of methane in cooking instead of coal and wood [27].

4.1 Short Term Analysis: Variations during Diwali Festival

Short term air quality degradation episodes can pose long term adversities on humans and environment. Daily average concentrations of criteria pollutants NO_2 and RSPM have been studied on the day of Diwali festival, one day before (pre Diwali) and one day after (post Diwali). Concentrations, seven days prior to festival and seven days after can be treated as normal day which can be used to compare the fluctuations of pollutants during festival days [16].

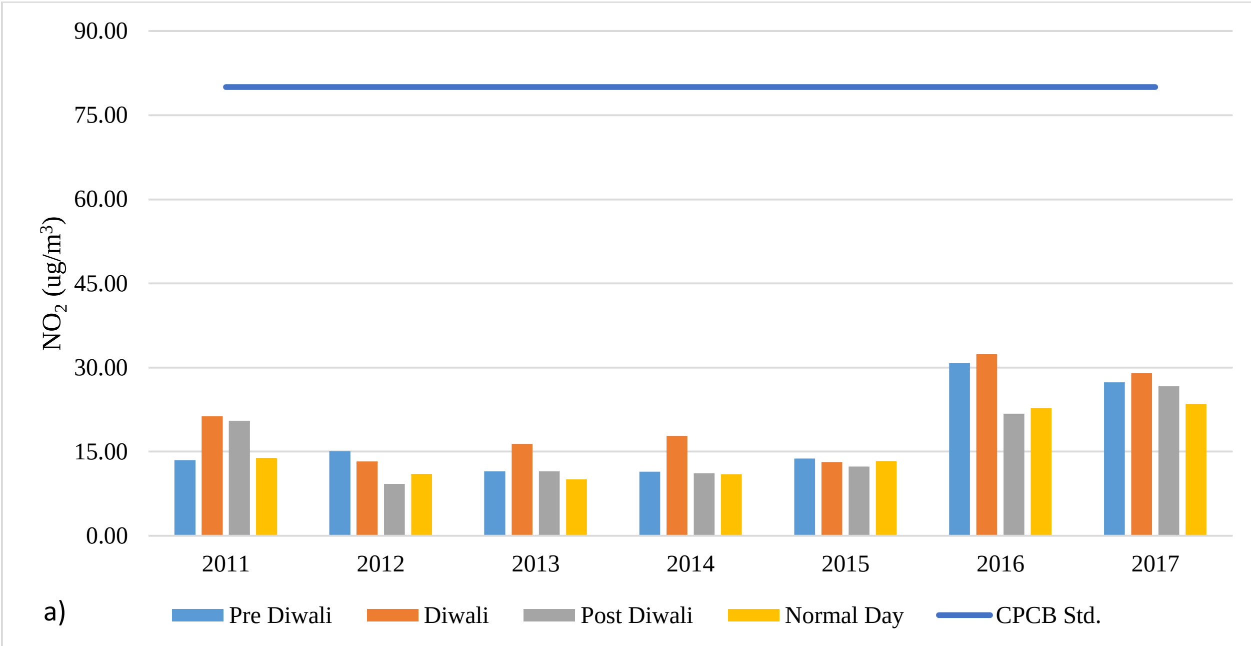
Figures 4.1(a-b) and 4.2 (a-b) shows a graphical comparison between the 24 hourly concentrations of the atmospheric pollutants over the Shimla city during festival period and a normal day. It can be observed that average concentrations of atmospheric pollutants increased from the day prior to festival and were significantly elevated possibly due to pyrotechnic display and then decreased. The concentrations of air pollutants at monitoring site II were much greater than concentrations of monitoring site I during festival days. This is due to reason that location of monitoring site is a residential cum commercial area where, there is a possibility of experiencing combined effect of fireworks and vehicular emissions during Diwali. RSPM and NO_2 concentrations at monitoring site II were higher by factor of 1.5 and 1.3 when compared to their concentrations at monitoring site I.





b)

Figure 4.1: Average Concentrations of pollutants monitored at Monitoring site I during festival days and a normal day



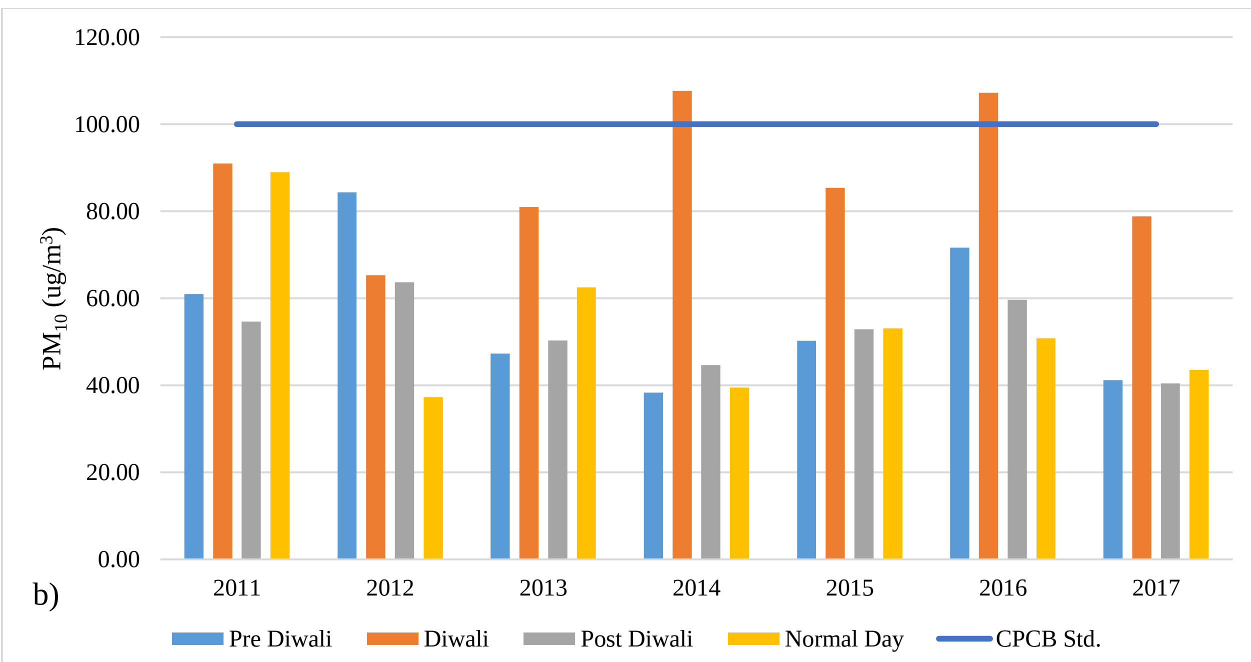


Figure 4.2: Average Concentrations of pollutants monitored at monitoring site II on festival days and a normal day

RSPM concentrations at monitoring site I increased by a factor of 1.5 on Diwali day as compared to any normal day however, this factor increased to 1.8 for the urban site. Similarly, levels NO_2 were raised by 1.4 to 1.5 times at monitoring site I and monitoring site II. Diwali days were also encountered by calm wind conditions which are known to further elevate the concentrations of pollutants in atmosphere [16,17].

