KUVEMPU UNIVERSITY

A THESIS ON

INVESTIGATIVE STUDIES ON DETERIORATION OF AIR QUALITY IN URBAN POCKETS AND DEVELOPMENT OF AIR QUALITY INDICES

SUBMITTED BY

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DECLARATION

I do hereby declare that the thesis titled **INVESTIGATIVE STUDIES ON DETERIORATION OF AIR QUALITY IN URBAN POCKETS AND DEVELOPMENT OF AIR QUALITY INDICES w**hich is submitted herewith to Kuvempu University for the award of the degree of **DOCTOR OF PHILOSCOPY** in **CIVIL ENGINEERING** is the result of the work done by me in the Department of Civil Engineering, University B.D.T. College of Engineering (Constituent College of Kuvempu University) Davangere – 577 004, under the guidance of **Dr. N.T. MANJUNATH**, Professor & Director, Centre for Env. Sci. Engg Tech, Department of Studies in Civil Engineering, University B.D.T. College of Engineering, Davangere. I further declare that the results of the work are not submitted for the award of any degree or diploma within the or in any other University or Institute.

lace : Davangere

)ate : 16/2/2017

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CERTIFICATE

This is to certify that the thesis titled **INVESTIGATIVE STUDIES ON DETERIORATION OF AIR QUALITY IN URBAN POCKETS AND DEVELOPMENT OF AIR QUALITY INDICES** submitted by **KRISHNA REDDY K.S.,** to the Kuvempu University for the award of the degree of **DOCTOR OF PHILOSOPHY** is a bonafide record of research work carried out by him under my supervision. The content of this thesis, in full or in part, have not been submitted to any other institute or university for the award of any degree.

Place : Davangere

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ABSTRACT

Environmental pollution remains a serious issue in the developing world, affecting the lives of billions of people, reducing their life expectancy, growth and development. India, among other developing nations of the world, is facing the challenge of industrial pollution at an alarming rate. This has made the constant surveillance of environmental characteristics a necessary task. There is an urgent need to identify critically polluted areas and identify their problematic dimensions. Accordingly, measures have to be taken to make the process of industrial development and economic growth more sustainable.

The high influx of population to urban areas, increase in consumption patterns and unplanned urban and industrial development has led to a higher rate of increase of air pollution. The problem is aggravated by the inadequacy of pollution control measures, lack of proper planning, lack of proper enforcement of laws and regulations, increasing desertification and decreasing vegetation cover. Exposure to vehicular air pollution especially the trace organics are suspected to be toxic, affects respiratory, nervous and cardiovascular systems of humans, resulting in impaired pulmonary functions, sickness and even death. Main air pollutants are particulate matter (PM_{10}, $PM_{2.5}$), SO_2, NO_X, CO, VOCs and Hydrocarbons.

Bangalore is one of the fastest growing cities in Asia 'growing rapidly in all directions. With accelerated economic development and coupled with uncontrolled urbanization, the number of vehicles on the road has increased exponentially over the last ten years. The cities vehicular population contributes 60-70 percent of the pollution load to the environment. It is imperative, therefore, that air pollution control strategies for mobile sources are urgently needed to mitigate the negative impacts on air quality on human health and environment in metropolitan Bangalore.

A vast amount of data on ambient air quality is generated and used to establish the quality of air in different areas. Further, the general public will not be satisfied with raw data, time series plots, statistical analysis, and other complex findings pertaining to air quality. Thus the need is to communicate air quality in an effective manner. Thus the concept of Air Quality Index (AQI) has been developed.

Under National Ambient Air Quality Monitoring Programme (NAMP), air pollution monitoring is being carried out throughout the country for the last few years. But it is difficult to state whether any city has been adequately studied. Further there is a tendency among government agencies to study only hot spots and industrial locations within the cities. Thus to assess the absolute air quality of any study area, the in-depth investigations and monitoring is essential and based on such studies air pollution mitigation can be suggested. Therefore for the present research work, the topic titled **INVESTIGATIVE STUDIES ON DETERIORATION OF AIR QUALITY IN URBAN POCKETS AND DEVELOPMENT OF AIR QUALITY INDICES** was selected.

Ten pockets consisting of Industrial, Commercial, Residential, Rural and Sensitive areas in Bangalore were considered for the present study. During the study period between 2011-2015, the pollutants viz. SO_2, NO_2 and PM_{10} were monitored and analysed. Monthly, yearly and seasonal AQI indices were calculate. Exceedence factor is also presented. Based on field work and analysis the inferences were drawn. The findings of the present study are documented in this report, systematically.

For convenient and clarity of presentation the present research report is documented consisting of the following chapters;

Chapter I Introduction

Chapter II Literature Review

Chapter III Materials and Methodology

Chapter IV Results and Discussions

Chapter V Mitigation Methods and Policies Suggested

Chapter VI Conclusions Recommendations and Scope for Further Study

Chapter I, throws light on importance of air quality and its monitoring, significance of air quality indexing. The objectives of the study are also documented in this Chapter.

In Chapter II, detailed literature review on the topic of research is illustrated. Issues like sources of air pollution, classification of air pollutants, effect of air

pollution, air quality standards, control measures, air quality indexing and indices, review of technical papers published by researchers etc., are documented in this chapter.

Chapter III, describes the materials and methodology adopted to carryout investigations.

The data obtained from the investigations and the analysis of the same has been presented in Chapter IV. The results revealed that the air quality at all the study pockets has deteriorated. Based on concentration of PM_{10} measured, monthly, seasonal and annual AQIs calculated and annual exceedence factor calculated, it was confirmed that industrial and commercial areas are heavily and seriously polluted, rural and background and sensitive areas are moderately to heavily polluted. Seasonal AQIs varying from 49 to 197 (during Winter), 41 to 190 (during Summer) and 46 to 168 (during Monsoon) were recorded. Annual AQIs ranging from 44 to 180 were observed. Exceedence factor (EF) calculated also confirmed the ambient air pollution of study pockets. Further PM_{10} was found to be critical pollutant followed by NO_2 and SO_2.

National level air pollution management system, Bangalore air quality management system, action plan suggested to control air pollution due to vehicular movement and industries, other abatement measures are documented in Chapter V.

The conclusions, limitations derived from present study and scope for future investigations formed the subject matter of Chapter VI.

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ABBREVIATIONS

API	**:**	Air Pollution Index
AQDI	**:**	Air Quality Depreciation Index
AQEI	**:**	Air Quality Exposure Index
AQHI	**:**	Air Quality Health Index
AQI	**:**	Air Quality Index
AQMRL	**:**	Air Quality Monitoring and Research Laboratories
ARI	**:**	Aggregate Risk Index
BAQMS	**:**	Bangalore Air Quality Management System
BBMP	**:**	Bhruhat Bangalore Maha Nagara Palike
CAQI	**:**	Common Air Quality Index
CEMSAP	**:**	Calcutta Environmental Strategy and Action Plan
CISTUP	**:**	Centre for Infrastructure, Sustainable Transportation and Urban Planning
COH	**:**	Coefficient of Haze
COPD	**:**	Chronic Obstructive Pulmonary Disease
CPCB	**:**	Central Pollution Control Board
CRRI	**:**	Central Road Research Institute
DAPPS	**:**	Dynamic Air Pollution Protection System
EMPRI	**:**	Environmental Management and Policy Research Institute
FAQI	**:**	Fuzzy Air Quality Index
GVAQI	**:**	Greater Vancouver Air Quality Index
IAPI	**:**	Integral Air Pollution Index
IISC	**:**	Indian Institute of Science
IM	**:**	Inspection and Maintenance
KSRTC	**:**	Karnataka State Road Transport Corporation
LPG	**:**	Liquefied Petroleum Gas
MOEF	**:**	Ministry of Environment and Forest
MPC	**:**	Maximum Permissible Concentration
MRAP	**:**	Morbidity Related to Air Pollution
MURC	**:**	Most Undesirable Respirable Contaminants Index
NAAQS	**:**	Indian National Ambient Air Quality Standards
NAMP	**:**	National Air Quality Monitoring Program
NAQI	**:**	National Air Quality Index
NCE	**:**	National Certification Examination
NEERI	**:**	National Environmental Engineering Research Institute
NGO	**:**	Non-Governmental Organization

NRSPM	**:**	Non-respirable suspended particulate matter
ORAQI	**:**	Oak Ridge Air Quality Index
PCR	**:**	Principal Component Regression
PI	**:**	Pollution Index
R&D	**:**	Research and Development
RAQI	**:**	Revised Air Quality Index
RSPM	**:**	Respirable Suspended Particulate Matter
RTI	**:**	Right to Information
RTO	**:**	Regional Transportation Office
SPM	**:**	Suspended Particulate Matter
TSPM	**:**	Total Suspended Particulate Matter
USEPA	**:**	United States Environmental Protection Agency
VOC	**:**	Volatile Organic Carbons
WHO	**:**	World Health Organisation

CHAPTER - I

INTRODUCTION

CHAPTER - I

INTRODUCTION

Environment and Development are considered as two sides of the same coin. The environment degradation, in fact, started with the propagation of human race. This process of environmental degradation was accelerated with the development of socio-economic activities, e,g, agriculture, industrialization, drugs and pharmaceuticals, transport, civil construction including roads and buildings, etc. With growing population, the requirements of food grains and other consumer items increased greatly, leading to further environment degradations. As long as the assimilation capacity of receiving systems, land, air, etc, was more than the pollution load, the importance of environmental degradation was not really appreciated. But today there are places where receiving systems are polluted to the extent that they have practically no assimilation capacity due to effluents / gaseous pollutants from industries and transportation sector.

Specially most people tend to associate air pollution problems with the coming of the industrial revolution, such problems, in one form or another, have plagued the human race for centuries. The earliest pollutants noted in the atmosphere were probably of natural origin. Smoke, fumes, ash, and gases from volcanoes and forest fires; and dust from windstorms in arid regions fog in humid, low-lying areas; and natural terpene hazes from pine trees in mountainous regions were part of our environment long before human - induced, or anthropogenic, problems came on the scene. Except in such extreme cases as volcanic eruption, pollution from natural sources does not usually, by itself, pose problems severe enough to endanger life and property. Ultimately, human activities are to blame for pollution problems that threaten to make portions of the earth's atmosphere an inhospitable environment.

About half of the world’s population now lives in urban areas because of the opportunity for a better quality of life. Many of these urban centres are expanding rapidly, leading to the growth of megacities. In these megacities air pollution is a growing problem because of the increasing urban population causing high densities of motor vehicle traffic, greater electric power generation and expanding commercial and industrial activities. Thus the concentration of people and activity are exerting increasing stress on the natural environment, with impacts at urban, regional and

global levels. Further the ill effects of air pollution on human health and global impacts are discussed in depth elsewhere in the literature.

Thus the atmosphere is used as a natural sink for pollutants. The assimilation capacity of the atmosphere, however is limited. The disposal of gaseous pollutants in the atmosphere depends the meteorological conditions prevailing. For example, gaseous pollutants many not pose a serious problem on rainy days, especially when the sky is overcast but the situation is complicated during the winter season when adverse conditions prevails in the atmosphere. Hence, from the point of view of dispersion of gaseous pollutants, it is essential to be constantly informed about the total pollution load, meteorological conditions, etc. It is, therefore, desirable to investigate air quality deterioration specially in urban pockets and to develop indices.

1.1 AIR QUALITY INDEX

Globally many cities continuously assess air quality using monitoring networks designed to measure and record air pollutant concentrations, at several points. In recent years, air quality information are provided by government agencies for the public comes in a number of forms like annual reports, environment reviews etc. Such reports require time, interest and necessary background to digest its contents. Further the large databases do not convey the air quality status to the government officials, policy makers and in particulars to the general public in a simple and straight forward manner. Therefore a more sophisticated tool has been developed to communicate the risk of ambient air concentrations using Air Quality Index (AQI).

The basic objective of any air quality index is to transform the measured concentrations of individual air pollutant into a single numerical index using suitable aggregation mechanism. Ideally, every index should reflect both the measured and publicly perceived quality of the ambient air for the time period it covers. As a result, air quality indices attempt to standardize and synthesize air pollution information and permit comparisons to be readily undertaken, and to satisfy public demands for accurate, easy to interpret data.

A number of methods were developed in the past by various researchers/environmental agencies for determination of AQI or API but there is no

universally accepted method exists, which is appropriate for all situations. Different method uses different aggregation function in calculating AQI or API and also considers different types and numbers of pollutants. The intended uses of AQI or API are to identify the poor air quality zones and public reporting for severity of exposure of poor air quality. Most of the AQI or API indices can be broadly classified as single pollutant index or multi-pollutant index with different aggregation method. Every indexing method has its own characteristic strengths and weaknesses that affect its suitability for particular applications.

Some of the many indices developed include: Integral air pollution index, fussy air quality index, oak ridge air quality index, air quality deteriorations index etc.

1.2. LITERATURE REVIEW

Many researchers across the globe have carried out studies to assess the air quality of urban pockets and to develop AQI and thereby to suggest the remedies to combat pollution. Gadgil and Jadhav (2004) carried out studies to quantify pollutants in the ambient air of Pune City. Air quality status of Hyderabad City has been reported by Sastry et al (2004).

Studies have been carried out to assess the traffic generated CO concentrations at the selected intersections in Bangalore city (Mahendra & Krishnamurthy; 2004). Urban ambient air quality in Chennai City based on exceedence factor criteria has been reported by Senthilnathan (2007). Gowtham and Anjali (2015) based on their studies carried out at four junctions of Vapi, reported that, overall AQI was found to fall under moderately polluted category. The analysis of the ambient air in Delhi employing AQI has been carried out by Prakash Mehata and Basin (2010) and they reported that SPM is a critical pollutant at the study sites considered for study. Harish Gupta et al (2012) discussed the usefulness of mathematical modelling and computational simulation techniques used to predict the horizontal and vertical concentrations of air pollutants. Similarly the studies have been carried out by various researchers to take stock of ambient air quality [Srivastava and Rajasree (2010), Harinath and Ushamurthy (2010), Agarwal et al (2001), Goyal and Sidartha (2003)]. However, in depth review of more than 80 research papers have been documented in the thesis report.

Under National Ambient Air Quality Monitoring Program (NAMP), air pollution monitoring is being carried out through out the country for the last few years. In Karnataka State, ambient air quality monitoring is being done in many major cities.

1.3 PROBLEM IDENTIFICATION

The scanning of extensive literature revealed that the air quality in particular and the quality of environment in general is deteriorating and hence there is a urgent need to monitor the air quality so that the suitable measures can be taken to restore/ maintain the quality of environment. The Government / Non-Government agencies have tried to rate the air quality of urban pockets, but the reports lack research orientation. Further, many researchers have carried out studies to take stock of ambient air quality and suggested remedies to combat pollution. However, the solution is site specific which depends on many factors. Therefore the author opines that the importance of site specific objectives and their selection are crucial for obtaining the most meaningful air quality index and there is a need for indepth studies to arrive at solution. Thus it was proposed to carryout research on the topic titled **"Investigative studies on Deterioration of Air Quality in urban pockets and Development of Air Quality Indices"** with the following objectives.

1.4 OBJECTIVES OF THE STUDY

Specific objectives of the present study include :

- To identify the urban pockets which are under severe air quality threat and background pocket.
- To determine the concentrations of air pollutants viz. PM_{10}, SO_2 and NO_2 during the course of study at selected sampling locations.
- To determine the ambient air quality status and trends.
- To collect traffic, meteriological and details of related activities.
- To develop the air quality index for selected pockets (monthly, seasonal and yearly).
- To develop exceedence factor
- To suggest remedial measures.

CHAPTER - II

LITERATURE REVIEW

CHAPTER - II

LITERATURE REVIEW

INTRODUCTION

With the technological advancements, a vast amount of data on ambient air quality is generated and used to establish the quality of air in different areas. The large monitoring data result in encyclopaedic volumes of information that neither gives a clear picture to a decision maker nor to a common man who simply wants to know how good or bad the air is? One way to describe air quality is to report the concentrations of all pollutants with acceptable levels (standards). As the number of sampling stations and pollution parameters (and their sampling frequencies) increase, such descriptions of air quality tend to become confusing even for the scientific and technical community.

As for the general public, they usually will not be satisfied with raw data, time series plots, statistical analyses, and other complex findings pertaining to air quality. The result is that people tend to lose interest and can neither appreciate the state of air quality nor the pollution mitigation efforts by regulatory agencies. Since awareness of daily levels of urban air pollution is important to those who suffer from illnesses caused by exposure to air pollution, the issue of air quality communication should be addressed in an effective manner. Further, the success of a nation to improve air quality depends on the support of its citizens who are well-informed about local and national air pollution problems and about the progress of mitigation efforts.

To address the above concerns, the concept of an Air Quality Index (AQI) has been developed and used effectively in many developed countries for over last three decades.

2.1 CLASSIFICATION OF AIR POLLUTANTS

Air pollutants can also be broadly classified into two general groups – primary or secondary air pollutants.

(a) Primary pollutants are those emitted directly from identifiable sources. It includes Finer particles (<100µ in diameter), Coarse particles (>100µ in dia), Sulphur compounds, Oxides of nitrogen, Carbon monoxide, Halogen compounds, Organic compounds, Radioactive compounds, etc.

(b) Secondary pollutants are those which are produced in the air by interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or system and roles in the photochemical reactions.

2.2 FORMS OF AIR-POLLUTANTS

a) ***Smoke:*** It is produced chiefly due to the incomplete combustion of fuel such as coal, oil petroleum etc. It contains carbon monoxide, carbon dioxide, etc.

b) ***Dust:*** is finely divided powder-like matters generated by crushing or grinding of stones or other inorganic substance.

c) ***Gases:*** These are formless fluids which can be transformed to liquid state by the change of temperature and pressure. These are formed by the decomposition of organic matters or burning of fuels.

d) ***Aerosol:*** The dispersion of microscopic solids or liquids in the atmosphere is termed as aerosol.

e) ***Particulate Matter:*** The matter which is generated from the sources such as industries, power generation plants, road-way dust, etc exist in atmosphere in suspension is known as particulate.

f) ***Pollen:*** The fertilizing or reproductive matters of flowers to form seeds are known as pollen. The pollen can float in air or it can be transferred from flower to flower by bees or butterflies.

g) ***Hydrogen-Sulphide (H_2S):*** It is generated from sewage treatment plants, tanning industries, dye manufacturing etc. It causes irritation and disorder of respiratory organ, etc.

h) ***Hydrogen Fluoride (HF):*** It is generated from chemical industry fertilizer industry, aluminum industry, etc. It causes skin diseases and bong, fluorisis, etc.

i) ***Hydrogen Peroxide (H_2O_2):*** It is generated from photo chemical smog products.

j) ***Hydrocarbon:*** It is generated from automobile exhaust.

k) ***Arsenic:*** It is generated from detergents, pesticides, etc.

2.3 SOURCES AND EFFECTS OF AIR POLLUTANTS

The sources of air pollution may be classified in two groups:

- Natural sources
- Manmade sources

2.3.1 Natural Sources

The following are the different forms of natural sources

(a) Atmospheric Reactions: In the atmosphere, different types of chemical reactions are always going on. In the lower atmosphere the gases or vapours are always converted into solids or liquids by condensation or oxidation. In upper atmosphere, the photo-chemical reactions are going on by the absorption of ultra-violet solar radiation. It. breaks the complex molecules of organic maters. The products of atmospheric reactions come down to earth by rain, snow fall etc.

(b) Dust and Aerosol: The dust and aerosol which are present in atmosphere consist of salt particles from sea water, air-borne particles remain in suspension in air.

(c) Microorganisms: These are in the form of algae, fungi, bacteria, yeast, etc. These organisms can be transported by wind to far distances and can affect; plants, animals and human beings.

(d) Pollen: These may enter the atmosphere from the flowers of trees, grasses and weeds and may be transported from place to place by wind.

(e) Radioactive Substances: The radioactivity of the atmosphere is caused by the radioactive minerals present in the crust of the earth and the action of cosmic rays. The radioactive substances such as radium uranium, thorium, etc are responsible for imparting the radioactivity of air.

2.3.2 Man-Made Sources

The sources of air pollution resulting from human activities can be categorized into following three types:

a) Mobile/Line Sources: These comprise of any form of combustion-engine vehicles. e.g. light duty gasoline-powered cars, light and heavy-duty diesel powered vehicles, two wheelers, and three wheelers including fugitive dusts from vehicle traffic.

b) Point Sources: Point sources include major industrial facilities like chemical plants, steel-plants, oil refineries, power plant, cement plants, hazardous waste incinerators, etc. Point sources are defined as those that emit 10 tons per year of nay of the criteria pollutants or hazardous air pollutants or 25 tons per year of a mixture of air toxics. Point sources (predominantly electrical utilities and industrial boilers) are also major emitters of nitrogen oxides (NOx) - accounting for about 40% of total releases. Point sources are less important sources of VOCs - releasing less than 15% of total volatile organic compounds.

c) Area Sources: Area sources include agricultural production, mining and quarrying and community source such as domestic fuel consumption, and cleaning plants. Though emissions from individual area sources are relatively small, collectively their emissions can be of concern - particularly where large numbers of sources are located in heavily populated areas. Areas sources are responsible for over 50% of particulate matter emissions. Area sources are

accountable for emissions of more volatile organic compound (VOC) in comparison to point or mobile sources. These VOCs are expected to contribute significantly to the formation of ground-level ozone.

d) **Secondary sources (Complex sources):** Photochemical smog, sulphate and nitrate particles, acid rain and resuspension of harmful substances from soil. [Srinivas; 1998]

2.4. RESPIRABLE SUSPENDED PARTICULATE MATTER (RSPM)

2.4.1 Sources

The sources of PM_{10} include road dust, windblown. dust, agriculture, construction and fireplaces. PM^{10} may also be formed from incomplete combustion of any fuel and from other pollutants viz. SOx, NOx, Organics, etc. Fine Particulate Matter or $PM_{2.5}$ is the aerosols having diameter less than 2.5 um. Particle in the 0.005 - 0.05 µm ranges are usually formed by condensation of vapors produced either by high temperature or by chemical processes. Particles in the 0.05- 2 µm range are usually formed by coagulation of smaller particles or from smaller particles through vapor condensation. PM2.5 are emitted from fuel combustion in motor vehicles, process combustion and from industrial sources, residential and agricultural burning. It is also formed from reactions of other pollutants [4]. The total contribution of PM_{10} & $PM_{2.5}$ emissions from all types of vehicles in Greater Mumbai region was estimated to be 2239 Metric Tonnes /year and 2070 Metric Tonnes /year respectively. The major sources of $PM_{2.5}$ were diesel, gasoline, road dust, coal and biomass, and secondary sulfates, nitrates and ammonium. $PM_{2.5}$ contribution due to diesel combustion in different seasons varied from 16 to 23% in Delhi, 15 to 43% in Kolkata and 16 to 38% in Mumbai & $PM_{2.5}$ contribution due to road dust was found vary from 4 to 41% in Delhi, 5 to 28% in Kolkata and 16 to 38% in Mumbai. Among the secondary pollutants, sulfates were also found to contribute $PM_{2.5}$ significantly to the extent of 6 to 10% in Delhi, 4tol5% in Kolkata and 12 to 15% in Mumbai [Goyal et al: 2007].

At present, most routine air quality monitoring systems generate data based on the measurement of PM_{10} and not on the size segregated. Consequently, the majority of epidemiological studies use PM_{10} as the exposure indicator. PM_{10} represents the

particle mass that enters the respiratory tract and, moreover, it includes both the coarse (particle size between 2.5 and 5 μm) and the fine particles (measuring less than 2.5 μm, $PM_{2.5}$) that are considered to contribute to the detrimental health effects observed in the urban environments. The former particles are primarily produced by mechanical processes such as construction activities, road dust re-suspension and wind; whereas the latter originate primarily from combustion sources. In most urban environments, both coarse and fine mode particles are present, but the proportion of particles in these two size ranges is likely to vary substantially from one city to another around the world, depending on local geography, meteorology and specific PM sources. In some areas, the combustion of wood and other biomass fuels can be an important source of particulate air pollution, the resulting combustion particles being largely in the fine ($PM_{2.5}$) mode. Although few epidemiological studies have compared the relative toxicity of the products of fossil fuel and biomass combustion, comparable effect estimates are found for a wide range of cities in both developed and developing countries. It is, therefore, reasonable to assume that the health effects of $PM_{2.5}$ from both the sources are broadly the same.

2.4.2 Effects on Human Health

PM_{10} are small enough to be inhaled and may enter deep into respiratory tract and pulmonary system of human beings. These particles are responsible for most of the airborne particle threat to human health because of their small size range and pose health hazard due to their inhalation and deep penetration in respiratory system during breathing.

The evidence on airborne particulate matter (PM) and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations in both developed and developing countries. All kinds of populations are affected, but the susceptibility to the pollution may vary with health, age, etc. The risk for various adverse outcome has been shown to increase with exposure, but the scale to suggest a threshold below which no adverse health effects would be anticipated is not available. In fact, the low end of the range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration; which for particles smaller than 2.5 μm ($PM_{2.5}$) has been estimated to be 3-5 $\mu g/m^3$ in both the United States and the western Europe.

The epidemiological evidence shows adverse effects of PM following both short-term and long-term exposures.

2.5 SULPHUR DIOXIDE (SO_2)

SO_2 is one of the major air pollutants discharged by various pollutant sources. It is an unpleasant and highly irritating gas, when present in concentrations greater than 1 ppm and adversely affects men, animals, plants and materials. It is most damaging among the various gaseous air pollutants. SO_2 is oxidized into SO_3 in the presence of light within a half to two days. SO_3 is quickly absorbed in rain and clouds to become H_2SO_4, thus producing a mist of sulphuric acid [Anjaneyulu: 2002, Derek Elson : 1982].

2.5.1 Sources

It is a colorless gas formed during the combustion of fuels containing sulphur, such as coal. Sulphur oxides are emitted in significant quantities from thermal power plants, smelting process of Sulphide ores to produce copper, lead & zinc and also from petroleum refining processes. A large quantity of SO_2 emissions from the refinery sector is associated with combustion in boilers of process heaters. Sulphuric acid plant produces significant SO_x emissions through combustion of sulfur containing raw materials and subsequent losses during conversion to SO_3 and then to sulphuric acid (H_2SO_4). Sulphur oxides are also produced during paper and pulp manufacturing as a result of combustion of sulphur containing materials. Other industries that emit SO_2 are aluminum smelter, thermal power plants and steel industry. The diesel driven vehicles are specific source of sulphur dioxide generated during combustion process [Rao & Rao : 2005]. Gurjar et al. (2004) study for Delhi for the period of 1990-2000 reveals that SO_2 are largely emitted-by thermal power plants, approximately of I about 68%. The study also finds that SO_2 emissions by the transport sector increased from 27% in 1990 to 39% in 2000 [Goyal et al: 2007].

2.5.2 Effects on Human Health

Sulphur dioxide can aggravate existing lung diseases, especially bronchitis, causes wheezing, shortness of breath, and coughing. Long-term exposures to sulphur dioxide leads to higher rates of respiratory illness. Oxides of sulphur (SO_x) cause

changes in lung functions in persons with asthma and exacerbate respiratory symptoms in sensitive individuals.

Controlled laboratory studies of the effects of the sulphur dioxide have shown that the adverse effects of this pollutant increase significantly when subjects undergo exercise, because switching from nose-to-mouth-breathing increases the dose of sulphur dioxide to the lower respiratory tract. Asthmatic patients and hay fever suffers are revealed as being particularly sensitive to sulphur dioxide, even at levels comparable with current ambient concentrations.

Sulphates may be responsible for increased asthma attacks, aggravation of heart and lung disease, lowered resistance to respiratory disease in children and other air-pollution related conditions. As an indication of the quantifiable effects of sulphates on health, claim that an annual average sulphates concentration of 100 $\mu g/m^3$ increases the mortality rate by 5%.

WHO has determined 250 $\mu g/m^3$ as the level for both smoke and sulphur at which worsening of the condition of patients from short-term exposure might be expected. For long-term exposure, it is suggested that 100 $\mu g/m^3$ is the level at which adults and children may suffer increased respiratory symptoms.

Table 2.1: Effects of SO_2 at Different Concentration on Human beings (Anjaneyulu: 2002)

Concentration of SO_2 (ppm)	**Effects**
0.25-0.50	Causes significant broncho- construction in asthmatics
1.00	Construction of air passage and psychological distress
3.00-5.00	Detectable by odour
10.00	Throat irritation
20.00	Eye irritation and cough
50.00-100.00	Maximum allowed exposure in 30 minutes
400.00-500.00	Dangerous even for short exposure

2.5.3 Effects on Plants

Plants are relatively more sensitive to SO_2 and get injury when they are open in day time. SO_2 is absorbed through the stomata into the mesophyll of the leaves. When its absorption exceeds a particular level, the cells become inactive and are killed, accusing tissue collapse and drying of leaves. The cells are injured and absorbed portion of the leaf becomes brownish red in colour. The effect is commonly known as chlorosis (loss/ reduction of the green plant pigment, chlorophyll). It affects stomata pores, stomata chloroplast and transpiration through stomata. SO_2 is adsorbed by pores which are oxidized to H_2SO_4 or sulphates ions. H_2SO_4 mists and aerosols are extensively toxics to plants and soil fertility. Sulphur dioxide damages vegetable crops and effects plants growth and nutrients quality of plant products. Acute exposure to high levels of SO_2 kills leaf tissues causing leaf necrosis. The edges and area between leaf veins are severally damaged. Its chronic exposure to plants causes bleaching of leaf pigments due to conversion of chlorophyll to phecophytin (reducing plant productivity) [Rao & Rao: 2005]. Susceptible spices like cucumber, oats and spinach may be damaged by exposure to air containing 0.05 to 0.5 ppm of SO_2 for 8 hours. An observation indicated that in a heat exposure to 0.8 ppm of SO_2 with smoke for 2.5 hours daily for two months cause reduction in root and shoot lengths, number of leaves per plant, wheat productivity, biomass and number of grains per spike and its yield [Bhargava: 1992].

2.5.4 Effects on Materials

SO_2 is not only injurious to man and plants, but also attacks rapidly the marble, limestone, roofing, slate, electrical contracts, paper, textile and buildings. It can even dissolve nylon. Some textile fiber obtained from vegetable origin/ sources lose strength when exposed to H_2SO_4. However, wool is somewhat more resistant. Paper also absorbs SO2 which is oxidized to H_2SO_4 causing the paper to become brittle and friable. Leather too has much affinity towards SO_2 which affects its strength and causes it to disintegrate. Emission of SO_2 from railway marshaling yard, thermal power stations, petroleum refineries, craft paper mills, smelter and industries adversely affect the historic monuments. The acid rain produced by oxidation of SO_2 corrodes metals attacks and washes out basic materials like lime from the soil. The rapid attack of H_2SO_4 on the marble is known as *"Stone Leprosy"*. The Calcium

Sulphates ($CaSO_4$) so formed on the surface of masonry due to Calcium Carbonate ($CaCO_3$) and Hydrogen Sulphates (H_2SO_4) is twice as bulky as calcium carbonate of the stone, which then looks leprous or diseased. Long exposure to SO2 increases the drying and hardening time of paints. It affects durability in paint films. SO_2 polluted air accelerates the corrosion rates of metals such as Fe, Zn, Cu and steel [Reddy et al : 2004].

2.6 NITROGEN OXIDES (NO_X)

Nitrogen oxides existing in the air as N_2O, NO_3, N_2O_3, N_2O_4, N_2O_5, NO and NO_2. The last two substances are artificially generated pollutants & sum of their concentrations is expressed by NO_x (NO and NO_2). Among these Nitric Oxide (NO) is the principal compound. It is formed by combustion of N_2 and O_2 during lighting discharges and bacterial oxidation of ammonia in soil. About 95% of the nitrogen oxide is emitted as NO and remaining 5% as NO_2.

2.6.1 Sources

NO_2 is a major component, of acid rain and ground-level ozone. Nitrogen oxides is a poisonous gas produced from burning fossil fuels like oil and gas at high temperatures, as in a combustion process. The primary sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels. Nitrogen dioxide (NO_2) along with particles in air can be seen as a reddish brown layer over many urban areas. Oxides of nitrogen along with VOCs results in formations of ground level ozone. Source of NO_x also include coal and petroleum boilers, various burning furnaces and equipment, engines for automobiles, ships and aircrafts and domestic heaters thus covering very wide range equipment and appliances involving burning processes. Gurjar et al (2004) have prepared a comprehensive emission inventory for Delhi for the period 1990-2000. The study reveals that transport sector contributes mostly over 80% to NO_x, CO and non-methane VOC emissions. The study also finds out that NO_2 are largely emitted from agriculture. Another study conducted by Central Road Research Institute (CRRI, 2002), estimated that the emission load of NO_x from transport sector in Mumbai contributed daily of about 46.4 Metric Tonnes [Goyal et al: 2007].

2.6.2 Effects on Human Health

Nitrogen dioxide irritates the nose and throat, and it appears to increase susceptibility to respiratory infections. Oxides of nitrogen cause changes in lung function in persons with asthma. Higher doses of NO_2 cause bronchitis and respiratory problems. An exposure towards 150-200 ppm of NO_2 results in "Bronchiolitis fibrosa obliterans", a dangerous disease which occurs within 3 to 5 weeks after the exposure and 500 to 600ppm of NO_2 for 2 to 10 days after result in death of the victim. NO_2 is reported as pulmonary irritant whose excess concentration causes pulmonary hemorrhage. Some cellular enzyme systems are susceptible to destruction by NO_2.

Kerr et al. showed that seven in thirteen asthmatics, one in seven bronchitis and one in ten showed normal subjects reported chest tightness, burning of eyes, headache or dyspnea with exercise at 940 µg /m^3 (0.5 ppm) of NO_x in the atmosphere.

WHO recommends that the maximum exposure level of nitrogen dioxide for the protection of public health should be 190-320 µg /m^3 (0.10-0.17 ppm) for one hour, not to be exceeded more than once per month.

Significant atmospheric effects of oxides of nitrogen include their role in reducing visibility and their potential for causing global surface temperature increase. Nitrogen dioxide absorbs visible light (and strongly absorbs ultraviolet radiation), and at a concentration of 470 µg /m^3 (0.25 ppm) will cause an appreciable reduction in visibility.

2.6.3 Effects on Plants

NO_2 is highly injurious plants. Vegetative growth is suppressed when they are exposed to 0.3-0.5 ppm for 10 to 15 days. Sensitive plants show visible leaf injury when exposed to 5-8 ppm of NO_2 for 1 to 3 hours. Higher concentration of NO_2 damages the leaves of plants, retard the photosynthetic activity and cause Chlorosis. Plants exposed to 100 ppm of NO_2 cause leaf spotting and breakdown of plants tissues. Exposure to 10 ppm of NO checks the metabolic activities in plant tissues e.g., bean and tomato plants, on fumigation showed decreased activity of CO_2 absorption and photosynthetic rate.

2.6.4 Effects on Materials

NO_x fades away a number of textile dyes like cotton, rayon, acetate and viscose rayon, it was found that NO_x levels reaches to 1 to 2 ppm, during the combustion of natural gas which is used to heat the dryers. Higher levels of NO_x cause 10% loss of fiber strength in cotton and rayon. NO_2 produces aerosols which damage the nylon fibers. Abnormally high levels of NO_2 present in ambient air, during dynamite blast operations in New York had adverse effects on nylon stockings and cotton. NO_2 along with hydrocarbons produces peroxides which combine with ozone and cause crack in rubber.

2.7 CARBON MONOXIDE (CO)

2.7.1 Sources

Carbon monoxide is an odorless, colorless and toxic gas. Because it is impossible to see, taste or smell the toxic fumes.

Sources of Carbon Monoxide are unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline powered equipment; automobile exhaust from attached garages; and tobacco smoke. Incomplete oxidation during combustion in gas ranges and unvented gas or kerosene heaters may cause high concentrations of CO in indoor air. Worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces) can be significant sources, or if the flow is improperly sized, blocked, disconnected, or is leaking. Auto, truck, or bus exhaust from attached garages, nearby roads, or parking areas can also be a source.

Carbon monoxide results from incomplete combustion of fuel and is emitted directly from vehicle tailpipes. Incomplete combustion is most likely to occur at low air-to-fuel ratios in the engine. The study conducted by Central Road Research Institute (CRRI, 2002), estimated that the emission load of CO from transport sector in Mumbai contributed daily of about 190 Metric Tonnes.

2.7.2 Effects on Human Health

Carbon monoxide enters the bloodstream through the lungs and forms carboxyl-hemoglobin, a compound that inhibits the blood's capacity to carry oxygen to organs and tissues. Persons with chronic heart disease are especially sensitive to carbon monoxide poisoning and may experience chest pain if they breathe the gas while exercising. Infants, elderly persons, and individuals with respiratory diseases or also particularly from cardiovascular/ peripheral vascular disease and exposure to elevated CO levels can cause impairment of visual perception, manual dexterity, learning ability and performance of complex tasks.

2.8 OZONE

Ozone is formed in the atmosphere by photochemical reactions in the presence of sunlight and precursor pollutants, such as the oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). It is destroyed by reactions with NO_2 and is deposited to the ground. Several studies have shown that ozone concentrations correlate with various other toxic photochemical oxidants arising from similar sources, including the peroxyacetyl nitrate, nitric acid and hydrogen peroxide. Measures to control tropospheric ozone levels focus its precursor gas emissions, but are likely to also control the levels and impacts of a number of other pollutants. Significant additions to the health effects evidence base have come from epidemiological time-series studies. Collectively these studies have revealed positive, small, though convincing, associations between daily mortality and ozone levels, which are independent of the reported that the small change in lung function (< 5% drop in FEV] between air and nitrogen dioxide exposure) and changes in airway responsiveness gives 375-565 $\mu g/m^3$ (0.20 to 0.30 ppm), as the lowest-observed-effect level. Therefore, breakpoints of 280 $\mu g/m^3$ for poor, 400 $\mu g/m^3$ for very poor and 400+ $\mu g/m^3$ for severe category are adopted. For moderately-polluted category an intermediate value of 180 $\mu g/m^3$ (between 80 and 280 $\mu g/m^3$) has been adopted. It may be noted that minor tweaking has been done with breakpoints so that these also corroborate with international breakpoints adopted by other countries.

There is some evidence that long-term exposure to ozone may cause chronic disease. As ozone concentrations increase, health effects at the population level become increasingly numerous and severe. Such effects can occur in places where concentrations are currently high due to human activities or are elevated during episodes of very hot weather. This conclusion is based on the findings of a large number of clinical inhalation and field studies. Both healthy adults and asthmatics would be expected to experience significant malfunctioning of their lungs, as well as airway inflammation that would cause symptoms and alter performance. There are additional concerns about increased respiratory morbidity in children. According to time-series evidence, exposure to concentrations of ozone of high magnitude, would result in a rise in the number of attributable deaths brought forward of 5-9%, relative to exposures at the estimated background level.

2.9 NH_3

Inhalation of high levels of NH_3 causes irritation to the nose, throat and respiratory tract. Increased inhalation may result in1 cough and an increased respiratory rate as well as respiratory distress. An association has been reported between exposure to ammonia and cough, phlegm, wheezing, and asthma at high concentration.

2.10 Pb

Pb is a toxic metal and its exposure through all routes results in increased blood lead level. At lower concentrations, the blood lead level is proportional to air concentration (after accounting for all resulting exposure routes). For example, 1 µg/m^3 of annual lead level will result in 5 µg/dL (on an average) of blood lead level (WHO 2000). The effect of blood level above 10 µg/dL is seen in hematological changes in sensitive population.

2.11 EFFECTS OF AIR POLLUTION ON PLANTS

The ill effect of air pollutants listed above on plants are showed in Table 2.2

Table 2.2 : Ill Effects Of Air Pollutants On Plants (Rao & Rao : 2005)

Sl. No.	Pollutants	Dose	Effects
1	Sulphur dioxide	Mild	Interveinal chlorotic bleaching of leaves
		Severe	Necrosis
2	Ozone	Mild	Flecks on upper surface, premature aging
		Severe	Collapse of leaf, necrosis and bleaching
3	Fluoride	Cumulative effect	Necrosis at leaf tip
4	Nitrogen dioxide	Mild	Suppressed growth, bleaching of leaves
5	Ethylene	Mild	Epinasty, leaf abscission
6	PAN	Mild	Bronzing of lower leaf surfaces, suppressed growth, and young leaves more susceptible.

2.12 URBAN AIR QUALITY STATUS: INTERNATIONAL SCENARIO

Urban air quality in mega-cities is causing concern throughout the world. In 1950, New York and London were the only mega-cities. That number grew to 4 by 1975 and to 20 by 2000. Nearly 48% of the world population lived in urban areas in 2003. Currently, there are more than 100 metropolitan areas with official population exceeding 3 million (United Nations, 2004).

Goyal et al. (2007) reviewed air quality status of 20 mega-cities of the world, wherein data were available for 15 cities. SPM levels were found to be high in Delhi, Jakarta and Cario. SO_2 levels were found to be high in Mexico, Shanghai, Rio-de Janerio, Beijing, Cario. NO_2 levels were found to be high in most of the cities, except Delhi, Kolkata, there also NO_2 levels exceeded in subsequent years.

Schwela et al. (2003) analyzed the ambient air quality status of 15 major cities in Asia using the data base for the period 1990-1999. Particulate matter (SPM and PM_{10}) was found carbon monoxide and hydrocarbon pollution in India [Anjaneyulu : 2002]. Diesel powered vehicles create relatively minor pollution problems compared to gasoline powered ones. Urbanisation has a strong bearing on the travel demands in the metropolitan cities throughout the world; the situation in India is not different. The transportation in India is usually long distance between homes and places of work, greater incentives for private transport, and inadequate and poor quality public transport have further aggravated the problem. In India the ambient atmospheric conditions have progressively deteriorated due to urbanization, industrial development, lack of awareness, poor maintenance of motor vehicles and poor road conditions.

As far as Indian air pollution scenario is concerned, most of the 23 Indian cities with million populations have been reported to have air pollution levels exceeding the world health organisation (WHO) recommended standards. In almost every city, the pollutant concentration levels are progressively getting from bad to worse because of the growing number of vehicles and with increasing energy consumption. According to WHO report 1994, the Indian capital, Delhi is the fourth most polluted city in the world .The situations in other Indian cities are also worsening with every passing day. According to the data available in the transport department, Bangalore has become more congested and the number of vehicles on the roads has increased tremendously from about 30 lakhs to 35 lakhs as observed in the year 2008-2010.