Table 4.1: AQI of Monitoring Site I

Year	Pre Diwali				Diwali	Post Diwali			
	7	5	3	1		1	3	5	7
2011	39	46		60	73	54		41	41
2012	47	24		56	59	48		37	35
2013	28	29		29	45	28		20	32
2014	27	37	39	60	81	45		36	58
2015	36	36		43	41	47		39	45
2016	44	37		39	66	49		50	39

Table 4.1: AQI of Monitoring Site II

Year	Pre Diwali				Diwali	Post Diwali			
	7	5	3	1		1	3	5	7
2011	36	48		61	91	55		58	89
2012	53	55		84	65	64		49	37
2013	24	31	42	47	81	50		30	63
2014	67	44		38	105	45		48	40
2015	92			50	85	53		72	53
2016	61	64	45	72	105	60		62	51
2017	69	50	25	41	79	40		65	44

Air Quality Index (AQI) was employed to validate the change in air quality during Diwali festival and compared with Pre Diwali (1, 3, 5, 7 days) and Post Diwali (1, 3, 5, 7 days) days for the data available. Table 4.1 and 4.2 illustrates the AQI calculated for the estimation of air quality at two sites during the festival of Diwali. The air quality of Shimla has been influenced by the RSPM concentrations. It can be observed by comparing the two tables that air quality of urban site was significantly affected by the firework display during festival period. Air quality ranged between good to satisfactory for most of the years except significant change was observed in year 2014 and 2016 where, it reached the levels of moderate pollution. Therefore, from the above results it is evident, air quality of Shimla gets affected by the short term variations on concentrations of pollutants mainly RSPM.

4.2 Long Term Analysis

Long term trend analysis involves studying the spatio-temporal variations of air pollutants annually as well as seasonally. This analysis becomes important because of strong association between long term exposures of air pollutants with human health. Short term variations are always dependent on the long term trends. Long term trends can be validated determining the annual Exceedance factors and percentage increase in concentrations [2].

4.2.1 Annual variations of pollutants

Annual average concentrations at monitoring site II were observed to be higher than monitoring site I. Table 4.3 shows the average annual concentrations of NO_2 and RSPM at two monitoring sites. The annual average concentrations of NO_2 were within prescribed limits as per NAAQS (40μg/m^3) for the entire period. However, RSPM concentrations were observed to be exceeding the NAAQS prescribed standards of 60μg/m^3 for the years 2012, 2015 and 2016 at monitoring site II.

Table 4.3: Annual average concentrations of monitored pollutants.

Year	Monitoring Site I		Monitoring Site I	
	Annual NO_2 Conc.	Annual RSPM Conc.	Annual NO_2 Conc.	Annual RSPM Conc.
2011	8.30	49.06	16.55	57.41
2012	9.48	49.89	13.56	63.78
2013	8.80	44.32	11.90	48.05
2014	9.92	43.89	12.17	49.84
2015	10.62	41.15	15.63	69.27
2016	14.59	42.59	19.97	63.75
2017	-	-	24.02	58.61

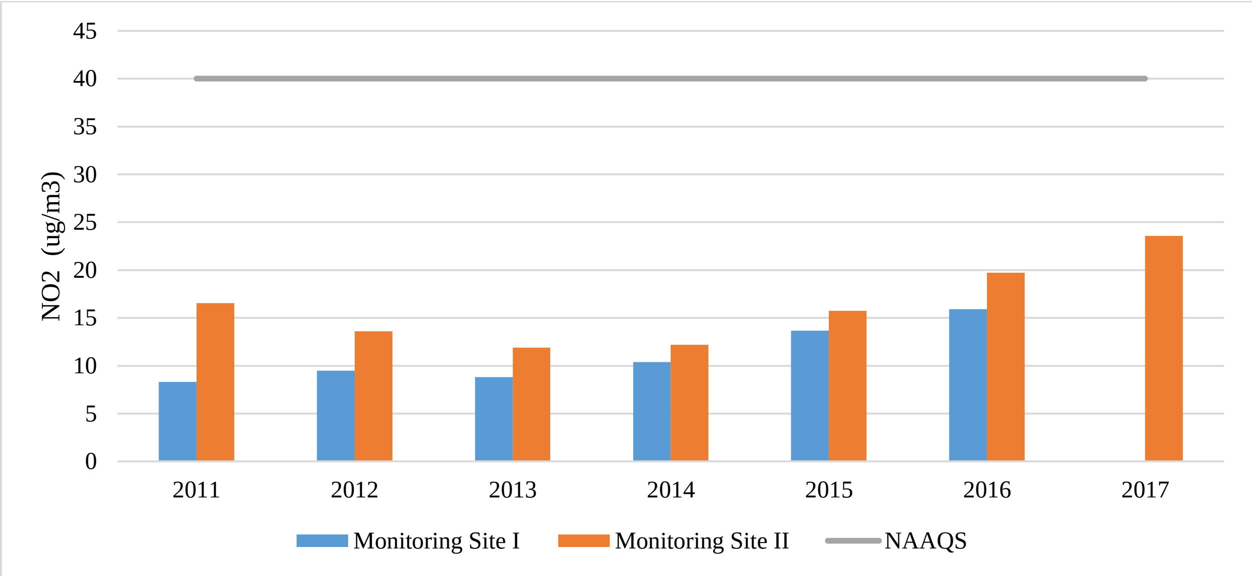


Figure 4.3- Annual average trends for NO_2

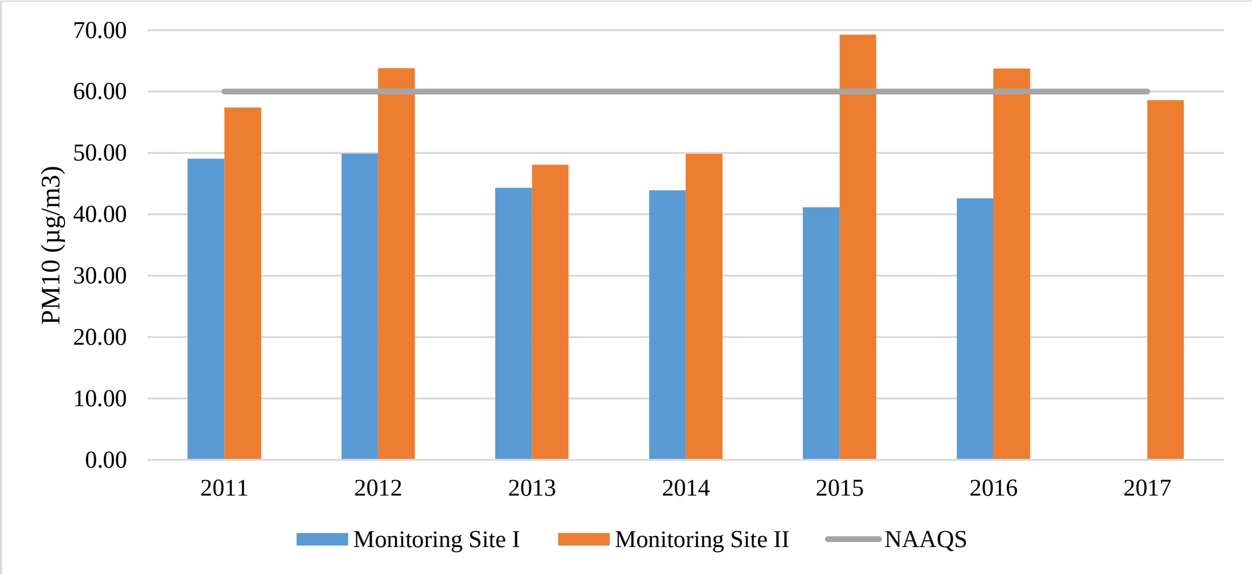


Figure 4.4: Annual average concentrations for RSPM

Figure 4.3 and 4.4 illustrates the graphical representation of variations in annual average concentrations. The annual average graphs were plotted and compared with NAAQS. It can be observed that NO_2 at both the sites have shown the increasing trend but higher levels can be found at the urban site.

Annual average RSPM concentrations at monitoring site I have shown no clear trends with, quantity of RSPM persisting within same ranges. The highest concentration was observed at monitoring site II for the year 2015 and since then particulate concentrations are decreasing. This decrease in RSPM levels at urban monitoring site can be attributed to the phasing out of older vehicles, improvement in vehicular technology and strictness in emission norms.

4.2.2 Annual Exceedance Factor

Annual Exceedance factors for estimated for the study period has been summarized in Table 4.4.It is calculated for the pollutant which dominates the atmosphere of the locality. In our case, RSPM pollutant can influence the air quality of Shimla city. It can be observed that air quality at monitoring site I is classified as 'moderate'. Similarly, the air quality at monitoring station II is varying between moderate to high category. Moreover, some of Exceedance Factors that represent moderate pollution are very close to next threshold limits (e.g. 0.98 for year 2017) and slight deterioration in existing air quality can change the categorization.

Table 4.4: Exceedance Factor for RSPM

Year	Monitoring Station -I		Monitoring Station -II	
	Exceedance Factor	Pollution Level	Exceedance Factor	Pollution Level
2011	0.82	Moderate	0.95	Moderate
2012	0.83	Moderate	1.06	High
2013	0.74	Moderate	0.80	Moderate
2014	0.73	Moderate	0.84	Moderate
2015	0.69	Moderate	1.16	High
2016	0.71	Moderate	1.05	High
2017	-	NA	0.98	Moderate

4.2.3 Seasonal Variations

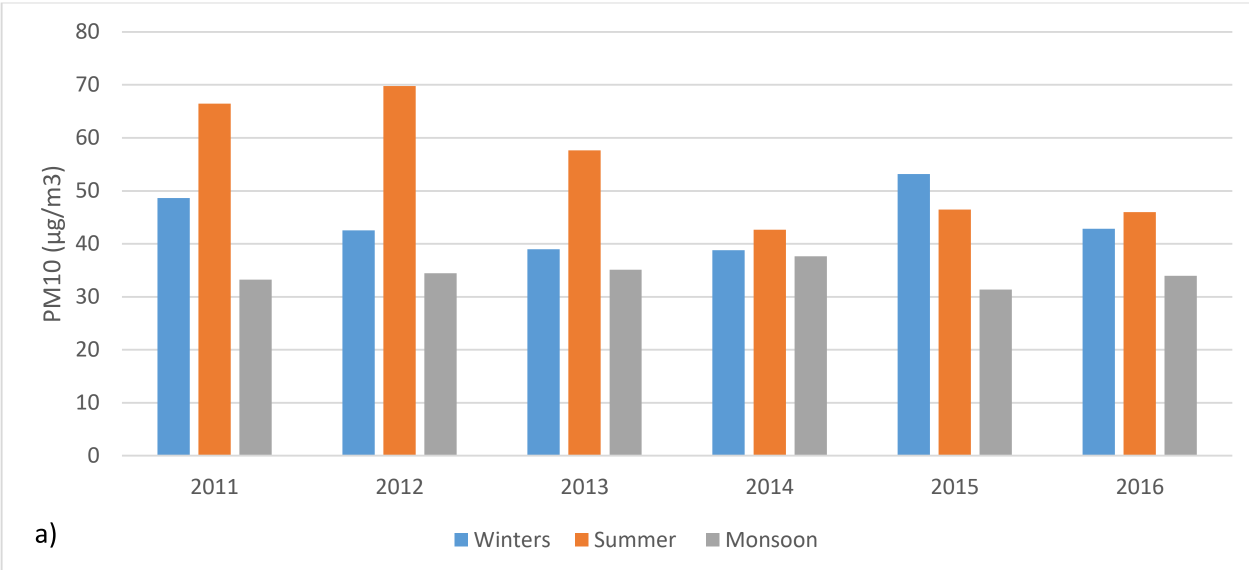
Table 4.5 displays the seasonal analysis of RSPM and NO_2. Three seasons namely winter, summer and monsoon were considered to estimate the variation in concentration of pollutants with respect to change in climatic conditions. It can be observed that variation in NO_2 concentrations during three seasons have been minimal. It is RSPM concentrations which will have dominating effect in altering the ambient air quality during different seasons.

Table 4.5: Seasonal Variations in Concentration of pollutants

Monitoring Station	Conc. in ug/m^3	Winters						
		Jan 2011-Feb 2011	Oct 2011-Feb 2012	Oct 2012-Feb 2013	Oct 2013-Feb 2014	Oct 2014-Feb 2015	Oct 2015-Feb 2016	Oct 2016-Feb 2017
Bus Stand	NO_2	16.32	16.22	11.80	11.26	14.23	15.97	23.93
	RSPM	52.81	61.10	49.34	44.29	62.03	68.30	69.52
Tekka Bench	NO_2	8.28	7.64	9.80	9.12	10.02	11.42	17.64
	RSPM	48.65	42.54	38.96	38.79	53.18	42.87	42.97
	Conc. in ug/m^3	Summers						
		Mar - June 2011	Mar - June 2012	Mar - June 2013	Mar - June 2014	Mar - June 2015	Mar - June 2016	Mar - June 2017
Bus Stand	NO_2	15.97	15.87	13.44	11.90	15.84	18.62	24.08
	RSPM	72.82	84.93	61.89	55.11	78.23	68.79	67.63
Tekka Bench	NO_2	8.46	9.61	9.09	9.94	10.79	12.75	-
	RSPM	66.44	69.80	57.66	42.65	46.44	45.96	-
	Conc. in ug/m^3	Monsoon						
		Mar - June 2011	Mar - June 2012	Mar - June 2013	Mar - June 2014	Mar - June 2015	Mar - June 2016	Mar - June 2017
Bus Stand	NO_2	16.68	11.60	10.17	11.26	15.37	18.47	23.36
	RSPM	43.42	43.74	33.76	42.90	59.34	45.51	46.68
Tekka Bench	NO2	8.68	9.81	8.19	9.87	10.29	13.37	-
	RSPM	33.25	34.47	35.14	37.63	31.34	33.95	-

Figure 4.5 represents the graphical analysis of seasonal variations of RSPM for the period of 2011-2017. It can be observed that highest concentrations of PM_{10} are observed during summer season and least during the monsoons. During the winter season, stable meteorological conditions like

calm winds, low temperature and reduced mixing height results in non-dispersion and entrapment of particulate matter concentrations. The situation is exacerbated due to biomass burning (wood burning to keep warm) during the winters.