Air pollution may be described as "imbalance in quality of air so as to cause adverse effects on living organisms exists on earth. It is said that clean dry air contains about 78.09% of nitrogen and 20.94% of oxygen by volume. The remaining 0.97% is composed of a gaseous mixture of several organic and inorganic elements and compounds. As air is obviously the first & foremost susceptible component of our environment. If air becomes toxic, the only alternative to sustain life is to wear some sort of life supporting system, which is unworkable and economically infeasible. Therefore, air quality management system is required to assess the ambient air quality [Agarwal : 2002].

2.13 DEFINITION OF AIR QUALITY INDEX

An air quality index is defined as an overall scheme that transforms the weighed values of individual air pollution related parameters (for example, pollutant concentrations) into a single number or set of numbers (Ott, 1978). The result is a set of rules (i.e. set of equations) that translate parameter values into a more simple form by means of numerical manipulation (Fig. 2.1).

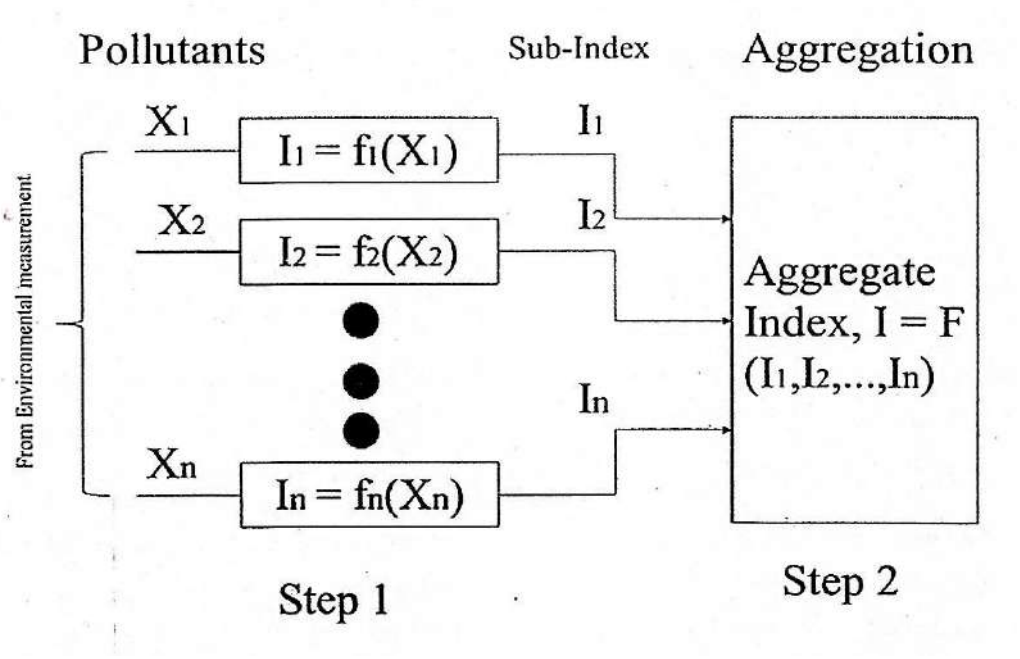


Fig. 2.1 Formation of an Aggregated AQI

If actual concentrations are reported in $\mu g/m^3$ or ppm (parts per million) along with standards, then it cannot be considered as an index. At the very last step, an index in any system is to group specific concentration ranges into air quality descriptor categories.

2.14 APPLICATIONS OF AIR QUALITY INDEX

Ott (1978) has listed the following six objectives that are served by an AQI:

1. **Resource Allocation:** To assist administrators in allocating funds and determining priorities. Enable evaluation of trade-offs involved in alternative air pollution control strategies.

2. **Ranking of Locations:** To assist in comparing air quality conditions at different locations/cities. Thus, pointing out areas and frequencies of potential hazards.
3. **Enforcement of Standards:** To determine extent to which the legislative standards and existing criteria are being adhered. Also helps in identifying faulty standards and inadequate monitoring programs.
4. **Trend Analysis:** To determine change in air quality (degradation or improvement) which have occurred over a specified period. This enables forecasting of air quality (i.e., tracking the behaviour of pollutants in air) and plan pollution control measures.
5. **Public Information:** To inform the public about environmental conditions (state of environment). It's useful for people who suffer from illness aggravated or caused by air pollution. Thus it enables them to modify their daily activities at times when they are informed of high pollution levels.
6. **Scientific Research:** As a means for reducing a large set of data to a comprehendible form that gives better insight to the researcher while conducting a study of some environmental phenomena. This enables more objective determination of the contribution of individual pollutants and sources to overall air quality. Such tools become more useful when used in conjunction with other sources such as local emission surveys.

Briefly, an AQI is useful for: (i) general public to know air quality in a simplified way, (ii) a politician to invoke quick actions, (iii) a decision maker to know the trend of events and to chalk out corrective pollution control strategies, (iv) a government official to study the impact of regulatory actions, and (v) a scientist who engages in scientific research using air quality data.

2.15 DESIGN CRITERIA FOR AN IDEAL AIR QUALITY INDEX

The basic objective of any air quality index is to transform the measured concentrations of individual air pollutant into a single numerical index using suitable aggregation mechanism. Ideally, every index should reflect both the measured and publicly perceived quality of the ambient air for the time period it covers. As a result, air quality indices attempt to standardize and synthesize air pollution information and permit comparisons to be readily undertaken, and to satisfy public demands for

accurate, easy to interpret data. In design of air quality indices, the following criteria should be used:

1. be readily understandable by the public;
2. include the major criteria pollutants and their synergism;
3. be expandable for other pollutants and averaging times;
4. be related to National Ambient Air Quality standards used in individual provinces;
5. avoid "eclipsing" (eclipsing occurs when an air pollution index does not indicate poor air quality despite the fact that concentrations of one or more air pollutants may have reached unacceptably high values);
6. avoid "ambiguity" (ambiguity occurs when an air pollution index gives falls alarm despite the fact that concentrations of all the pollutants are within the permissible limit except one);
7. be usable as an alert system;
8. be based on valid air quality data obtained from monitoring stations that are situated so as to represent the general air quality in the community:

2.16 STRUCTURE OF AN INDEX

Primarily two steps are involved in formulating an AQ1: (i) formation of sub-indices (for each pollutant) and (ii) aggregation of sub-indices to get an overall AQI.

Formation of sub-indices (I_1, I_2,...., I_n) for n pollutant variables (X_1, X_2...., X_n) is carried out using sub-index functions that are based on air quality standards and health effects. Mathematically;

[l] $I_1 = f(X_i)$, i=l,2,...,n

Each sub-index represents a relationship between pollutant concentrations and health effects. The functional relationship between sub-index value (I_i) and pollutant concentrations (X_i) is explained later in the text.

Aggregation of sub-indices, I, is carried out with some mathematical function (described below) to obtain the overall index (I), referred to as AQI.

[2] $I=F(I_1,I_2,....,I_n)$

The aggregation function usually is a summation or multiplication operation or simply a maximum operator.

Sub-indices (Step 1)

Sub-index function represents the relationship between pollutant concentration X_i and corresponding sub-index I_i. It is an attempt to reflect environmental consequences as the concentration of specific pollutant changes. It may take a variety of forms such as linear, non-linear and segmented linear. Typically, the I-X relationship is represented as follows:

[3] $I = \alpha X + \beta$

Where, α =slope of the line, β = intercept at X=0.

The general equation for the sub-index (I_i) for a given pollutant concentration (C_p); as based on 'linear segmented principle' is calculated as:

[4] $I,=[\{(I_{HI}-I_{LO})/(B_{HI}-B_{LO})\} *(C_P-B_{LO})]+ I_{LO}$

where,

B_{HI} = Breakpoint concentration greater or equal to given concentration.
B_{LO} = Breakpoint concentration smaller or equal to given concentration.
I_{HI}=AQI value corresponding to B_{HI}
I_{LO} = AQI value corresponding to B_{LO}
C_p = Pollutant concentration

For example, we take PM_{10} with concentration of 85µg/m^3, B_{HI}, B_{LO}, I_{HI}, I_{LO} values from Greater Vancouver AQI (Table 2.4) and using equation [4]

Sub Index (I_p) = {(100 - 50)/(l 00 - 50)}* (85- 50) + 50

= 85

Similarly, Sub Index can be calculated for other pollutants as well.

Aggregation of Sub-indices (Step 2)

Once the sub-indices are formed, they are combined or aggregated in a simple additive form or weighted additive form:

Weigh ted Additive Form

[5] I = Aggregated Index = $\Sigma w_i I_i$ (For i= 1,…..,n)

where,

$\Sigma w_i I_i$

I_i = sub-index for pollutant i

n = number of pollutant variables

w_i= weightage of the pollutant

2.17 CURRENT STATUS OF AQI APPLICATION IN INDIA

There have not been significant efforts to develop and use AQI in India, primarily due to the fact that the National Air Quality Monitoring Programme has started only in 1984. Although NEERI, Nagpur started monitoring programme in 10 cities in 1978 and Bombay Municipal Corporation even before 1978, attempts were not made to use AQI for data interpretation and public.

2.18 NATIONAL AIR QUALITY INDEX FOR 24 CITIES AT 70 LOCATIONS OF INDIA

2.18.1 National Network

At present, continuous air quality monitoring stations from 23 cities are connected to the web-based system. Efforts are being made to connect more cities, where continuous monitoring systems are operated by various State Pollution Control Boards (SPCBs). It is planned to strengthen the network of monitoring systems in all 46 cities having population more than a million and 20 State Capitals, and networking them to the central AQI portal, in phased manner. With regard to manual stations in the million plus cities (46 cities), SPCBs have been advised to use AQI calculator and publicize it with minimum time lag, as required for laboratory analysis. Central Pollution Control Board has initiated ***National Air Quality Monitoring Programme (NAMP; manual monitoring system)*** in the year 1984. Under NAMP, three air

pollutants viz.. Sulphur Dioxide (S02), Nitrogen Dioxide (N02) and Particulate Matter size equal to or less than 10 micron (PM_{10}), have been identified for regular monitoring at all the locations. The NAMP network presently comprises 621 operating monitoring stations located in 262 cities/towns in 29 states and 5 union territories across the country. National AQI bulletin was calculated for the month of May 2016 for 7 states covering 24 cities at 70 locations / ambient air quality monitoring stations with 604 AQI values. The status of the cities with respect to AQI during May 2016 is summarized below.

2.18.2 Overall AQI Category-wise Observation

Of the total cities covered (24 cities), 14% of AQI value i.e. 82 AQI values in the country out of total 604 AQI values revealed good air quality and 39 % of AQI value i.e. 235 AQI values in the country showed satisfactory air quality where the predominant pollutant during those days was PM_{10} and $PM_{2.5}$. Further, the data showed that 39 % of AQI value i.e. 234 AQI values in the country out of total 604 AQI values showed moderate air quality where the predominant pollutant during those days was PMIO and 7% of AQI value i.e. 44 AQI values in the country out of total 604 AQI values showed poor air quality where the predominant pollutant during those days was PM_{10}. Of the total cities covered (24 cities), I % of AQI value i.e. 9 AQI values in the country of total 604 AQI values showed very poor air quality where the predominant pollutant during those days was PM_{10}.

2.18.3 Overall Summary of Possible Health Impacts

The analysis of AQI values precisely indicating that 317 AQI values are falling in first two categories (good and satisfactory) of national AQI. A total of 53% of AQI values fall in good and satisfactory categories which indicates that the people in these areas suffer either minimal impact of the concentration of the pollutants or minor breathing discomfort for the sensitive people. The analysis of AQI values further expressing that 278 AQI values are falling in second two categories (moderate and poor) of national AQI. A total of 46% of AQI values fall in moderate and poor categories which indicates that the people in these areas may suffer from breathing discomfort to the people with lungs, asthma and heart diseases or to most people on prolonged exposure. The analysis of AQI values indicating that 9 AQI values are falling in third two categories (very poor and severe) of national AQI. A total of 1%

of AQI values fall in very poor and severe categories which indicates that the people in these areas may suffer from respiratory illness on prolonged exposure Affects healthy people and seriously impacts those with existing diseases. It is pertinent to mention that impact of pollutants or air quality depends on the changes in lower atmospheric stability of the area and daily calculated index/sub-index of various pollutants along with period of exposure of pollutants to human being and the immunity status of the individuals.

2.19 REVIEW OF AIR QUALITY INDICES (AQI)

The large databases often do not convey the air quality status to the scientific community, government officials, policy makers, and in particular to the general public in a simple and straightforward manner. This problem is addressed by determining the Air Quality Index (AQI) of a given area. AQI, which is also known as Air Pollution Index (API) or Pollutant Standards Index (PSI), was developed by various environmental agencies/researchers for different country/regions. Though, there is a widespread use of air pollution (quality) index systems but currently no internationally accepted methodology for constructing such a system are available. Here under the section, an attempt has been done to demonstrate the critical review on different AQI systems.

In 1976, the U.S. EPA established a Pollutant Standards Index (PSI) which rated air quality. They suggested the formula for aggregating pollutants to deter-mine PSI. The index ranged from 0-500, with 100 equal to the National Ambient Air Quality Standards (NAAQS). The PSI is calculated for every pollutant with a NAAQS, but the only level reported for a given time and location is for the pollutant most exceeding its standard. The daily PSI is determined by the highest value of one of the five main air pollutants: particulate material (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2). The PSI does not indicate exposure to many other pollutants, some of which may be dangerous for people with respiratory problems. The PSI was revised, renamed to the Air Quality Index (AQI), and subsequently implemented in 1999 by the U.S. EPA.

2.19.1 AQI system of U.S. EPA

U.S. EPA's AQI is defined with respect to the five main common pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$) and sulphur dioxide (SO_2). The individual pollutant index as in the eqn. (1) is calculated first by using the following linear interpolation equation, pollutant concentration data and reference concentration. The breakpoint concentrations have been defined by the EPA on the basis of National Ambient Air Quality Standards (NAAQS) as shown in Table 1, and on the results of epidemiological studies which refer to the effect of single pollutants on human health.

$$I_p = \frac{(I_{HI} - I_{LO})}{BP_{HI} - BP_{LO}} (C_P - BP_{LO}) + I_{LO} \quad (1)$$

where

I_P=Index for pollutant P

C_P= Rounded concentration of pollutant P

BP_{HI}= Break point that is greater than or equal to C_P

BP_{LO}=Breakpoint that is less than or equal to C_P

I_{HI}=AQI value corresponding to BPHI ILO=AQI value corresponding to BPLO

The highest individual pollutant index, I_P, represents the Air Quality Index (AQI) of the location.

The above method does not have the flexibility to incorporate any number of air pollutants. The method also not considers the pollutant aggregation and spatial aggregation. It can be used for determining the short term and long term air quality indices.

Cheng et al. (2004) proposed a revised EPA air qual-ity index (RAQI) by introducing an entropy function to include effect of the concentrations of the rest of pollutants other than the pollutant with maximum AQI. The revised Air Quality Index (RAQI) can be determined by eqn. (2) as given below:

$$RAQI = Max\,(I_1, I_2 \ldots I_n) \times \frac{Avg_{daily} \sum_{j=1}^{n} I_j}{Avg_{annual}\,[Avg_{daily} \sum_{j=1}^{n} I_j]} \times \frac{Avg_{annual}\{Entropy_{daily} * Max[I_1, I_2, \ldots I_n]\}}{Entropy_{daily} * Max[I_1, I_2, \ldots I_n]} \quad (2)$$

The second term on RHS establishes the background arithmetic mean index in which the numerator is the sum of the daily arithmetic averages of all sub-indexes ($I_1 \ldots I_n$), and the denominator is the yearly average of the sum of daily average for these pollutants.

The third term in RHS represents the background arithmetic mean entropy index in which the numerator is the yearly average of the average daily entropy, and the denominator is the entropy function of the sub-index pollutants.

The RAQI method facilitates for aggregation of pollutants sub-indices and also health based study but failed to measure uncertainty and spatial aggregation.

Table 2.3 : Breakpoint Concentration of Air Pollutants Defined by U.S. EPA [Kanchan et al: 2015]

Breakpoints							AQI	Category
O_3 (ppm) 8-hour	O_3 (ppm) 8-hour[1]	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)		
0-0.064	–	0-54	0-15.4	0-4.4	0-0.034	([2])	0-50	Good
0.065-0.084	–	55-154	15.5-40.4	4.5-9.4	0.035-0.144	([2])	51-100	Moderate
0.085-0.104	0.125-0.164	155-254	40.5-65.4	9.5-12.4	0.145-0.224	([2])	101-150	Unhealthy for sensitive groups
0.105-0.124	0.165-204	255-354	65.5-150.4	12.5-15.4	0.225-0.304	([2])	151-200	Unhealthy
0.125-0.374 (0.155-0.404)[4]	0.205-0.404	355-424	150.5-250.4	15.5-30.4	0.305-0.604	0.65-1.24	201-300	Very unhealthy
([3])	0.405-504	425-504	250.5-350.4	30.5-40.4	0.605-0.804	1.25-1.64	301-400	Hazardous
([3])	0.505-0.604	505-604	350.5-500.4	40.5-50.4	0.805-1.004	1.65-2.04	401-500	Hazardous

[1]Areas are required to report the AQI based on 8 hour ozone values. However, there are areas where an AQI based on 1-hour ozone values would be more protective. In these cases the index for both the 8-hour and the 1-hour ozone values may be calculated and the maximum AQI reported.
[2]NO_2 has no short term NAAQS and can generate an AQI only above a value of 200.
[3]8-hour O_3 values do not define higher AQI values ($\geq$301). AQI values of 301 or higher are calculated with 1-hour O_3 concentration.
[4]The numbers in parentheses are associated 1 hour values to be used in this overlapping category only.

2.19.2 Common Air Quality Index (CAQI)

The CAQI was developed by the Citeair project in 2008, which was co-funded by the INTERREG IIIC and INTERREG IVC programs in Europe. To present the air quality situation in European cities in a comparable and understandable way, all detailed measurements are transformed into a single relative figure called the Common Air Quality Index (CAQI). An important feature of this index system is that it differentiates between traffic and city background conditions. The Common Air Quality Index (CAQI) is designed to pre-sent and compare air quality in near-real time on an hourly or daily basis. It has 5 levels, using a scale from 0 (very low) to >100 (very high) and the matching colours range from light green to dark red. The CAQI is computed according to the grid system (shown in Table 2.4) by linear interpolation between the class borders. The final index is the highest value of the sub-indices for each component (pollutant); nevertheless, the choice of the classes for the CAQI is inspired by the EC legislation. The CAQI do not take into account the adverse effects due to the coexistence of all the pollutants.

The above method can be applied to make comparative study of urban air quality in real time without facilitating or considering the spatial aggregation, pollutant aggregation, uncertainty measures and health effects.

Table 2.4 : Pollutants and Calculation Grid for the CAQI [Kanchan et al : 2015]

Index class	Grid	Traffic				City background					
		Mandatory pollutant			Auxiliary pollutant	Mandatory pollutant			Auxiliary pollutant		
		NO_2	PM_{10}		CO	NO_2	PM_{10}		O_3	CO	SO_2
			1-hr	24-hrs			1-hr	24-hrs			
Very low	0 25	0 50	0 25	0 12	0 5000	0 50	0 25	0 12	0 60	0 5000	0 50
Low	26 50	51 100	26 50	13 25	5001 7500	51 100	26 50	13 25	61 120	5001 7500	51 100
Medium	51 75	101 200	51 90	26 50	7501 10000	101 200	51 90	26 50	121 180	7501 10000	101 300
High	76 100	201 400	91 180	51 100	10001 20000	201 400	91 180	51 100	181 240	10001 20000	301 500
Very high	>100	>400	>180	>100	>20000	>400	>180	>100	>240	>20000	>500

NO_2, O_3, SO_2: hourly value/maximum hourly value in $\mu g/m^3$
CO: 8 hours moving average maximum 8 hours moving average in $\mu g/m^3$
PM_{10}: hourly value/daily value in $\mu g/m^3$

2.19.3 Oak Ridge Air Quality Index (ORAQI)

The Oak Ridge Air Quality Index (ORAQI) method was developed by Oak Ridge National Laboratory. The Oak Ridge Air Quality Index is defined for any number of pollutants. Thom and Ott (1975) suggested the use of Oak Ridge Air Quality Index (ORAQI). The ORAQI is given by eqn. (3)

$$ORAQI = \left(a \sum \frac{C_i}{C_s}\right)^b \quad (3)$$

where,

C_i = Monitored/Predicted concentration of pollutant 'i'

C_s = National ambient air quality standard (NAAQS) for pollutant 'i'

a & b=constant for specific number of pollutants

The above method can be applied to assess the air quality in urban area without facilitating or considering the spatial aggregation, and uncertainty measures but considers pollutant aggregation and health effects.

2.19.4 New Air Quality Index (NAQI)

New Air Quality Index is based on Factor Analysis of the major pollutants. The index is proposed by Bishoi et al. in 2009. The method is based on principal component factors which causes the variation of AQI. The concentration of each pollutant or there deviation from the mean or their standardized values are expressed as a linear combination of these factors. The factors contribute to about 60% of the variation of AQI are considered and the rest can be neglected (Dunteman, 1994; Johnston, 1978; Harman, 1968). Also, the first factor will cause the highest variance of AQI. The second will contribute less variance than first but more than the third factor and so on. These factors are also called the principal components or eigen vector pairs.

The New Air Quality Index (NAQI) is given by the equation as below in the eqn. (4)

$$NAQI = \{\sum_{i=1}^{n}(P_i E_i) / \sum_{i=1}^{n} E_i\} \quad (4)$$

where n=3, P_1, P_2, P_3 are the three Principal Components for which the cumulative variance is more than 60%. E_1, E_2 and E_3 are the initial eigen values (≥1) with respect to the percentage variance.

The principal components were given by Lohani (1984) in the eqn. (5)

$$P_i = \sum_{j=1}^{n} \frac{a_{ji} X_j}{\lambda_i} \quad (5)$$

where λ_i is the Eigen value associated with P_i

x_j is the concentration of i^{th} pollutant and can be determined as:

$$X_j = \sum_{1}^{n} a_{ji} P_i$$

The method can be applied to assess the relative air quality without facilitating or considering the spatial aggregation, health effects and uncertainty measures but considers pollutant aggregation.

2.19.5 Pollution Index (PI)

Pollution index (PI) was developed and applied by Cannistraro, et al. in 2009 for reporting air quality status in the city of Naples, Italy. The pollution index method is based on a simple indicator of the air quality in an urban context that is useful for communicating to citizens' information about the state of air quality of a waste urban area. The calculation of the PI is based on the weighted mean value of the sub-indexes of the most critical pollutants. Additive effects of air pollutants have also been considered and the PI re-evaluated. It is expressed by a numerical index ranging from 1 to 7. A highest value of the index represents a highest value of environmental pollution, and, of course a highest health risk. This index of air quality has been

developed by means of a series of critical pollutants in the Italian urban contexts and correlated with pollution level and health risk and level of satisfaction of the people. PI can be calculated with the arithmetic averages of sub-indices of two most critical pollutants. This is given by eqn. (6) as given below:

$$I = \frac{(I_1 + I_2)}{2} \tag{6}$$

The two sub-indices (I_1 and I_2) are calculated for the two most critical pollutants having the highest concentrations. The sub-indices of each pollutant can be determined by eqn. (7) as given below:

$$I_x = \frac{V_{max\,hx}}{V_{rif}} * 100 \tag{7}$$

where, I_x is the sub-index of x^{th} pollutant

$V_{max\ hx}$ is the maximum 1 hour mean value of the x^{th} pollutant in a day in all the monitoring stations of the area.

V_{rif} is maximum 1 hour limit value of the x^{th} pollutant for protection of human health.

The Pollution index classification, quality indicator, and its health risks are represented in Table 2.5.

The method considers the pollutant aggregation and health effects to determine the air quality index but not considers spatial aggregation and uncertainty issues.

Table 2.5 : Values, Index and Health Risks for PI [Kanchan et al: 2015]

Numeric value	Quality indicator	Numeric index	Health risks
0-50	Optimum	1	No risks for people
51-75	Good	2	No risks for people
76-100	Moderate	3	No risks for people
101-125	Mediocre	4	Generally there aren't risks for people. People with asthma, chronic bronchitis, croniche o cardiopathy may feel light respiratory symptoms only during an intense physical activity
126-150	Not much healthy	5	There risks for people with heart diseases, olds and children
151-175	Unhealthy	6	Many people may feel light adverse symptoms, however reversible. Weak people may feel gravest symptoms.
>175	Very unhealthy	7	People may feel light adverse effects for health. There are more risks for olds, children and people with respiratory diseases.

2.19.6 Air Quality Depreciation Index (AQDI)

AQDI was used by Singh in 2006 to measure the depreciation in air quality using the value function curves for individual pollutants. The method considers the pollutant aggregation to determine the depreciation in air quality with respect to standard air quality. The air quality depreciation is measured in a scale between 0 to -10. An index value of '0' represents most desirable air quality having no depreciation from the best possible air quality with respect to the pollutants under consideration, while an index value of -10 represents maximum depreciation or worst air quality. The shifting of Index value from 0 towards -10 represents successive depreciation in air quality from the most desirable. The AQDI is given as follows in the eqn. (8)

$$AQ_{dep} = \{\sum_{i=1}^{n}(AQ_i * CW_i)\} - \{\sum_{i=1}^{n} CW_i\} \quad (8)$$

where,

AQ_i =Air Quality Index for the i^{th} parameter and obtained from value function curve defined by Jain et al. in 1977. In the value function curve 0 represent the worst quality and 1 represent the best quality of air due to pollutant under consideration.

CW_i is composite weight for i^{th} parameter.

n is the total no of pollutants considered.

Composite weight (CW_i) in eqn. (8) can be calculated using the following eqn. (9).

$$CW_i = \left\{ \frac{TW_i}{\sum_{i=1}^{n} TW_i} \right\} * 10 \qquad (9)$$

where,

TW_i = total weight of the i^{th} parameter =AW_i |+ $BPIW_i$ +HW_i

AW_i = aesthetic weight of i^{th} parameter

$BPIW_i$ = bio-physical impact weight of i^{th} parameter

HW_i = health weight of i^{th} parameter

TW_i is computed by assigning weights between 1 to 5 to AW_i, $BPIW_i$, and HW_i by a team of assessors or experts. 1 is the least and 5 is the highest weight.

2.19.7 Integral Air Pollution Index (IAPI)

Integral air pollution index (IAPI) for Russian cities that is simply a sum of the pre-selected number of the highest individual pollutant indices calculated by normalising the pollution concentrations to maximum permissible concentration (MPC) has been suggested. Russian health experts had established maximum permissible concentrations (MPC) for more than 400 pollutants. To understand the degree of air pollution, the measured value of concentration pollutants are compared with either short-term MPC or mean value of long-term MPCs.

The sub-indices of IAPI can be determined using eqn. (10) as shown below:

$$I_{1i} = \frac{X_i}{MPC_i} \tag{10}$$

where, x_i is the concentration of i^{th} pollutant,

I_i is the sub-index of i^{th} pollutant,

c_i is the degree of exponent, and

MPC_i is the maximum permissible concentration of i^{th} pollutant

The degree of air pollution with any pollutant can be expressed through comparison with the degree of air pollution with sulphur dioxide using the degree exponent c_i as shown in eqn. (11):

$$I_{2i} = \left(\frac{x_i}{MPC_i}\right)^{C_i} \tag{11}$$

The reason behind sulphur dioxide was used as a basis is that this pollutant is monitor in all cities. IAPI can be determined by the arithmetic sum of all the sub-indices corresponding to each air pollutants considered for air quality assessment.

2.19.8 Aggregate Air Quality Index (AQI)

An aggregate AQI, the index is based on the combined effects of five criteria pollutants (CO, SO_2, NO_2, O_3, and PM_{10}) taking into account the European standards was proposed. This method was used for air quality evaluation for each monitoring station situated in whole area of Athens, Greece. The indexing system is based on the AQI sys-tem developed by Swamee and Tyagi in 1999. An aggregate AQI can be determined by eqn. (13) shown below:

$$I = [\sum_{i=1}^{n} (AQI_i)^p]^{\frac{1}{p}} \tag{13}$$

where, I is the aggregate AQI,

AQI_i = the sub-index for i^{th} pollutant, and

p=a constant.

According to eqn. (13), when p =∞ the index I is equal to the max AQI of a single pollutant, regardless of the rest of the pollutants' AQI value. This kind of calculation corresponds to the way that EPA calculates the overall AQI; however, it underestimates the air pollution levels. When p is equal to 1, at the other extreme, the overall index (I) is equal to the sum of all AQI indices. The selection of the most proper value for p is still an open support this statement.

The sub-indices are expressed as functions of the ratio of pollutant concentration q to standard concentration qs, shown in eqn. (14):

$$AQI_i = AQIs\left(\frac{q}{q_s}\right) \tag{14}$$

where, AQI_i =Sub-index of i^{th} pollutant, and

AQIs= a scaling coefficient equal to 500.

2.19.9 The Aggregate Risk Index (ARI)

The aggregate risk index for assessing the health impact due to air pollution in the South East of France was designed. The ARI is a measure of the mortality risk associated with simultaneous exposure to the common air pollutants and provides a ready method of comparing the relative contribution of each pollutant to total risk. An arbitrary index scale (1-10), with a colour coding system, was used to facilitate risk communication. The ARI is based on the exposure-response relationship and Relative Risk (RR) of the well-established increased daily mortality, enabling an assessment of additive effects of short-term exposure to the major air pollutants. This study presents the modified formula of AQI based on Cairncross's concept (Cairncross et al., 2007).

The total attributable risk for simultaneous short-term exposure to several air pollutants is given by the eqn. (15):

$$ARI = \sum_i (RR_i - 1) = \sum Index_i = \sum a_i * c_i \tag{15}$$

To account for the reality of the multiple exposures impacts of chemical agents, the final index is the sum of the normalised values of the individual RR_i values. It thus provides a ready method of comparing the relative contribution of each pollutant to total risk. The index is defined to reflect the contribution of individual

pollutants to total risk. C_i is the corresponding time-averaged concentrations (in mg/m^3) and the coefficient "ai" is proportional to the incremental risk values (RR_i -1). This index uses exposure-response relative risk functions and a particular set of RR_i values for a given health endpoint associated with increasing major air pollutants. These functions and values were published by the WHO (2008, 2004, 2001), APHEA (Air Pollution and Health- a European Approach)-2, (2006) and InVS (PSAS-9 project, French air pollution and health surveillance program, 2008, 2006, 2002) under a procedure for health impact assessment.

From the published RR_i values for i^{th} pollutant, the coefficients for the terms ai can be determined using eqn. (16) in order to derive a numerical scale specific to each of the pollutants.

$$a_i = \frac{a_{PM10} * (RR_i - 1)}{(RR_{PM10} - 1)} \tag{16}$$

The breakpoint values between different levels considered correspond to the air quality standards defined by the WHO (2005). The air quality classes and the relevant RR values are determined in terms of the PM_{10} concentration (significant RR_i values). The breakpoint concentrations for the remaining pollutants are calculated proportionally to the individual levels of the relative risk.

2.19.10 AQI Based on PCA-Neural Network Model

Kumar and Goyal (2013) designed forecasting sys-tem for daily AQI using a coupled artificial neural net-work (ANN) - Principal component analysis (PCA) model. The architecture of the system is shown in Fig.2.6. It was designed for forecasting AQI in one day advance using the previous day's AQI and meteorological variables.

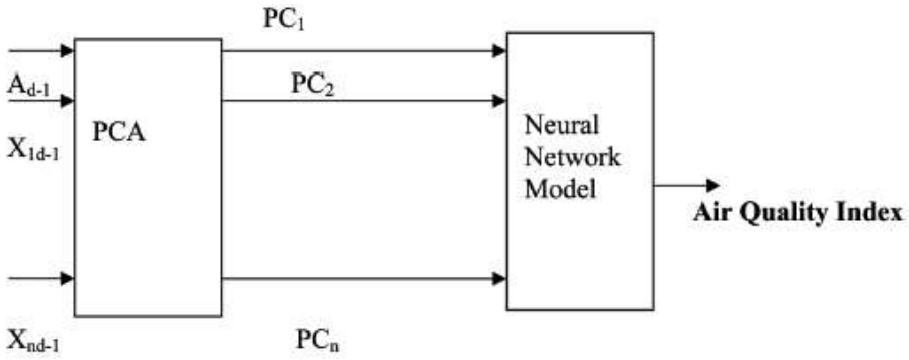


Fig. 2.2 Architecture of PCA-Neural Network Model for the Forecasting of AQI [Kanchan et al: 2015]

There are two steps involved in determining the AQI. The first step is the formation of sub-indices for each pollutant and the second one is the aggregation of sub indices. The sub-indices were calculated using the same formula as that of U.S. EPA but the breakpoint concentration of each pollutant is based on the Indian NAAQS and epidemiological studies, which are indicating the risk of adverse health effects of specific pollutants.

The AQI value was calculated for each individual pollutant (SO_2, NO_2, RSPM, and SPM) and highest among them was declared as the AQI of the day. The previous day's AQI value was used as one of the input parameters in the PCA-ANN model for forecasting the AQI value of subsequent day.

2.19.11 Fuzzy Air Quality Index

A method for prediction of AQI on the basis of fuzzy aggregation was developed. The out-put AQI value using fuzzy aggregation method was compared to that of the output from conventional method. It was demonstrated that computing with linguistic terms using fuzzy inference system improves tolerance for impression data.

The relationship between air pollutants and output parameter (FAQI) is mathematically expressed as given in the eqn. (17)

$$FAQI=f\,(SPM, RPM, SO_2, NO_X) \qquad (17)$$

Gorai et al. (2014) developed a fuzzy pattern recognition model for AQI determination. The method was used for air quality assessment of Agra city. This method considered five air pollutants (PM_{10}, CO, SO_2, NO_2, and O_3) for AQI

determination. The method also con-siders weights of the individual pollutants on the basis of its degree of health impacts during aggregation. Analytical hierarchical process (AHP) was used for determination of weights of various pollutants. The air quality index is ranged from 1 to 6. The higher is the value of AQI, higher is the health risk and vice versa. Authors suggested that depending upon the risk level, air quality mangers can take preventive measures for reducing the level of index. Though, the formula or method used for determination AQI is relatively complex in comparison to that of the arithmetic aggregation method but this can be easily programmed for determination of AQI.

2.19.12 Air Quality Health Index

A new Air Quality health index (AQHI) was developed in Canada to understand the state of local air quality with respect of public health. AQHI is available for about ten communities in Canada, including Vancouver and Victoria.

The AQHI is constructed as the sum of excess mortality risk associated with NO_2, ground-level O_3, and $PM_{2.5}$ at certain concentrations. It is calculated hourly based on 3-hour rolling average pollutant concentrations, and is then adjusted to a scale of 1 to 10. The value of 10 corresponds to the highest observed weighted average in an initial data set covering a reference period from 1998 to 2000 (Stieb et al., 2008; Taylor, 2008).

The scientific basis for the formulation of AQHI is based on the epidemiological research undertaken at Health Canada. Relative risk (RR) values are estimated, based on the local time series analyses of air pollution and mortality (Stieb et al., 2008; Taylor, 2008). Air Quality Health Index is determined by the eqn. (18) as shown below:

$$AQHI = \frac{10}{c} \sum_{i=1 \cdots p} 100(e^{\beta_i X_i} - 1) \tag{18}$$

where, βi is the regression coefficient from same Poisson model linking the i^{th} air pollutant with mortality, x_i is the concentration of the i^{th} pollutant, and c is the scaling factor.

2.19.13 Air Pollution Indexing System in South Africa

An air pollution index was developed in a dynamic air pollution prediction system (DAPPS) project, which was led by a consortium of four South African partners, including the Cape Peninsula University of Technology (Cairncross et al., 2007). The API system is based on the relative risk of the well-established excess daily mortality associated with short-term exposure to common air pollutants, including PM_{10}, $PM_{2.5}$, SO_2, O_3, NO_2, and CO. A scale of 0 to 10 was used for the assessment of air quality. Incremental risk values for each pollutant are assumed to be constant, and a continuous exposure metrics, the exposures that correspond to the same relative risk are assigned the same sub-index value. The final API is the sum of the normalized values of the individual indices for all pollutants is given by the eqn.(19)

$$API = \sum PSI_i = \sum a \cdot C \tag{19}$$

where, C is the time averaged concentration of pollutant, and a is a coefficient directly proportional to the incremental risk value associated with the pollutant.

The proposed API was applied to ambient concentration data collected at monitoring stations in the City of Cape Town for testing.

2.19.14 Air Pollution Indexing System in China

China's state pollution control board is responsible for measuring the air pollution in the cities. The air pollution index (API) in China is based on the five atmospheric pollutants sulfur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulates (PM_{10}), carbon monoxide (CO), and ozone (O_3) measured in the monitoring stations. Chinese API system follow the same method for calculating the air quality index but the health definition corresponding to each AQI classes are different.

A simple air quality index (AQI) was developed for the Helsinki Metropolitan Area in order to inform the public about the air quality status for better understanding. The pollutants consider in the AQI system are CO (1 hr. and 8 hrs.), NO_2 (1 hr. and 24 hrs.), SO_2 (1 hr. and 24 hrs.), O_3 (1 hr.) and PM_{10} (24 hrs.). The AQI is based on acute health effects, but long term effects on nature and materials are also taken into

consideration. Sub-indices are calculated hourly for all pollutants and for a given hour the highest sub-index becomes the AQI.

2.19.15 Root-Sum-Power Form (non-linear aggregation form)

[6] I = Aggregated Index = $[\sum I_i^p]^{(1/p)}$

where, p is the positive real number >1.

As the index did not include any other pollutants besides SO_2 and COH, it had limited application. It is also subjected to eclipsing and ambiguity phenomena (arithmetic mean weighted as linear sum). This index was intended more as a system for triggering control actions during air pollution episodes than a means for reporting air quality data to the public.

2.19.16 Fenstock Air Quality Index (AQI)

An index has been proposed to assess the relative severity of air pollution and applied it to assess AQI of 29 US cities. This was the first index to estimate air pollutant concentrations from the data on source emissions and meteorological conditions in each city:

$$AQI = W_i I_i$$

where, W_i =weightages for CO, TSP and SO_2

l_i = estimated sub-indices for CO, TSP and SO_2

This index is applicable to square urban area with wind always parallel to one side for uniform meteorological conditions under neutral stability with continuous source distributed uniformly. This AQI is not used for daily air quality reports but for estimating overall air pollution potential for a metropolitan area.

2.19.17 Ontario Air Pollution Index

This index was intended to provide the public with daily information about air quality levels and to trigger control actions during air pollution episodes. It includes two pollutants variables:

$$API = 0.2\ (30.5\ COH + 126\ SO_2)^{1.35}$$

2.19.18 Oak Ridge Air Quality Index (ORAQI)

Oak Ridge National Laboratory published the ORAQI in 1971. It was based on the 24-hour average concentrations of the following five pollutants:

1. SO_2
2. NO_2
3. PM
4. CO
5. Photochemical Oxidants

The sub-index is calculated as the ratio of the observed pollutant concentration to its respective standard. As reported by Babcock and Nagda (1972), the ORAQI aggregation function was a non-linear function:

$$ORAQI = \{5.7 = \sum I_i\}^{1.37}$$

where, $I_i = (X/Xs)_i$

X = Observed pollutant concentration

Xs = Pollutant Standard

I = Pollutant

The standards for the pollutants used in developing ORAQI are given in Table 2.3

The constants (e.g. 5.7 and 1.37 in equation) are so selected that the ORAQI = 10 when all concentrations are at their naturally occurring or backgrounds levels and ORAQI = 100 when all concentrations are at their standards.

Although well-defined descriptors are given, its developers imply no correlation with health effects. It is subjected to eclipsing and ambiguity. It is also difficult to explain to public and involves complex calculations.

2.19.19 Greater Vancouver Air Quality Index (GVAQI)

The GVAQI is based on Canadian Federal Government air quality objectives that are designed to protect public health and environment. The index includes the following pollutants:

1. SO_2
2. NO_2
3. O_3
4. TSP
5. COH
6. PM_{10}

GVAQI values are divided into ranges. The federal Desirable, Acceptable and Tolerable air quality objectives levels are assigned GVAQI values of 25, 50 and 100 respectively. Intermediate values can be obtained by extrapolation. Each range is associated with descriptor categories.

The overall GVAQI value is determined by calculating a sub-index for each pollutant measurement and averaging time. Each sub-index is calculated by straight-line extrapolation of the break point concentrations corresponding to GVAQI values of 25, 50 and 100 respectively. The maximum sub-index is reported as the GVAQI, based on the assumption that the combined effect of a number of air pollutants is related to the highest concentrations relative to air quality objectives. The particular pollutant responsible for the maximum Sub-Index is called the "Index pollutant". It is reported with the GVAQI when the index value is greater than 25. Each GVAQI range is associated with descriptor categories, general health effects and cautionary statements.

2.19.20 Most Undesirable Respirable Contaminants Index (MURC)

MURC was published in 1968. This was routinely used in the city of Detroit to report air quality data to the public and was broadcast between 8:30 A.M. and 9.00 A.M. each day on local radio stations. MURC is based on just one pollutant variable, coefficient of Haze (COH)

$$MURC = 70X^{0.7}$$

where, X = COH units

This equation is obtained such that COH values ranging from 0.3 - 2.15 give MURC values ranging from 30 - 120 approximately. Five different descriptors are reported for varying ranges of the MURC index shown in the Table 2.5.

The function was so chosen to reflect a good average approximation of the actual weight of SPM in the atmosphere as measured by high volume sampler. However, for MURC values higher than 120, the correlation with SPM concentration does not hold.

2.20 INDIAN SCENARIO ON STANDARDS

India has experienced significant increases in industrial activities and vehicular growth in recent years. The increased anthropogenic activities have resulted in increased pollutant emissions and the deterioration of environmental quality and human health. To assess quality of air and to take steps for prevention, control and abatement of air pollution, Central Pollution Control Board (CPCB), Ministry of Environment and Forest (MOEF) is executing a nation-wide ambient air quality monitoring through a National Air Quality Monitoring Programme (NAMP). Recently Ministry of Environment and Forest (MOEF), Government of India announced the new National Ambient Air Quality Standards-2009 in the official Gazette.