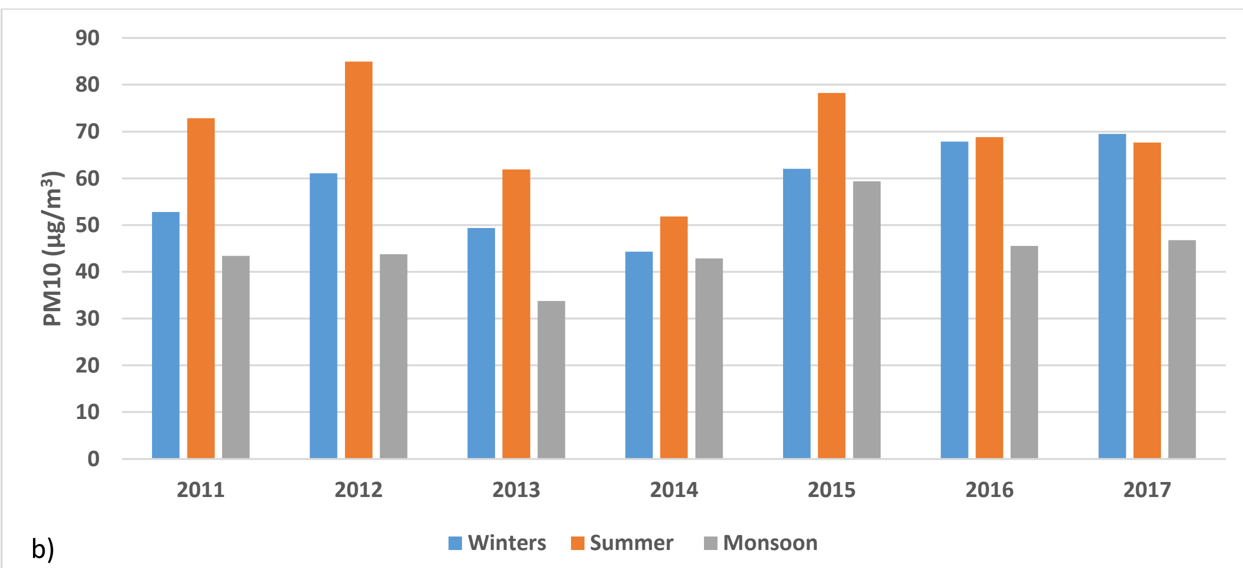


Figure 4.5: Seasonal Variations of RSPM for a) Monitoring Site I b) Monitoring Site II

However, seasonal trends at the study location showed the highest concentrations of particulate matter during summer months: March to June. This is attributed mainly to the abrupt increase in floating population and number of vehicles in city. City suffers severe road congestions and unorganized traffic movements. This sudden increase in tourist influx is due to summer vacations of several institutions in surrounding states. Increased traffic density on congested roads leads to greater tire attrition and thereby resuspension of dust. High temperatures in summer seasons enhances the dryness of air thus, elevating the particulate resuspension on roads. Forests in vicinity of Shimla are vulnerable to wildfires, which are natural sources of particulate emissions. Other factors that influence PM_{10} concentrations include dispersion of bio-aerosols like pollen grains and wind dusts.

PM_{10} concentrations were reported minimal for monsoon period. This is mainly due to washing out of particulates with rain water during wet deposition process. Higher relative humidity in monsoon period also restricts the suspension of particulates in atmosphere.

4.2.4 Weekend-Weekday Analysis Seasonal Variations

This analysis carried out over the weekend-weekday scenario for monitoring site II to study the impact of anthropogenic activities especially traffic volume in the city.

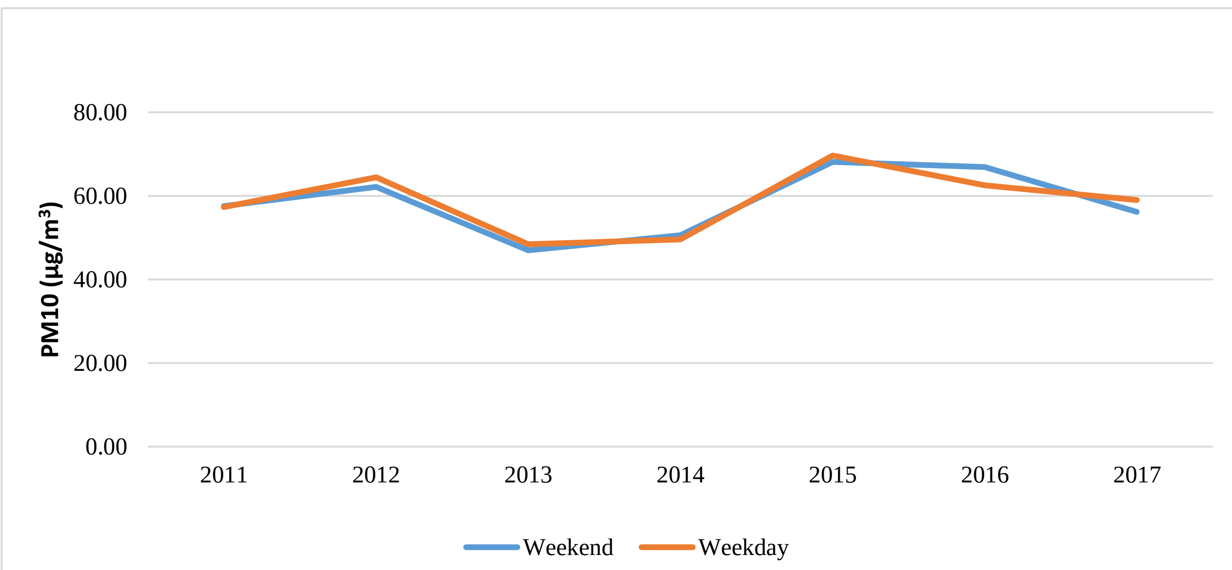


Figure 4.6: Weekend-weekday annual average concentration of PM_{10} at monitoring site -II

For our study location, annual PM_{10} concentrations were observed to be highest on weekends for the study years 2011, 2014 and 2016 and for weekdays on 2012, 2013, 2015 and 2017. However, it is evident from the Figure 4.6 that there is no significant variations in annual concentrations of RSPM for weekday-weekend analysis.

4.3 Association of meteorological parameters with air pollutants

Wind rose diagram depicts the wind speed and its direction over a specific period of time. Longest spoke represents the direction of wind which has the largest frequency. Wind rose diagrams for the study period have been disclosed in Appendix B. It was observed after analysing the meteorological data of the city for study period that calm conditions were prevalent for 87% of the time on a normal day and about 9.2% wind direction was North-Easterly.

Table 4.6: Value of correlation coefficient between PM_{10} and Meteorological Parameters

Meteorological Parameters	Monitoring Station I	Monitoring Station II
Wind Speed (m/s)	0.053	0.028
Precipitation (mm)	-0.17	-0.12
Temperature (^{0}C)	0.11	0.06
Relative Humidity (%)	-0.30	-0.26

Table 4.6 displays the values of correlation coefficient between RSPM concentrations and major meteorological parameters at both the stations. For our conditions, weak positive correlation was obtained between wind speed and concentrations of RSPM. There exists a negative correlation between precipitation and particulate concentrations. This is because of the reason that particulates gets washed away in rains by the process of wet deposition. Negative correlation between particulate matter and relative humidity validates our results of low concentrations during monsoon period. In overall conditions, it was observed that stronger correlation existed at monitoring site I in comparison to monitoring site II.

CHAPTER 5

AMBIENT AIR QUALITY ANALYSIS – AIR QUALITY MODELLING

This part includes the performance evaluation of two models used for prediction of particulate matter concentrations. Graphical representation has been used to compare the predicted and monitored concentrations, while the suitability of model for use in study area has been described by statistical indicators.

Weighted emission factor (WEF) has been calculated using the emission factors specified by ARAI.

$$WEF = \frac{[\sum N\,(j).EF(i,y)]}{Total\ Number\ of\ Vehicles}$$

Where,

WEF is weighted emission factor (g/km)

N(j) is number of vehicles of a particular type ‘j’

EF(i,j) is emission factor of pollutant ‘i’ for the vehicle type ‘j’ (g/km)

The data regarding total number of vehicles in Shimla city was obtained from Department of transport, H.P.

Since, modelling was performed for prediction of monitored concentrations at urban site for the years 2015 and 2016, the data of traffic volume studies could not be gathered and appropriate traffic volume derived from the literature of study location. It is also assumed that rate of increase in traffic volume and emissions is 10%.

Four conditions have been used to find the best fit model which can be used for prediction of concentrations of study location. Modelling studies have been conducted with respect to the urban site i.e. monitoring site II. These conditions are:

- Prediction of concentrations using mean background concentrations of monitoring site I
- Prediction of concentrations using night time (10 PM-6AM) background concentrations of monitoring site I
- Prediction of concentrations using night time (10PM-6AM) concentrations of urban site as background concentration.

- Prediction of concentrations by using vehicle proportioned night time (10PM-6AM) concentrations of urban site as background concentrations. Traffic volume studies were conducted for three consecutive days at the monitoring site II.

5.1 CALINE 4

Data used for CANILE 4 included vehicle related data, meteorological parameters and data such as source height, link geometry, mixing zone width, and receptor coordinates etc.

The features and components involved in modelling the concentrations of particulate matter for our study area has been described in the Table 5.1.

Table 5.1: Features of Study Area

S.No.	Parameter	Remarks
1.	Traffic Volume and Emission factors	2015: 4000 PCU & .78 g/mile 2016: 4500 PCU & .87g/mile
2.	Source Height	0 (At grade)
3.	Link Geometry	X1,Y1-(-84.95,0) X1,Y2-(26.34,0)
4.	Receptor Coordinates	(X,Y,Z)- (0, -4, 7.92)
5.	Wind Speed and Direction	Daily Data available
6.	Dry Bulb Temperature	
7.	Background Concentrations	

Due to unavailability of data regarding parameters like settling velocity, deposition velocity and mixing zone height, pre -installed values were used for model prediction. The following tables show the average predicted concentrations for the four cases for 2015 and 2016:

Table 5.2: Monitored and Modelled Concentration of PM_{10}

Case	2015		2016	
	C_{obs}	C_{pred}	C_{obs}	C_{pred}
Predicted concentrations (avg background - Ridge)	70	45	64	47
Predicted concentrations (10-6AM background - Ridge)	70	43	64	46
Predicted concentrations (10-6AM background - bus stand)	69	71	63	67
Predicted concentrations (10-6AM background- vehicle proportioned - bus stand)	69	59	63	56