Despite the fact that pollutant concentrations near major industries, intersections and roadways in the cities are exceeding the Indian national ambient air quality standards (NAAQS), Air Quality Index for classifying the air quality in India is still under developing stage. National Ambient Air Quality Monitoring Programme in India has not yet scaled out any AQI levels over the region of India. Few studies have recently proposed AQI for some of the selected cities in India. Through CPCB, MOEF sponsored project, a study carried out at Indian Institute of Technology (IIT) Kanpur have recently come up with the preliminary Indian Air Quality Index (IND-AQI) where they have proposed the break-point concentrations and air quality standard are reported for criteria pollutant (http://home.iitk.ac.in/). The break-point concentration for the safe limit (good AQI) proposed in their study is analogous with recent notification of the NAAQS for most of the criteria pollutant, whereas it differs for Ozone and for PM2.5, the break-point concentration for AQI is not provided.

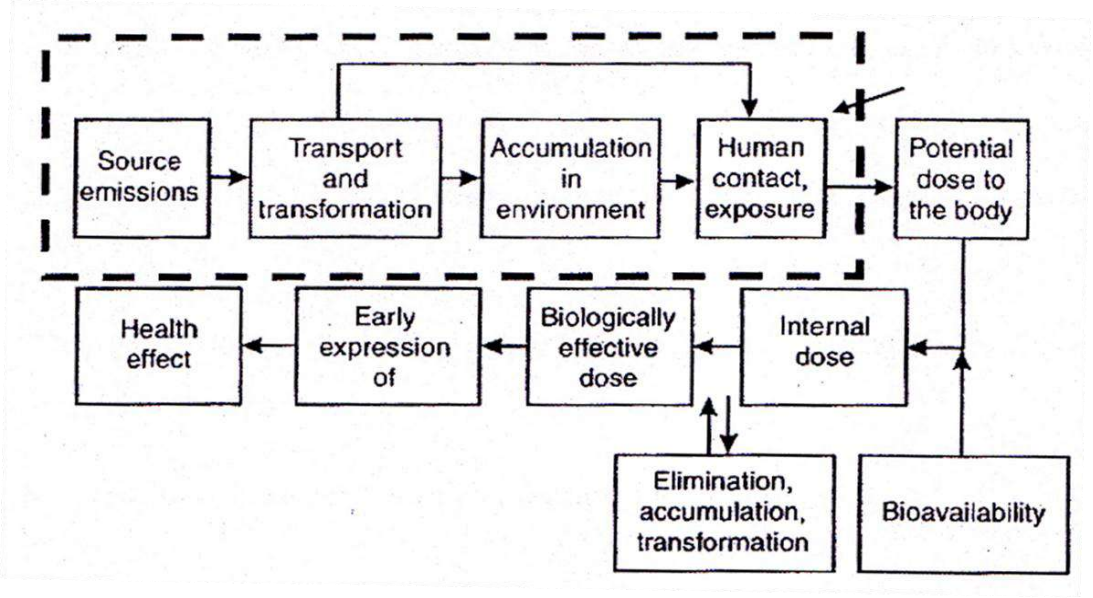


Fig. 2.3 Progression of Factors that Influence the Behavior of a Contaminant within the Environment, its Uptake by Humans, and the Resulting Health Effects. [Kanchan et al : 2015]

Although this information base has gaps and uncertainties, it offers a strong foundation for the guidelines recommendation. Several key findings that have emerged in recent years merit special mention. In this report, based on our scientific judgment and available scientific evidences, an attempt has been made to fulfill the existing gaps by keeping the National Ambient Air Quality Standards as base line criteria, so that the revised Air Quality Index for criteria pollutant 0_3, CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ can be calculated in different ranges as practiced worldwide where air quality forecasting system is placed and operational on routine basis. This will ensure that we do not remain left behind and always remain in the frontier in science at international level. The scientific basis for fulfilling the missing information is also briefly discussed. This concept of AQI is all the more important in India where the common man is not much familiar with technical terminology and measuring units (like ppm /ppb /ppt or ug/mg^3). Hence the AQI (which is represented in unit-less number) and its categorization in different colors which is based on the quality of air with respect to Human health will pave the way for a common man to understand its impact in most simplistic manner. It is also felt that at this juncture when the country is heading towards the development of first air quality forecasting system which is associated with an international sport event viz. Commonwealth games-2010, it is the most appropriate time to define the AQI for India which is attempted in this work.

Revised National Ambient Air Quality Standards

Table 2.6: Revised Ambient Air Quality Standards

(MOEF Notification G.S.R 826(E) Dated 16.11.2009)

Pollutant	Time Weighted Average (TWA)	Concentration in Ambient air	
		Industrial, Residential, Rural & other Areas	Ecologically Sensitive Area (Notified by Central Govt)
Sulphur dioxide (SO_2)	Annual Average* 24 hours**	50.0 µg/m^3 80.0 µg/m^3	20.0 µg/m^3 80.0 µg/m^3
Oxides of Nitrogen as NO_2	Annual Average* 24 hours**	40.0 µg/m^3 80.0 µg/m^3	30.0 µg/m^3 80.0 µg/m^3
Particulate matter (size < 10 µm) or PM_{10}	Annual Average 24 hours**	60.0 µg/m^3 100.0 µg/m^3	60.0 µg/m^3 100.0 µg/m^3
Particulate matter (size < 2.5 µm)	Annual Average* 24 hours**	40.0 µg/m^3 60.0 µg/m^3	40.0 µg/m^3 60.0 µg/m^3
Ozone (O3)	8 hours** 1 hour	100.0 µg/m^3 180.0 µg/m^3	100.0 µg/m^3 180.0 µg/m^3
Lead (Pb)	Annual Average* 24 hours**	0.5 µg/m^3 1.0 µg/m^3	0.5 µg/m^3 1.0 µg/m^3
Carbon Monoxide (CO)	8 hours** 1 hour	2.0 mg/m^3 4.0 mg/m^3	2.0 mg/m^3 4.0 mg/m^3
Ammonia (NH3)	Annual Average* 24 hours**	100.0 µg/m^3 400.0 µg/m^3	100.0 µg/m^3 400.0 µg/m^3
Benzene (C_6H_6)	Annual Average*	5.0 µg/m^3	5.0 µg/m^3
Benzo (a) pyrene (BaP) particulate phase only	Annual *	1.0 ng/m^3	1.0 ng/m^3
Arsenic (As)	Annual *	6.0 ng/m^3	6.0 ng/m^3
Nickel (Ni)	Annual *	20.0 ng/m^3	20.0 ng/m^3

Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week, 24 hourly at uniform intervals.

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

2.21 AIR POLLUTION ACTS AND RULES

Laws and regulations are at the heart of air pollution management in India. According to the, Constitution of India environment is a concurrent subject between the States and the Center, implying that both can enact laws. The Air Act, 1981 and the Environment Act. 1986 are the basic laws that are enacted to protect the atmosphere from pollution, in addition to the Motor Vehicles Act 1988. The Air Act was enacted with the objective of "prevention, control and abatement of air pollution", while the Environmental Act "for the protection and improvement of environment". These acts were born out of national commitments to the international treaty -the U.N, Conference on Human Environment held in Stockholm, in 1972.

The Air Act is an "Act to provide for the prevention, control and abatement of air pollution, for the establishment with a view to carrying out the aforesaid purposes, of Boards, for conferring on and assigning to such Boards, powers and functions relating thereto and for matters connected therewith".. The Environmental Protection Act is an "Act to provide for the protection and improvement of environment and for matters connected therewith". It is a comprehensive law, allowing for setting of the emission norms by the Central government, and also, the state governments, if they are stricter than the Central norms, including the emissions from automobile sources.

The language of the Air Rules of the Center and the state government generally suggest that they are more focused on regulating air pollution from industrial sources.- Section 17(1)(g) of Air Act permits the state Board to stipulate more stringent automobile and industrial emissions standards than the those of the Central Board, and Section 20 of the Air Act makes it obligatory for the state government to issue instructions to the motor vehicles registration authorities to comply with the State Boards standards. In India the automobile emission standards are established by the Ministry of Surface Transport and are part of the Motor Vehicles Act 1988. The automobile emission standards for in-fleet vehicles are regulated under the Pollution Under. Control (PUC) certification program, which is implemented by the Transport Department. Inspectors of both the Motor Vehicles and Police are empowered to conduct roadside inspection of vehicles for valid PUC certificates.

Laws to regulate many of the potential pollution activities such as. refuse burning, re-suspended road dust, air pollution from construction activities etc., are covered by the city municipal laws and rules.

2.22 METEOROLOGICAL FACTORS AFFECTING DISPERSION OF POLLUTANTS

The degree to which air pollutants discharged from various sources concentrate in a particular area depends largely on meteorological conditions. The application of dispersion theory and knowledge of local weather conditions are necessary to determine the required stack height for an emission, and to evaluate the intensity of Air pollution. Even though the total discharge of contaminants into the atmosphere in a given area remains constant from day to day, the degree of air pollution may vary widely because of differences in meteorological conditions. It is essential to understand the correlation between meteorological factors and ambient air quality to correctly interpret the data and also to assess the effect of various pollution control measures on ambient air quality. More are the calm conditions allow for less dispersion of pollutants results in their build up in ambient atmosphere and hence results in higher levels of pollution. [NAAQMS/29/2006-07]

In a specified place the emission of pollutants may be the same but the weather can trigger an air pollution episode. The important meteorological parameters that influence air pollution can be classified into primary and secondary parameters as follows.

2.22.1 Primary Parameters

- Wind direction and speed
- Temperature
- Atmospheric stability
- Mixing height

The parameters vary widely as function of latitude, season and topography. Just as weather affects the severity of air pollution, similarly air pollution, may in turn affect weather conditions. Air pollution may influence the weather in several ways.

Visibility may be reduced, fog frequency and duration may be increased and the incoming solar radiation may be decreased, particularly in the Ultra-Violet end of the spectrum.

2.22.1.1 Wind direction and Speed

The direction and speed of surface winds govern the drift and diffusion of air pollutants discharged near the ground level. The higher the wind speed at or near the point of discharge of pollution, more rapidly pollutants are carried away from the source. The pollutants so dispersed will not exist at the same concentration but will rapidly be diluted with greater and greater volumes of air. On the other hand, when wind speeds are low, pollutants tend to be concentrated near the area of discharge and longer the periods of such light winds, the greater will be the concentration of pollutants.

2.22.1.2 Temperature

Once pollutants are emitted into the air, the weather largely determines how well they disperse. Turbulence mixes pollutants into the surrounding air. For example, during a hot summer day, the air near the surface can be much warmer than the air above. Sometimes large volumes of this warm air will rise to greater heights, this result in vigorous mixing.

2.22.1.3 Atmosphere stability and temperature inversions

In well mixed air which is dry, for every 1000ft (300m) increase in altitude, the temperature decreases by about 3.3°F (about 1.8°C) this vertical temperature gradient is known as lapse rate. When a reverse or negative lapse rate occurs, a dense cold stratum of air at ground level gets covered by lighter warmer air at higher level this phenomenon is known as inversion. During inversion vertical air movement is stopped and pollution will be concentrated beneath the inversion layer that is denser air at ground level.

2.22.1.4 Mixing height

It can be defined as that height above the earth's surface to which pollutants will extend from 500m to 1000m, primarily through the action of atmospheric turbulence. It is usually related to one or more of the three factors: wind direction,

wind speed and wind turbulence. Under certain circumstances, it may be related to all three.

2.22.2 Secondary parameters

- Precipitation
- Humidity
- Solar radiation
- Visibility

2.22.2.1 Precipitation

Rainfall or precipitation exerts a two-fold cleansing action on the pollutants discharged into the atmosphere. It accelerates the deposition of particulate matter on the ground and hence its removal from the atmosphere. It also helps to remove the concentration of gaseous pollutants which are soluble in water. Precipitation can be determined by using various types of rain gauges.

2.22.2.2 Humidity

The moisture content of the atmosphere influences the corrosive action of the air pollutants and indicates the potentiality for fog formation in relation to the degree of air pollution. The various mean by which humidity may be expressed as relative humidity is most frequently used in air pollution studies.

2.22.2.3 Solar Radiation

Depending on the location, solar radiation can have a pronounced effect on the type and rate of chemical reactions in the atmosphere. The application of these meteorological factors may be considered in the control of pollution from an industrial plant, in the selection of its location, in the design of equipment and in its day-to-day operation. In addition, these factors are to be taken into account in laying out zones for industrial use, in identifying casual factors in existing pollution problems and in establishing air quality criteria. The influence of both regional and local weather should be considered for dispersion of air pollutants.

2.22.2.4 Visibility

In meteorology, visibility is a measure of the distance at which an object or light can be clearly discerned. Visibility affects all forms of traffic: roads, sailing and aviation. A visibility reduction is probably the most apparent symptom of air pollution. Visibility degradation is caused by the absorption and scattering of light by particles and gases in the atmosphere. Scattering by particulate, on the other hand, impairs visibility much more readily. Visibility is reduced by significant scattering from particles between an observer and a distant object. The particles scatter light from the sun and the rest of the sky through the line of sight of the observer, thereby decreasing the contrast between the object and the background sky. Particles that are most effective at reducing visibility usually are in the range of 0.1-1.0 um diameter is enough to reduce visibility.

2.23 SPECIFIC REVIEWS

Abam and Unachukwu (2009) studied the transport-related pollution in Calabar Nigeria which was significant with possibly severe health consequences. Priority parameters: CO, NO_2, SO_2, PM_{10} and noise level were monitored. Other relevant parameters monitored includes ambient temperature, wind direction, wind velocity and traffic count. They revealed that pollution at traffic intersection is threatening and that motor vehicle remains the dominant sources of urban air pollution. Addressing this situation requires a holistic understanding of causal factors related to emissions.

Akbar Ziauddin and Siddiqui (2006) collected data of air pollution at a number of places in a growing city and represent it in the form of Air Quality Index. The ambient air quality survey was carried out in 15 monitoring stations with respect to SPM, RSPM, SO_2, and NOx where sampling had been carried out for 24 hours period. Pollutant concentrations were used to calculate the Air Quality Index. Five stations showed critical conditions of air quality with AQI values above 100. Seven sites showed AQI values between 76 and 100, representing heavy air pollution. Two sites showed moderate air pollution and one site showed light air pollution.

Anamika Tripathi et al (2010) studied the assessment of ambient air quality index with respect to SPM SO_2 and NO_x considered over the period of one year (March 2007 to February 2008) The air quality index had been determined at three different sites namely PTC, Townhall and Mughalpura of Morahabhad city.

Anikender Kumar and Goyal (2010) studied day-to-day air quality conditions for four different seasons namely summer, monsoon, post monsoon and winter through statistical error analysis and forecast short term daily AQI through previous day's AQI and previous day's meteorological parameters using principal component regression (PCR) technique. AQI has been estimated for the period of seven years from 2000-2006 at ITO (a busiest traffic intersection) for criteria pollutants such as Respirable Suspended Particulate Matter (RSPM), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) and Suspended Particulate Matter (SPM) using a method of US Environmental Protection Agency (USEPA).

Anand Kumar et al (2011) studied ambient air quality status in Jaipur city, Rajasthan, India using air quality index. They collected data of fair pollutants from 12 sites in residential industrial and commercial area of the city. The survey was carried out to evaluate SPM, SO_2, and NO_x during 2009-10 for a period of 24 hours in the winter season. These pollutant concentrations showed SPM and RSPM concentration were exceed Central Pollution Board.

Ankita Shukla et al (2010) studied the estimation of composite air quality index of pollutants in the atmosphere namely suspended particulate matter, NO_x and SO_2 at five different selected locations in Lucknow city. Each pollutant was observed by 12 hours from 8:00 to 20:00 hours. According to air quality scale, the air quality status had been measured at each location. From the study it was found that the residential zone has highest air quality index in comparison to other zones. From the results it had also been found that among all different kind of pollutant emissions, the discharge of suspended particulate matter is found much higher than standard value at all selected locations. It was also observed that air quality index value of all location comes under category of severe pollution according to rating scale of AQI. This higher value of air quality index may cause asthma and other bronchial diseases in people living around that particular zone. They even suggested that mitigation

measures should be taken to control the emission of pollutants primarily suspended particulate matter affecting the air quality.

Antonella Plaia et al (2010) reviewed about the air pollution indices proposed in literature and/or adopted by Governments, trying also to categorize them into homogeneous groups. For the classification different approaches can be followed. Since in real life exposure to mixtures of chemicals occurs, with additive, synergistic or antagonistic effects, they distinguished between indices that consider the conjoint effect of pollutants and indices that are only based on the actual most dangerous pollutant.

Avnish Chauhan et al (2010) studied the significant differences in seasonal variations of air pollutants concentrations like PM_{10} (RSPM), suspended particulate matter (SPM), sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) at urban, industrial, commercial and agricultural areas of Uttarakhand. Meteorological parameters like temperature, relative humidity, wind speed and rainfall were also recorded simultaneously during the sampling period. Monthly and seasonal variation of these pollutants had been observed and recorded. The annual average and range values were calculated. It had been observed that the concentrations of the pollutants are high in winter in comparison to the summer or the monsoon seasons.

Biswanath Bishoi et al (2009) carried out comparison of AQI based on factor analysis and US -EPA methods and an attempt made to calculate NAQI. It was observed that sampling site in the study was Jawaharlal Nehru University (JNU) Campus, an area situated in south of Delhi that a significant difference exists between NAQI and EPAQI. However, NAQI followed the trends of EPAQI when plotted against time. Further, the indexes were used to rank various seasons in terms of air pollution. The higher index value indicates more pollution in relative terms.

David Shooter and Peter Brimblecombe (2005) attempted to meet the public's needs for information on air quality a variety of indexes had been developed and they continue to evolve. To show the complexity and the diversity of such indices, a variety of current air quality indices were described and compared in regard to their performance and ability to deliver quality information to the general public. An AQI also needs to be useful for forecasting, and the method of calculation needs to be sufficiently flexible to allow for pollutants to be added or subtracted as changes to

their health impact are revealed. Current AQIs potentially contribute to public understanding by providing information that was easily accessible and allows them the opportunity to modify their behavior appropriately in response to changes in air quality.

EOTVOS (2007) studied the importance of integrating biological pollutants into air quality indices. Indices contain only chemical pollutants, while certain biological pollutants can enhance the effects of the chemical pollutants and vice versa. In order to increase the efficacy of these indices to the civil society we aim to introduce geographic information system (GIS) methods into publishing air quality information

Fabio Murena (2003) developed two different pollution indexes and implemented at the urban area of Naples (Italy) and data collected from nine monitoring stations measuring conventional pollutants: CO, NO_2, NMHC, SO_2, PM_{10}, O_3 and SO_2 were analyzed. The first index aims at measuring the status of air pollution with respect to its effect on human health .The second index aims at showing clearly the occurrence of exceedences of limit values established by EC directives.

Gopal Upadhyaya and Nilesh Dashore (2010) proposed IND -AQI which was sponsored project from the Central Pollution Control Board, Delhi in simple terms are SO_2, NO_2, PM_{10}, CO and O_3). Index by using fuzzy method was calculated. An individual score is assigned to the level of each pollutant and the final AQI was the highest of those scores. Air quality measurement are commonly reported in terms of microgram per cubic meter ($\mu g/m^3$) or parts per million (ppm)

Gurdeep Singh (2004) proposed air quality depreciation index in some coal mining areas of Kobra industrial belt of Chhattisgarh, India allows for more realistic air quality assessment as compared to interpretive evaluations that revolve around comparing observed concentrations to national ambient air quality standards. The air quality depreciation index can be an invaluable tool to map periodic deterioration in air quality with respect to its potential for environmental damages. They believed that adoption of such an index to monitor air quality at all the mining locations in India, will help mutual comparisons in a much more realistic and meaningful manner. Since the air quality depreciation index is neither geographically specific nor constrained for

the type or number of pollutants, it can be easily used for different situations and applications.

Gurfran Beig (2010) proposed air quality index for India during Common Wealth Games which was held in New Delhi by using Scientific Studies land scientific judgement. AQI break points based on their scientific understandings and atmosphere chemistry knowledge of the subject was designed.

Gurjar et al (2007) studied the evaluation of emissions and air quality in megacities in terms of their trace gas and particle emissions and ambient air quality, notably total suspended particles (TSP), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). They proposed a multi-pollutant index (MPI) considering the combined level of the three criteria pollutants (i.e., TSP, SO_2, and NO_2) in view of the World Health Organization (WHO) Guidelines for air quality. The conventional indices based on the concentration of a single pollutant were limited in their scope, and fail to identify where the overall air quality is poorest and potentially presents the greatest health risk. Another key issue related to monitoring in megacities was the specific location of air quality measurements, which can produce biased results and influence the resulting index values and so there calls for standardization of sitting criteria and number of sites needed per megacity in working towards better global tracking of air quality in megacities.

Helmut Mayer et al (2004) studied air quality stress and air quality indices suited to assess the integral air quality that is not restricted to a single air pollutant, formulations for statistical air stress indices and an impact-related air quality index (DAQx) were presented. Their sensitivity depending on emission and air mass exchange conditions was investigated by test calculations based on air pollution data from three different sites in south-west Germany characterized by different air pollution levels.

Jayapriya and Saseetharam (2009) monitorized the ambient air quality for major pollutants such as SPM, RSPM, SO_2 and NO_x. Results showed that the air quality parameters tested are well within the standards prescribed by National Ambient Air Quality Standards (NAAQS). It concluded that there is no serious problem of air pollution from the above tested air pollutants in the vicinity of disposal

site and is not a cause of concern to public healthy as no adverse impacts is expected at the present state.

Jonathan Samet and Yong Chung (2008) determined some problems of atmospheric pollution and related health concerns are local, many are regional, national, and transnational.

Kaushik et al (2000) studied the ambient air quality status for total suspended particulate matter (TSPM), Respirable suspended particulate matter (PM_{10}), sulfur dioxide (SO_2), and for oxides of nitrogen (NO_2) during different seasons from 8 districts of Haryana during January, 1999 to September, 2000. The four types of sampling sites with different anthropogenic activities i.e. residential, sensitive, commercial and industrial were identified in each city. Air Quality Index (AQI) prepared for these cities shows that residential, sensitive and commercial areas were moderately to severely polluted which is a cause of concern for the residents of these cities. The high levels of TSPM and SO_2 especially in winter were of major health concern because of their synergistic action. The ambient concentration of all the air pollutants decrease in post-monsoon as the monsoonal rain is responsible for the washing of ambient air pollutants. When compared with respective standards, the AQI of residential and commercial areas is high and indicates the possible threat of air pollutants to the residents of these localities. The present study also, revealed a significant increase in the total number of patients admitted for respiratory problems in winter.

Keiko Hirota (2010) studied vehicle related policies for air pollution reduction in ten Asian countries and emphasizes monitoring problems such as vehicle registration systems, inspection and maintenance (I/M) systems and fuel quality monitoring systems for vehicles in use to improve air quality.

Konstantions Votalis et al (2006) proposed the status of environmental quality by using of heavily industrialized coal basin in North western Macedonia, Greece by using environmental quality index (EQI). They involved three main components: Social research, the opinion of environmental experts and the combination of new or existing indices. Even they did survey on Public opinion, and the weights of specific problems were obtained through Delphi method.

Mahendra and Krishnamurthy (2004) carried out air quality deterioration due to pollution from road traffic in Bangalore city and they were measured traffic flows continuously. In the morning peak traffic hours by video-technique at selected major inter section and air pollutants levels were continuously measured at the height of 3 m from road surface and analyzed in the Ambient Air Quality Monitoring Mobile Laboratory. It was evident that two wheeler vehicles were amounted to about 50% of total traffic flow and predominant at all the study inter section. The traffic-generated day time 8-hours average CO concentration levels were exceeding the standard permissible limit of 2.0 mg/m^3 prescribed by CPCB at all the study intersection. This might be attributed to the interrupted flow of traffic near the intersection due to the frequent 'stop' and 'go' situation. The day time 8-hour average SO_2 and SPM concentration values were well within the relevant ambient air quality standards of 80 and 200 $\mu g/m^3$, respectively at selected study intersections. Further study concluded that the important decisions need to be taken urgently concerning motor vehicle induced atmospheric pollution in order to minimize the future cost of effects on health and environment. These decisions relate, in particular, to smoothen the traffic flow in the city were using appropriate traffic management measures such as intersection channelization, one, one-way street system, removal of unnecessary stoppages etc,. Lastly, study suggested to reducing air pollution in the city by minimum use of two-wheeler and auto-rickshaws were essential. This can be possible by providing efficient and guaranteed transport facilities such as Metro- Bus System evaluated light rail transit system or Circular underground railway system.

Manita Prakash and Bassin (2009) studied analysis of the ambient air in Delhi city employing air quality index (AQI). The 24-hourly average concentrations of four major criteria pollutants, viz. Suspended particulate matter (SPM), Respirable suspended particulate matter (RSPM), Sulphur Dioxide (SO_2), and Nitrogen Dioxide (NO_2) for the year at three different locations in Delhi city (industrial at Mayapuri, commercial at Town Hall and residential at Sarojini Nagar) had been observed then they the calculated AQIs.

Manju Mohan and Anurag Kandya (2007) studied on the annual and seasonal variations of Air Quality Index over a period of 9 years (1996-2004) based on daily averaged concentration data of criteria air pollutants has been conducted for Delhi. AQI percentages in different severity class from daily measurements can

provide an in-depth analysis of seasonal and annual variations than the averaged values. Shazadabaug and Shahdara were found to be least polluted with good AQI. Amongst remaining five sites, Ashok Vihar and Nizamuddin showed the best air quality in the year 2001 while Janakpuri and Sirifort showed best AQI in the year 2003 with ITO in 1999. After having worst AQI in 2002, AQI at ITO has improved in subsequent years. At both, Janakpuri and Sirifort, there was deterioration of AQI in the year 2004.A shift in worst AQI season from winter to summer was noted and also an increased NO_2 concentration at all sites increased from 2000 onwards. There seems to be change in the nature of pollutants and more photochemical activity with changed regulations and emissions in the city. At certain traffic junctions and locations in the city improvement in air quality is noticed after the introduction of metro rail network.

Mrinal Ghose et al (2004) studied the status of air pollution at traffic intersection of Kolkata and it was found to be critical and it had taken the problem to a threatening dimension. Even with the introduction of advanced emissions control technology motor vehicles remain the dominant sources of urban air pollution. Addressing this problem requires a better understanding of the source and causes of emission and effective means of addressing in-use emissions. There a great appeal for a stringent inspection and maintenance (I/M) programs in the city. There is no well-defined guideline for the assessment of urban air pollution and no systematic study has been reported for Indian cities. There will be an immense implication of the suggested approach and the future application of such assessment in many to manage the urban air pollution problem. The methodology adopted might have formed a guideline for such studies and may be useful on industrial scale for various cities.

Nagappa and Sadashivaiaih (2008) studied the status of ambient air quality at major traffic intersection of Bangalore city. Air pollutants like Sulphur dioxide (SO_2), Oxides of nitrogen (NO_x), PM_{10} (Particles smaller than 10m), and $PM_{2.5}$ were measured. The air pollution measurement were carried out for two weeks, starting from Feb 22, 2008 to march 1, 2008 with a frequency of twice a week at one location sampling as per the CPGB guideline. Their studied clearly revealed that the high levels of air pollutants like PM_{10}, $PM_{2.5}$, at traffic intersections and SO_2 and NO_x are below National Ambient Air Quality Standards. Fine dust PM_{10}, $PM_{2.5}$ characterization reveals that $PM_{2.5}$ contains 93% to 63% organics and 6.3% to 36% of metallic content and PM 10 contains 78% to 38.95% organics and 21.1% to 61% of

metallic contents. It can be concluded that the Bangalore city is reeling under high particulate matter concentration and suitable management options were needed to be taken.

Nagappa and Sharathchandra (2008) carried out ambient air quality monitoring programme under NAMP. The data of ambient air quality collected during the period of 2002-2008 in Bangalore city, 2006-08 for other cities like Mysore, Hubli-Dharwad, Mangalore, Hassan, Gulburga and Belgaum, have been analyzed. The selected sampling sites belong to three different types of anthropogenic activities i.e. sensitive, residential, and commercial and industrial areas in each city. It has been found that the observed ambient air concentration of SPM a d RSPM was well above the prescribed standards at almost all the sites except Mysore and Mangalore, while the average ambient air concentration of SO_2 and NO_x were below the permissible limits at all the areas i.e. sensitive, residential and commercial, are moderately to severely polluted which is a cause of concern.

Papiya Roy et al (2010) proposed air quality depreciation index and shown that the index allows for more realistic air quality assessment as compared to interpretive evaluations that revolve around comparing observed concentrations to national ambient air quality standards. The Air Quality Depreciation index can be an invaluable tool to map periodic deterioration in air quality with respect to its potential for environmental damages. They believed that adoption of such an index to monitor air quality at all the mining locations in India will help mutual comparisons in a much more realistic and meaningful manner. This work was just a step in this direction. Since the air quality depreciation index is neither geographically specific nor constrained for the type or number of pollutants, it could be easily used for different situations and applications.

Pradeepta et al (2010) discussed the use of Air Quality Index (AQI) for describing air pollution and computed for ten air quality sampling stations in Choudwar area of Cuttack District within the radius 10 kms from the core zone. There are several methods to communicate the use of different environmental quality parameters. The data obtained from monitoring of ambient air at ten locations within the study area were used to calculate the AQI for each season during the study period, which is a single value of combination of all pollutants viz. SPM. NO_2 and SO_2. The

comparison and explanation of AQI, SPM SO_2 and NO_2 values at different location within one season in the study period.

Prakash Mamta and Bassin (2010) reported the analysis of the ambient air in Delhi city employing air quality index (AQI) by using RSPM SO_2 and NO_x for 3 years at different locations. The AQIs were calculated using AQI procedure. The study revealed that SPM was mainly responsible for maximum times in all sites. This could be due to rapid increase in urban population, growth of vehicular pollution frequent dust storms, infrastructure development like construction of flyovers, metro rail services etc.

Pulikesi et al (2005) carried out studies on air quality monitoring in Chennai, India, in the summer .This paper represented data on the measurement of the surface O_3, NO_x, RSPM, and TSPM concentration and meteorological parameter in five different sites of Chennai. The following conclusion was drawn from the presented study. The mean O_3 concentration in all sites had been observed to be higher in the wind flow from SEE and WSW. The transport of ozone rich air from the sea had been found higher on the coast than the interior. It also had been observed that surface concentration O_3 increase with increase in temperature and decrease with relative humidity. Reduction in O_3 may be due to the increase in NO_3. The level of NO_x was below the Indian standards. The daily mean concentration of TSPM was found to be above the NAAQS Standards. In Vallalarnagar station alone the NO_x, RSPM, and TSPM value were found to be higher than those of other sites. The present work has been undertaken mainly to generate new set of data on surface O_3 and understand the relation between O_3, NO_x, PM, and metrological parameters for Chennai city.

Raghu Nath Chankrabarty and Shibnath Chankrabarty (1999) described the quality of ambient air, the importance of simple means were felt. Air Pollution indices (API) system is one such means by which one can explain the quality of air to common man. Different air pollution indices systems were discussed. Example of calculation of API from the raw data collected for pilot study on air quality monitoring and management for Calcutta environmental management strategy and action plan (CEMSAP) was showed. API was also calculated from air quality data collected at Jadavpur University. Konstantions I Votalis et al (2006) proposed the status of environmental quality by using of heavily industrialized coal basin in North

western Macedonia, Greece by using environmental quality index (EQI). They involved three main components: Social research, the opinion of environmental experts and the combination of new or existing indices. Even they did survey on Public opinion, and the weights of specific problems were obtained through Delphi method.

Ramesh (2004) studied the air quality status and trends of Pondicherry UT during the period of 1993 to 2000 with reference to the three different locations. Their study revealed that air quality has got deteriorated due to rapid industrialization and vascular exhaust.

Ravi Shankar and Ramarao (2002) studied the impact of air quality on human health from Air Quality Monitoring and Research Laboratories, Mumbai (AQMRL) and the same were utilized for analysis as they follow the WHO guidelines for measurement). Temperature, humidity, wind speed and direction and rainfall data were acquired from the local Meteorological Survey of India to assess the spatial distribution of air pollutants. They focused on the air pollutants and their safe levels and the trends in Mumbai as well as the health conditions of the exposed people in the survey areas. In health outcomes major thrust has been given to the normal subjects, morbidity related to air pollution (MRAP) and morbidity not related to air pollution (MNRAP), thereby establishing a causal relationship between air pollution and human health. Both bivariate and multivariate techniques (logistic regression analysis) were used as statistical tools in their study.

Sarath Guttikunda (2010) studied five main pollutants - PM, O_3, SO_2, NO_x, and CO in Delhi. Each of these pollutants has an air quality standard which was used to calculate the overall AQI and explained importance of this index to the policy makers and very obvious to the public. As part of the integrated air quality management, the combination of regulations, awareness and capacity building, and partnerships between stakeholders (including artists, in this case) contribute equally towards improving air quality in a city. Their approach where each instrument (e.g., information) supports the other instrument (e.g., awareness) yields quicker and better results.

Sastry et al (2004) studied the air quality status of Hyderabad city by monitoring at 11 locations during march 2003. These observations on air quality

status and AQEI (air quality exposure index) predicted that most of the localities in Hyderabad were experiencing the air pollution stress and the trend is likely to worsen in near future if proper control measures are not implemented. From the monitoring of vehicular emission in Hyderabad city, it was observed that the SPM, RSPM, and CO concentration were above the prescribed standards, while SO_2 and NO_x were within the permissible limits except at one site (Chaderghat) for NO_x which was observed to be high than the standards.

Senthilnathan (2007) carried out five years air monitoring study to access the primary pollutants present in the ambient air in the Chennai city during 1999-2003 at two different sampling stations. Monthly mean and exceedences factor values were determined. It was observed that the concentration of SPM at the sampling stations was very high, when compared with the values prescribed by National Air Quality Standards (NAAQS) and it was confirmed by the exceedences factor calculations. During monsoon, concentration of particulate pollutants rather than the gaseous pollutants, like SO_2 and NO_x can be reduced because rain could wash away the particulate pollutants, thereby flushing the particulate to the atmosphere. It also found the solution for fuel consumption and alternate fuel for automobiles.

Shiva Nagendra et al (2007) measured the status of ambient air quality near busy traffic intersections in Bangalore of Ananda Rao circle (AQM station 1), AMCO batteries, Kimco circle (AQM station 2) and Graphite India, white field circle (AQM station 3). India. The measured air quality indices had been calculated using the US Environmental Protection Agency procedure. The result indicated that the air pollution at all the three air quality monitoring stations can be characterized as 'good' and 'moderate' for SO_2 and NO_x concentrations for all days from 1997 to 2004. Analysis of air quality indices values for both forms of suspended matter concentrations during 1999-2005 indicates 91% and 94% of the times days were in category 'good' and 'moderate'. The yearly average air quality indices values of Respirable suspended particulate matter and suspended particulate matter concentrations indicated decreasing trend and were coming under the category of 'good' and 'moderate' form the category of 'poor' and 'very poor'.

Tiwari and Mansoor Ali (1987) discussed significance of the air quality index AQ1 and suggested a method to calculate the AQI from the values of various

pollutants. Monthly AQIs was calculated from various localities of Calcutta during 1978 to 1979. Their results shown that air quality data 1979 of Calcutta was deteriorated significantly when compared to 1978.

Vijay Bhaskar and Vikram Mehta (2010) studied the airborne particulate pollutants data were collected for a period of 4 years (2005-2008) at 13 locations in Ahmedabad, a mega city in Gujarat State in western India. The particulate pollutants data were collected by the Gujarat Pollution Control Board with respirable dust samplers (RDS). The observed suspended particulate matter (spm) concentrations varied from 66.0 to 786.0 $\mu g/m^3$, and concentrations of particulate matter of aerodynamic diameters less than 10 microns (PM10) ranged between 17.0 to 327.0 $\mu g/m^3$. The seasonal- and annual-average concentrations of the two pollutants were mostly above Indian air quality standards and were generally comparable with those observed in most other Indian urban areas. During this study period, there was a continuous decrease of particulate pollutants concentrations within Ahmedabad; however, the concentrations were just above the permissible limits set by the Central Pollution Control Board (CPCB). These particulate pollutants concentrations were compared with meteorological variables such as rainfall, humidity, temperature, and wind speed. Both SPM and PM_{10} showed significant negative correlations with rainfall. An Air Quality Index (AQI) was calculated for all stations for all months. AQI values varied from 25 to 193.3. AQI was high in summer season and low in monsoon season. AQI values varied from Good (0-50) to Hazardous (300-500). On the basis of the AQI scale, it is found that the atmospheric environment of Ahmedabad is moderately polluted to unhealthy range.

Warade and Gaikwad (2009) monitored ambient air quality at four sampling location around Nasik city, Ambad Industry, Sinner Industry & Satpur industry. The data obtained at one of the sampling location had been compared with standard data. The observation indicates that there is a marked safety in the computation methodology. The observation also indicated that the fugitive emission had significant impact on the ambient air quality.

CHAPTER - III

MATERIALS AND METHODS

CHAPTER – III

MATERIALS AND METHODOLOGY

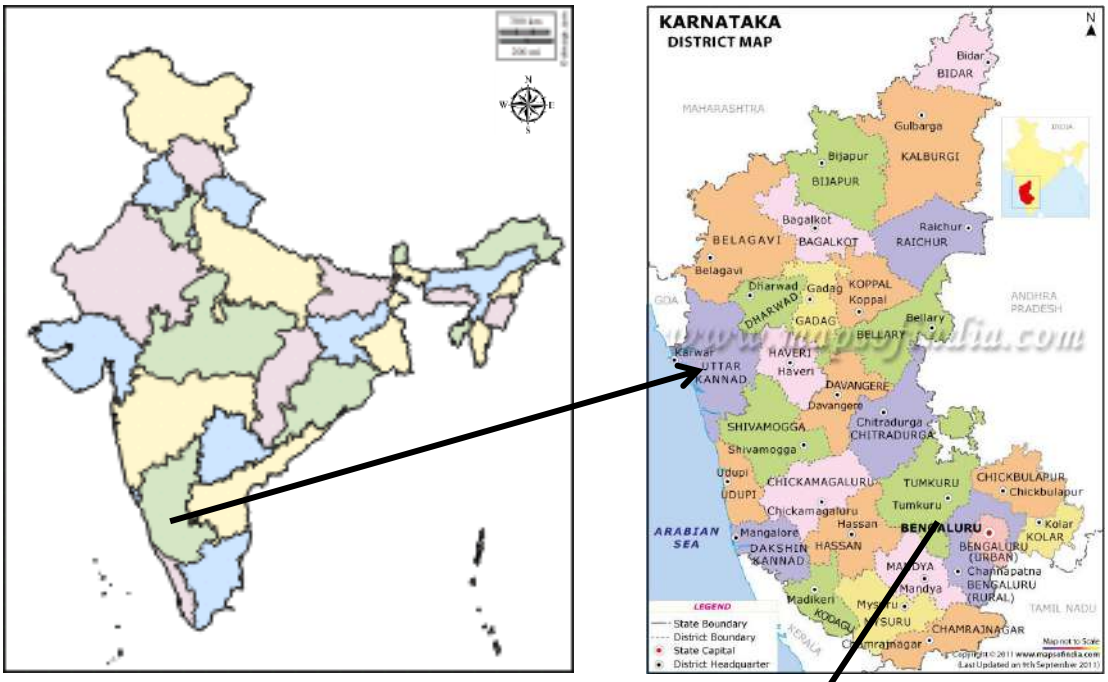
Materials and methodology adopted for the present research work is documented in this chapter. Issues covered include :

- Description of the study area
- Location of sampling / monitoring stations
- Salient features of monitoring stations
- Parameters monitored
- Study period
- Sampling methods adopted
- Experimental programme
- AQI calculation
- Exceedence factor calculation
- Collection of meteorological data
- Vehicular traffic data

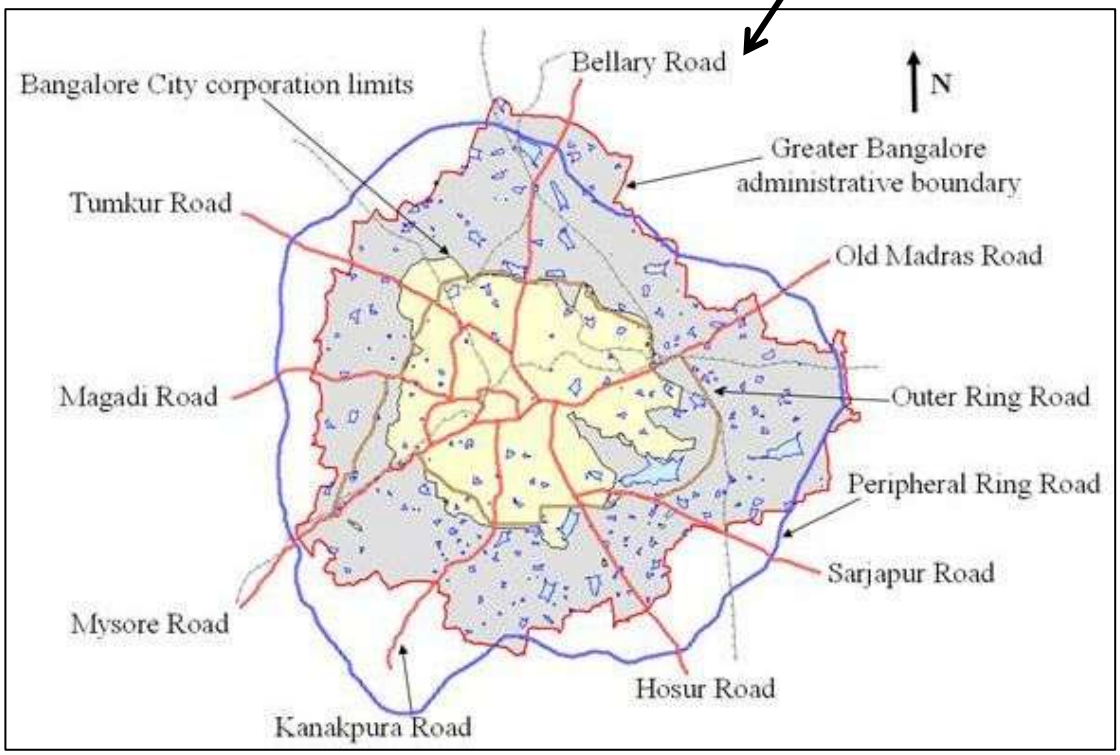
3.1 DESCRIPTION OF STUDY AREA

The study area, Bangalore, Capital of Karnataka considered for the present study is shown in the fig.3.1.