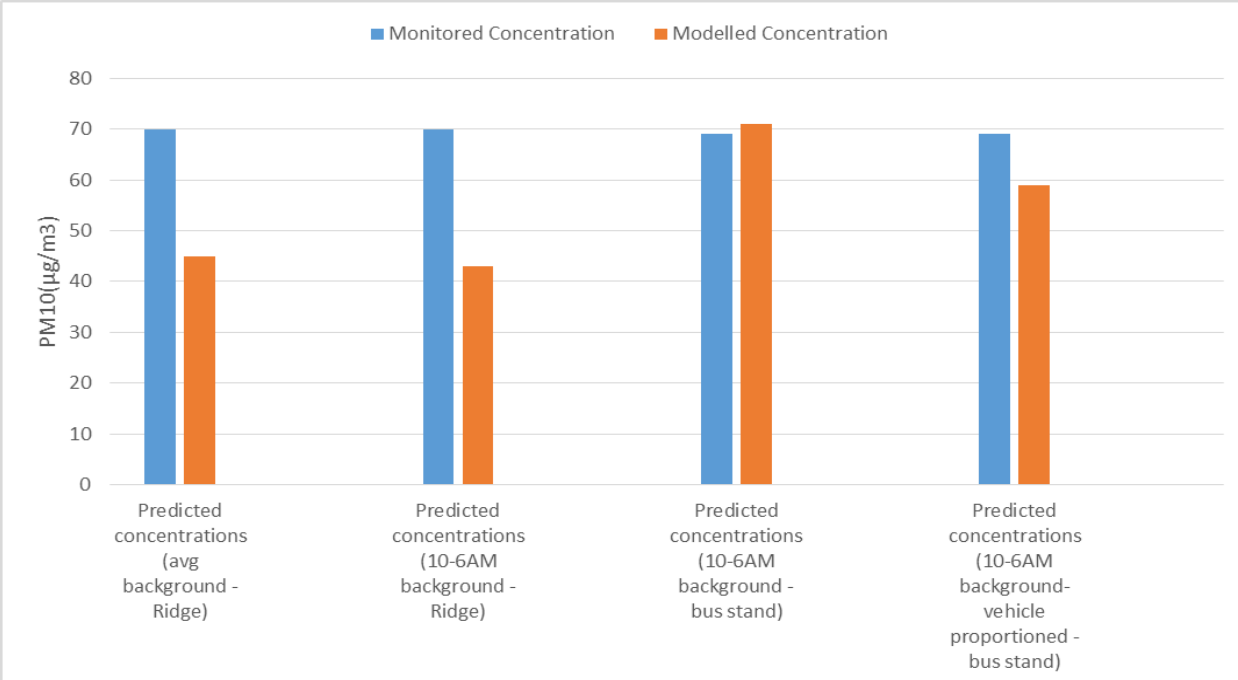


Figure 5.1: Monitored vs Modelled Concentration for 2015

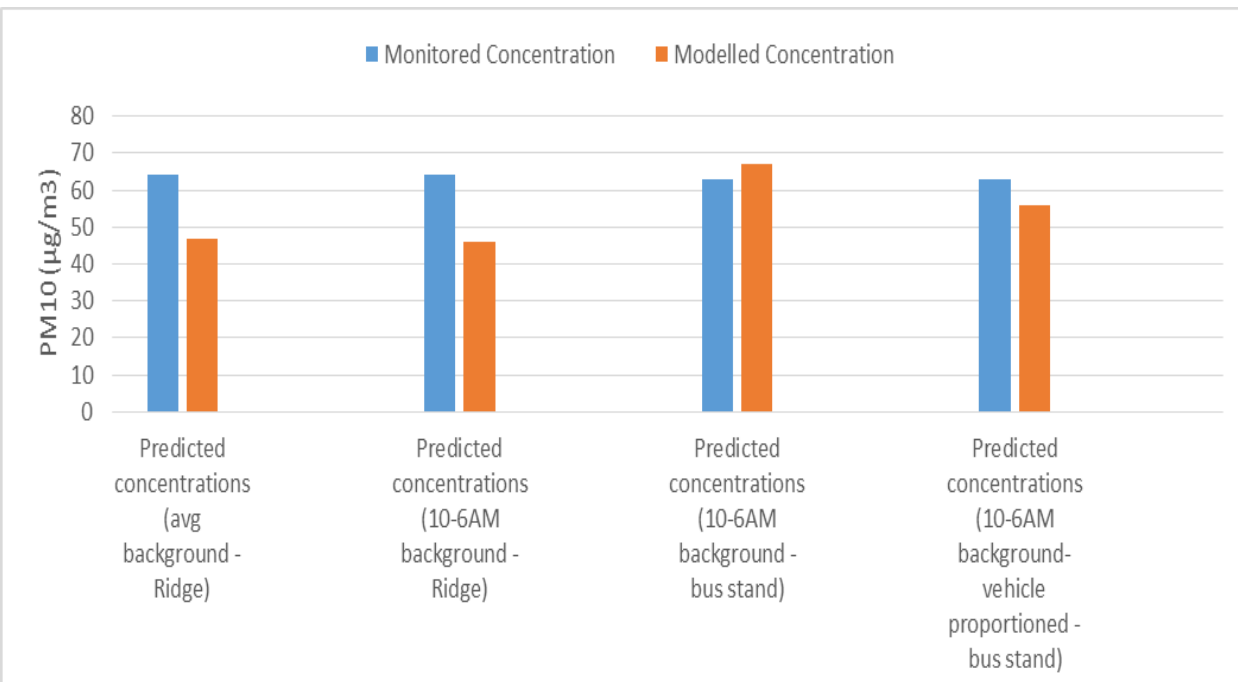


Figure 5.2: Monitored vs Modelled Concentration for 2016

Thus, graphical representation of annual mean concentrations of monitored and modelled concentrations revealed that CALINE 4 under predicted the concentrations for three relevant cases.

5.2 STREET Model

The main aspect of STREET model is description of type of canyon in which concentration predictions are made. It is based on the aspect ratio. Height of canyon considered for modelling studies was 12m while the receptor height was 7.92m.Thus,

$$Aspect\ Ratio = \frac{12}{7.92} = 1.51$$

This aspect ratio can be described as an intermediate canyon. The empirical constant parameter K used three values (6,7,8) for calculation of vehicular emissions.

Table 5.3: Monitored and Modelled Concentration of PM_{10} for year 2015

Case	K=6		K=7		K=8	
	C_{obs}	C_{pred}	C_{obs}	C_{pred}	C_{obs}	C_{pred}
Predicted concentrations (avg background - Ridge)	70	41	70	41	70	42
Predicted concentrations (10-6AM background - Ridge)	71	38	71	38	71	39
Predicted concentrations (10-6AM background - bus stand)	69	68	69	68	69	68
Predicted concentrations (10-6AM background-vehicle proportioned - bus stand)	69	56	69	56	69	56

Table 5.4: Monitored and Modelled Concentration of PM_{10} for year 2016

Case	K=6		K=7		K=8	
	C_{obs}	C_{pred}	C_{obs}	C_{pred}	C_{obs}	C_{pred}
Predicted concentrations (avg background - Ridge)	64	43	64	43	64	43
Predicted concentrations (10-6AM background - Ridge)	64	42	64	42	63	42
Predicted concentrations (10-6AM background - bus stand)	63	62	63	62	63	62
Predicted concentrations (10-6AM background-vehicle proportioned - bus stand)	63	51	63	51	63	51

Generally, variation in value of K ranging between 6 to 8 affects the prediction of pollutants. But in our case no significant change in model was observed when all three values of K were used.

5.3 Performance Evaluation of Models

Table 5.6 and Table 5.7 shows the statistical evaluations of both the models. The mean and NMSE values validates the efficient working of CALINE 4 for the prediction of particulate matter concentration with some degree of accuracy, whereas STREET model resulted under prediction of pollutant concentration. FB values indicate the considerable amount of compliance between the forecasted and measured pollutants. However, IA values are high for STREET model which highlights the relatively error free results indicating the adherence of legitimate modelling approach. Pearson's coefficient of correlation "R" is relatively low for both the models, but in comparison predicted concentrations of STREET model are better correlated than the CALINE 4 results. In overall evaluation of parameters, predictions of CALINE 4 are much superior than the estimates calculated using the STREET model.

Table 5.5: Statistical evaluation of PM_{10} for year 2015

Case I: Predicted concentrations (avg background - Ridge)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	70	45	41	41	42
SD	16	15	14	14	14
R	1.00	0.24	0.29	0.29	0.29
FB	0.00	-0.44	-0.51	-0.51	-0.51
NMSE	0.00	0.31	0.39	0.39	0.39
IA	1.00	0.44	0.57	0.57	0.57
FAC2	1.00	0.79	0.70	0.70	0.70

Case II: Predicted concentrations (10-6AM background - Ridge)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	70	43	38	38	39
SD	16	19	18	18	18
R	1.00	0.23	0.27	0.27	0.27
FB	0.00	-0.49	-0.59	-0.59	-0.59
NMSE	0.00	0.42	0.53	0.53	0.53
IA	1.00	0.42	0.59	0.59	0.59
FAC2	1.00	0.69	0.57	0.57	0.59

Case III: Predicted concentrations (10-6AM background - bus stand)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	69	71	68	68	68
SD	16	19	19	19	19
R	1.00	0.84	0.85	0.85	0.85
FB	0.00	0.03	-0.02	-0.02	-0.02
NMSE	0.00	0.02	0.02	0.02	0.02
IA	1.00	0.91	0.09	0.09	0.09
FAC2	1.00	1.00	0.99	0.99	0.99

Case IV:Predicted concentrations (10-6AM background-vehicle proportioned - bus stand)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	69	59	56	56	56
SD	16	16	15	15	15
R	1.00	0.84	0.85	0.85	0.85
FB	0.00	-0.15	-0.22	-0.21	-0.21
NMSE	0.00	0.04	0.07	0.07	0.07
IA	1.00	0.84	0.21	0.21	0.21
FAC2	1.00	0.99	0.99	0.99	0.99

Table 5.6: Statistical evaluation of PM_{10} for year 2016

Case I: Predicted concentrations (avg background - Ridge)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	64	47	43	43	43
SD	18	13	13	13	13
R	1.00	0.47	0.50	0.50	0.49
FB	0.00	-0.31	-0.39	-0.39	-0.39
NMSE	0.00	0.19	0.25	0.25	0.25
IA	1.00	0.58	0.44	0.44	0.44
FAC2	1.00	0.91	0.85	0.86	0.86

Case II: Predicted concentrations (10-6AM background - Ridge)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	64	46	42	42	42
SD	17	18	18	18	18
R	1.00	0.43	0.45	0.45	0.44
FB	0.00	-0.32	-0.41	-0.41	-0.41
NMSE	0.00	0.22	0.30	0.30	0.30
IA	1.00	0.58	0.46	0.46	0.46
FAC2	1.00	0.86	0.68	0.68	0.68

Case III: Predicted concentrations (10-6AM background - bus stand)

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	63	67	62	62	62
SD	17	22	22	22	22
R	1.00	0.80	0.80	0.80	0.80
FB	0.00	0.05	-0.02	-0.02	-0.01
NMSE	0.00	0.05	0.04	0.04	0.04
IA	1.00	0.86	0.12	0.12	0.12
FAC2	1.00	1.00	1.00	1.00	1.00

Case IV:Predicted concentrations (10-6AM background-vehicle

Statistical parameters	Monitored	CALINE 4	STREET K=6	STREET K=7	STREET K=8
Mean	63	56	51	51	51
SD	18	17	18	18	18
R	1.00	0.78	0.80	0.80	0.80
FB	0.00	-0.12	-0.21	-0.21	-0.21
NMSE	0.00	0.06	0.08	0.08	0.08
IA	1.00	0.84	0.20	0.20	0.20
FAC2	1.00	1.00	0.97	0.97	0.97

SUMMARY AND CONCLUSIONS

1. Ambient air quality of Shimla city during festival of Diwali was investigated to evaluate the short term trends. AQI calculations confirmed the adversities of high pollutant concentrations generated due to pyrotechnic activities.
2. Annual trend analysis of RSPM and NO_2 was performed to assess the long term exposure of air pollutants and the variations were also validated using Annual Exceedance Factor.
3. Seasonal analysis revealed the elevation of pollutant concentrations during summer season and least effect during rainy season.
4. PM_{10} concentrations were also correlated with the meteorological parameters like wind speed, wind direction, relative humidity and temperature.
5. Two air quality dispersion models were evaluated for prediction of pollutant concentrations. The performance of CALINE 4 was relatively well in comparison to the other model used for pollutant forecasting for the city.

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APPENDIX

APPENDIX-A

AIR QUALITY INDEX

Table 1: AQI values and corresponding ambient concentrations (health breakpoints)

AQI Category, Pollutants and Health Breakpoints						
AQI Category (Range)			**PM_{10}**		**NO_2**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Good (0-50)	**0**	**50**	**0**	**50**	**0**	**40**
Satisfactory (51-100)	**51**	**100**	**51**	**100**	**41**	**80**
Moderately polluted (101-200)	**101**	**200**	**101**	**250**	**81**	**180**
Poor (201-300)	**201**	**300**	**251**	**350**	**181**	**280**
Very poor (301-400)	**301**	**400**	**351**	**430**	**281**	**400**
Severe (401-500)	**401**	**500**	**430 +**		**400+**	

Table 2: Annual AQI

Year		2011	2012	2013	2014	2015	2016	2017
Bus Stand	AQI	58	62	49	50	69	63	59
Tekka Bench	AQI	48	49	44	44	42	43	41

Table 3: Monthly AQI (Tekka Bench)

Month/Year	2011	2012	2013	2014	2015	2016	2017
January	46	36	42	41	59	45	42
February	52	52	39	38	43	52	41
March	59	68	45	37	39	40	
April	73	55	45	37	44	49	
May	65	72	78	52	53	53	
June	63	82	58	45	50	40	
July	38	47	43	44	31	37	
August	31	33	27	36	23	26	
September	31	24	34	33	41	38	
October	44	39	42	46	39	42	
November	45	39	35	52	38	42	
December	33	36	38	62	39	47	

Table 4: Monthly AQI (Bus Stand)

Month/Year	2011	2012	2013	2014	2015	2016	2017
January	52	65	57	44	67	68	62
February	54	74	45	47	71	69	71
March	63	95	49	43	76	66	58
April	66	59	47	47	77	69	68
May	98	80	87	61	78	75	73
June	69	99	65	56	81	65	69
July	48	66	41	45	74	46	51
August	38	32	29	48	52	35	42
September	38	32	31	36	53	55	47
October	62	41	33	54	66	72	54
November	56	54	50	51	68	63	65
December	48	48	49	66	68	75	51

Table 5: Seasonal variations in AQI

Air Quality Index calculated for the three seasons at two sites also verify that the air quality deteriorates during winter as well as summer season.

Monitoring Station		Winters						
		Jan 2011-Feb 2011	Oct 2011-Feb 2012	Oct 2012-Feb 2013	Oct 2013-Feb 2014	Oct 2014-Feb 2015	Oct 2015-Feb 2016	Oct 2016-Feb 2017
Bus Stand	AQI	53	61	49	44	62	68	69
Tekka Bench	AQI	49	43	39	39	53	43	43
		Summers						
		Mar - June 2011	Mar - June 2012	Mar - June 2013	Mar - June 2014	Mar - June 2015	Mar - June 2016	Mar - June 2017
Bus Stand	AQI	72	83	62	52	78	69	67
Tekka Bench	AQI	65	69	57	43	46	46	-
		Monsoon						
		Mar - June 2011	Mar - June 2012	Mar - June 2013	Mar - June 2014	Mar - June 2015	Mar - June 2016	Mar - June 2017
Bus Stand	AQI	43	43	34	43	59	45	47
Tekka Bench	AQI	33	34	35	38	31	34	-