Bengaluru city, which lies in the Bengaluru urban district, is the capital of Karnataka. Greater Bengaluru lies between 77°37’ 19.54” E and 12°59’ 09.76’’N, with an area of 741sq.km.



India **Karnataka**



Bangalore

Fig. 3.1 Map Showing Study Area Bangalore

3.1.1 About Bengaluru

Bengaluru, the capital of Karnataka, is the principal administrative, cultural, commercial and industrial centre.

Over the years, the profile of Bengaluru has changed drastically and is currently better known as one of the country's major IT centre rather than as 'garden city'. With economic development, there has been tremendous pressure on economic resources. Air quality is one of the environmental parameters, which has been negatively influenced by the economic growth of the city. Deterioration of the air quality in Bengaluru can be attributed by rapid increase in population and corresponding fuel combustion activities, which include transport, industrial, and domestic sectors.

The number of vehicles too increased rapidly to about 60 lakhs in 2015, majority of which are private vehicles such as two-wheelers and cars. In terms of contribution to the air pollution load, besides the transport sector emissions, the movement of vehicles over paved roads leads to re-suspension of road dust that also contributes to the particulate matter emissions. Though there are no major highly polluting industries in Bengaluru, however there do exist a number of industries located in some of the earmarked industrial areas in the city. These industries include engineering, metal, textile, wood, printing, rubber and plastics, chemicals, glass, etc. Diesel generator (DG) sets are additional source of pollution because of power cuts. Besides the industries, most of the commercial establishments and some households in Bengaluru have DG sets. Domestic fuel combustion too has been proportionately rising with the rise in population.

3.1.2 Topography

Bengaluru is situated in the southeast of Karnataka, at an average elevation of 920 m above mean sea level, and covers district borders with Kolar District in the northeast, Tumkur District in the northwest, Mandya District in the southwest, Chamarajanagar District in the south and the neighboring state of Tamil Nadu in the southeast. Bengaluru Urban District is divided into three taluks: Bengaluru North, Bengaluru South, and Anekal. Bengaluru North taluk is a relatively level plateau,

while Bengaluru South taluk has an uneven landscape with intermingling hills and valleys. The highest point in Bengaluru is Doddabettahalli, which is 962 m and lies on this ridge. There are no major rivers running through the City. The river Arkavathi (a tributary of the Kaveri) passes near Nandi Hills, 60 km north of Bengaluru, while the river Kaveri has its nearest approach near Srirangapatnam, southwest of Bengaluru. Bengaluru has few number of freshwater lakes and water tanks, the largest of which are Madivala Tank, Hebbal Lake, Ulsoor Lake, and Sankey Tank.

3.1.3 Climate

The district enjoys a very agreeable climate free from extremes. The climate of Bengaluru is classified as the tropical wet and seasonally dry with four seasons. The dry season with clear bright weather is from December to February. The summer season from March to June is followed by South-West monsoon from July to October. The temperature varies from a mean maximum of 33.4°C in April/May to the mean minimum of 15° C in December/January. The mean monthly relative humidity ranges from 44% (min) in March to 85% (max) in October. Rainy season is characterized by spells during June to September and October to November, corresponding to South-West and North- East monsoon, the mean annual rainfall is reported to be 889 mm. The surface winds in Bengaluru have a seasonal character with clear cut easterly and westerly predominant directions. The site meteorology has an important influence on the buildup, diffusion and transportation of atmospheric pollutants and therefore meteorological data was collected for a set of meteorological parameters from the IMD (Indian Meterological Department)station at Bengaluru. During the period May to September, the winds are WSW to W, while during the period November to March, they are ENE to ESE. April and October are transition months when changeover from the Easterly to the Westerly wind regime and vice versa takes place.

3.1.4 Population

The City experienced rapid growth in the decades 1941-51, and by 1961 Bengaluru became the sixth largest city in India. The 2011 census population of Bengaluru was 96 lakh, The growth of Bengaluru from a town to a metropolis has been a result of five growth events:

- Shifting of the State Capital from Mysore to Bengaluru.
- Establishment of the Cantonment.
- Setting up of Public Sector Undertakings/Academic Institutions.
- Development of Textile Industry.
- Development of Information Technology/ITES/Biotech based industries.

3.1.4.1 Composition of Population Growth

About one third of the population increase in the Bengaluru region is attributed to the fact that new areas were added to the Bengaluru urban agglomeration. Adjusting this factor, the net increase in population during 1991-2001 was approximately 22%.Table 3.1 and 3.2 shows the growth composition of population.

Table 3.1 Composition of Population Growth

(Source: City Development Plan For Bengaluru-BDA)

Composition	1981-91 (lakhs)	% of Total	1991-2001 (lakhs)	Percentage of Total
Natural increase	2.66	22%	3.42	22%
In-migration	5.44	45%	7.00	45%
Jurisdictional change	4.03	33%	5.19	33%
Total increase	12.09	100%	15.57	100%

Table 3.2 Growth Rate in Decades

(Source: Census of India, 2011)

Year	2001	2011	Growth rate	2016
Population	6,537,124	9,621,551	47.18 %	1,03,51,429 (predicted)
Vehicles	14.73Lakhs	37.91Lakhs	7-10%	5l lakhs

The population of Bengaluru grew by about 30 lakhs in 10 years. The primary abstracts of the census of India, 2011 puts the city's population as 96 lakhs with the annual growth rate of 47.18% during 2001-2011. Rapidly increasing population has results in high growth of transportation over the years. Bengaluru, the IT hub of the nation is one of the sought after cities of the nation and has witnessed rapid growth of industries in the past few years, this growth of industries in the city contributed significantly to the rise in vehicle population.

3.1.5 Sources of Pollution in Bengaluru

In Bengaluru the sources of air pollution are vehicular, industrial, commercial and domestic activities. The point sources of pollution are mainly, large and medium scale industries involving processes and large number of D.G. sets causing large scale air emissions, while automobiles constitute the most non-point polluting source. Small-scale industries burning up fuel for processing, hotels and house-holds using cooking fuels are some other sources.

3.1.5.1 Vehicular Sources

The problems associated with air pollution in Bengaluru are mostly due to the large number of privately owned motor vehicles, adulterated fuel supply, vehicles of obsolete two stroke technologies, road congestion, poor public transit system, bad maintenance etc. Over the years there has been a dramatic increase in the number of vehicles particularly the two wheelers that are added to the already burgeoning vehicular population. The absence of an efficient local transit system provided by the Bengaluru Metropolitan Transport Corporation (BMTC) has led to this addition in the

number of vehicles. The problem has manifested in congestion and parking, besides the problems of pollution and energy waste.

3.1.5.2 Industrial Sources

Bengaluru has a long history of industrialization and even before 1926, the District gazetteer has recorded 46 industries which have grown to 426 large and medium scale industries in 1998-99. The concentration of the industries in and around Bengaluru City has also considerably increased in recent times.

Also the increase in the number of industrial layouts have risen from year to year with major additions from the electronic and manufacturing units at the industrial areas at White Field, Jigani Industrial Estate, Electronic City near Anekal, Bommasandra Industrial area, Bidadi Industrial area and Peenya Industrial Estate. The industrial growth in and around Bengaluru has naturally catalyzed more commercial activity and there by increased pollution. There are about 4,399 registered factories located in Bengaluru urban district, out of which about 4,015 factories are located in and around Bengaluru city alone. Out of these about 215 are coming under the category of industries involving hazardous processes.

3.1.5.3 Other Sources

Apart from vehicular and industrial sources, there are other sources which contribute to ambient air pollution. One of these sources is Diesel Generating Sets. Due to discontinuous power supply, there are large number of DG sets in commercial establishments and industries. These DG sets are a significant contributor of air pollutants.

The total pollution load in Bengaluru in 2007 was estimated to be 54.4 T/d for PM_{10}, 217.4 T/day for NOx and 14.6 T/day for SO_2. At the city level, the major sources of PM_{10} emissions are transport (42%), road dust resuspension (20%), construction activity (14%), industry (14%), and domestic (3%).likewise at city level, industry (56%),DG set (23%) and transport (16%) are the major sources.

3.2 LOCATION OF SAMPLING STATIONS

Air quality monitoring in the study pocket was carried out at 10 pockets covering residential, commercial, industrial, and sensitive/hospital areas. The geographical details of study pockets selected are shown in Table 3.3. The figure 3.2 depicts the location of these stations in the study area.

Table – 3.3 : Pockets Considered for Study

Station Code	Location of the Station	Category of Area	Latitude/ Longitude
A	Export Promotion Centre, White Field Industrial Area (Graphite India Ltd.,)	Industrial	12º, 58', 31.2'' N 77º, 42', 36.1'' E
B	KHB Industrial Area, Yelahanka	Industrial	13º, 6', 26.6'' N 77º, 34', 43.1''E
C	Yeshwanthapur Police Station	Other Areas (Commercial)	13º, 01', 4.8'' N 77º, 33', 35'' E
D	AMCO Batteries Mysore Road	Other Areas (Commercial)	12º, 57', 84'' N 77º, 32', 25.7'' E
E	Victorial Hospital, Bangalore	Other Areas	12º, 57', 47.2'' N 77º, 34', 30.3'' E
F	City Railway Station, Bangalore	Other Areas (Commercial)	12º, 58', 38.8'' N 77º, 34', 16.1'' E
G	Central Silk Board, Hosur Road	Other Areas (Commercial)	12°, 55' 00.7" N 77°,37' 19.2" E
G	Kazisummanahalli, White Field Road (Background Station)	Rural	13°, 02' 02.14" N 77°, 45' 53.12" E
I	TERI Office, Domlur	Residential	12°,41' 32.4" N 79°,37' 36.3" E
J	Banasavadi Police Station	Other Areas (Residential)	12°,59' 73" N 77°38' 19" E

In these pockets selected the location of sampling station was so selected that, the station is in the free atmosphere without interferences from stagnant spaces or large buildings etc. The following points were kept in mind while selecting the sampling stations.

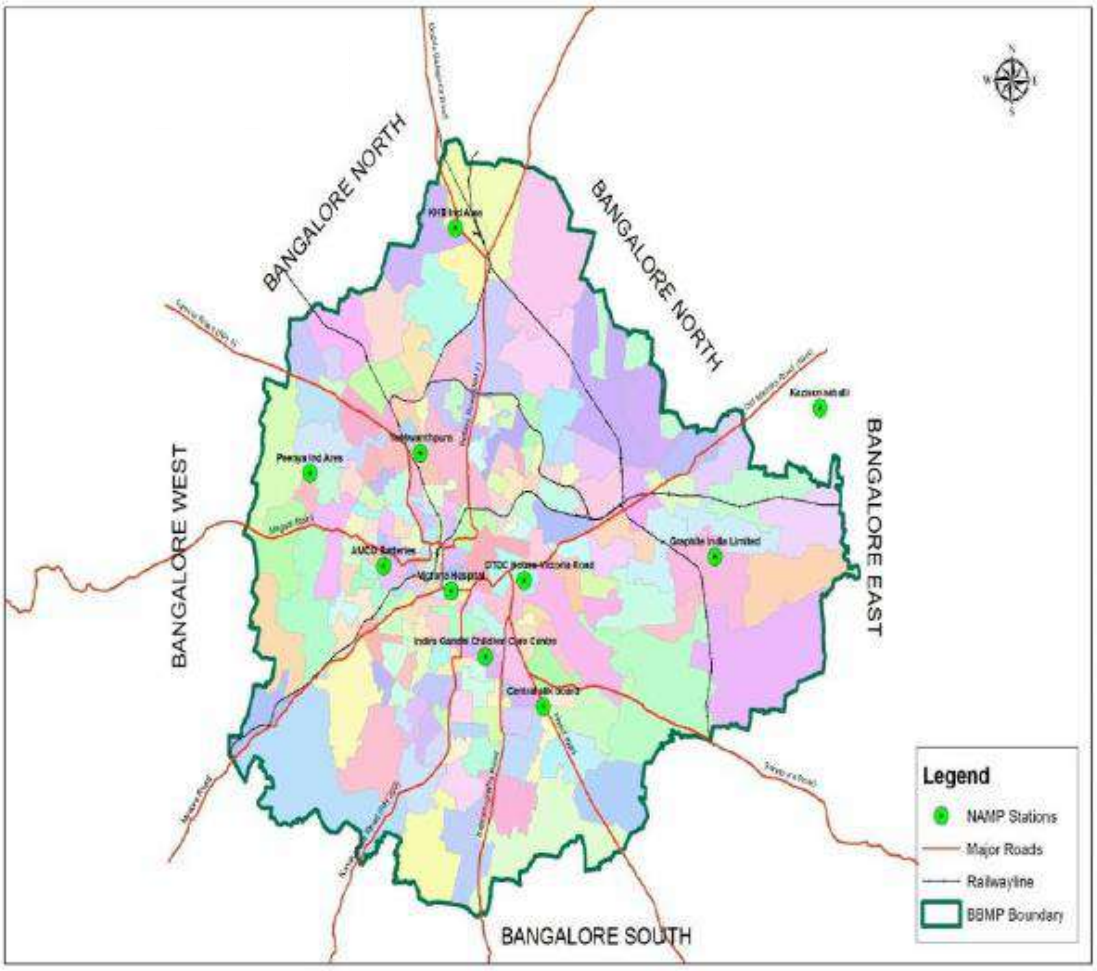


Fig. 3.2 Representative Sampling Stations Considered for Study

- The building where continuous power supply is readily available.
- Height of the equipment is between 310 m above the ground so as to obtain ambient air samples not affected by local polluting factors.
- Having easy accessibility but have security so as to avoid any tamponing.
- Having free exposure away from tall buildings and other obstructions so that free flow of air is not obstructed.

3.3 SALIENT FEATURES OF MONITORING . SAMPLING STATIONS

Export Promotion Cente, White Field – Industrial Area (Graphite India Ltd.)

Is mainly industrial area located at 12° 58' 31.2" N latitude, 77° 42’ 36.1" E longitude with pockets of residential areas in the vicinity. The locality saw huge amount of real estate activity in the recent years due to location of world renowned Software Technology Park (ITPL) in the locality.

KHB Industrial area is an industrial area inside Yelahanka New Town, near Solectron EMS India Limited. It is located at 13° 6' 26.6" N latitude & 77° 34' 43" E longitude. Important Roads: Doddaballapur Road. It is 1.6 km from Yelahanka New Town Bus Stand. As it is an industrial area contributing huge amount of pollution.

Yeshwanthpur located at 13° 01' 4.8" N latitude, 77° 33' 35" E longitude, is a residential area with industries and industrial suburbs, situated adjoining to Peenya industrial area. Yeshwanthpur Railway Station is the nearest station to-catch local trains. Airport is located 65km away. CV Raman Road, BEL Road and Tumkur Road are the major roads connecting Yeshwanthpur to rest of the city. As the commercial activity is high, resulting more number of vehicular populations.

AMCO Batteries Factory is mainly residential area located at 12° 57’ 84" N latitude, 77° 32’ 25.7”E longitude with pockets of small scale industries nearby. State highway #29 to Mysore passes beside the factory contributing to huge amount of vehicular population.

Victoria Hospital located at 12° 57' 47.2" N latitude, 77' 34' 30.3" E longitude. It is a sensitive area, hence more number of vehicles, resulting in huge amount of vehicular pollution.

It is located in the hub of the city and is easily accessible. This is a teaching hospital and is attached to Bangalore Medical College and Research Institute, which is one of the premier Medical Colleges of India.

City railway station:

City Railway Station is a place mark, situated in Bangalore Urban at 12° 58' 38.76" N latitude, 77° 34' 16.1" E longitude and it is a residential & other area. As the population is high, due to large transportation and commercial activity causing high vehicular pollution.

Central Silk Board:

Silk Board junction and Whitefield are the most polluted areas in Bengaluru. At Silk Board and Whitefield, though, it's traffic congestion that is to blame for the high levels of pollution. Silk Board is the gateway to the IT corridors of Marathahalli, Whitefield and Sarjapur in one direction and Electronics City on the other.

Kazisumnanahalli (Background Station):

This is far away from traffic area located in the village background at 13°, 02',14" N latitude, 77°, 45', 53.12" E longitude and has relatively clear atmosphere.

TERI office:

The Southern Regional Centre was setup in Bengaluru in 1990 with the primary objective to promote concepts and practices for improving industrial energy efficiency through a concerted programme of research, consultancy, training, and information dissemination.

3.4 PARAMETER MONITORED

The significant parameters identified for the study include particulate matter (PM_{10}), oxides of nitrogen (NO_X as NO_2) and sulphur dioxide (SO_2).

3.5 STUDY PERIOD

Study period was 2011 to 2015 consisting of 3 seasons in a year.

3.6 SAMPLING METHOD ADOPTED

At 10 pockets selected for study Air Quality Monitoring was carried out regularly twice a month, 24 hours a day using manual equipment's.

3.7 EXPERIMENTAL PROGRAMME

3.7.1 Sampling and Analysis of SO_2 in Ambient Air (improved West and Geake Method)

3.7.1.1 Standard

The Revised Ambient Air Quality Standards (MOEF Notification G.S.R 826(E) dated 16.11.2009) for sulphur dioxide is presented in the table 3.4.

Table 3.4 : Standards for Sulphur-dioxide

Pollutant	Time Weighted average	Concentration in Ambient Air	
Sulphur Dioxide (SO_2), µg/m^3		Industrial, Residential, Rural and other areas	Ecologically sensitive area (Notified by central government)
	Annual	50	20
	24 Hours	80	80

3.7.1.2 Instrument/Equipment

The following items are necessary to perform the monitoring and analysis of Sulphur Dioxide in ambient air.

- **Vacuum pump :** Capable of maintaining an air pressure differential greater than 0.7 atmospheres at the desired flow rate.
- **Calibrated flow:** Measuring device to control the airflow from 0.2 to 1 1/min.
- **Absorber :** All glass midgets impinge.
- **Spectrophotometer :**Capable of measuring absorbance at 560nm equipped with l cm path length cells.
- **Glass wares :** Low actinic glassware must be used for analysis.

3.7.1.3 Principle

Modified West & Geake Method (IS 5182 Part 2 Method of Measurement of Air Pollution: Sulphur dioxide) is used to measure Sulphur dioxide. Air is absorbed in a solution of potassium tetrachloromercurate (TCM) and forms a dichlorosulphitomercurate complex, which resists oxidation by the oxygen in the air. Once formed, this complex is stable to strong oxidants such as ozone and oxides of nitrogen and therefore, the absorber solution may be stored for some time prior to analysis. The complex is made to react with para-rosaniline and formaldehyde to form the intensely colored pararosaniline methylsulphonic acid. The absorbance of the solution is measured by means of spectrophotometer at 560nm.

3.7.1.4 Sampling and Analysis

SO_2 was collected by bubbling air through 30 ml of absorbing solution in an impinger and sample for four hours at the flow rate of l L/min, Stable solution of nitrate solution was formed in this process so after sampling measured the volume of sample and transferred to a sample storage bottle.

During sampling any water lost by evaporation, in the laboratory were made up to 30 ml by adding additional absorbing medium and adjusted to 30 ml mark, by pipetting out 10 ml of the collected sample into a 25 ml volumetric flask, 1 ml of 0.6 sulphamic acid was added and allowed to react for 10 minutes to destroy the nitrite resulting from oxides of nitrogen ,and 2ml of 0.2% formaldehyde solution and 2 ml pararosaniline solution were added to make up to 25ml with distilled water, and blank also Prepared in the same manner using 10ml of unexposed absorbing reagent. After allowing for 3min, a color developed before 60minutes, the absorbance of samples and reagent blank at 560 nm were measured and recorded. For optical reference distilled water was used as blank.

3.7.1.5 Calibration using Standard Curve

By Plotting a curve of absorbance (Y axis) versus concentration (X axis) a line can be drawn to best fit and the slope can be determined. The reciprocal of slope gives the calibration factor (CF).

3.7.1.6 Calculation

$$\mathbf{C\ (SO_2\ \mu g/m^3) = (A_s - A_b)\ x\ CF\ x\ VJ\ V_a\ x\ V_t}$$

Where,

C (SO_2) = Concentration of Sulphur Dioxide, µg/m

A_s = Absorbance of sample

A_b = Absorbance of reagent blank

CF = Calibration factor

V_a = Volume of air sampled, m

V_s = Volume of sample, ml

V_t = Volume of aliquot taken for analysis, ml

3.7.2 Sampling and Analysis of Nitrogen Dioxide in Ambient Air (Modified Jacob and Hochheiser Method)

3.7.2.1 Standard

The Revised Ambient Air Quality Standards (MOEF Notification G.S.R 826(E) dated 16.11.2009) for Nitrogen dioxide is presented in the Table 3.5

Table 3.5 : Standards for Nitrogen Dioxide

Pollutant	Time Weighted average	Concentration in Ambient Air	
Nitrogen Dioxide (NO_2), µg/m^3		Industrial, Residential, Rural and other areas	Ecologically sensitive area (Notified by central government)
	Annual	40	30
	24 Hours	80	80

3.7.2.2 Instrument/Equipment

The following items are necessary to perform the monitoring and analysis of nitrogen dioxide in ambient air.

- **Analytical balance**
- **Vacuum pump :** Capable of maintaining a vacuum of at least 0.6 atmospheres across the flow control device flow control device capable of maintaining a constant flow through the sampling 200-1000 ml per minute Solution. To control the airflow from 0.2 to 1 1/min. A midget impinge. Capable of measuring absorbance at 540 nm equipped with 1cm path length cell. :- Low actinic glassware must be used for analysis.
- **Calibrated Measuring device**
- **Absorber**
- **Spectrophotometer**
- **Glass wares**

3.7.2.3 Principle

Ambient Nitrogen Dioxide (NO_2) is collected by bubbling air through a solution of sodium hydroxide and sodium arsenate. The concentration of nitrite ion (NO_2) produced during sampling is determined calorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(l-naphthyl)-Ethylenediamine-Di-Hydrochloride (NEDA) and measuring the absorbance of highly colored Azo-Dye solution by means of spectrophotometer at 540 nm.

3.7.2.4 Sampling and Analysis

NO_2 was collected by bubbling air through 30 ml of absorbing solution in an impinger and sampled for four hours at the flow rate of 0.2 to 1 L/min. After sampling, measure the volume of sample and transfer to a sample storage bottle.

During sampling any water lost by evaporation should be made up by adding distilled water up to the calibration mark on the absorber, mixed thoroughly, and Pipette out 10 ml of the collected sample into a 50 ml volumetric flask. Pipette 1 ml of hydrogen peroxide solution, 10 ml of sulphanilamide solution, and 1.4 ml of NED A

solution, with thorough mixing after the addition of each reagent and make up to 50 ml with distilled water. Prepare a blank in the same manner using 10 ml of unexposed absorbing reagent. After about 10 min, colour developments intervals, measured and recorded the absorbance of samples and reagent blank at 540 nm. Use distilled water (blank) as the optical reference.

3.7.2.4 Calibration using Standard Curve

A curve of absorbance (Y axis) versus concentration (X axis) was plotted and a line drawn to best fit which determines the slope. The reciprocal of slope gives the calibration factor (CF).

Calculation

$$\mathbf{C\ (NO_2\ ug/m^3) = (A, - A_b) \times CF \times VJ\ V_a \times V_t \times 0.82}$$

Where,

C (NO_2) = Concentration of Nitrogen dioxide, µg/m

A_s = Absorbance of sample

A_b = Absorbance of reagent blank

CF = Calibration factor

V_a = Volume of air sampled, m

V_s = Volume of sample, ml

V_t = Volume of aliquot taken for analysis, ml

0.82 = Sampling efficiency

3.7.3 Sampling and Analysis of RSPM in Ambient Air (Gravimetric Method)

3.7.3.1 Standard

The Revised Ambient Air Quality Standards (MOEF Notification G.S.R 826(E) dated 16.11.2009) for Particulate Matter (PM_{10}) is presented in the Table 3.6.

Table 3.6 : Standards for PM_{10}

Pollutant	Time Weighted average	Concentration in Ambient Air	
Particulate Matter, PM_{10} $\mu g/m^3$		Industrial, Residential, Rural and other areas	Ecologically sensitive area (Notified by central government)
	Annual	60	60
	24 Hours	100	100

3.7.3.2 Principle of the method

Air is drawn through a size-selective inlet and through a 20.3 X 25.4 cm (8 X 10 inch) filter at a flow rate, which is typically 1132 L/min. Particles with aerodynamic diameter less than the cut-point of the inlet are collected, by the filter. The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of PM_{10} in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

Calculation

$$\mathbf{C\ (RSPM) = (W_f - W_i) \times 10^6 / V}$$

Where,

C (RSPM) = Concentration of Respirable Suspended Particulate Matter µg/m.

W_f = Initial weight of filter in g

W_i = Initial weight of filter in g 10 = Conversion of g to µg

V = Volume of air sampled, m^3

3.8 METHODS ADOPTED FOR AQI CALCULATION

AQI can represent the overall air quality status in a better way since the cumulative effect of all the pollutants and the related standard can be taken into account. As a result an equation, which transforms the parameter values by means of numerical manipulation into a more simple and precise form can be obtained. The index of specific pollutant is derived mainly from the physical measurement of pollutants like SPM, RSPM, SO_2 and NO_X. There are several methods and equations used for determining the AQI. In the present study AQI for each location in the study area has been using NAQI prompted by USEPA and is based on a combination of different pollutant viz. SPM, SO_2, NO_2

$$AQI = \frac{1}{3}\left[\frac{(C_{RSPM})}{(S_{RSPM})} + \frac{(C_{so2})}{(S_{so2})} + \frac{(C_{NO2})}{(S_{NO2})}\right] x\ 100$$

Where,

C_{SO2} = Individual Values of sulphur dioxide

C_{NO2} = Individual values of oxides of nitrogen

C_{RSPM}= Individual values of Respirable suspended particulate matter and

S_{S02}, $S_{NOX,}$ and S_{RSPM} = Standards of ambient air quality of sulphur dioxide, oxides of nitrogen, Respirable suspended particulate matter respectively.

Where ‘C’ stands for observed calculated concentration and ‘S’ stands for standard concentration.

Rating scale of air quality index is shown in Table 3.7

Table 3.7 : Rating Scale of Air Quality Index

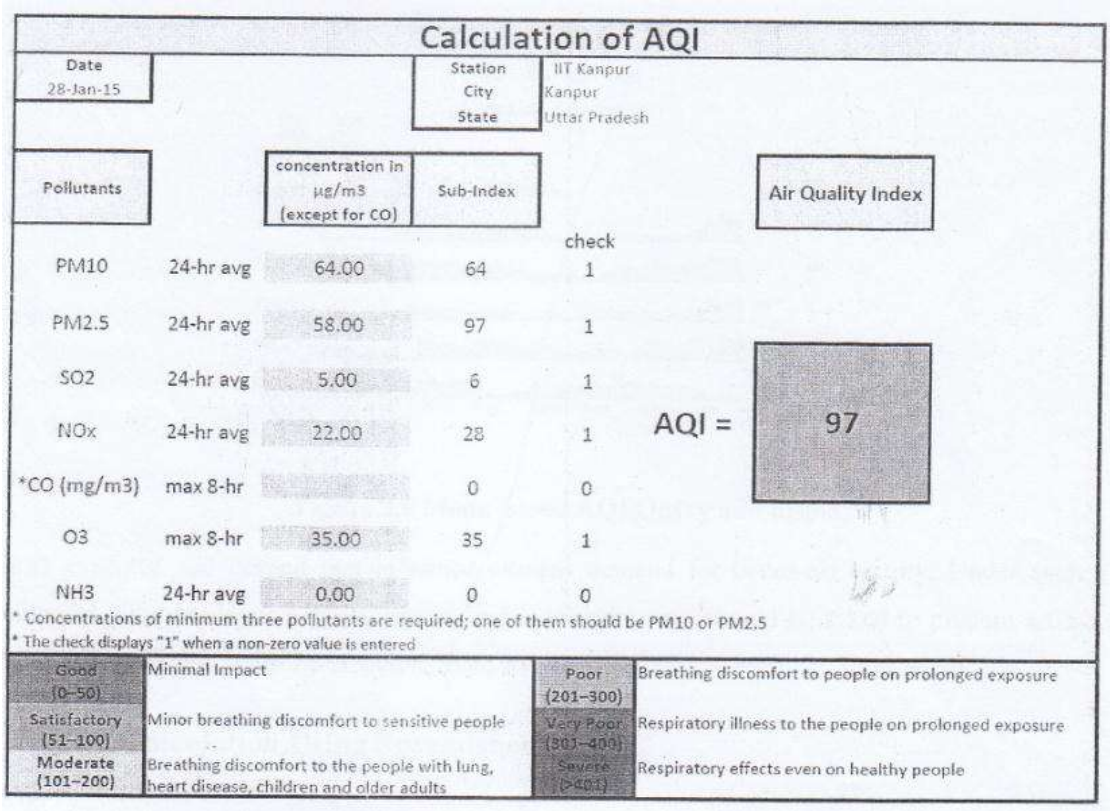
Index Value	Remarks	AQI and level of Health Concern
0-25	Clean air	The AQI is **Good**. The quality of air is good and hence no cautionary actions are needed.
26-50	Light air pollution	The AQI is **Acceptable**. The quality of air is slightly polluted and hence little care is to be taken.
51-75	Moderate air pollution	The AQI is **Unhealthy**. The quality of air is moderately polluted and it is not good for sensitive groups of people with asthma compounds.
76-100	Heavy air pollution	The AQI is **Very unhealthy**. The quality of air is highly polluted and hence major attention is required to avoid further increase.
>100	Severe air pollution	The AQI is **Hazardous**. The quality of air is severely polluted and it is very unhealthy to children, asthmatics and people suffering with bronchial disease.

- **"GOOD''** Air quality is considered satisfactory, indicating little or no risk, no cautionary actions are needed.
- **"ACCEPTABLE''** Air quality is acceptable; the quality of air is slightly polluted and hence health concern for a very small number of people who are unusually sensitive to air pollution.
- **"UNHEALTHY''** Members of sensitive groups may experience health effects. The general public is not likely to be affected.
- **"VERY UNHEALTHY"** Health warnings - Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects; the entire population is more likely to be affected.
- **"HAZARDOUS''** Health alert- everyone may experience more serious health effects like bronchitis, respiratory or cardiovascular problems, asthma attacks, etc.

3.9 AQI CALCULATION USING SPREAD SHEET XL

AQI for a particular day and at a desired location can be calculated using the MS Excel (Fig. 3.3), wherein a user friendly evaluation of AQI has been developed. The user needs to input at least three values of pollutant concentration (including at least one of PM_{10} or $PM_{2.5}$) in the blue cells and the sub-indices are calculated thus displaying the final AQI along with the colour signifying the AQI category. The health impacts corresponding to the AQI category are detailed in the legend at the bottom of the sheet. This XL program can be obtained from CPCB.

Overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either $PM_{2.5}$ or PM_{10}. Else, data are considered insufficient for calculating AQI. Similarly, a minimum of 16 hours' data is considered necessary for calculating subindex.



Calculation of AQI

Date 28-Jan-15		Station	IIT Kanpur	
		City	Kanpur	
		State	Uttar Pradesh	

Pollutants		concentration in µg/m3 (except for CO)	Sub-Index	check	Air Quality Index
PM10	24-hr avg	64.00	64	1	
PM2.5	24-hr avg	58.00	97	1	
SO2	24-hr avg	5.00	6	1	
NOx	24-hr avg	22.00	28	1	AQI = 97
*CO (mg/m3)	max 8-hr		0	0	
O3	max 8-hr	35.00	35	1	
NH3	24-hr avg	0.00	0	0	

* Concentrations of minimum three pollutants are required; one of them should be PM10 or PM2.5
* The check displays "1" when a non-zero value is entered

Good (0–50)	Minimal Impact	Poor (201–300)	Breathing discomfort to people on prolonged exposure
Satisfactory (51–100)	Minor breathing discomfort to sensitive people	Very Poor (301–400)	Respiratory illness to the people on prolonged exposure
Moderate (101–200)	Breathing discomfort to the people with lung, heart disease, children and older adults	Severe (>401)	Respiratory effects even on healthy people

Fig. 3.3 Spread Sheet for AQI Calculation (www.CPCB)

3.10 EXCEEDENCE FACTOR (EF) AND MAPPING USING GIS

Exceedence factor(EF) is calculated for each pollutant such as SO_2, NO_2 and RSPM for each station, and the air quality is expressed in terms of low, moderate, high and critical for various sites monitored. The concentration ranges for different levels have been assigned based on the Notified Standards for different pollutants and area classes by calculating an Exceedence Factor (the ratio of annual mean concentration of a pollutant with that of a respective standard). [KSPCB,2014] Rates scale for exceedence factor is shown in Table 3.8.

$$\text{Exceedence Factor} = \frac{\text{Observed annual mean concentration of a criteria pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

Table 3.8 : Air Quality Categories Based on Exceedence Factor.

Exceedence Factor Values	Color Code	Description
0.0 to 0.5	Green	Low pollution(L)
0.5 to 1.0	Blue	Moderate pollution(M)
1.0 to 1.5	Orange	High pollution(H)
1.5 & above	Red	Critical pollution(C)

3.11 COLLECTION OF METEOROLOGICAL DATA

Meteorological factors play an important role in determining ambient concentrations of air pollutants. It is essential to understand the correlation between meteorological factors and ambient air quality to correctly interpret the data and also to assess the effect of various pollution control measures on ambient air quality. Meteorological information is, thus, very essential in locating the industry and planning control measures for air pollution. The ambient air quality is not only influenced by the rate at which pollutants are released but also by certain physical parameters like meteorological conditions, wind speeds and direction, temperature, humidity etc. which influence the concentration of pollutants by dispersion or diffusion. Bangalore is endowed with a very salubrious and equable climate and hence

classified as seasonally dry tropical sravanna climate with three seasons. Winter-season from November to February. The summer season is from March to June which is followed by south-west monsoon season from July to October. The Meteorological data needed was collected from Indian Meteorological Department, Bangalore.

3.12 VEHICULAR TRAFFIC

The assessment of traffic impact on air quality is necessary for the rapidly developing city of Bangalore. Thus vehicular traffic data in relation to the study pockets selected was collected from transportation department.

Fig.3.4 reflects the process flow diagram of overall methodology.

Monitoring instrument placed at sampling stations (specimen) and other details are shown in Plates 3.1 to 3.4

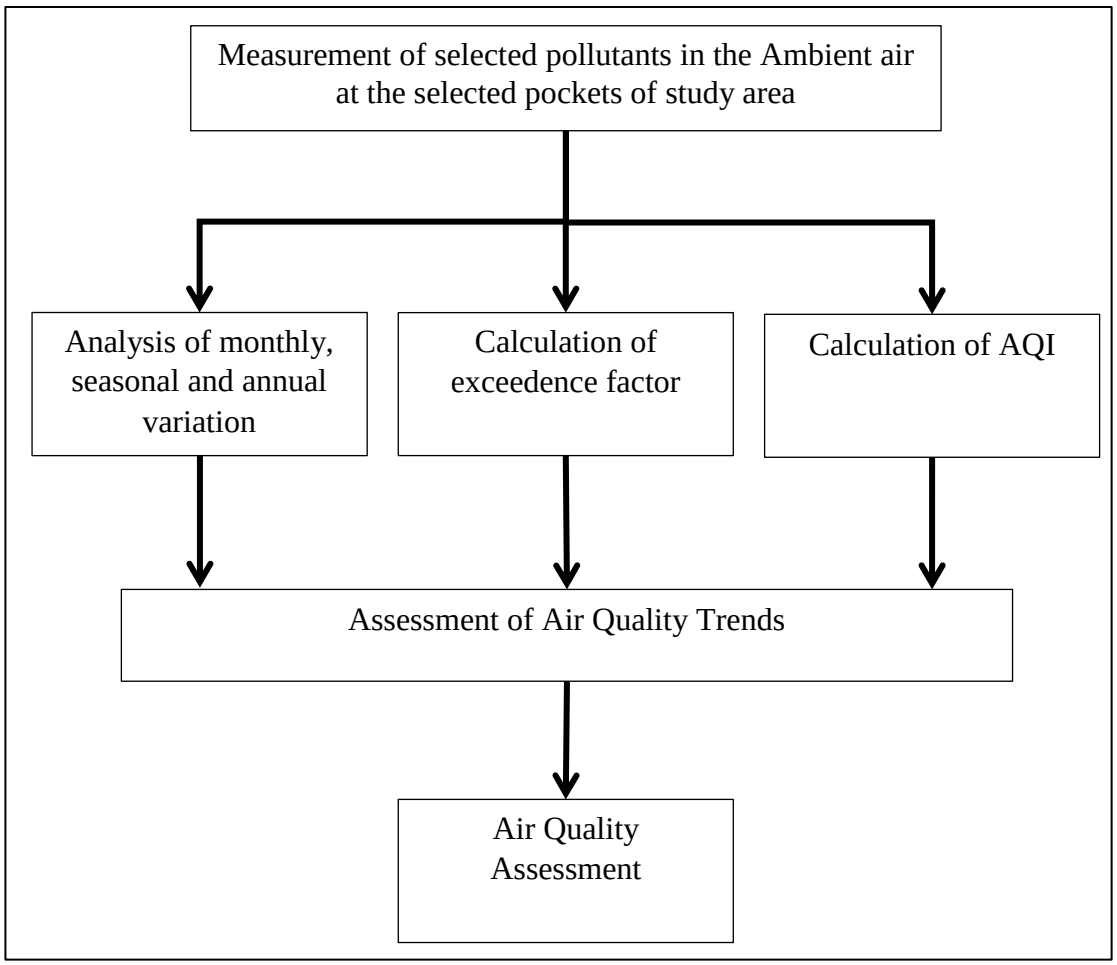


Fig. 3.4 Process Flow Diagram of Overall Methodology

Amco Batteries, Mysore Rd, B'lore

KHB Colony, B'lore

Kajisonnenahalli, B'lore

Terri Office, B'lore

Plate 3.1 Ambient Air Quality Monitoring at Representative Stations

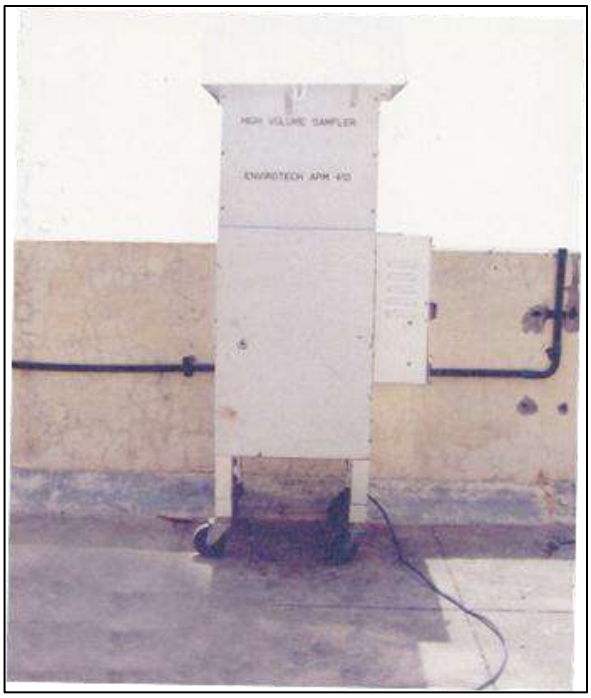


Plate 3.2 Pictorial view of High Volume Air Sampler

Plate 3.3 View of Gas Collection Arrangement on High Volume Air Sampler

Plate 3.4 Monitoring process in progress

CHAPTER - IV

RESULTS AND DISCUSSIONS

CHAPTER - IV

RESULTS AND DISCUSSION

Ambient air quality at selected ten pockets in the study area, Bangalore was monitored as per the standard procedures, documented in the Chapter-III. Accordingly monthly, seasonal and annual concentrations of pollutants monitored are tabulated and also represented graphically. Based on the concentrations of pollutants recorded, monthly, annual and seasonal AQIs were determined. Exceedence factor was also calculated. Inferences were drawn based on the analysis of observations and calculations made. In this chapter observations recorded, calculations made and inferences drawn are documented.

4.1. AIR QUALITY STATUS AT POCKET : A (Whitefield Industrial Area)

Average monthly concentration of pollutants considered for the present study, measured during the study period from 2011 to 2015 and thus monthly AQIs calculated are presented in Tables 4.1 to 4.5. Further the Tables 4.6 to 4.11 depicts the seasonal and annual variation of pollutants and AQIs at the monitoring station 'A'. Annual AQIs trends of monthly variations of PM_{10} at all the study pockets are shown in figs. 4.1 to 4.12. fig.4.13 depicts the monthly variation of SO_2 during the study period at this station. Further the variation of NO_2 at various study pockets in different years (2011 to 2015) and in 12 months of a year are graphically represented in the fig. 4.14 to 4.25. Bar charts (fig. 4.26 to 4.40) throws light on variation trends of AQIs for 3 seasons during different years of study periods at ten stations monitored. Also the bar charts (fig. 4.41 to 4.45) depicts the annual AQIs calculated for all the stations monitored.

Based on the analysis of results the followings inferences were drawn :

- During the study period, the calculated AQI values at this station 'A' were found to vary from 43 to 341.
- AQI trends indicated the increase in ambient air pollution from year to year (2011 to 2014). In 2015 the air pollution slightly less than that in 2015 was observed.

- During more than 86% of the months the severe air pollution (AQI more than 100) at this study pocket has been recorded. During remaining 14% of the months moderate (AQI: 51 to 75) to heavy air pollution (AQI: 76 to 100) has been recorded.
- PM_{10} concentration (97% of the observed values) exceeding the permissible value (many a times 4 times more than the permissible limit) has been recorded.
- Amongst the total AQI values documented in the Table 4.1 to 4.5, 33% of values were fond the exceed 150 (1.5 times the severe air pollution value).
- Seasonal AQI values documented in the Table 4.6 to 4.10 clearly indicated the severe air pollution during 2012, 2013, 2014 and 2015. Only during 2011 the air pollution of intensity heavy to severe was observed.
- In general maximum air pollution was observed during the winter season followed by summer and monsoon season.
- Maximum seasonal AQIs recorded during winter, summer and monsoon were found to be respectively 197, 164 and 135. Accordingly the minimum values were 137, 80 and 76 respectively.
- In any season considered, during the study period, the PM_{10} concentration more than the permissible concentration was observed.
- Further the annual AQIs from 2011 to 2015 confirmed the severity of air pollution in the study pocket 'A'. AQIs varying from 107 to 175 speaks that the pocket is affected by severe air pollution.

Thus, based on monthly, seasonal and annual AQIs, it was inferred that the quality of the ambient air in this pocket 'A' has been deteriorated considerably.

Table – 4.1 : Monthly Air Quality Data / Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	246	16.7	30.3	197	197	21	38
February	-	-	-	-	-	-	-
March	154	20.5	30.1	136	136	26	38
April	40	46	40.6	58	40	58	51
May	59	31.0	44.0	59	59	39	55
June	65	13	32	65	65	16	40
July	105	21.2	29.5	103	103	27	37
August	87	16.4	30.8	87	87	21	39
September	-	-	-	-	-	-	-
October	35	18.7	34.6	43	35	23	43
November	157	16.9	30.6	138	138	21	38
December	107	17.3	31.1	105	105	22	39

Table – 4.2 : Monthly Air Quality Data / Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	100	17.7	31.0	100	100	22	39
February	108	16.9	30.5	105	105	21	38
March	141	17.8	30.0	127	127	22	38
April	61	13.7	32.0	61	61	17	40
May	122	15.0	30.7	115	115	19	38
June	242	18.0	32.0	195	135	23	40
July	117	17.2	31.0	111	111	22	39
August	150	15.5	27.3	133	133	19	34
September	215	15.6	29.6	177	177	20	37
October	125	15.4	30.7	117	117	19	38
November	186	16.0	31.9	157	157	20	40
December	166	15.2	30.0	144	144	19	38

Table – 4.3 : Monthly Air Quality Data / Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	169	16	31	146	146	30	39
February	153	17	30	139	139	21	38
March	188	16	30	159	159	20	38
April	110	14	29	107	107	18	36
May	156	15	30	137	137	19	38
June	98	15	30	98	98	19	38
July	80	15	29	80	80	19	36
August	102	14	26	101	101	18	33
September	120	13	28	113	113	16	35
October	182	16	30	159	159	20	38
November	135	18	33	123	123	23	41
December	160	16	30	140	140	20	38

Table – 4.4 : Monthly Air Quality Data / Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	141	14	30	127	127	18	38
February	143	15	29	129	129	19	36
March	188	16	30	159	159	20	38
April	219	16.8	30.8	179	179	21	39
May	181	14.1	29.8	154	154	18	37
June	196	13	29	164	164	16	36
July	128	12.8	29.0	119	119	16	36
August	174	14	29.6	149	149	18	37
September	120	12.7	28.2	113	113	16	35
October	383	15.1	33.3	341	341	19	42
November	327	19	66.5	277	277	24	83
December	372	11.5	27.8	328	328	14	34

Table – 4.5 : Monthly Air Quality Data / Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	260	6.7	35.8	210	210	8	45
February	201	6.1	35.2	167	167	8	44
March	195	6.1	26.8	163	163	8	34
April	243	6.1	24	195	195	8	30
May	204	5.8	18.6	169	169	7	23
June	119	5.8	17.4	113	113	7	22
July	99	5.5	15.7	99	99	7	20
August	114	5.1	14.1	109	109	6	18
September	159	5.3	13.8	139	139	7	17
October	169	2.2	12.9	146	146	3	16
November	140	2.0	21.4	127	127	3	27
December	275	2.0	22.9	225	225	3	29

Table – 4.6 : Seasonal Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	170	17	30.7	147	147	21	38
Summer (Mar to Jun)	79.5	27.6	36.7	80	80	35	46
Monsoon (July to Oct)	75.7	19	31.6	76	76	24	40

Table – 4.7 : Seasonal Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	140	16.5	31.0	127	127	21	39
Summer (Mar to Jun)	141.5	16.0	31.2	128	128	20	39
Monsoon (July to Oct)	151.8	16.0	29.7	135	135	20	37

Table – 4.8 : Seasonal Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	155.8	16.8	31	137	137	21	39
Summer (Mar to Jun)	138	15	29.8	125	125	19	37
Monsoon (July to Oct)	122.8	14.5	28.3	115	115	18	35

Table – 4.9 : Seasonal Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	245.8	15	38.3	197	197	19	48
Summer (Mar to Jun)	196	12.5	30.0	164	164	16	38
Monsoon (July to Oct)	201.3	13.7	29.9	168	168	17	37

Table – 4.10 : Seasonal Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	219	4.2	28.8	179	179	5	36
Summer (Mar to Jun)	190.3	6.0	21.7	160	160	8	27
Monsoon (July to Oct)	135.3	4.5	14.1	124	124	6	18

Table – 4.11 : Yearly Air Quality Indices for the Study Pocket:

Export Promotional Park ITPL

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	110	21.8	33.40	107	107	27	42
2012	144.4	16.2	30.60	130	130	20	38
2013	138.8	15.4	29.7	126	126	19	37
2014	211.9	14.5	37.7	175	175	18	41
2015	181.5	4.9	21.6	154	154	6	27

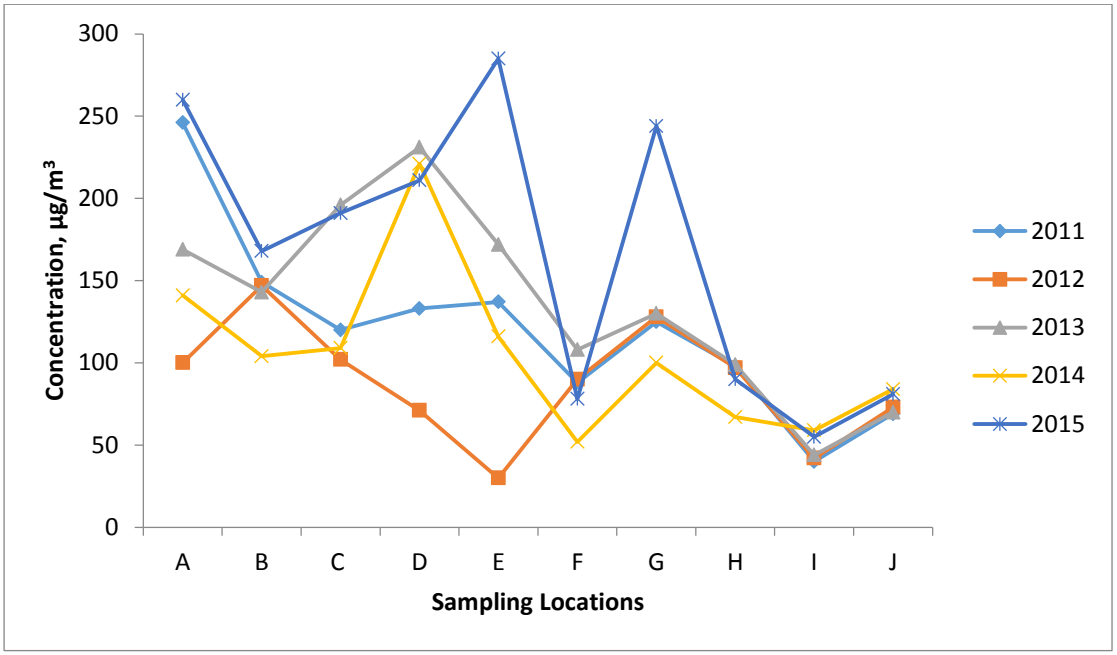


Fig. 4.1 : Variation of PM_{10} at Various Locations (Month : January)

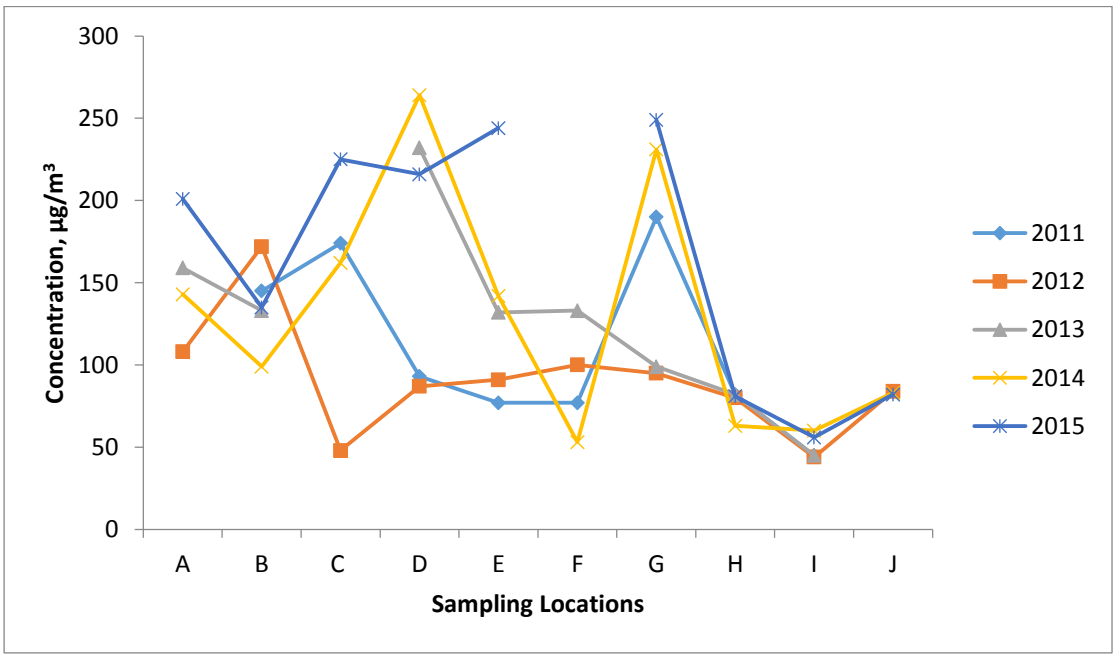


Fig. 4.2 : Variation of PM_{10} at Various Locations (Month : February)

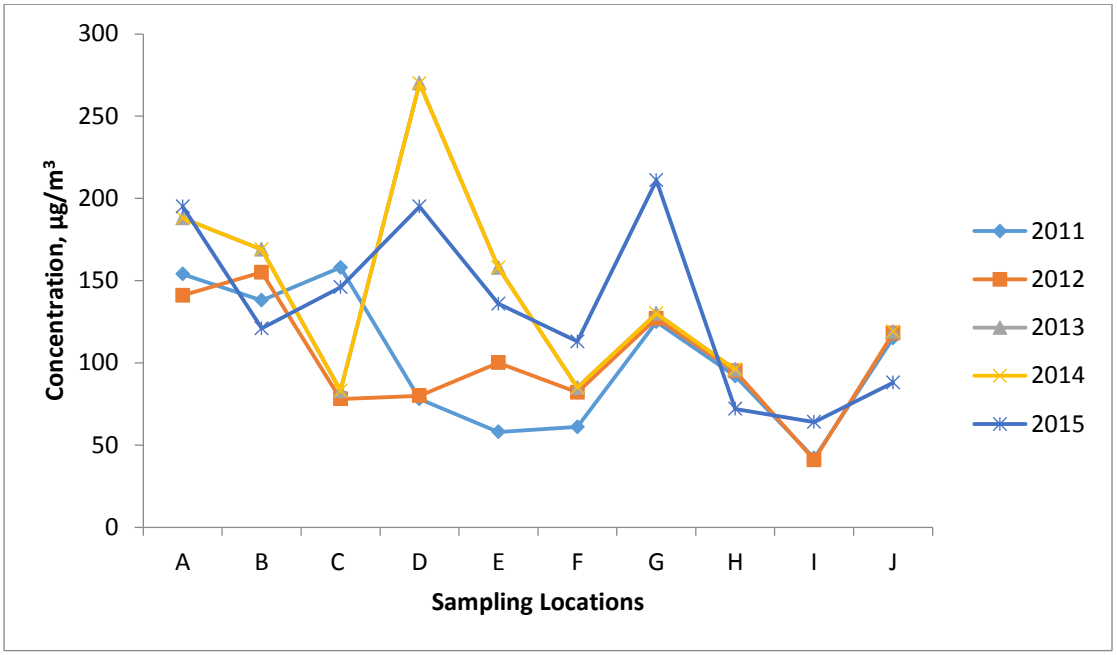


Fig. 4,3 : Variation of PM_{10} at Various Locations (Month : March)

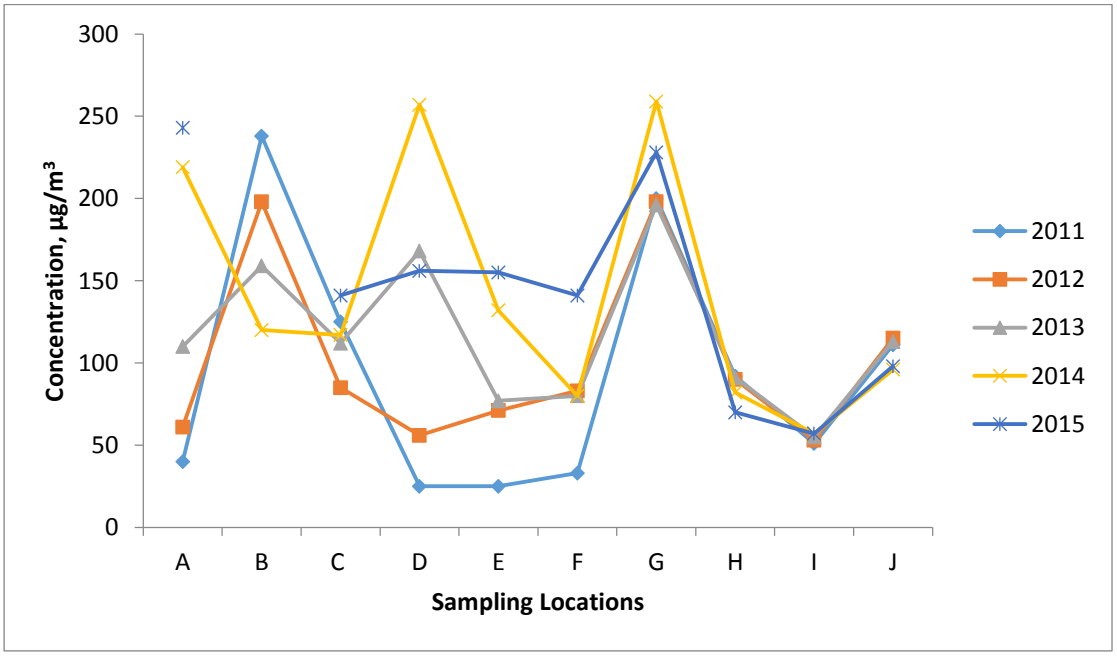


Fig. 4.4 : Variation of PM_{10} at Various Locations (Month : April)

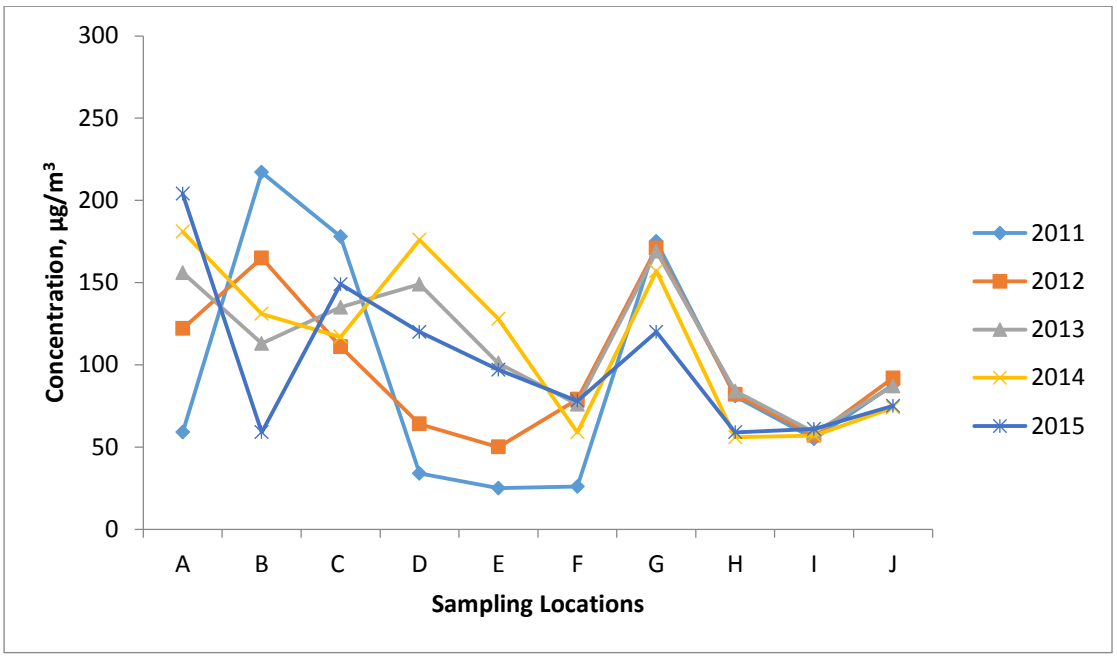


Fig. 4.5 : Variation of PM_{10} at Various Locations (Month : May)

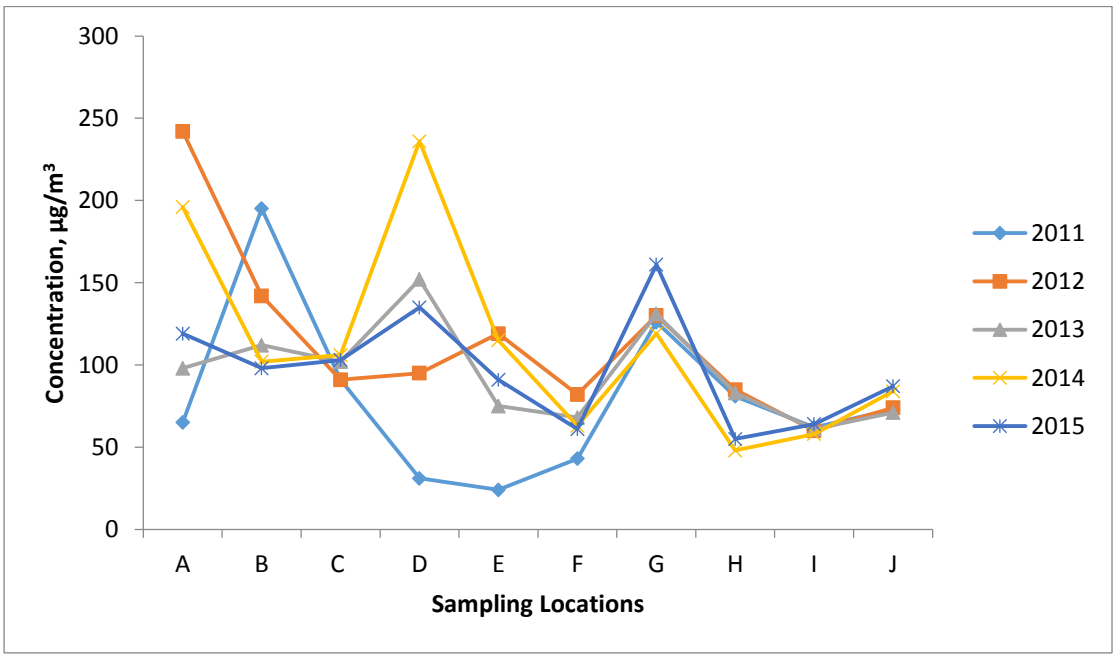


Fig. 4.6 : Variation of PM_{10} at Various Locations (Month : June)

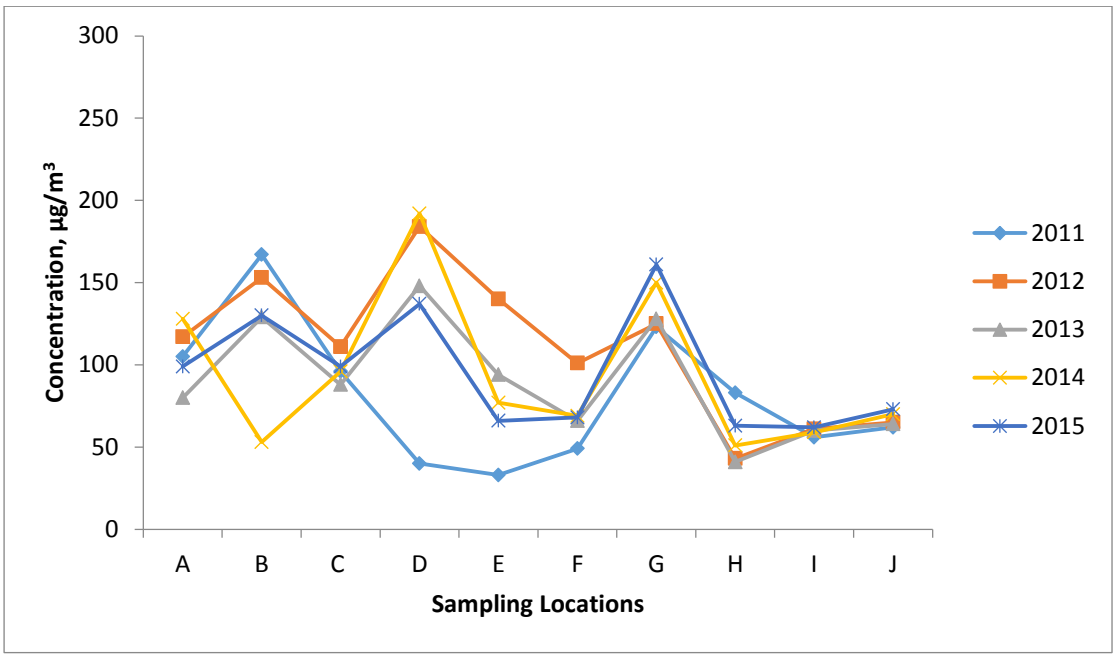


Fig. 4.7 : Variation of PM_{10} at Various Locations (Month : July)

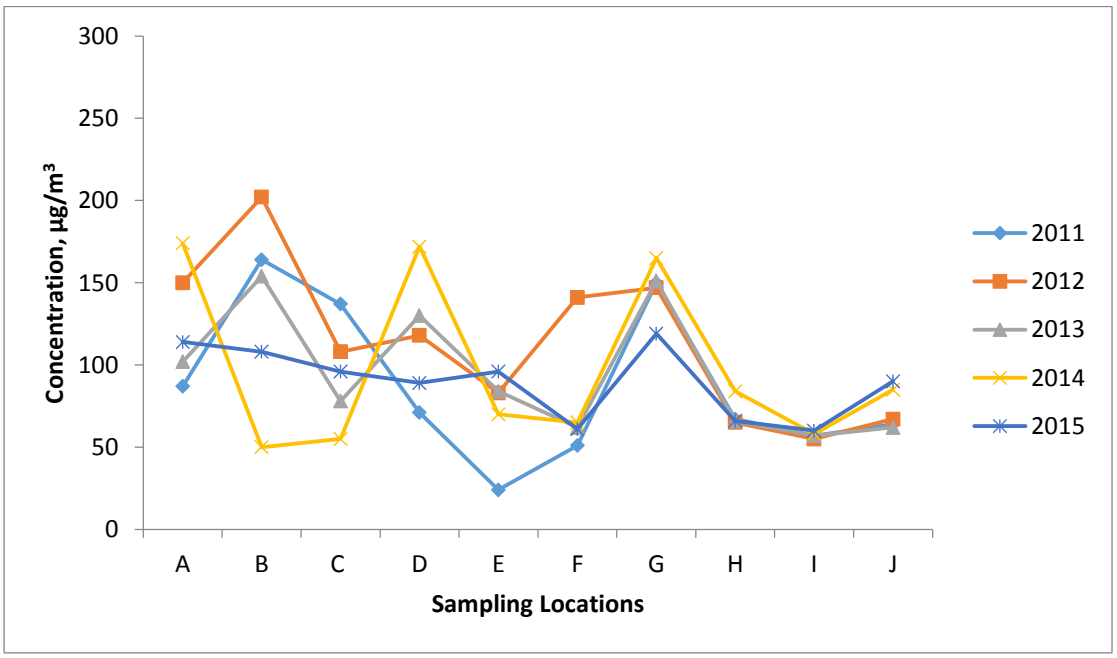


Fig. 4.8 : Variation of PM_{10} at Various Locations (Month : August)

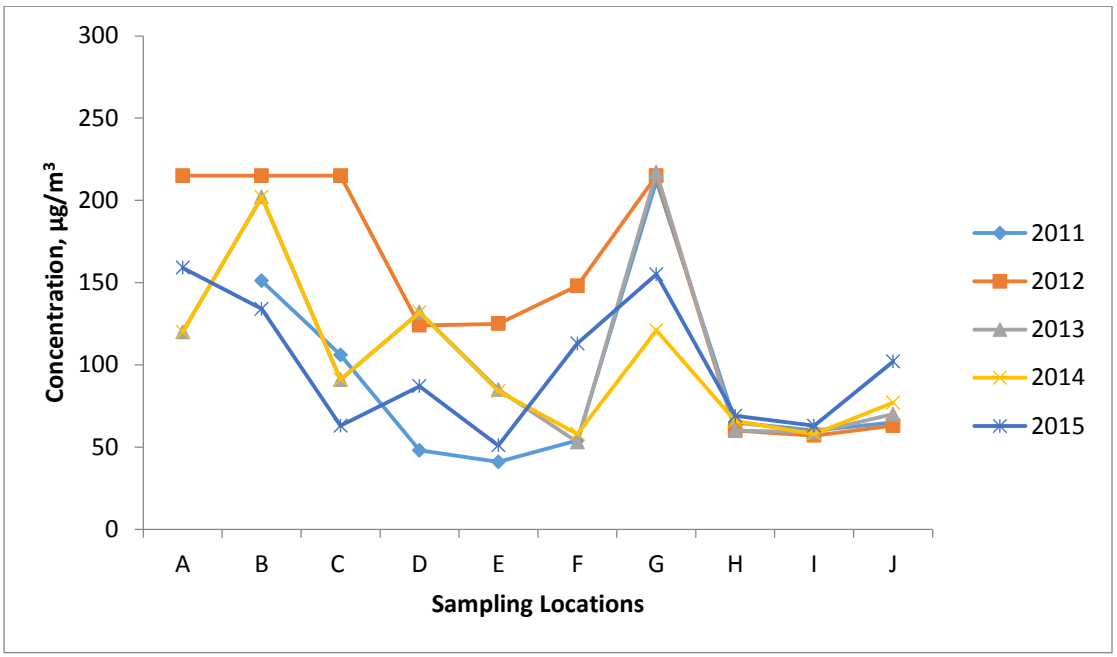


Fig. 4.9 : Variation of PM_{10} at Various Locations (Month : September)

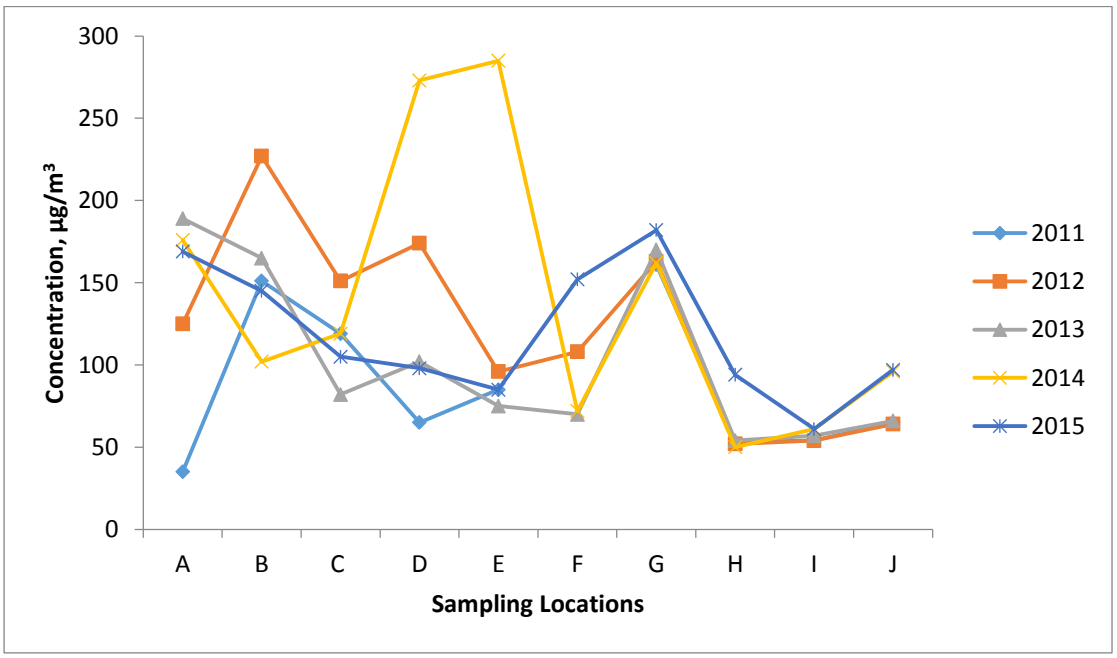


Fig. 4.10 : Variation of PM_{10} at Various Locations (Month : October)

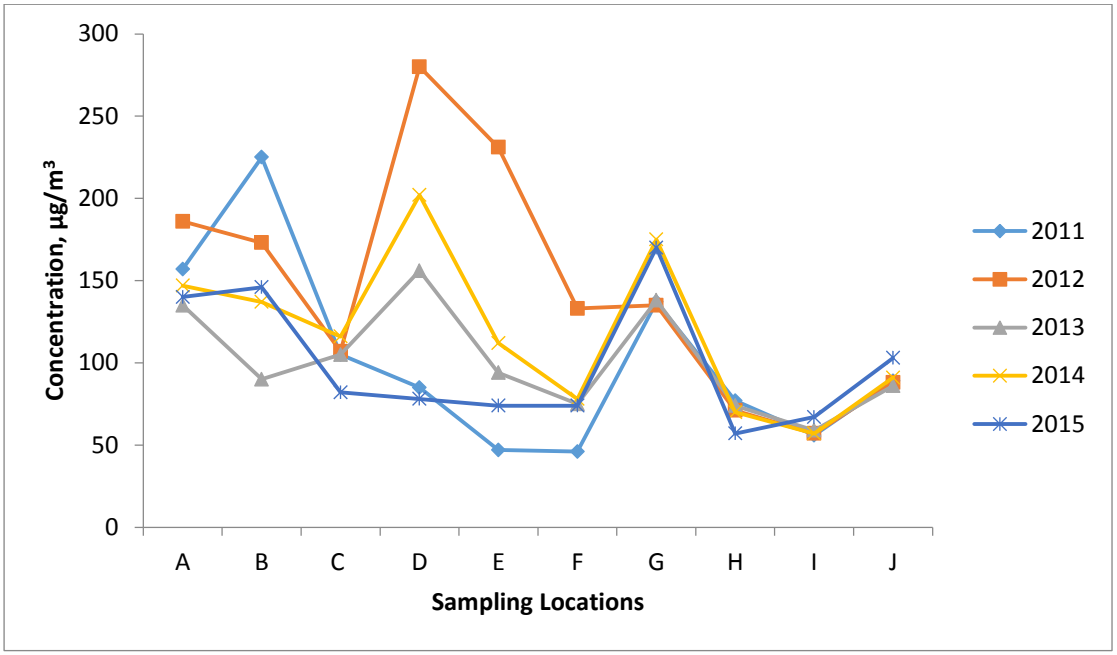


Fig. 4.11 : Variation of PM_{10} at Various Locations (Month : November)

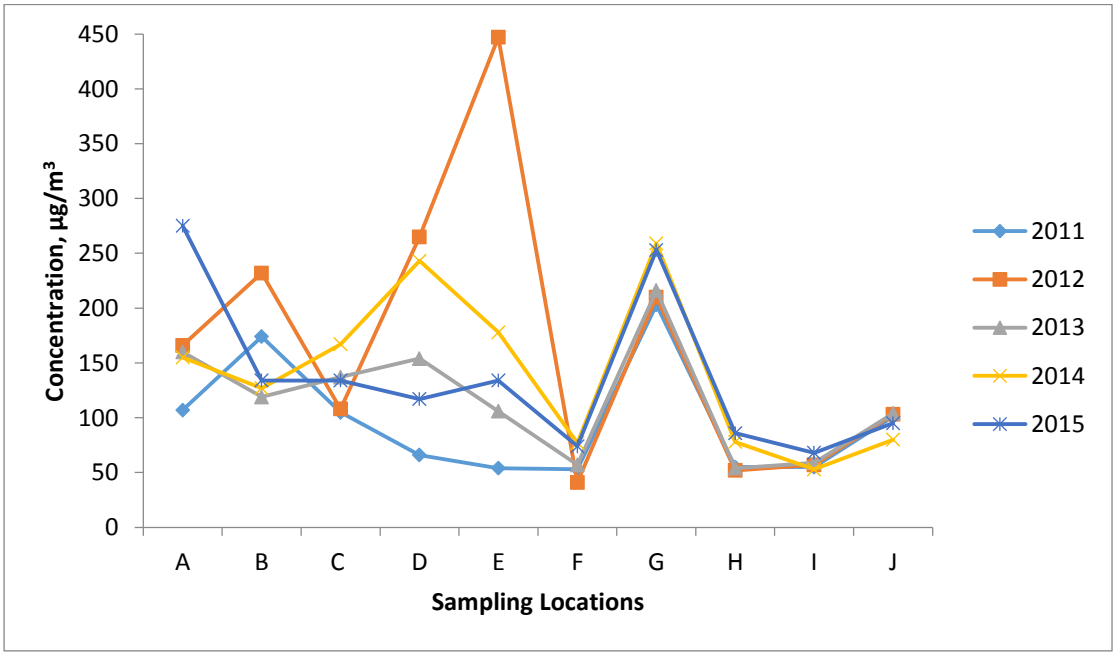


Fig. 4.12: Variation of PM_{10} at Various Locations (Month : December)

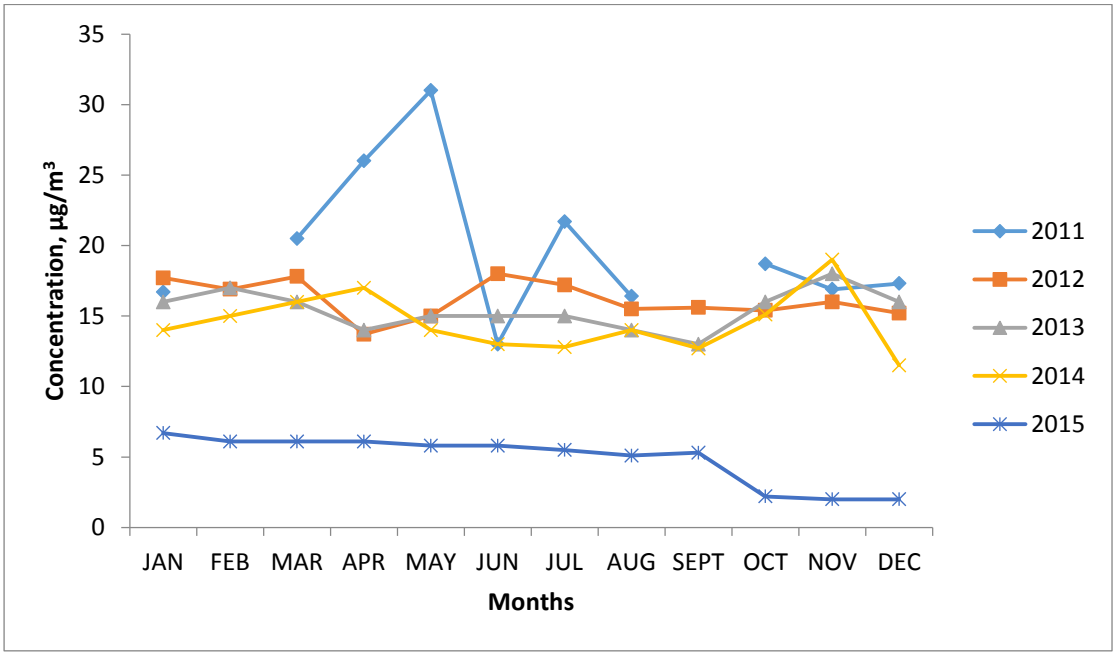


Fig. 4.13 : Monthly Variation of SO_2 During the Study Period (Station : A)

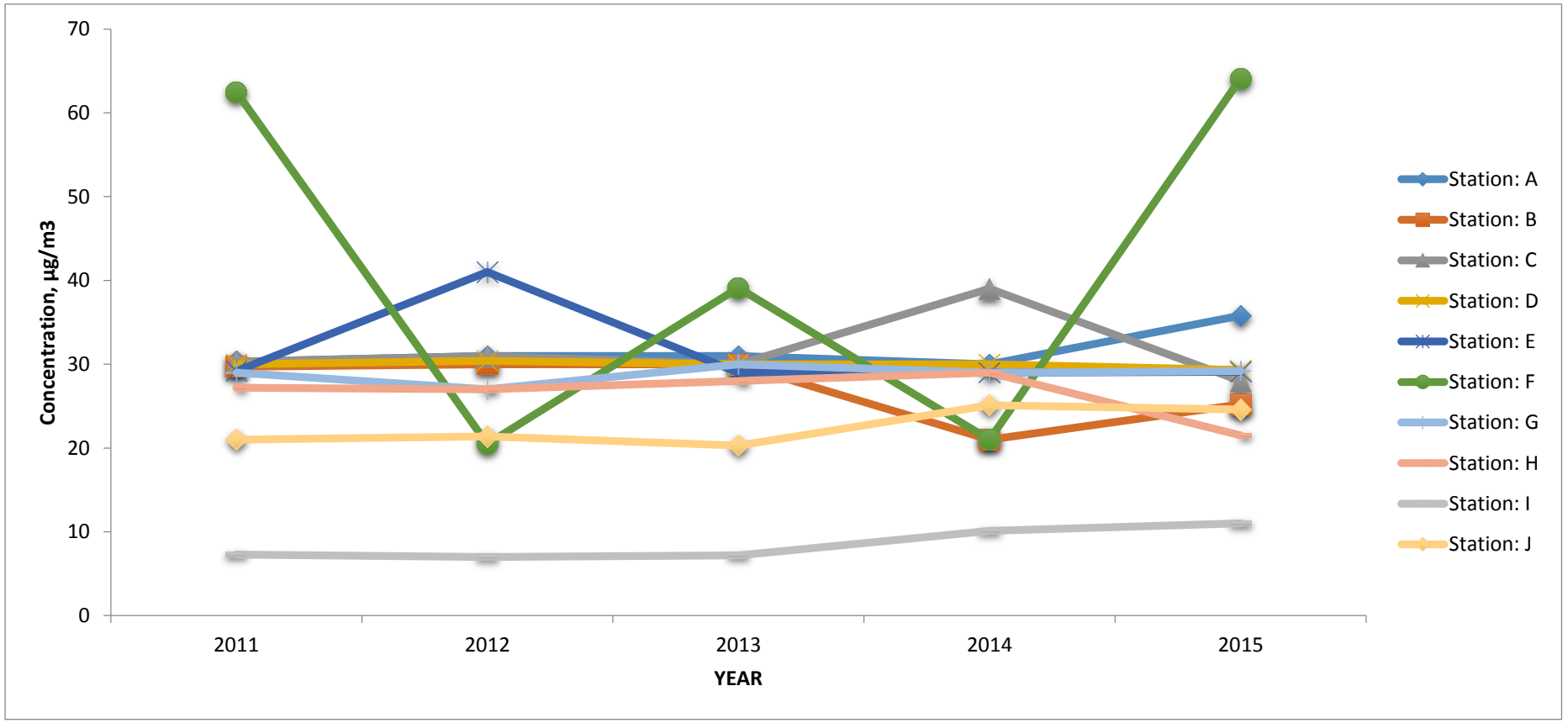


Fig. 4.14 : Variation of NO_2 During the Study Period at Sampling Stations (Month: January)

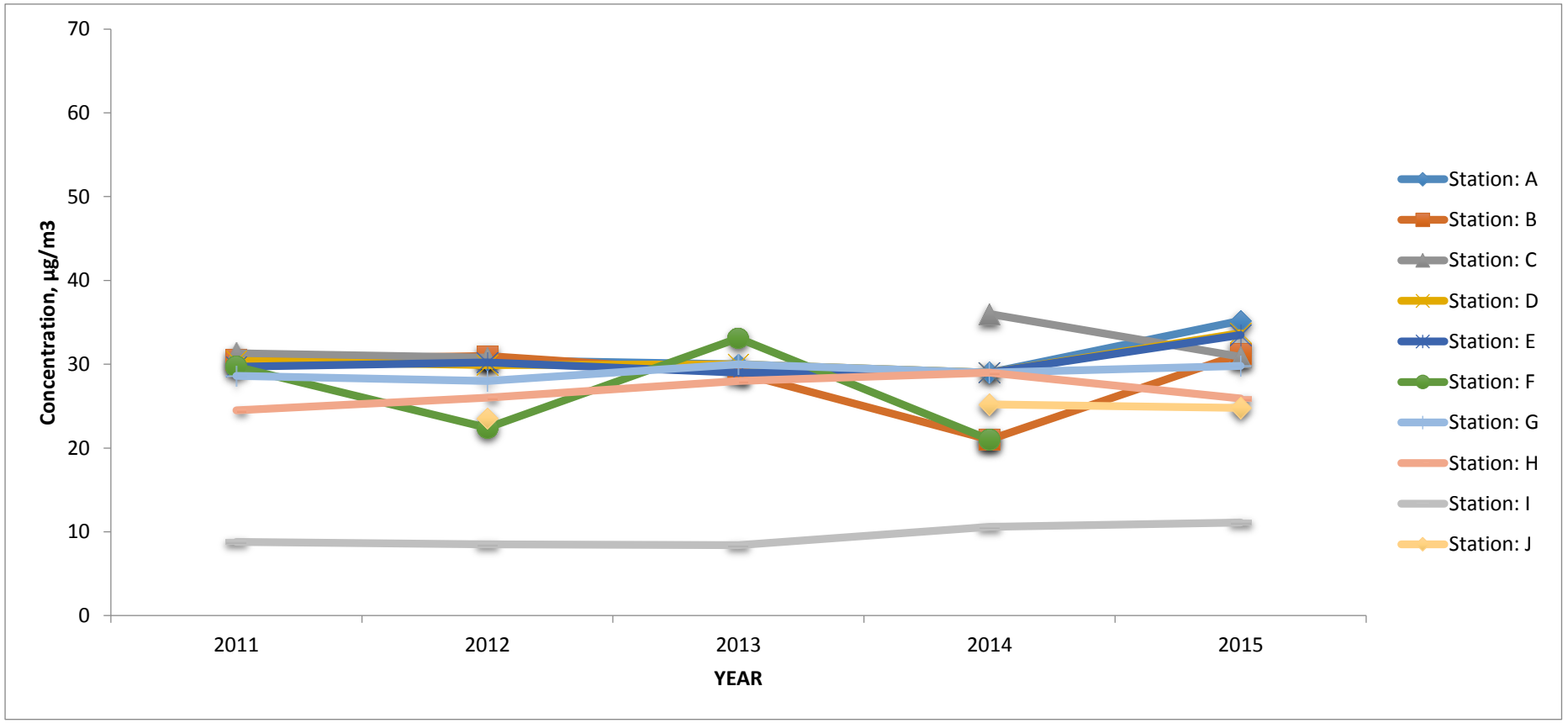


Fig. 4.15 : Variation of NO_2 During the Study Period at Sampling Stations (Month: February)