APPENDIX-B

Wind Rose Diagrams

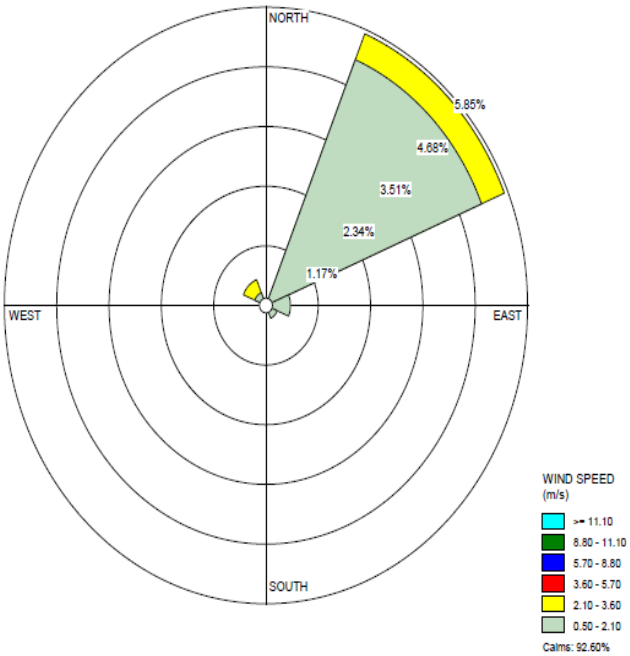


Figure C-1 : 2011

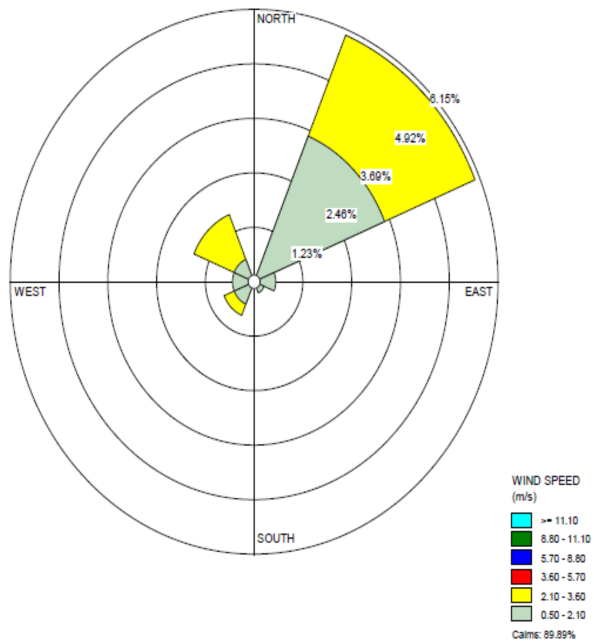


Figure C-2 : 2012

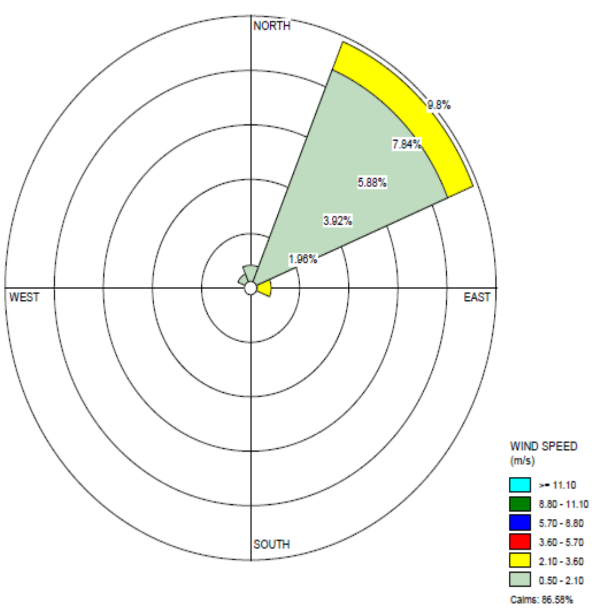


Figure C-3 : 2013

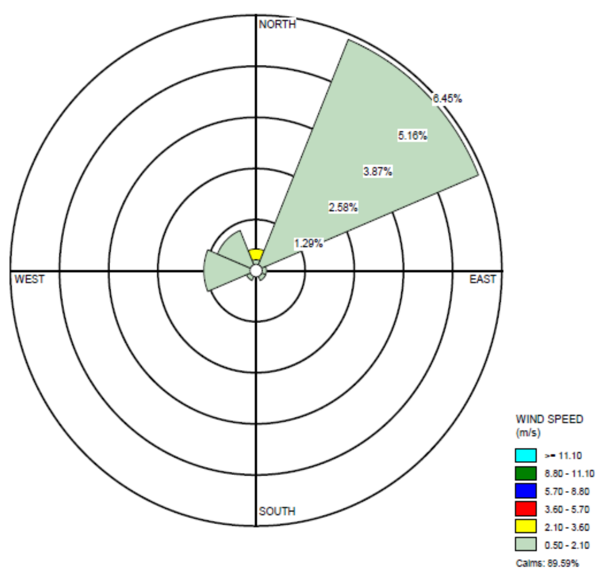


Figure C-4: 2014

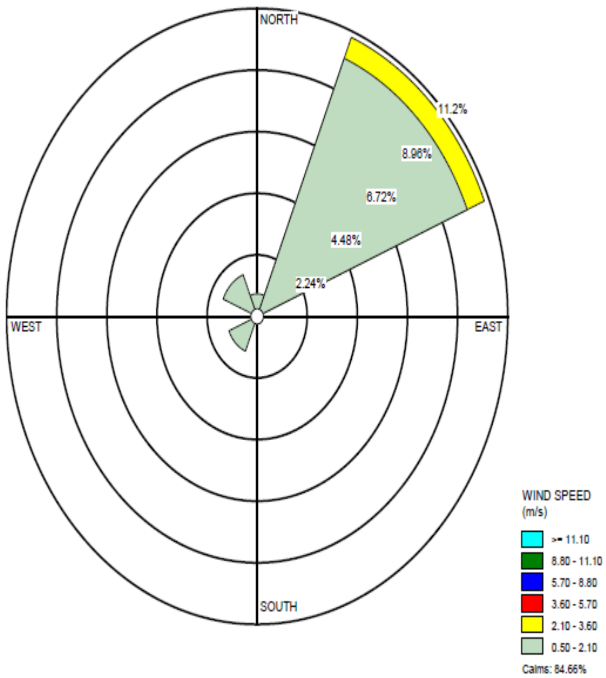
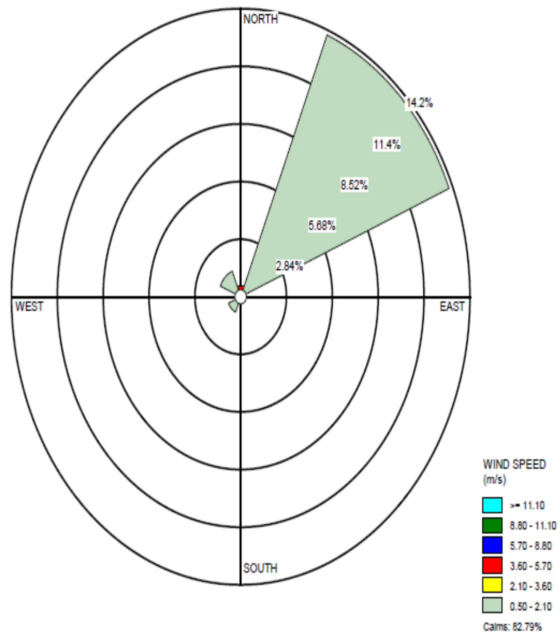


Figure C-6: 2015



FigureC-7: 2016

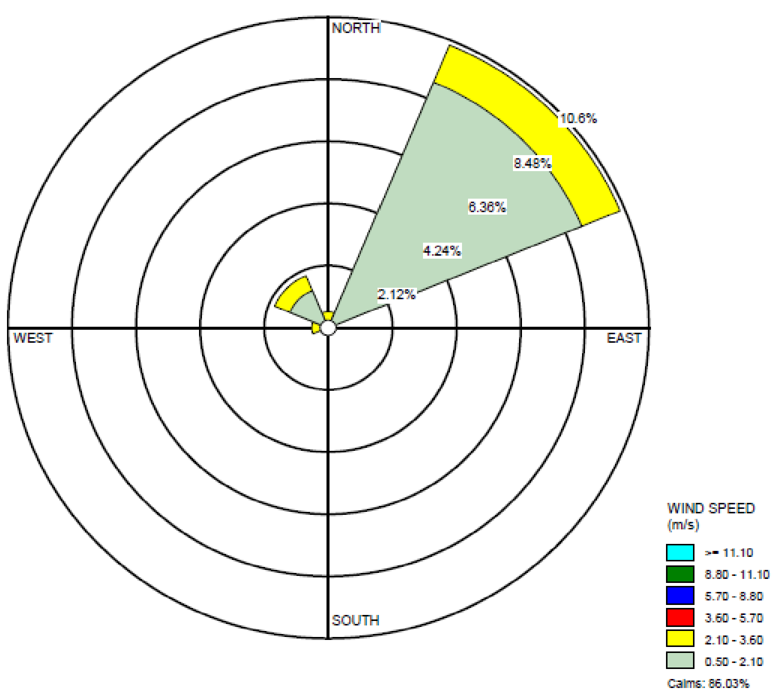


Figure C-8: 2017