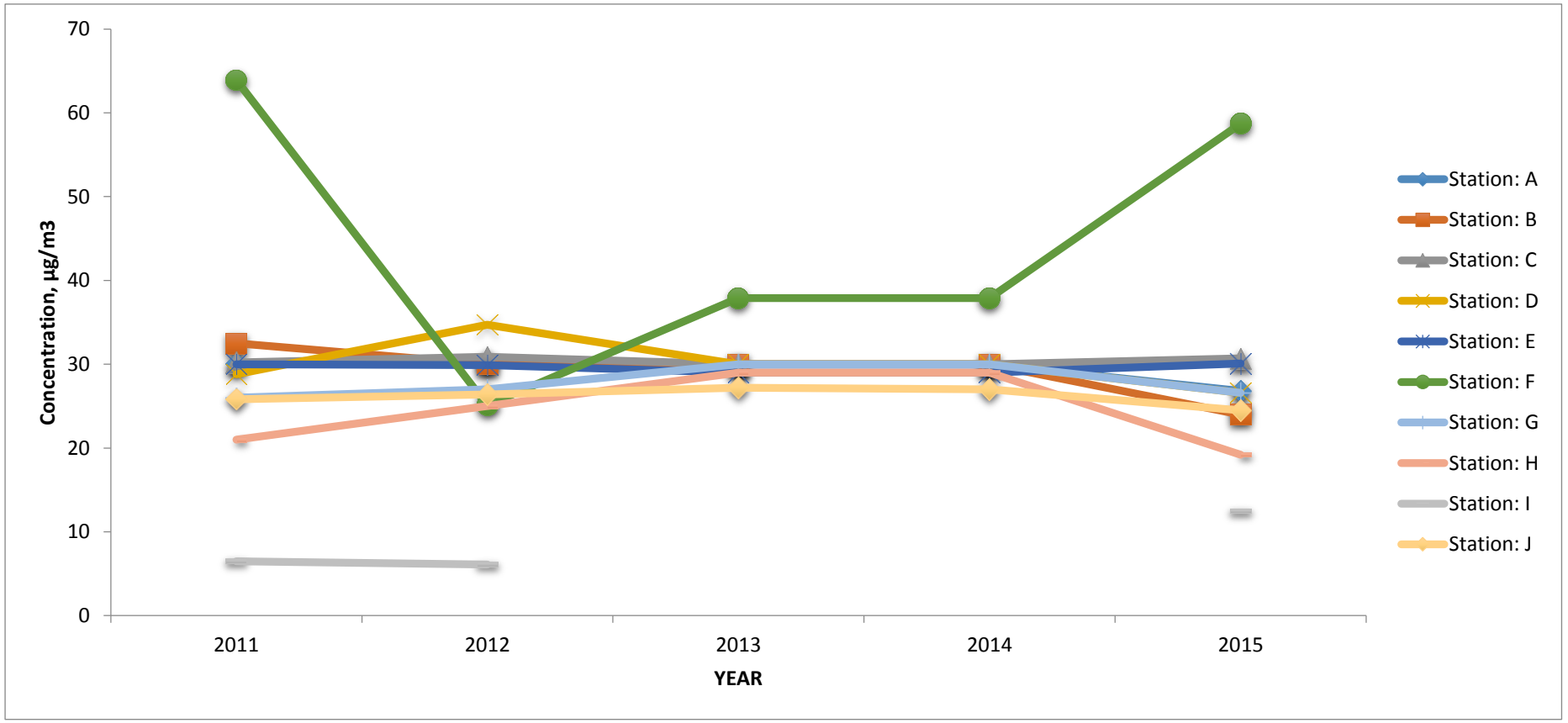


Fig. 4.16 : Variation of NO_2 During the Study Period at Sampling Stations (Month: March)

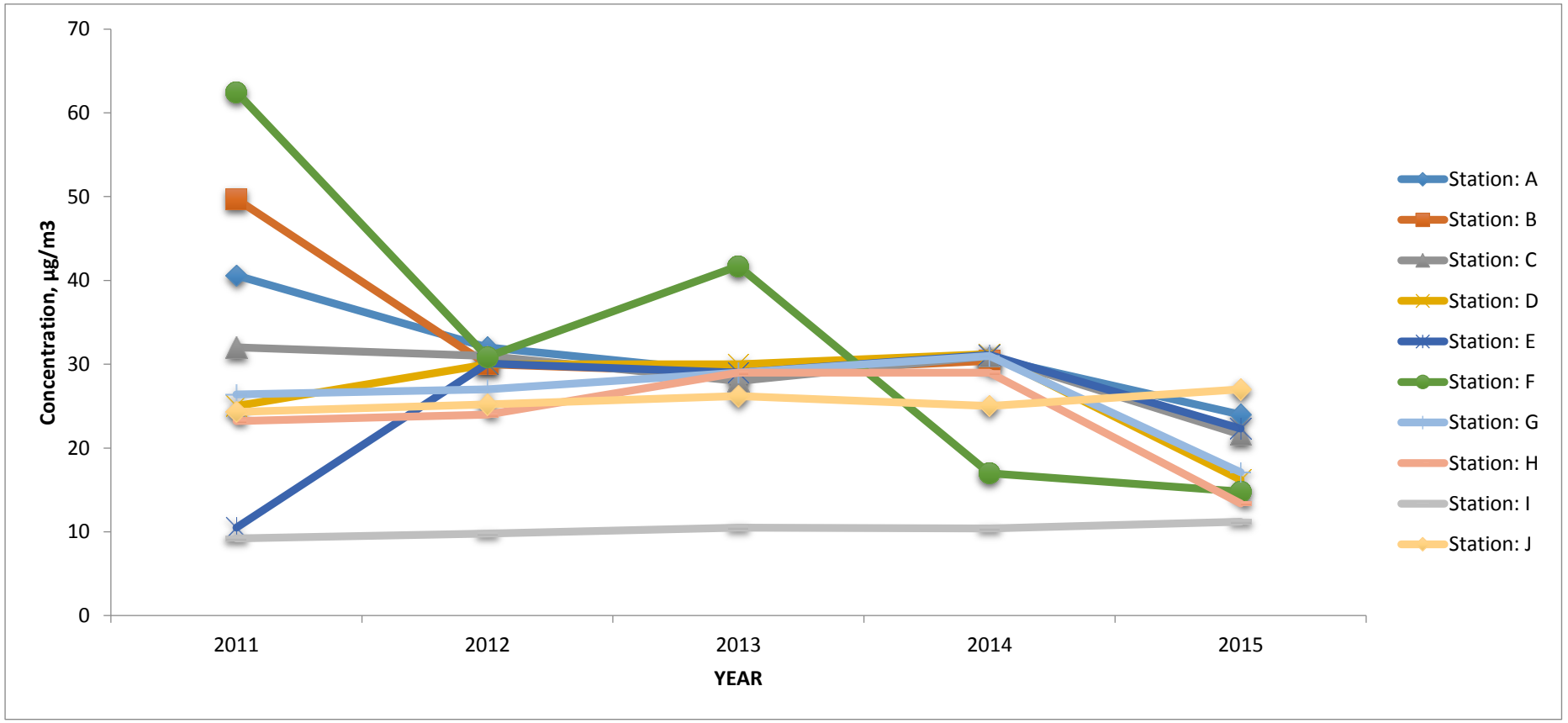


Fig. 4.17 : Variation of NO_2 During the Study Period at Sampling Stations (Month: April)

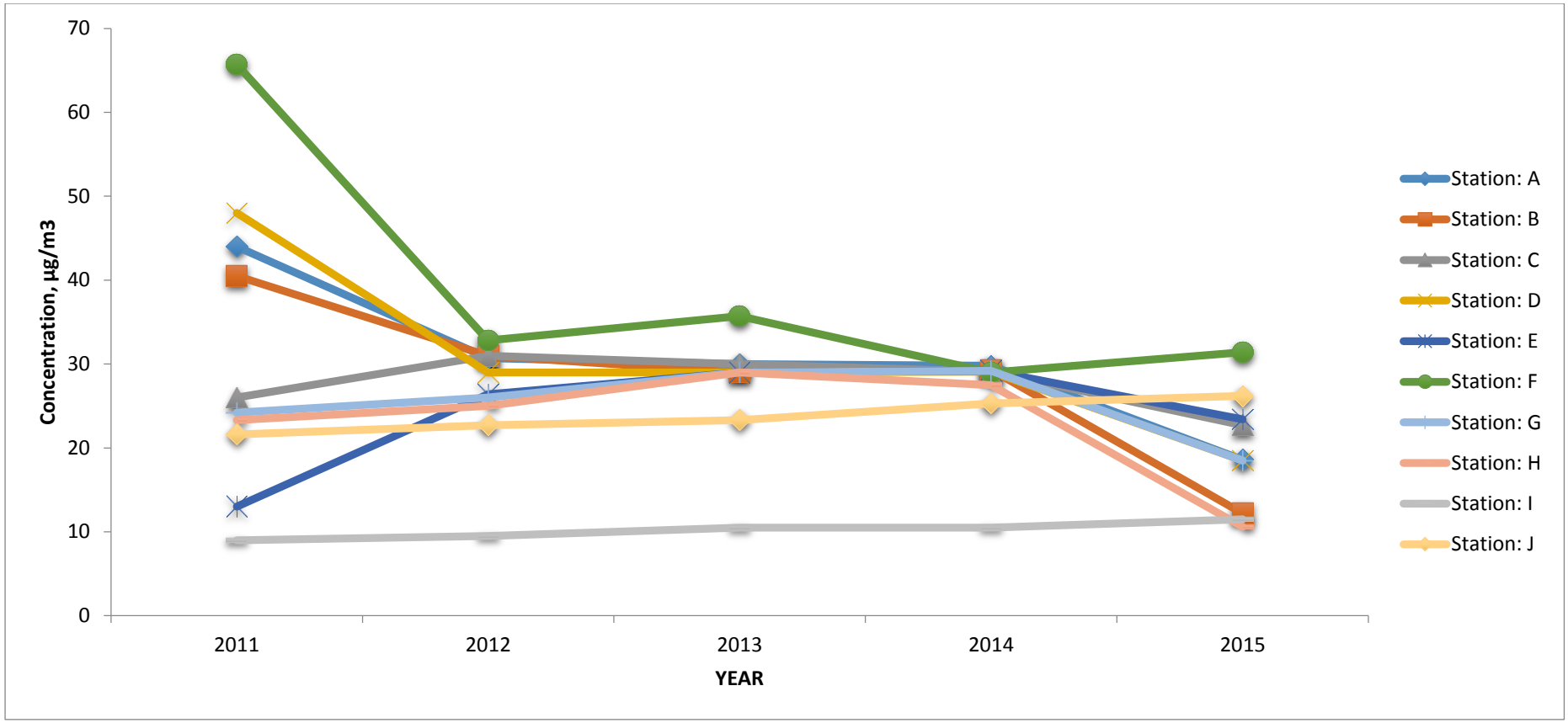


Fig. 4.18 : Variation of NO_2 During the Study Period at Sampling Stations (Month: May)

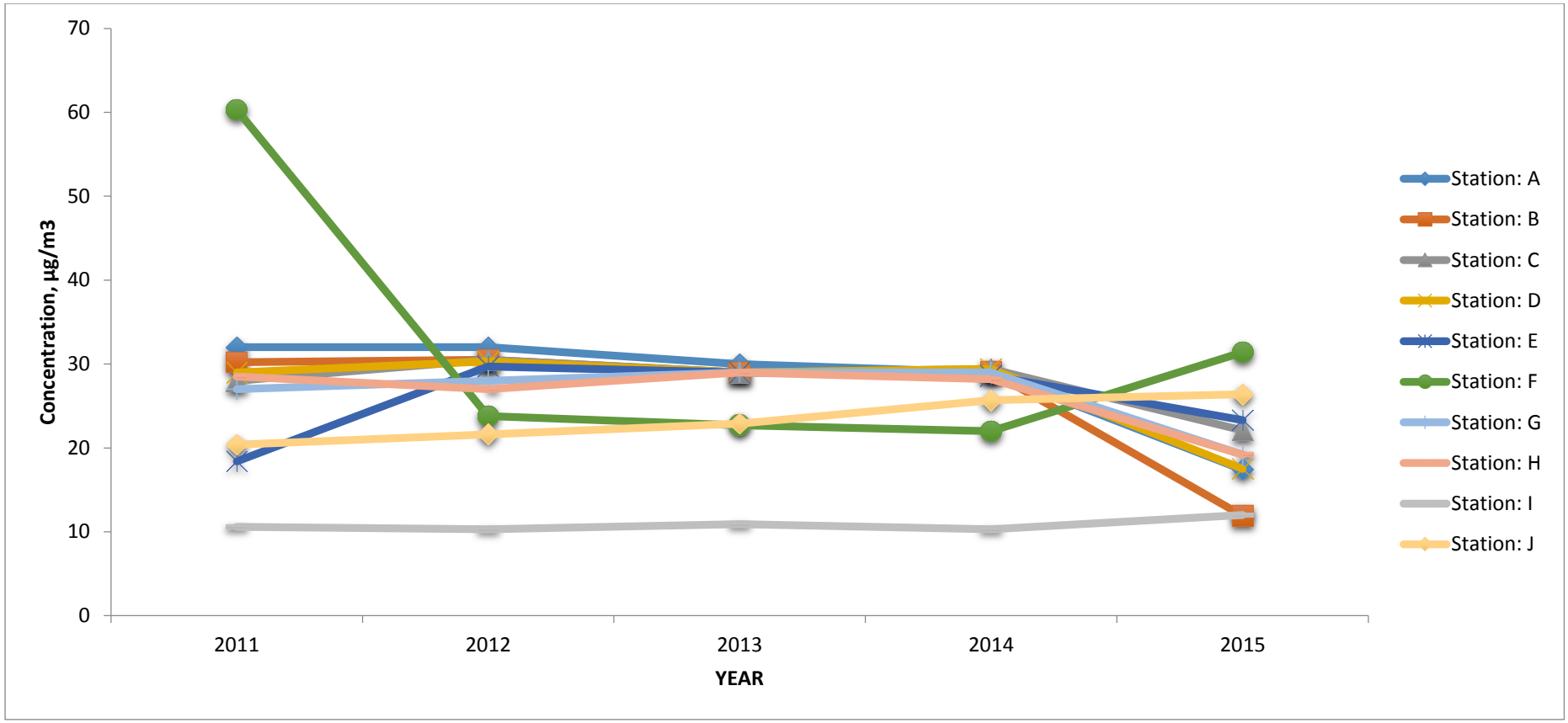


Fig. 4.19 : Variation of NO_2 During the Study Period at Sampling Stations (Month: June)

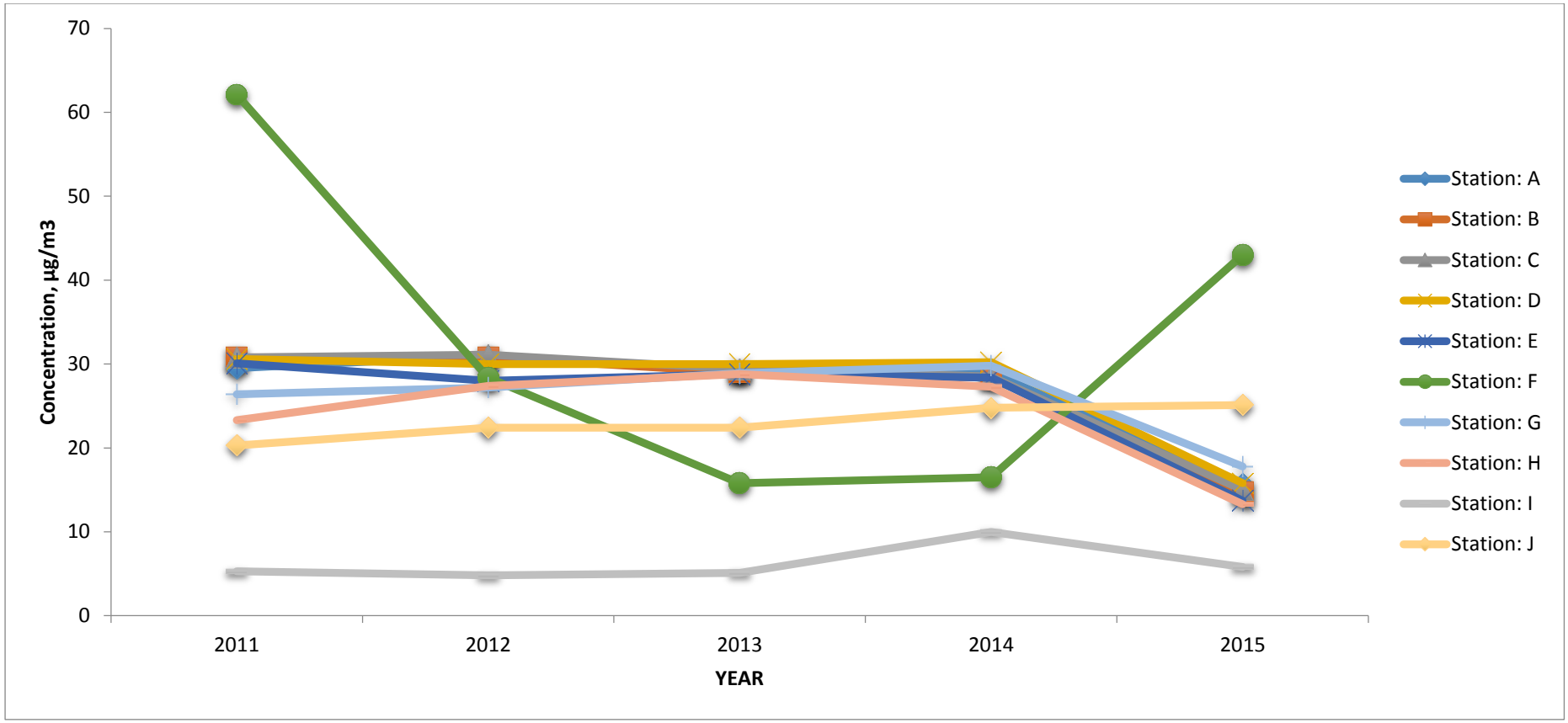


Fig. 4.20 : Variation of NO_2 During the Study Period at Sampling Stations (Month: July)

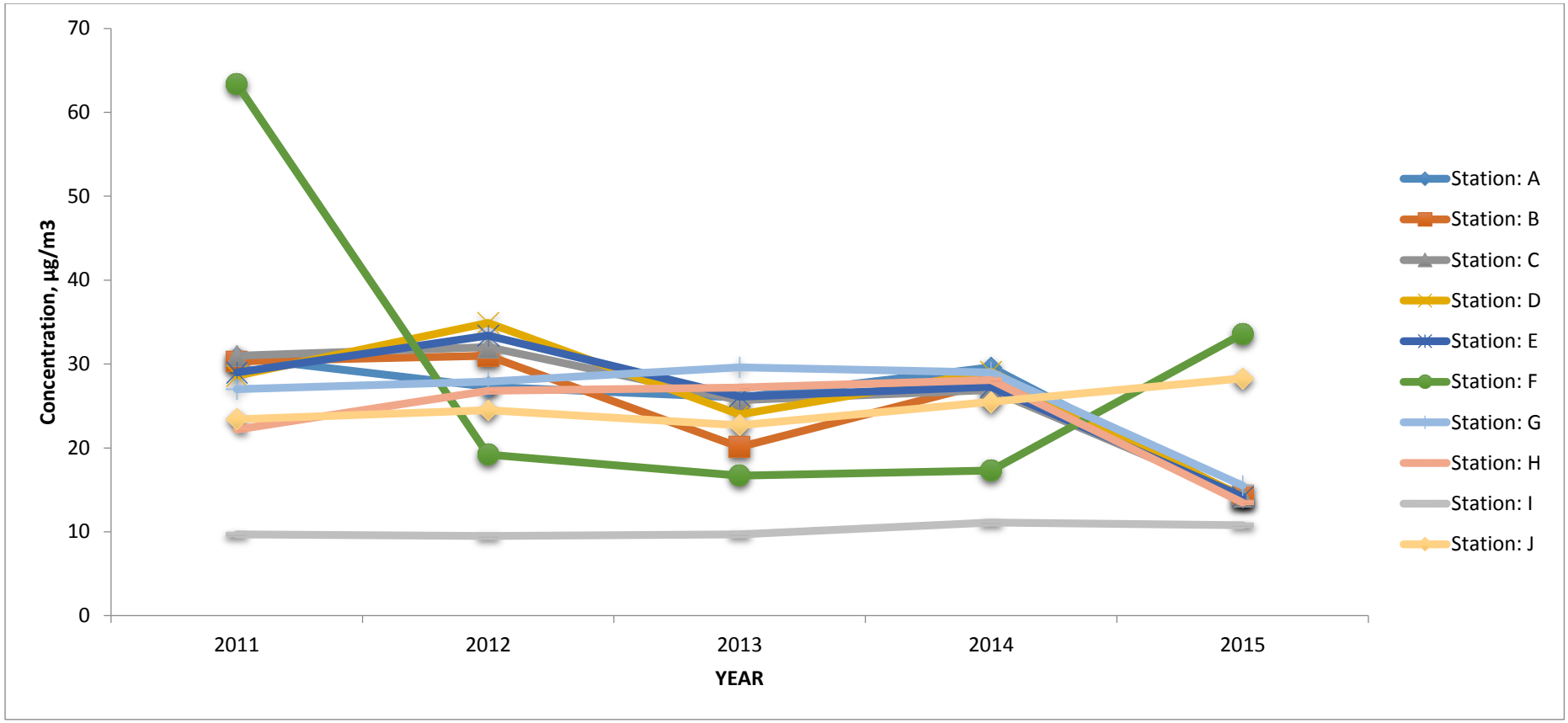


Fig. 4.21 : Variation of NO_2 During the Study Period at Sampling Stations (Month: August)

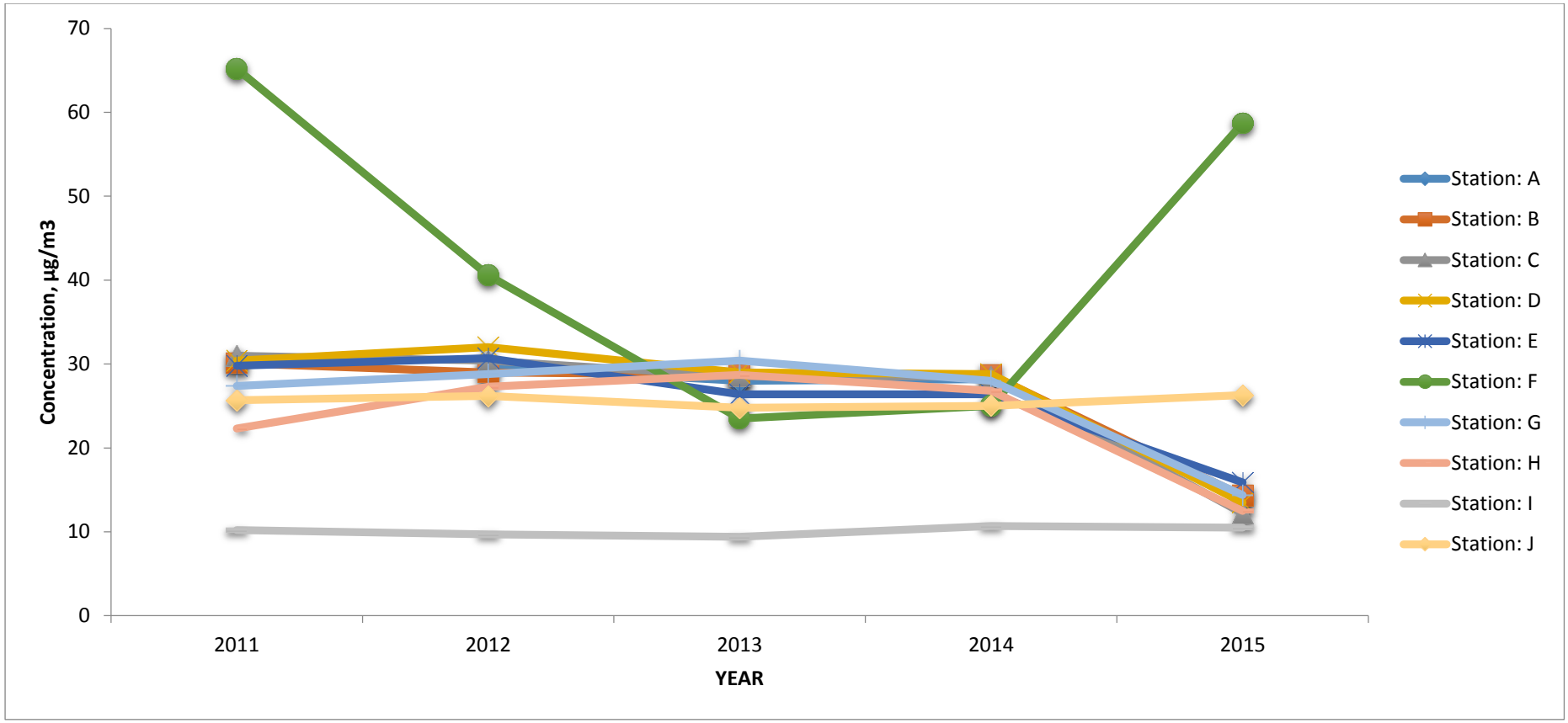


Fig. 4.22 : Variation of NO_2 During the Study Period at Sampling Stations (Month: September)

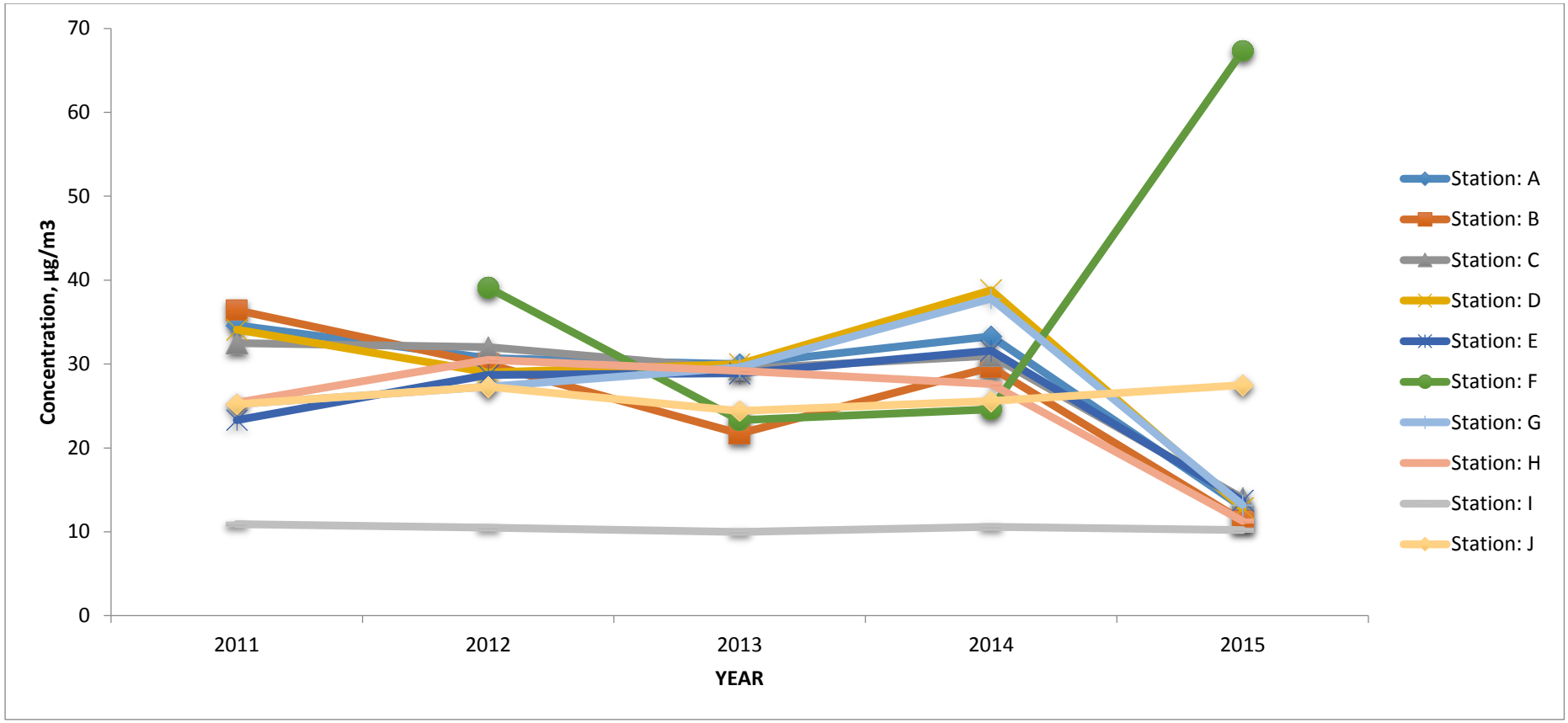


Fig. 4.23 : Variation of NO_2 During the Study Period at Sampling Stations (Month: October)

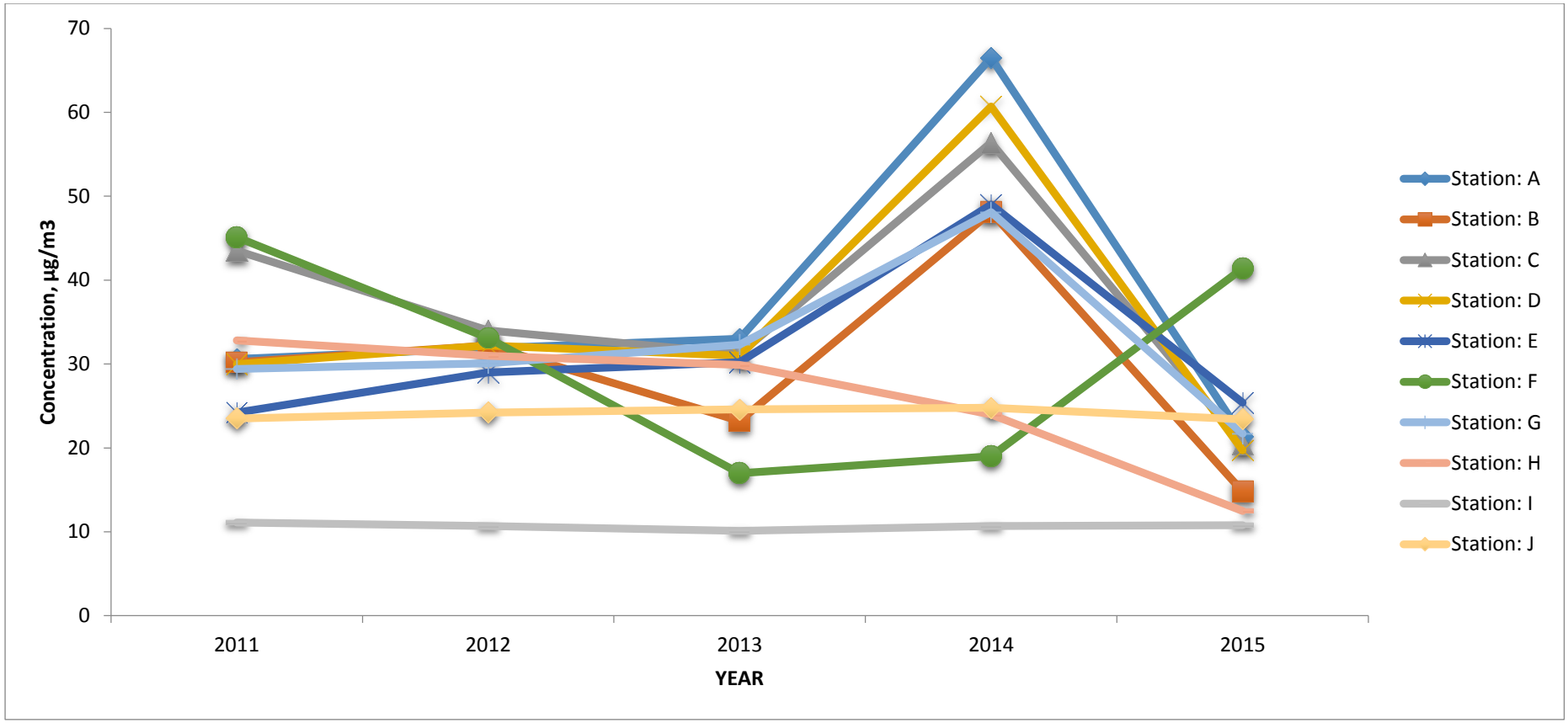


Fig. 4.24 : Variation of NO_2 During the Study Period at Sampling Stations (Month: November)

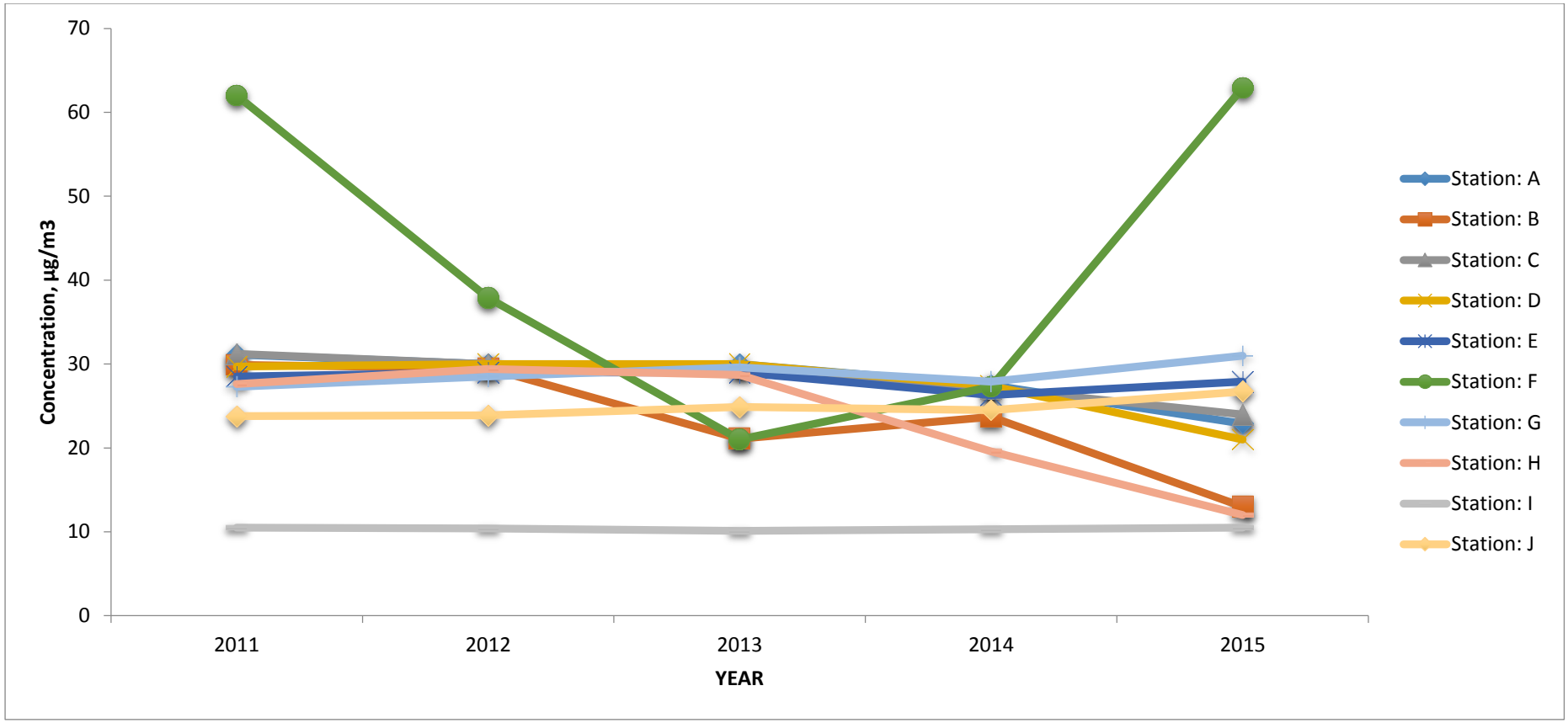


Fig. 4.25 : Variation of NO_2 During the Study Period at Sampling Stations (Month: December)

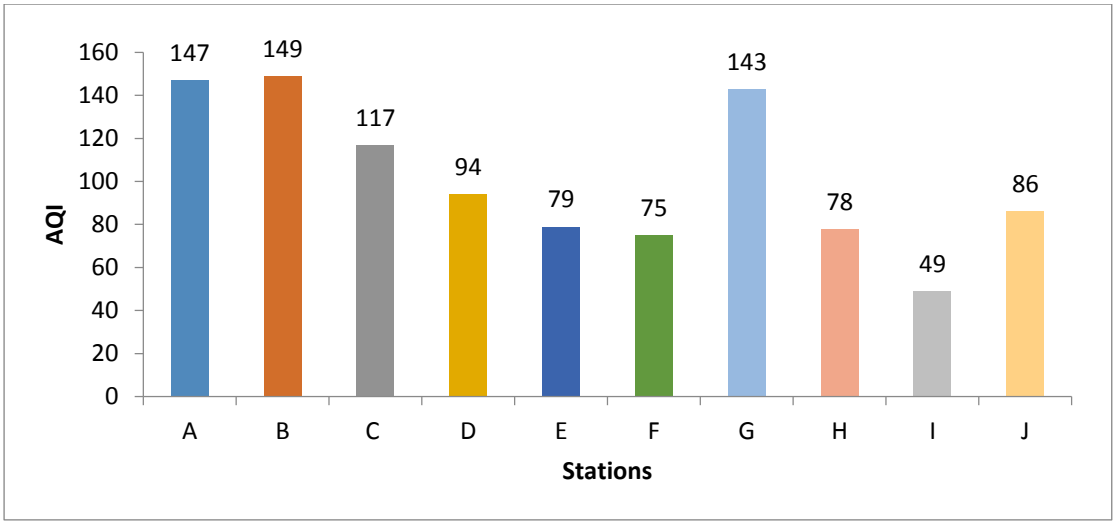


Fig. 4.26 : Seasonal AQI for Stations Monitored (2011, Winter)

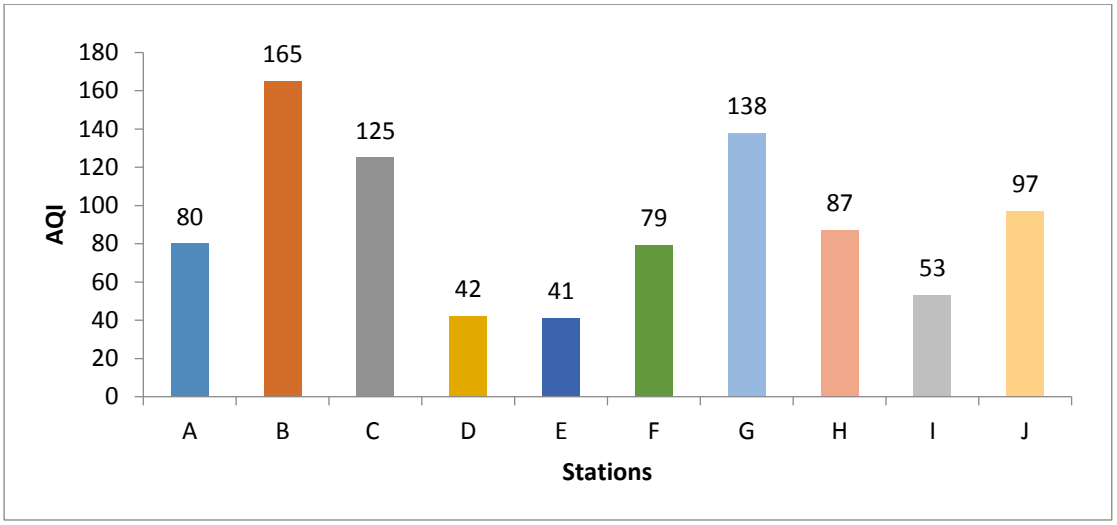


Fig. 4.27 : Seasonal AQI for Stations Monitored (2011, Summer)

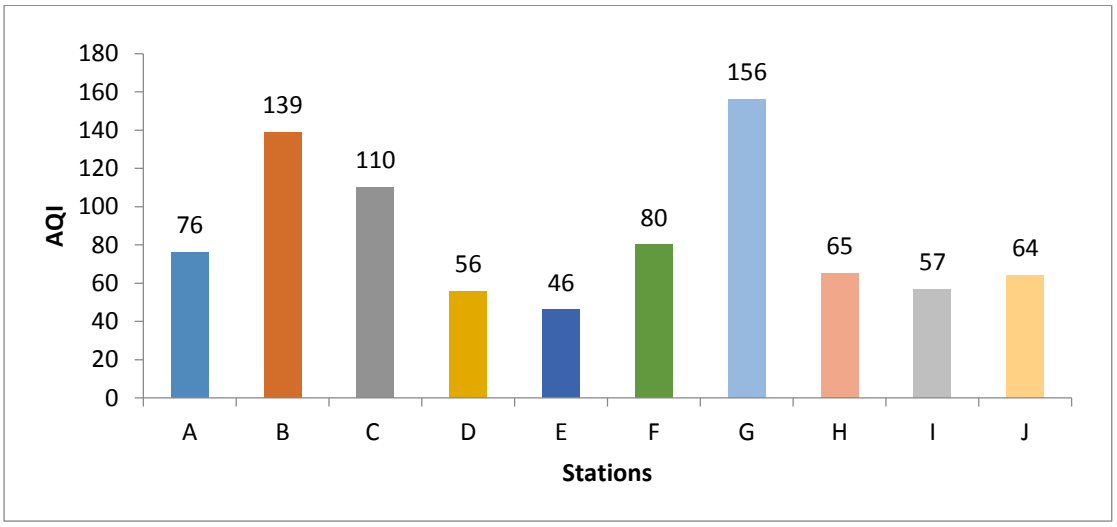


Fig. 4.28 : Seasonal AQI for Stations Monitored (2011, Monsoon)

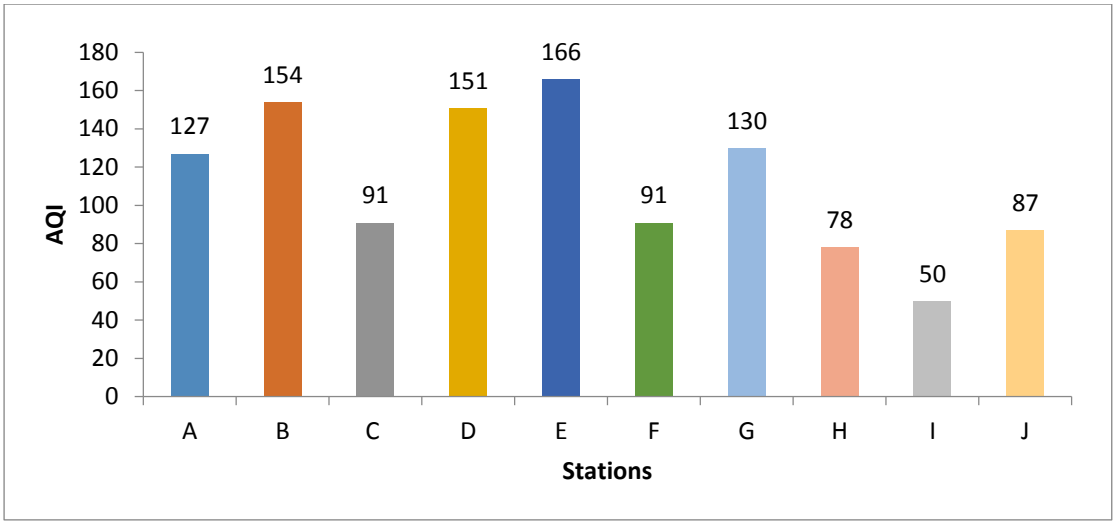


Fig. 4.29 : Seasonal AQI for Stations Monitored (2012, Winter)

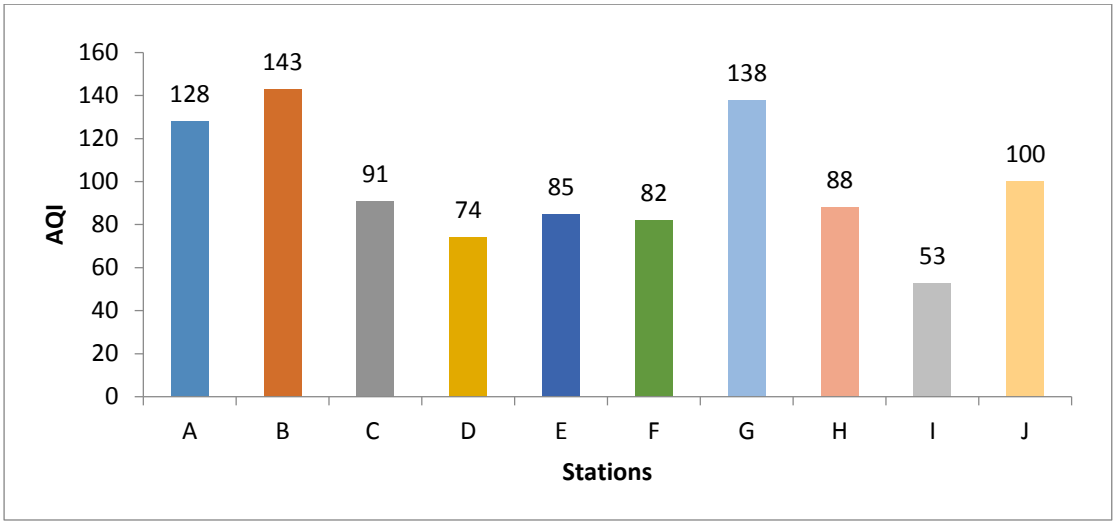


Fig. 4.30 : Seasonal AQI for Stations Monitored (2012, Summer)

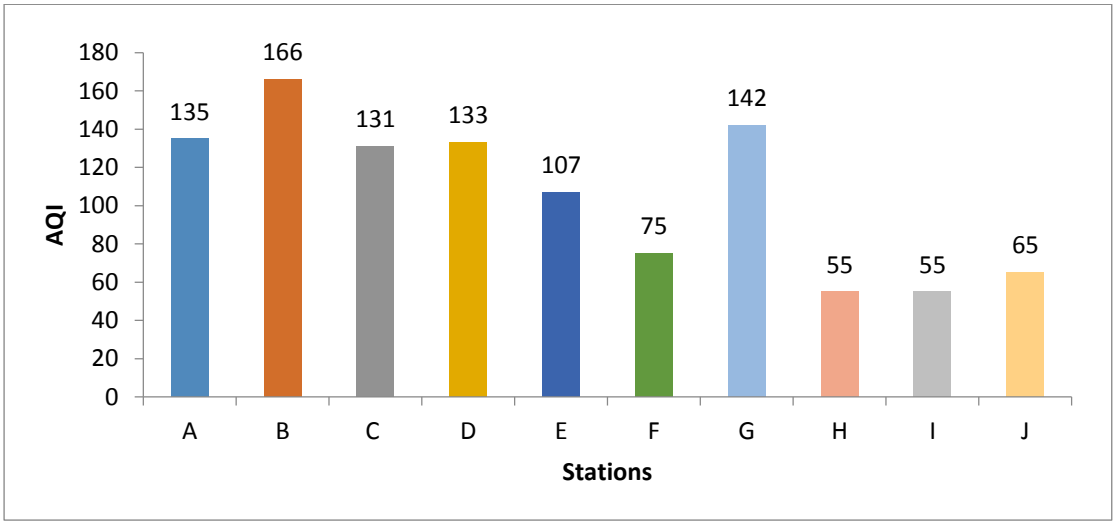


Fig. 4.31 : Seasonal AQI for Stations Monitored (2012, Monsoon)

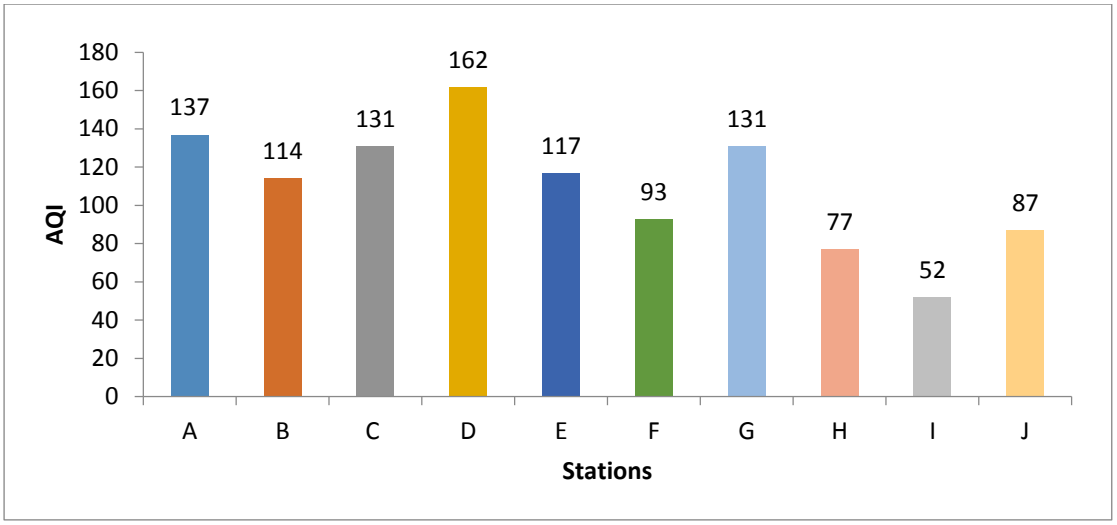


Fig. 4.32 : Seasonal AQI for Stations Monitored (2013, Winter)

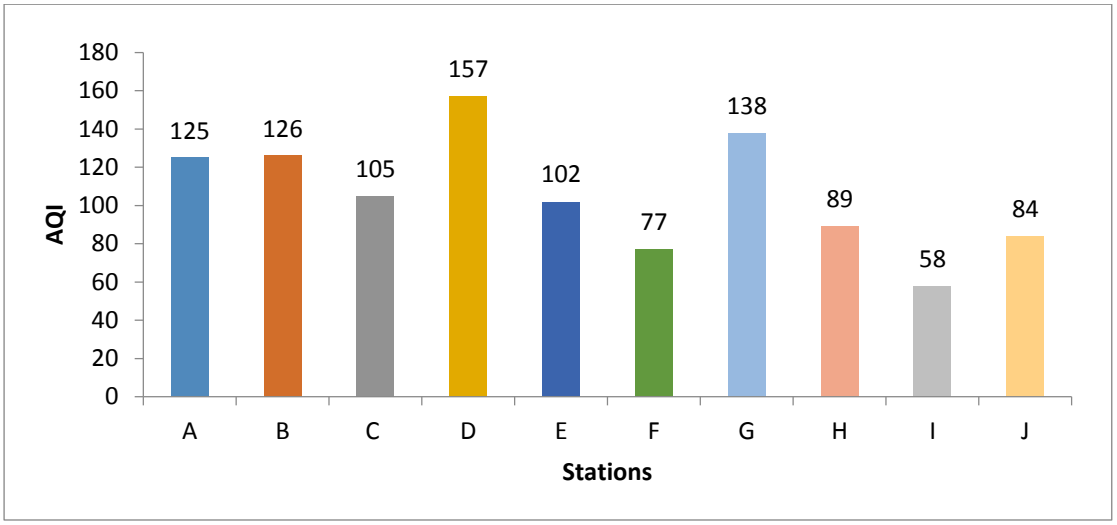


Fig. 4.33 : Seasonal AQI for Stations Monitored (2013, Summer)

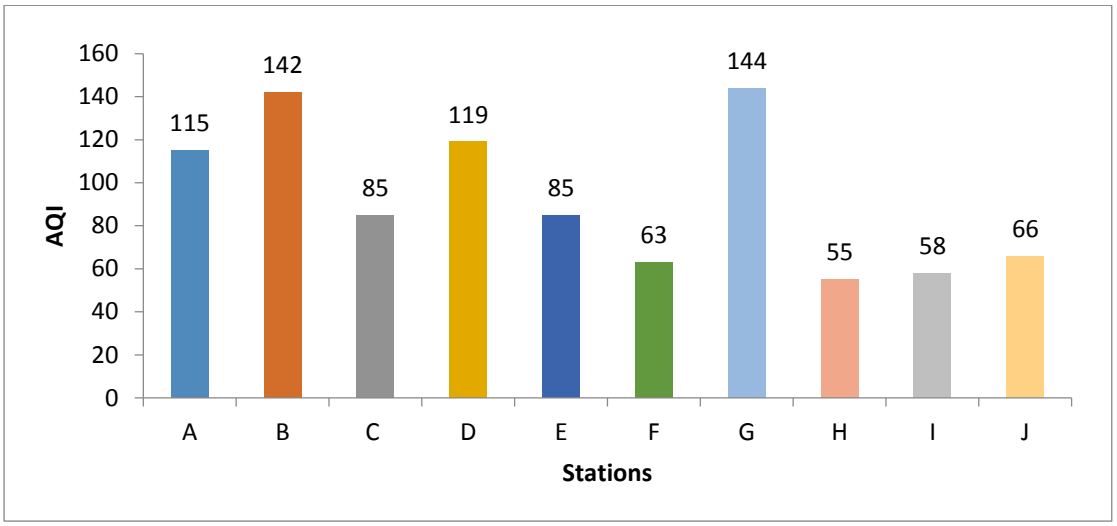


Fig. 4.34 : Seasonal AQI for Stations Monitored (2013, Monsoon)

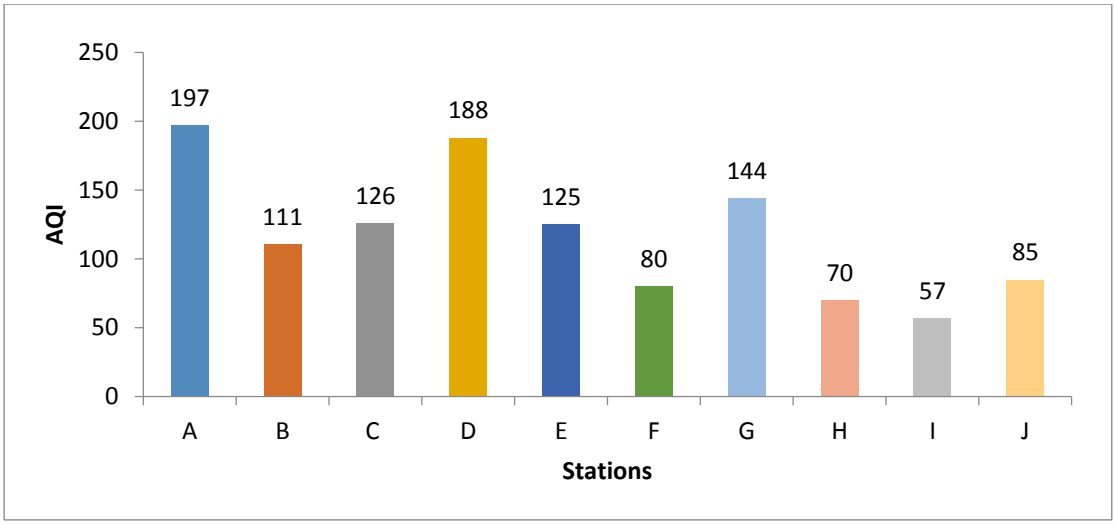


Fig. 4.35 : Seasonal AQI for Stations Monitored (2014, Winter)

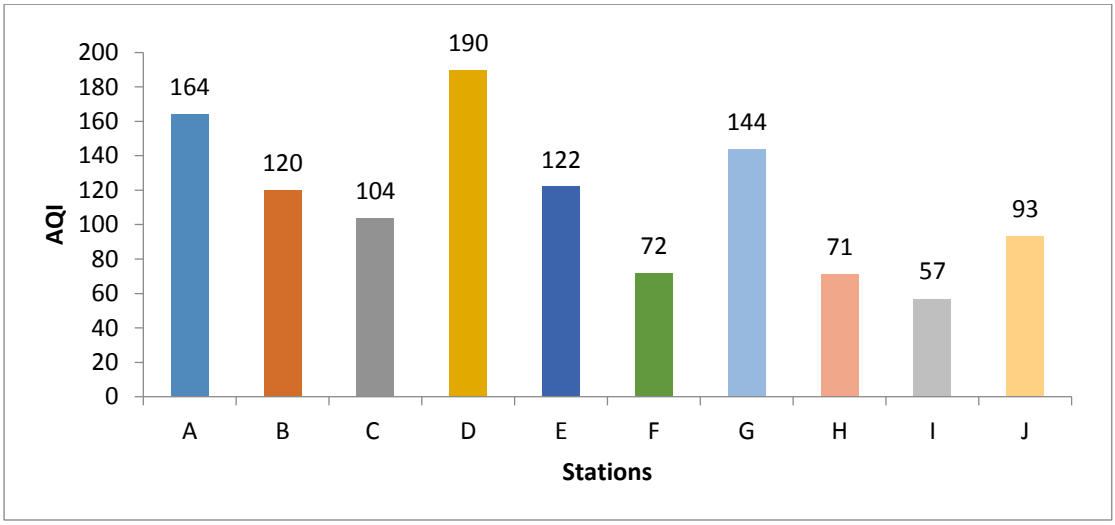


Fig. 4.36 : Seasonal AQI for Stations Monitored (2014, Summer)

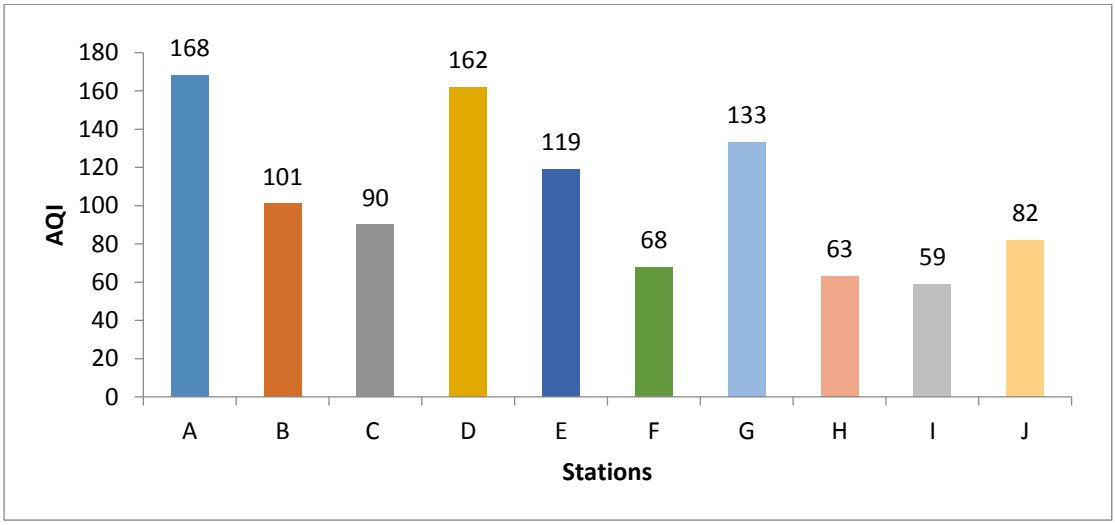


Fig. 4.37 : Seasonal AQI for Stations Monitored (2014, Monsoon)

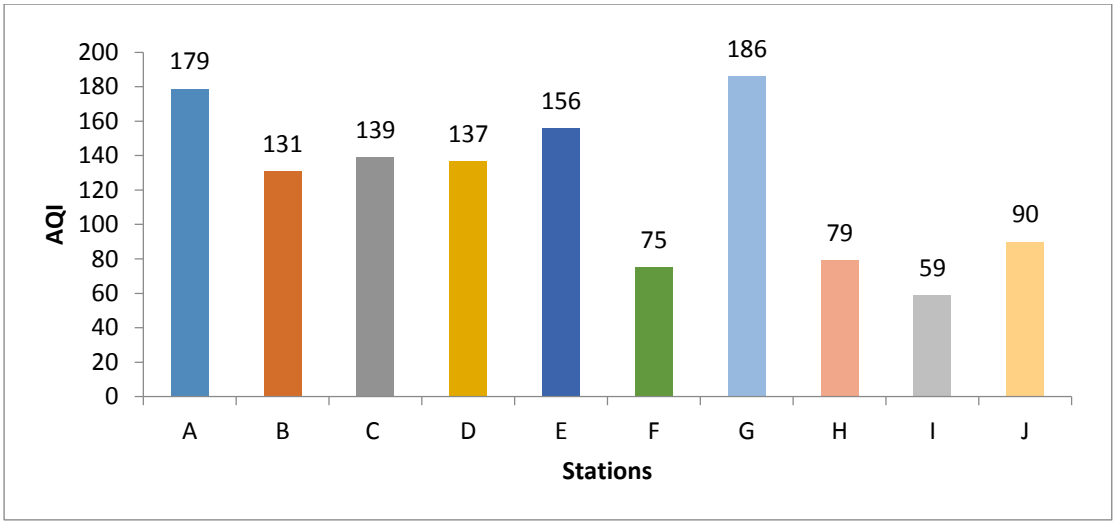


Fig. 4.38 : Seasonal AQI for Stations Monitored (2015, Winter)

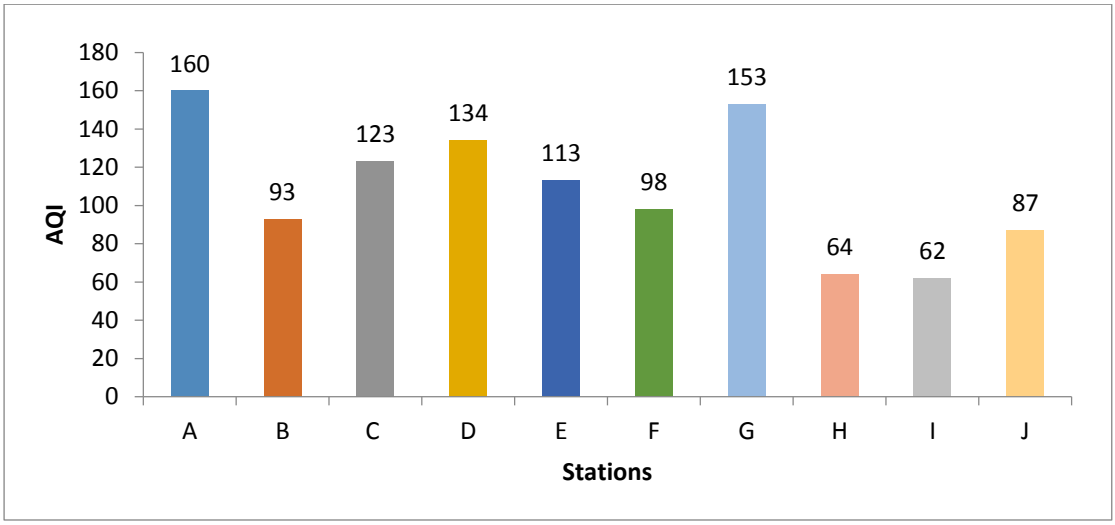


Fig. 4.39 : Seasonal AQI for Stations Monitored (2015, Summer)

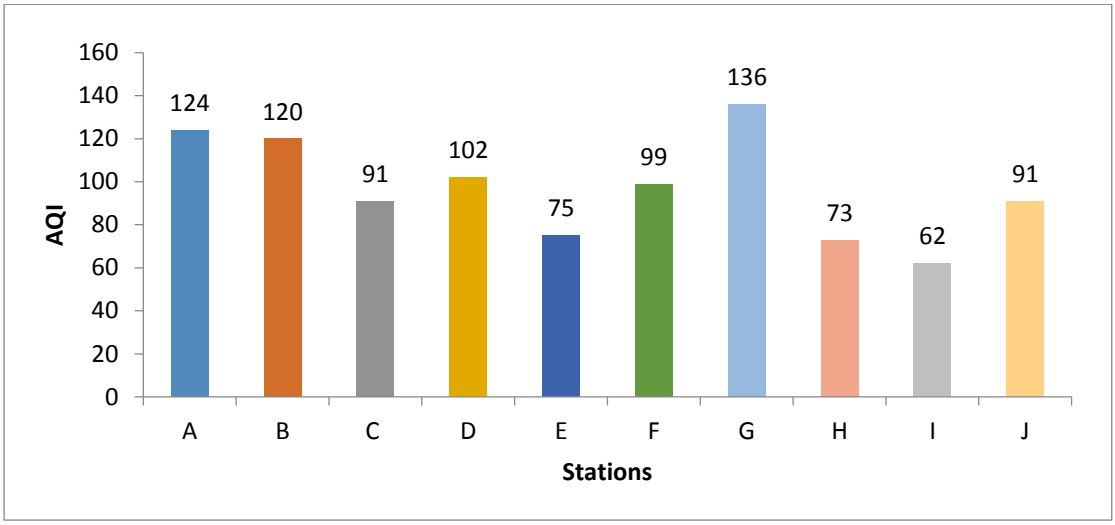


Fig. 4.40 : Seasonal AQI for Stations Monitored (2015, Monsoon)

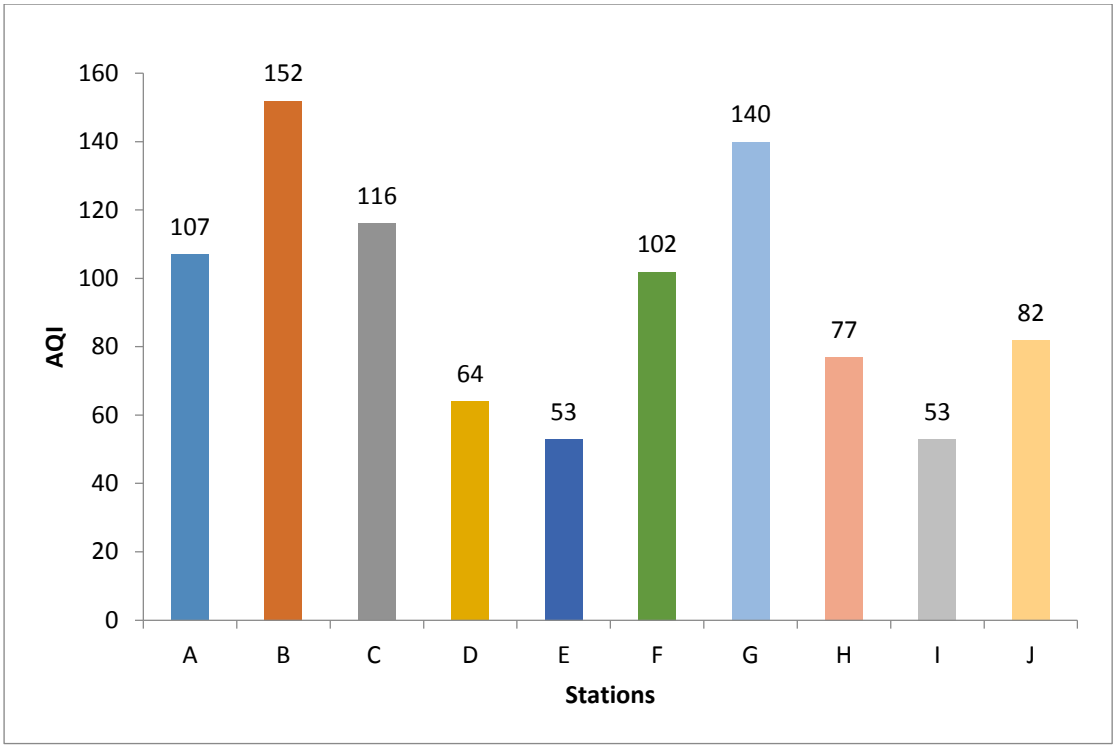


Fig. 4.41 : Yearly AQI for Stations Monitored (2011)

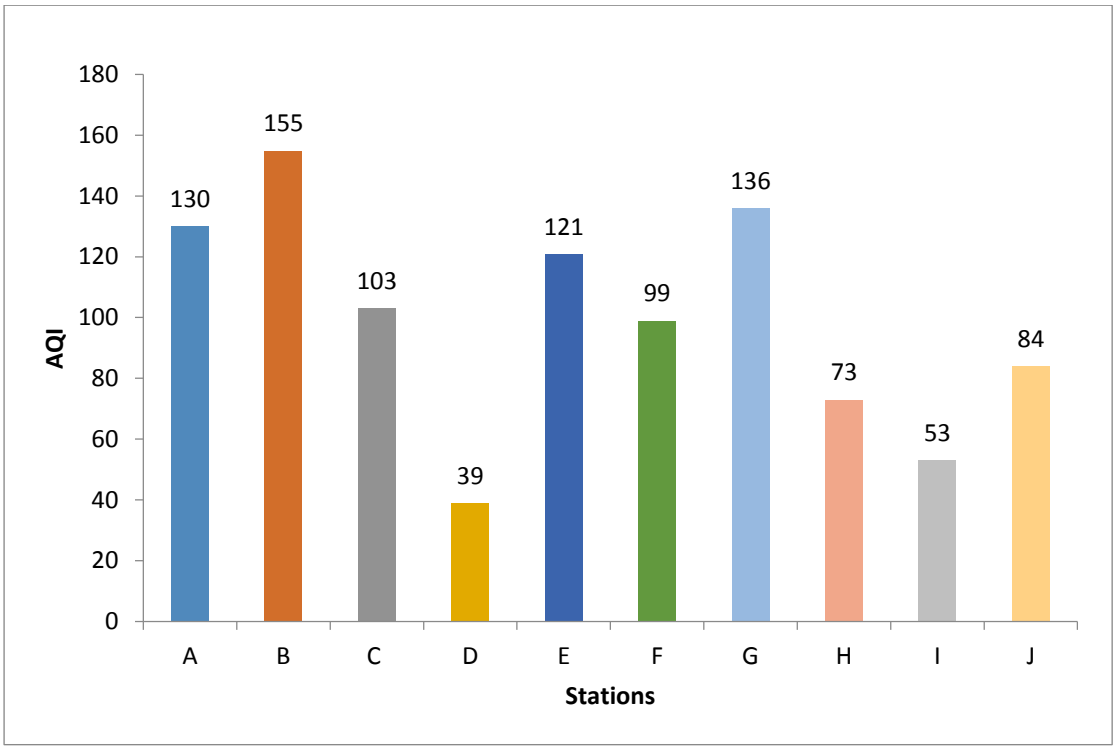


Fig. 4.42 : Yearly AQI for Stations Monitored (2012)

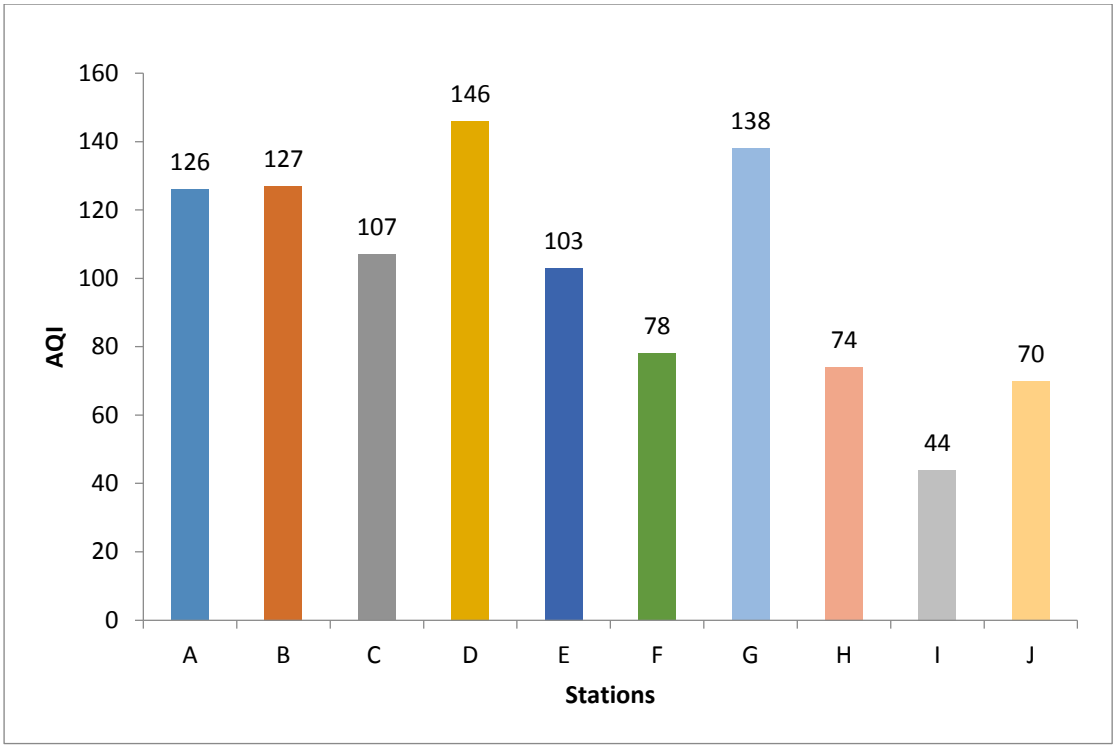


Fig. 4.43 : Yearly AQI for Stations Monitored (2013)

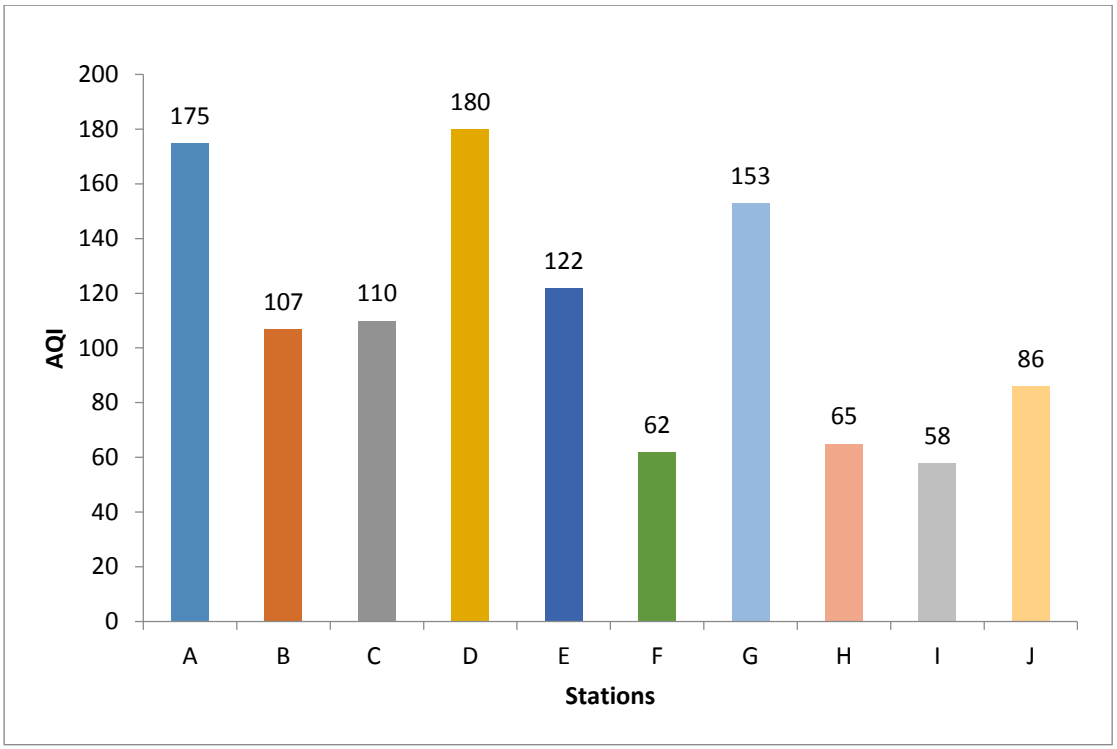


Fig. 4.44 : Yearly AQI for Stations Monitored (2014)

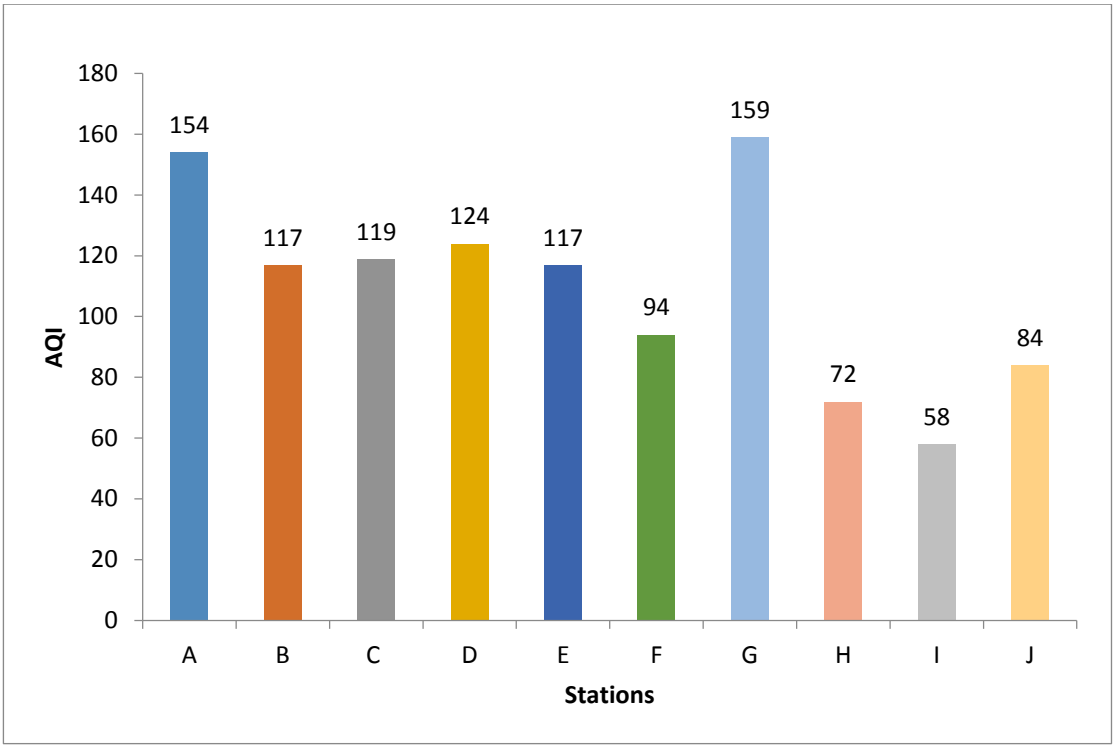


Fig. 4.45 : Yearly AQI for Stations Monitored (2015)

4.2 AIR QUALITY STATUS AT POCKET: B (KHB Industrial Area)

The Tables 4.12 to 4.16 depicts the average monthly concentration of pollutants viz. PM_{10}, SO_2 and NO_2 measured during the study period of five years. Accordingly the calculated AQIs are also presented in these Tables (4.12 to 4.16). Seasonal concentrations of pollutants and AQIs of this study pocket are summarized in the Tables 4.17 to 4.21. Table 4.22 depicts the annual variation in ambient air quality in terms of pollutant concentrations and AQIs. Monthly variation of SO_2 at this study pocket 'B' during the study period is shown in fig.4.46. As mentioned in the section 4.1 above, variation of PM_{10}, AQIs of this pocket along with the other pockets are shown in figs. 4.14 to 4.45.

At this station / pocket – 'B', the ambient air quality was found to be deteriorating at an alarming rate. Based on 91.5% of AQIs documented, it is opined that the area (Pocket B) is affected by severe air pollution and 8.5% values indicated the heavy air pollution. The maximum and minimum AQIs of 168 and 50 respectively were recorded. Unlike in the Pocket : A, here also the main culprit pollutant was found to be PM_{10}. PM_{10} concentrations were found to exceed the permissible concentration at most of the times (96.6% times). Further it was notices that the air pollution trends in this pocket resembles much to that of pocket 'A'. In general progressive deterioration in air quality from year 2011 to 2015 has been observed.

Seasonal AQIs documented in Tables 4.17 to 4.21 confirmed the severe air pollution in the study Pocket 'B'. Minimum and maximum seasonal AQIs recorded were found to be respectively 93 and 165. Unlike in Pocket 'A', the seasonal variation could not be tagged to particular season and the author opines that, to explain such a diversified air quality trends, in depth correlation between pollutants, meteriology, traffic movement, local conditions are required to be established and such a activity is out of the preview of the present research work. Again the annual AQIs (Table 4.22) reconfirmed the deterioration of ambient air quality (AQI varying from 107 to 155).

Thus the AQIs clearly indicated the severity of air pollution in the study Pocket 'B'.

Table – 4.12 : Monthly Air Quality Data / Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	149	15.5	29.7	133	133	19	37
February	145	14.7	30.5	130	130	18	38
March	138	14.8	32.5	125	125	19	41
April	238	30.3	49.7	192	192	38	62
May	217	26.7	40.5	178	178	33	51
June	195	11.5	30.2	163	163	14	38
July	167	16	30.8	145	145	20	39
August	164	15.7	30.3	143	143	20	38
September	151	15.2	30.1	134	134	19	38
October	151	21.2	36.4	134	134	27	46
November	225	14.7	30.2	183	183	18	38
December	174	14.3	29.9	149	149	18	37

Table – 4.13 : Monthly Air Quality Data / Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	147	15.6	30.0	131	131	20	38
February	172	16.1	31.0	148	148	20	39
March	155	15.9	30.0	137	137	20	38
April	198	15.6	30.0	165	165	20	38
May	165	15.6	31.0	143	143	20	39
June	142	15.3	30.5	128	128	19	38
July	153	15.9	30.8	135	135	20	39
August	202	16.0	31.0	168	168	20	39
September	215	15.2	29.0	177	177	19	36
October	227	15.0	30.0	185	185	19	38
November	173	17.0	32.2	149	149	21	40
December	232	15.3	29.5	188	188	19	37

Table – 4.14 : Monthly Air Quality Data / Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	143	14	30	129	129	18	38
February	133	14	29	122	122	18	39
March	169	15	30	146	146	19	38
April	159	14	29	139	139	18	36
May	113	14	29	109	109	18	36
June	112	13	29	108	108	16	36
July	129	13.3	20.1	119	119	17	36
August	154	13.4	28.7	136	136	17	25
September	202	13.4	21.7	168	168	17	36
October	165	14.7	21.7	143	143	18	27
November	90	17.0	23.2	90	90	21	29
December	119	13.8	21.1	113	113	17	26

Table – 4.15 : Monthly Air Quality Data / Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	104	14	21	103	103	18	26
February	99	13	21	99	99	16	36
March	169	15	30	146	146	19	38
April	120	15.2	30.4	113	113	19	38
May	131	14.1	29.3	121	121	18	37
June	102	13.2	29.1	101	101	17	36
July	53	12.6	28.4	53	53	16	36
August	50	11.7	27.8	50	50	15	35
September	202	13.4	28.7	168	168	17	36
October	102	12.7	29.6	101	101	16	37
November	137	11.5	48.1	125	125	14	60
December	127	10	23.7	118	118	13	30

Table – 4.16 : Monthly Air Quality Data / Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	168	6.6	25.2	145	145	8	32
February	135	5.8	31.2	123	123	7	39
March	121	5.7	24	114	114	7	30
April	-	-	-	-	-	-	-
May	59	5.2	12.2	59	59	7	15
June	98	5.1	11.9	98	98	6	15
July	130	5.4	14.7	120	120	7	18
August	108	5.4	14.3	105	105	7	18
September	134	5	14.3	123	123	6	18
October	145	2	11.3	130	130	3	14
November	146	2.3	14.8	131	131	3	19
December	134	2.0	13	123	123	3	16

Table – 4.17 : Seasonal Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	173.3	14.8	30.1	149	149	19	38
Summer (Mar to Jun)	197	17.4	38.2	165	165	22	48
Monsoon (July to Oct)	158.3	17	31.8	139	139	21	40

Table – 4.18 : Seasonal Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	181	16	30.7	154	154	20	38
Summer (Mar to Jun)	165	15.6	30.4	143	143	20	38
Monsoon (July to Oct)	199.3	15.5	30.2	166	166	19	38

Table – 4.19 : Seasonal Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	121.3	14.7	25.8	114	114	18	37
Summer (Mar to Jun)	138.3	14	29.3	126	126	18	37
Monsoon (July to Oct)	162.5	13.7	24.9	142	142	17	31

Table – 4.20 : Seasonal Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	116.8	12.1	28.5	111	111	15	36
Summer (Mar to Jun)	130.5	11.9	29.7	120	120	15	37
Monsoon (July to Oct)	101.8	12.6	28.6	101	101	16	36

Table – 4.21 : Seasonal Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	145.8	4.2	18.6	131	131	5	23
Summer (Mar to Jun)	92.7	5.3	16.0	93	93	7	20
Monsoon (July to Oct)	129.3	4.5	13.7	120	120	6	17

Table – 4.22 : Yearly Air Quality Indices for the Study Pocket:

KHB Industrial Area

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	178.0	17.60	33.40	152	152	22	42
2012	181.5	15.70	30.40	155	155	20	38
2013	140.7	14.1	26.7	127	127	18	33
2014	110.1	13.0	28.3	107	107	16	35
2015	125.3	4.5	17.0	117	117	6	21

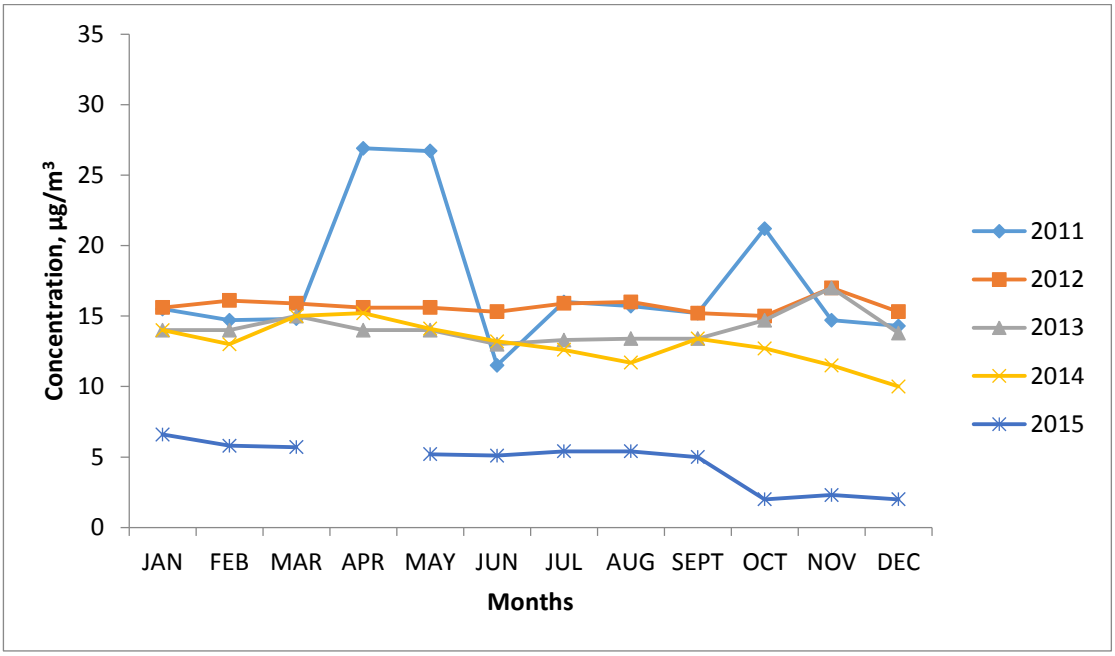


Fig. 4.46 : Monthly Variation of SO_2 During the Study Period (Station : B)

4.3 OTHER AREAS/COMMERCIAL AREAS (Pockets C,D,F and G)

The average monthly concentrations of pollutants measured during the study period and thereby the AQIs calculated at Pockets C,D,F and G are presented in Tables 4.23 to 4.42. Similarly the average seasonal and annual concentrations of pollutants and corresponding AQIs at these study pockets are shown in Tables 4.43 to 4.66. Also linear graphs (fig. 4.47 to 4.50) depicts average monthly concentrations of SO_2 during the study period at Pockets C, D, F and G respectively. Again as listed in the section 4.1 above, variation of PM_{10}, AQIs of these pockets along with the Pockets A, B, E, H, I and J are shown in figs. 4.14 to 4.45.

The following inferences were drawn, based on the analysis of results documented in Tables and presented in Graphs and Bar Charts.

- Monthly AQIs at study Pockets C, D, and G revealed that, most of the times the ambient air is severely polluted (AQI >100) and pockets are unfit for living of human beings.
- Compared to commercial Pockets C, D and G, the pocket F was found to be less polluted. AQIs ranging from 47 to 75 (moderate air pollution : 29% of the values), 77 to 100 (Heavy air pollution: 49% of the values) and 101 to 184 (severe air pollution : 22% of the values) at the Pocket F.
- Ranges of monthly AQI values calculated based on average monthly concentrations of pollutants measured at stations C, D and G are as follows:
    - Heavy and severe air pollution
        - 78 to 183 (Station C: 96.6% of the values)
        - 78 to 230 (Station D: 81.7% of the values)
        - 95 to 209 (Station G: 100% of the values)
    - Moderate air pollution
        - 55 to 63 (Station C: 3.4% of the values)
        - 56 to 71 (Station D: 3.3% of the values)
    - Light air pollution
        - 31 to 48 (Station D: 15% of the values)

    Thus it can be said that, amongst these three commercial study pockets, ambient air quality at station G is more deteriorated followed by station C and D respectively.

- With in the statistical limitations, at all these four commercial study pockets the seasonal AQIs during the study period of five years clearly indicated that the areas are most of the times suffering from severe air pollution followed by heavy air pollution.
- The ranges of seasonal AQIs recorded were found to be 85 to 138, 74 to 190, 75 to 99 and 130 to 186 at Pockets C, D, F and G respectively. These ranges clearly speaks that, station/pocket – G, Central Silk Board is experiencing worst air pollution, compared to other commercial pockets.
- With in the statistical limitations, it can be said that at these study pockets the pollution is more during winter, followed by summer and monsoon.
- Further the annual AQIs for these commercial study pockets confirmed the severity of air pollution at Pocket G (136 to 159). Relatively less pollution was indicated by annual AQIs at station F (62 to 102) compared to other commercial pockets.

4.4 AIR QUALITY STATUS AT STUDY POCKET: E (Victoria Hospital)

Findings of ambient air quality monitored at this sensitive hospital area (Pocket E) are documented in Tables 4.67 to 4.77. Fig. 4.51 describes the trends of monthly variation of SO_2 at this pocket during the study period. Further the graphs and bar charts (fig. 4.14 to 4.45) throws light on variation of NO_2, seasonal and annual variation of AQIs at all the study pockets during the study period (2011 to 2015).

AQIs were found to vary from 24 to 421. Based on these values it was inferred that, this sensitive hospital area is also not free from air pollution which is unwarranted. Light to severe air pollution has been observed during different months and years of study period. Amongst the 60 AQIs recorded 40 AQIs were found to exceed the threshold AQI value indicating heavy to severe air pollution in the pocket.

With in the statistical limitations it was inferred that, the air pollution in this pocket is increasing from year to year. Except in 2011, the seasonal AQIs documented (Table 4.72 to 4.76) revealed that the ambient air in the sensitive pocket is deteriorating at an alarming rate and trends are much unhealthy. AQIs ranging from

85 to 166 (Heavy to Severe air pollution) were observed during the study period of 2012 to 2015. Further during this period, annual AQIs also indicated the severe air pollution in the area.

4.5 AIR QUALITY STATUS AT BACKGROUND, RURAL AND RESIDENTIAL AREAS (Pockets H, I and J: Kazisummanahalli, TERI Office and Basavanagudi Police Station)

Tables 4.78 to 4.109 throws light on findings of ambient air quality at these study pockets, viz average, monthly, seasonal and annual concentrations of pollutants considered for study and corresponding AQIs. At these study stations monthly variation of SO_2 during the study period are presented in figs. 4.52 to 4.54 respectively. On the other hand variation of (monthly, seasonal and annual) NO_2 and AQIs at these stations along with these values recorded/calculated for other monitoring station are presented in Tables 4.14 to 4.45 as mentioned in Section 4.1.

Based on the seasonal and annual AQIs, it was inferred that, the Pockets H and I are experiencing Light to moderate air pollution and while Pocket J (Basavanagudi Police Station) is experiencing Heavy air pollution. Within the statistical limitations, in a pocket, the air quality during different years of study period was found to be same. The ranges of annual AQIs for Kajisammanahalli, TERI Office and Basavanagudi Police Station were found to be respectively 65 to 77, 44 to 58 and 70 to 86.

Table – 4.23 : Monthly Air Quality Data / Indices for the Study Pocket: Yashwanthapur

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	120	17.1	30.3	113	113	21	38
February	174	16.6	31.3	149	149	21	39
March	158	15.8	30.2	139	139	20	38
April	125	26.4	32.0	117	117	33	40
May	178	18	26	152	152	23	33
June	91	10.9	28	91	91	14	35
July	96	16.9	30.8	96	96	21	39
August	137	16.9	31.0	125	125	21	39
September	106	17.9	31.0	104	104	22	39
October	119	16.6	32.5	113	113	16.6	32.5
November	105	15.7	43.5	103	103	20	54
December	105	16.7	31.2	103	103	21	39

Table – 4.24 : Monthly Air Quality Data / Indices for the Study Pocket: Yashwanthapur

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	102	16.5	31.0	101	101	21	39
February	48	12.2	30.8	78	78	22	39
March	78	17.6	30.9	48	48	22	39
April	85	16.5	31.0	85	85	21	39
May	111	16.4	31.0	107	107	21	39
June	91	16.4	30.5	91	91	21	38
July	111	16.9	31.1	107	107	21	39
August	108	15.9	32.0	105	105	20	40
September	215	16.30	30.4	177	177	20	38
October	151	16.5	32.0	134	134	21	40
November	107	16.5	34.0	105	105	21	43
December	108	14.9	30.0	105	105	19	38

Table – 4.25 : Monthly Air Quality Data / Indices for the Study Pocket: Yashwanthapur

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	196	15	30	164	164	19	38
February	-	-	-	-	-	-	-
March	83	15	30	83	83	19	38
April	112	13	28	108	108	16	35
May	135	15	30	123	123	19	38
June	103	14	29	101	101	18	36
July	88	14.1	29.4	88	88	18	37
August	78	12	25.7	78	78	15	32
September	91	12.9	28.5	91	91	16	36
October	82	14.8	29.4	82	82	19	37
November	105	17.1	31.2	103	103	21	39
December	137	14.5	29.6	125	125	18	37

Table – 4.26 : Monthly Air Quality Data / Indices for the Study Pocket: Yashwanthapur

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	109	13	39	106	106	16	49
February	162	15	36	141	141	19	45
March	83	15	30	83	83	19	38
April	117	15.8	31	111	111	20	39
May	117	13.3	29.1	111	111	17	36
June	106	13.8	29.4	104	104	17	37
July	96	12.6	28.5	96	96	16	36
August	55	9.4	26.9	55	55	12	34
September	91	12.9	28.5	91	91	16	36
October	119	11.2	31.0	113	113	14	39
November	116	11.7	56.4	111	111	15	71
December	167	10.5	27.1	145	145	13	34

Table – 4.27 : Monthly Air Quality Data / Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	191	6.6	28	161	161	8	35
February	225	6.0	30.9	183	183	8	39
March	146	6.1	30.7	131	131	8	38
April	141	6.2	21.6	127	127	8	27
May	149	6.0	22.7	133	133	8	28
June	103	5.9	22.1	102	102	7	28
July	99	5.4	15	99	99	7	19
August	96	5.1	14.2	96	96	6	18
September	63	4.7	12.2	63	63	6	15
October	105	3.0	14	103	103	4	18
November	82	2.3	20.4	82	82	3	26
December	134	2.0	24	123	123	3	30

Table – 4.28 : Monthly Air Quality Data / Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	133	14.1	29.9	122	122	18	37
February	93	14	30.4	93	93	18	38
March	78	14.5	28.8	78	78	18	36
April	25	23.6	25.0	31	31	30	31
May	34	25.1	48.0	60	60	31	60
June	31	11	29	36	36	14	36
July	40	13.6	30.6	40	40	17	38
August	71	14.5	28.6	71	71	18	36
September	48	14.8	30.4	48	48	19	38
October	65	17.2	34.1	65	65	22	43
November	85	13.7	30.0	85	85	17	38
December	66	16.6	29.7	66	66	21	37

Table – 4.29 : Monthly Air Quality Data / Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	71	30.3	30.4	71	71	38	38
February	87	15.2	29.9	87	87	19	37
March	80	15.1	34.7	80	80	19	43
April	56	14.8	30.0	56	56	19	38
May	64	13.6	29.0	64	64	17	36
June	95	15.1	30.3	95	95	19	38
July	184	15.0	30.0	156	156	19	38
August	118	18.6	34.9	112	112	23	44
September	124	15.2	32.0	116	116	19	40
October	174	14.3	29.0	149	149	18	36
November	280	14.4	32.2	230	230	18	40
December	265	13.7	30.0	215	215	17	38

Table – 4.30 : Monthly Air Quality Data / Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	231	14	30	146	146	18	37
February	232	14	30	188	188	18	38
March	270	15	30	220	220	19	38
April	168	14	30	145	145	18	38
May	149	14	29	133	133	18	36
June	152	15	29	135	135	19	36
July	148	15	30	132	132	19	38
August	130	15	24	120	120	19	30
September	132	13	29	121	121	16	36
October	102	15	30	101	101	19	38
November	156	16	31	137	137	20	39
December	154	15	30	136	136	19	38

Table – 4.31 : Monthly Air Quality Data / Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	221	14	30	181	181	18	38
February	264	13	29	214	214	16	36
March	270	15	30	220	220	19	38
April	257	15.5	31.2	207	207	19	39
May	176	13.6	29.1	151	151	17	36
June	236	13	29.4	191	191	16	37
July	192	15	30.2	161	161	19	38
August	172	13.6	29.1	148	148	17	36
September	132	13.4	28.8	121	121	17	36
October	273	15	38.8	223	223	19	49
November	202	13.7	60.7	168	168	17	76
December	243	11.3	27.4	195	195	14	34

Table – 4.32 : Monthly Air Quality Data / Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	211	6.6	29.3	174	174	8	37
February	216	6.2	33.7	177	177	8	42
March	195	6.2	26.6	163	163	8	33
April	156	6.1	16.2	137	137	8	20
May	120	6.9	18.5	113	113	9	23
June	135	5.9	17.5	123	123	7	22
July	137	5.7	15.8	125	125	7	20
August	89	5.8	14.2	89	89	7	18
September	87	4.9	13.5	87	87	6	17
October	98	2.2	12.8	98	98	3	16
November	78	3.2	19.7	78	78	4	25
December	117	2.0	21	111	111	3	26

Table – 4.33 : Monthly Air Quality Data / Indices for the Study Pocket:

City Railway Station

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	88	12.1	72.5	91	91	15	91
February	77	12.8	29.7	77	77	16	37
March	61	16.7	63.9	184	184	21	184
April	33	13.7	62.5	78	78	17	78
May	26	9	65.7	82	82	11	82
June	43	9.4	60.3	75	75	12	75
July	49	11.7	62.1	78	78	0	78
August	51	12.3	63.4	79	79	15	79
September	54	11.8	65.2	82	82	15	82
October	-	-	-	-	-	-	-
November	46	7.5	45.1	60	60	9	56
December	53	6.1	92.0	112	112	8	112

Table – 4.34 : Monthly Air Quality Data / Indices for the Study Pocket:

City Railway Station

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	90	5.1	20.5	90	90	6	26
February	100	5.2	22.4	100	100	7	28
March	82	9.1	25.1	82	82	11	31
April	83	10.9	30.9	83	83	14	39
May	79	12.7	32.8	79	79	16	41
June	82	7.5	23.8	82	82	9	30
July	101	12.5	28.4	101	101	16	36
August	141	10.9	19.2	127	127	14	24
September	148	6.1	40.6	132	132	8	51
October	108	7.1	39.1	105	105	9	49
November	133	6.6	33.1	122	122	8	41
December	41	6.20	37.9	47	41	8	47

Table – 4.35 : Monthly Air Quality Data / Indices for the Study Pocket:

City Railway Station

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	108	7.1	39.1	105	105	9	49
February	133	6.6	33.1	122	122	8	45
March	85	6.2	37.9	85	85	8	47
April	80	6.3	41.7	80	80	8	52
May	76	8.8	35.7	76	76	11	45
June	68	9.3	22.7	68	68	12	28
July	66	7.5	15.8	66	66	9	20
August	62	7.2	16.7	62	62	9	21
September	53	6.9	23.5	53	53	9	29
October	70	7.4	23.3	70	70	9	29
November	75	9.9	17	75	75	12	21
December	57	10.4	21	57	57	13	26

Table – 4.36 : Monthly Air Quality Data / Indices for the Study Pocket:

City Railway Station

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	52	11	21	52	52	14	26
February	53	10	21	53	53	13	26
March	85	6.4	37.9	85	85	8	47
April	80	11	17	80	80	14	21
May	59	10	29	59	59	13	36
June	63	10	22	63	63	13	28
July	69	8.2	16.5	69	69	10	21
August	65	8.0	17.3	65	65	10	22
September	58	7.2	25	58	58	9	31
October	72	7.7	24.6	72	72	10	31
November	78	10.3	19	78	78	13	24
December	77	7.8	27.3	78	78	10	34

Table – 4.37 : Monthly Air Quality Data / Indices for the Study Pocket:

City Railway Station

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	78	7.1	64.1	80	80	19	80
February	-	-	-	-	-	-	-
March	113	3.7	58.7	109	109	5	73
April	141	12.2	14.8	127	127	15	19
May	78	4.0	40.2	78	78	5	50
June	61	4.7	31.4	61	61	6	39
July	68	3.0	43	68	68	4	54
August	61	3.2	33.6	61	61	4	42
September	113	3.7	58.7	109	109	5	73
October	152	4.2	67.3	135	135	5	84
November	74	6.6	41.4	74	74	8	52
December	74	11.6	62.9	74	74	15	79

Table – 4.38 : Monthly Air Quality Data / Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	125	10	29	117	117	13	36
February	190	13	28.6	160	160	16	36
March	125	15	26	117	117	19	33
April	200	9	26.4	167	167	11	33
May	175	10.3	24.2	150	150	13	33
June	126	10.8	27	117	117	14	34
July	123	9.6	26.4	115	115	12	33
August	150	11.5	27	133	133	14	34
September	212	10.6	27.4	175	175	13	34
October	161	12.3	25.2	141	141	15	32
November	137	15.6	29.4	125	125	20	37
December	203	14.3	27.3	169	169	18	34

Table – 4.39 : Monthly Air Quality Data / Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	128	12	27	119	119	15	34
February	95	15	28	95	95	19	35
March	127	13	27	118	118	16	34
April	198	12	27	165	165	15	34
May	171	12	26	147	147	15	33
June	130	12	28	120	120	15	35
July	125	11	27.2	117	117	14	34
August	147	12.8	27.9	131	131	16	35
September	215	11.2	28.8	177	177	14	36
October	163	11.8	27.3	142	142	15	34
November	135	16.5	30.1	123	123	21	38
December	210	14.7	28.5	173	173	18	36

Table – 4.40 : Monthly Air Quality Data / Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	130	14	30	120	120	18	38
February	99	14	30	99	99	18	38
March	130	15	30	120	120	19	38
April	196	14	29	164	164	18	36
May	169	14	29	146	146	18	36
June	131	14	29	121	121	18	36
July	128	13.7	28.9	119	119	17	36
August	151	15.1	29.6	134	134	19	37
September	217	13.9	30.4	178	178	17	38
October	170	14.3	29.6	147	147	18	37
November	138	16.9	37.3	125	125	21	40
December	216	15.1	29.6	177	177	19	37

Table – 4.41 : Monthly Air Quality Data / Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	100	16	29	100	100	20	36
February	231	14	29	187	187	18	36
March	130	15	30	120	120	19	38
April	259	16	31	209	209	20	39
May	157	13.2	29.2	138	138	17	37
June	119	13.4	29	113	113	17	36
July	150	13.9	29.8	133	133	17	37
August	165	13.5	29	143	143	17	36
September	121	12.6	28	114	114	16	35
October	162	13.8	37.8	141	141	17	47
November	175	12.6	48.1	150	150	16	60
December	259	10.1	27.9	209	209	13	35

Table – 4.42 : Monthly Air Quality Data / Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	244	6.5	29.2	196	196	8	37
February	249	6.2	29.8	199	199	8	37
March	211	6.1	26.6	174	174	8	33
April	228	5.9	17.1	185	185	7	21
May	120	6.9	18.5	113	113	9	23
June	161	5.9	19.2	141	141	7	24
July	161	5.9	17.8	141	141	7	22
August	119	5.7	15.5	113	113	7	18
September	155	5.2	14.4	137	137	7	18
October	182	2.2	13.2	155	155	3	17
November	170	2.7	21.7	147	147	3	27
December	253	2.0	31.0	203	203	3	39

Table – 4.43 : Seasonal Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	126	16.5	34.1	117	117	21	43
Summer (Mar to Jun)	138	17.8	29.1	125	125	22	36
Monsoon (July to Oct)	114.5	17.1	31.3	111	111	21	39

Table – 4.44 : Seasonal Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	91.3	16.3	31.5	91	91	20	39
Summer (Mar to Jun)	91.3	16.7	30.9	91	91	21	39
Monsoon (July to Oct)	146.3	16.4	31.4	131	131	21	39

Table – 4.45 : Seasonal Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	146	15.6	30.3	131	131	20	38
Summer (Mar to Jun)	108	14.0	29.3	105	105	18	37
Monsoon (July to Oct)	84.8	13.5	28.3	85	85	17	35

Table – 4.46 : Seasonal Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	138.5	12.6	39.6	126	126	16	50
Summer (Mar to Jun)	105.8	15	29.9	104	104	19	37
Monsoon (July to Oct)	90.3	11.5	28.7	90	90	14	36

Table – 4.47 : Seasonal Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	158	4.2	25.8	139	139	5	36
Summer (Mar to Jun)	134.8	3.6	24.3	123	123	5	30
Monsoon (July to Oct)	90.8	4.4	13.9	91	91	6	17

Table – 4.48 : Yearly Air Quality Indices for the Study Pocket:

Yashwanthapur

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	123.7	18.3	33	116	116	23	41
2012	105	3.6	22.6	103	103	5	28
2013	109.9	14.3	29.2	107	107	18	37
2014	114.7	12.9	32.8	110	110	16	41
2015	127.8	4.9	21.3	119	119	6	27

Table – 4.49 : Seasonal Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	94.3	14.6	30	94	94	18	38
Summer (Mar to Jun)	42	16.1	32.7	42	42	20	41
Monsoon (July to Oct)	56	15.0	30.9	56	56	19	39

Table – 4.50 : Seasonal Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	175.8	18.4	30.6	151	151	23	38
Summer (Mar to Jun)	73.8	14.7	31.0	74	74	18	39
Monsoon (July to Oct)	150	15.8	31.5	133	133	20	39

Table – 4.51 : Seasonal Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	193.3	14.8	30.3	162	162	19	38
Summer (Mar to Jun)	184.8	14.5	29.5	157	157	18	37
Monsoon (July to Oct)	128	14.5	28.2	119	119	18	35

Table – 4.52 : Seasonal Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	232.5	13	29.3	188	188	16	37
Summer (Mar to Jun)	234.8	14.3	30.0	190	190	18	38
Monsoon (July to Oct)	192.3	14.3	31.7	162	162	18	40

Table – 4.53 : Seasonal Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	155.5	4.5	25.9	137	137	6	32
Summer (Mar to Jun)	151.5	5.8	19.7	134	134	7	25
Monsoon (July to Oct)	102.8	4.7	14.1	102	102	6	18

Table – 4.54 : Yearly Air Quality Indices for the Study Pocket:

AMCO Batteries

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	64.1	16.10	31.20	64	64	20	39
2012	13.2	16.3	31.0	39	39	20	39
2013	168.7	14.6	29.3	146	146	18	37
2014	219.3	13.8	32.8	180	180	17	41
2015	136.6	5.10	19.9	124	124	6	25

Table – 4.55 : Seasonal Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	66	9.6	59.8	75	66	12	75
Summer (Mar to Jun)	40.8	12.2	63.1	79	41	15	79
Monsoon (July to Oct)	51.3	11.9	63.6	80	51	15	80

Table – 4.56 : Seasonal Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	91	5.8	28.5	91	91	7	36
Summer (Mar to Jun)	81.5	10	28.2	82	82	13	35
Monsoon (July to Oct)	74.5	9.2	31.9	75	75	12	40

Table – 4.57 : Seasonal Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	93.3	8.5	27.6	93	93	11	35
Summer (Mar to Jun)	77.3	7.7	34.5	77	77	10	35
Monsoon (July to Oct)	62.8	7.3	19.8	63	63	9	25

Table – 4.58 : Seasonal Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	65	9.8	22.1	80	65	12	80
Summer (Mar to Jun)	71.8	9.4	26.5	72	72	12	33
Monsoon (July to Oct)	68.3	8.3	20.9	68	68	10	26

Table – 4.59 : Seasonal Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	75.3	8.4	56.1	75	75		
Summer (Mar to Jun)	98.3	8.5	36.3	98	98	11	45
Monsoon (July to Oct)	98.5	3.5	50.7	99	99	4	63

Table – 4.60 : Yearly Air Quality Indices for the Study Pocket:

City Railway Station

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	54.5	11.7	82.1	102	54	15	102
2012	99.0	8.30	29.5	99	99	10	37
2013	77.8	7.8	27.3	78	78	10	34
2014	62.2	10.3	20.7	62	62	13	26
2015	93.5	5.7	45.2	94	94	7	57

Table – 4.61 : Seasonal Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	163.8	13.2	28.6	143	143	17	36
Summer (Mar to Jun)	156.5	11.3	25.9	138	138	14	32
Monsoon (July to Oct)	183.8	11.0	26.5	156	156	14	33

Table – 4.62 : Seasonal Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	144.5	14.6	28.6	130	130	18	36
Summer (Mar to Jun)	156.5	12.3	25.9	138	138	15	32
Monsoon (July to Oct)	162.5	13.5	26.5	142	142	17	33

Table – 4.63 : Seasonal Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	145.8	15	30.5	131	131	19	38
Summer (Mar to Jun)	156.5	14.3	29.5	138	138	18	37
Monsoon (July to Oct)	166.5	14.3	29.6	144	144	18	37

Table – 4.64 : Seasonal Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	166.3	13.2	33.5	144	144	17	37
Summer (Mar to Jun)	166.3	14.4	29.8	144	144	18	37
Monsoon (July to Oct)	149.5	13.5	31.2	133	133	17	39

Table – 4.65 : Seasonal Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	229	4.3	27.9	186	186	5	35
Summer (Mar to Jun)	180	6.2	20.4	153	153	8	26
Monsoon (July to Oct)	154.3	4.8	15.2	136	136	6	19

Table – 4.66 : Yearly Air Quality Indices for the Study Pocket:

Central Silk Board

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	160.6	11.8	27	140	140	15	18
2012	153.7	13	27.7	136	136	16	35
2013	156.4	14.5	29.8	138	138	18	37
2014	179.5	13.7	31.5	153	153	17	39
2015	187.8	5.10	21.2	159	159	6	27

Table – 4.67 : Monthly Air Quality Data / Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	137	13.2	29.2	125	125	17	37
February	77	12.8	29.7	77	77	16	37
March	58	12.2	30.0	58	58	15	38
April	25	11.5	10.5	25	25	14	13
May	25	14.8	13.0	25	25	9	16
June	24	6.9	18.4	24	24	18	23
July	33	14.3	30.1	38	38	16	38
August	24	12.7	29.0	36	36	16	36
September	41	12.7	29.8	41	41	16	37
October	85	16	23.3	85	85	16	23.3
November	47	12.8	24.2	47	47	16	30
December	54	12.8	28.5	54	54	16	36

Table – 4.68 : Monthly Air Quality Data / Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	30	13.3	41.0	51	30	17	51
February	90.6	12.9	30.2	91	91	16	38
March	100	13.0	29.9	100	100	16	37
April	71	13.1	30.1	71	71	16	38
May	50	12.3	26.4	50	50	15	33
June	119	12.7	29.7	113	113	16	37
July	140	12.6	28.0	127	127	16	35
August	83	12.5	33.4	83	83	16	42
September	125	15.4	30.7	117	117	19	38
October	96	13.1	28.7	96	96	16	36
November	231	16.0	33.2	187	187	20	42
December	447	13.7	29.0	421	421	17	36

Table – 4.69 : Monthly Air Quality Data / Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	172	13	29	148	148	16	36
February	132	13	29	121	121	16	36
March	158	13	29	139	139	16	36
April	77	13	29	77	77	16	39
May	101	13	29	101	101	16	36
June	75	12	29	75	75	16	36
July	94	12.5	28.8	94	94	16	36
August	84	12.1	26.1	84	84	15	33
September	85	12	26.4	85	85	15	33
October	75	12.6	28.9	75	75	16	36
November	94	14.2	30.2	94	94	18	38
December	106	12	29	104	104	15	36

Table – 4.70 : Monthly Air Quality Data / Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	116	12	29	111	111	15	36
February	142	13	29	128	128	16	36
March	158	13	29	139	139	16	36
April	132	16.3	31.1	121	121	20	39
May	128	16.3	29.2	119	119	20	37
June	115	16.3	28.6	110	110	20	36
July	77	11.5	28.4	77	77	14	36
August	70	10	27.3	70	70	13	34
September	84	12	26.4	84	84	15	33
October	285	12.3	31.6	235	235	15	40
November	112	11.6	49	108	108	15	61
December	178	10.1	26.3	152	152	13	33

Table – 4.71 : Monthly Air Quality Data / Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	285	2.0	29.1	235	235	25	36
February	244	6.3	33.5	196	196	8	42
March	136	5.9	30.1	124	124	7	38
April	155	6.1	22.3	137	137	8	28
May	97	6.2	23.4	165	165	8	29
June	91	7.0	23.3	91	91	9	29
July	66	6	13.7	66	66	8	17
August	96	5.2	14.7	96	96	7	18
September	51	5.1	15.9	51	51	6	20
October	85	2	13.7	85	85	3	17
November	74	2.5	25.4	74	74	3	32
December	134	2	27.9	123	123	3	35

Table – 4.72 : Seasonal Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	78.8	12.9	27.9	79	79	16	35
Summer (Mar to Jun)	41.3	11.4	32.7	41	41	14	41
Monsoon (July to Oct)	45.8	14	18.0	46	46	18	23

Table – 4.73 : Seasonal Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	199.7	14.0	33.4	166	166	18	42
Summer (Mar to Jun)	85	12.8	29	85	85	16	36
Monsoon (July to Oct)	111	13.4	30.2	107	107	17	38

Table – 4.74 : Seasonal Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	126	12.3	29.3	117	117	15	37
Summer (Mar to Jun)	102.8	12.8	29	102	102	16	36
Monsoon (July to Oct)	84.5	12.3	27.6	85	85	15	35

Table – 4.75 : Seasonal Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	137	11.7	33.3	125	125	15	35
Summer (Mar to Jun)	133.3	15.5	29.5	122	122	19	42
Monsoon (July to Oct)	129	11.5	28.4	119	119	14	36

Table – 4.76 : Seasonal Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	184.3	3.2	29	156	156	4	36
Summer (Mar to Jun)	119.8	6.3	24.8	113	113	8	31
Monsoon (July to Oct)	74.5	4.6	14.4	75	75	6	18

Table – 4.77 : Yearly Air Quality Indices for the Study Pocket:

Victoria Hospital

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	52.5	12.7	24.6	53	53	16	31
2012	131.9	13.4	30.9	121	121	17	39
2013	104.4	12.7	28.6	103	103	16	36
2014	133.6	12.9	30.5	122	122	16	38
2015	126.2	5.0	22.7	117	117	6	28

Table – 4.78 : Monthly Air Quality Data / Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	98	16.5	27.2	98	98	21	34
February	92	10	24.5	82	82	13	31
March	92	17.5	21.3	92	92	22	31
April	92	16.4	23.2	92	92	21	29
May	81	10.5	23.3	81	81	13	29
June	81	9.2	28.5	81	81	12	36
July	83	14.5	23.3	83	83	18	29
August	70	15.9	22.2	67	67	20	28
September	65	10.4	22.3	65	65	13	28
October	53	15.6	25.4	53	53	20	32
November	77	13.1	32.8	77	77	16	41
December	55	15.2	27.6	55	55	19	35

Table – 4.79 : Monthly Air Quality Data / Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	97	10	27	97	97	13	34
February	80	11	26	80	80	14	33
March	95	14	25	95	95	18	31
April	90	13	24	90	90	16	30
May	82	12	25	82	82	15	30
June	85	10	27	85	85	13	34
July	43	12	27.4	43	43	15	34
August	65	11.8	26.8	65	65	15	34
September	60	11.3	27.3	60	60	14	34
October	52	12.4	30.5	52	52	16	38
November	71	10.2	31	71	71	13	38
December	52	10.5	29.4	52	52	13	37

Table – 4.80 : Monthly Air Quality Data / Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	99	12.28	28.7	99	99	15	35
February	82	12	28	82	82	15	35
March	96	13	29	96	96	16	36
April	91	12	29	91	91	15	36
May	84	13	29	84	84	16	36
June	83	13	29	83	83	16	36
July	41	12.8	28.8	41	41	16	36
August	66	13.5	27.2	66	66	17	34
September	60	13.5	28.7	60	60	17	36
October	54	13.3	29.2	54	54	17	37
November	74	11.1	29.9	74	74	14	37
December	54	11.2	28.7	54	54	14	36

Table – 4.81 : Monthly Air Quality Data / Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	67	12	29	67	67	15	36
February	63	11	29	63	63	14	36
March	96	13	29	96	96	16	36
April	82	13.3	29	82	82	17	36
May	56	12	27.5	56	56	15	34
June	48	11.6	28.2	48	48	15	35
July	51	11.6	27.3	51	51	15	34
August	84	11.9	28.1	84	84	15	35
September	66	10.4	26.8	66	66	13	34
October	50	10.9	27.6	50	50	14	35
November	70	10	24	70	70	13	30
December	78	8.9	19.6	78	78	11	25

Table – 4.82 : Monthly Air Quality Data / Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	90	5.8	21.5	90	90	7	27
February	81	5.3	25.9	81	81	7	32
March	72	5.7	19.2	72	72	7	24
April	70	5.4	13.4	70	70	7	17
May	59	5.1	10.6	59	59	6	13
June	55	5.0	11.0	55	55	6	14
July	63	5.1	13.3	63	63	6	17
August	66	4.9	13.5	66	66	6	17
September	69	4.8	12.5	69	69	6	16
October	94	2.0	11.3	94	94	3	14
November	57	2.6	12.5	57	57	3	16
December	86	2.0	12	86	86	3	15

Table – 4.83 : Seasonal Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	78	12.2	27	78	78	15	34
Summer (Mar to Jun)	86.5	13.4	24	87	87	17	30
Monsoon (July to Oct)	64.8	12.8	23.3	65	65	16	30

Table – 4.84 : Seasonal Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	77.5	10.4	28.4	78	78	13	36
Summer (Mar to Jun)	88	12.3	25.3	88	88	15	36
Monsoon (July to Oct)	55	11.9	28.0	55	55	15	35

Table – 4.85 : Seasonal Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	77.3	11.6	28.7	77	77	15	36
Summer (Mar to Jun)	88.5	12.8	29	89	89	16	36
Monsoon (July to Oct)	55.3	33.4	28.5	55	55	42	36

Table – 4.86 : Seasonal Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	69.5	10.5	25.4	70	70	13	32
Summer (Mar to Jun)	70.5	11.8	28.4	71	71	15	36
Monsoon (July to Oct)	62.8	11.2	27.5	63	63	14	34

Table – 4.87 : Seasonal Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	78.5	3.9	18	79	79	5	23
Summer (Mar to Jun)	64	5.3	13.6	64	64	7	23
Monsoon (July to Oct)	73	4.2	10.2	73	73	5	13

Table – 4.88 : Yearly Air Quality Indices for the Study Pocket: Kajisummanahalli

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	77.2	13.2	25.1	77	77	17	31
2012	72.7	11.5	27.2	73	73	14	34
2013	73.8	12.5	28.7	74	74	16	36
2014	65.1	11.3	27.0	65	65	14	34
2015	71.8	4.5	14.7	72	72	6	18

Table – 4.89 : Monthly Air Quality Data / Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	40	5.4	7.8	40	40	7	9
February	45	5.5	8.8	45	45	7	9
March	42	6.2	6.5	42	42	8	11
April	51	6.5	9.2	51	51	8	12
May	55	6.1	9.0	55	55	8	11
June	62	7.0	10.6	62	62	9	13
July	56	3.6	5.3	56	56	5	7
August	57	7.2	9.7	57	57	9	12
September	60	7.0	10.2	60	60	9	13
October	54	6.8	10.9	54	54	9	14
November	56	7.1	11.1	56	56	9	14
December	55	6.5	10.5	55	55	8	13

Table – 4.90 : Monthly Air Quality Data / Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	42	5.2	7.0	42	42	7	9
February	44	5.7	8.5	44	44	7	11
March	41	5.9	6.1	41	41	7	8
April	53	6.8	9.8	53	53	9	12
May	57	6.0	9.5	57	57	8	12
June	60	7.5	10.3	60	60	9	13
July	61	3.4	4.8	61	61	4	6
August	55	6.8	9.5	55	55	9	12
September	57	6.5	9.7	57	57	8	12
October	54	6.5	10.5	54	54	8	13
November	57	6.8	10.7	57	57	9	13
December	57	6.3	10.4	57	57	8	13

Table – 4.91 : Monthly Air Quality Data / Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	43.9	4.9	7.2	44	44	6	9
February	45.1	5.3	8.4	46	46	7	11
March	-	-	-	-	-	-	-
April	55	7.3	10.5	55	55	9	13
May	59	6.5	10.5	59	59	8	13
June	61	7.7	10.9	61	61	8	13
July	60	3.7	5.1	60	60	10	14
August	57	7.1	9.7	57	57	9	12
September	59	6.9	9.4	59	59	9	12
October	57	6.9	10.0	57	57	9	13
November	59	7.0	10.1	59	59	9	13
December	59	6.7	10.1	59	59	8	13

Table – 4.92 : Monthly Air Quality Data / Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	59	6.5	10.1	59	59	8	13
February	60	6.9	10.6	60	60	9	13
March	-	-	-	-	-	-	-
April	57	6.7	10.4	57	57	8	13
May	57	6.8	10.5	57	57	9	13
June	58	7.6	10.3	58	58	10	13
July	59	7.1	10.0	59	59	9	13
August	58	7.2	11.1	58	58	9	14
September	58	6.4	10.7	58	58	8	13
October	61	6.3	10.6	61	61	8	13
November	57	5.3	10.7	57	57	7	13
December	53	5	10.3	53	53	6	13

Table – 4.93 : Monthly Air Quality Data / Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	55	5.1	11.0	55	55	6	14
February	56	5.6	11.1	56	56	7	14
March	64	6.5	12.5	64	64	8	16
April	57	7.8	11.2	57	57	10	14
May	61	6.9	11.5	61	61	9	14
June	64	8.3	12.0	64	64	10	15
July	62	4.2	5.8	62	62	5	7
August	60	7.5	10.8	60	60	9	14
September	63	7.8	10.5	63	63	10	13
October	61	7.5	10.2	61	61	9	13
November	67	7.9	10.8	67	67	10	14
December	68	7.3	10.5	68	68	9	13

Table – 4.94 : Seasonal Air Quality Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	49	6.1	9.5	49	49	8	33
Summer (Mar to Jun)	52.5	6.5	8.8	53	53	8	11
Monsoon (July to Oct)	56.8	6.2	10.1	57	57	8	13

Table – 4.95 : Seasonal Air Quality Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	50	6.0	9.2	50	50	8	13
Summer (Mar to Jun)	52.8	6.6	8.9	53	53	8	11
Monsoon (July to Oct)	54.5	5.8	8.6	55	55	7	11

Table – 4.96 : Seasonal Air Quality Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	51.8	6.0	9.0	52	52	8	11
Summer (Mar to Jun)	58.3	7.2	10.6	58	58	9	13
Monsoon (July to Oct)	58.3	6.2	9.8	58	58	8	12

Table – 4.97 : Seasonal Air Quality Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	57.3	5.9	10.4	57	57	7	13
Summer (Mar to Jun)	57.3	7.0	13.4	57	57	9	17
Monsoon (July to Oct)	59	6.8	10.6	59	59	9	17

Table – 4.98 : Seasonal Air Quality Indices for the Study Pocket:

TERI Office - Domlur

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	59	6.5	10.9	59	59	8	14
Summer (Mar to Jun)	61.5	7.4	11.8	62	62	9	15
Monsoon (July to Oct)	61.5	6.8	9.3	62	62	9	12

Table – 4.99 : Yearly Air Quality Indices for the Study Pocket:

TERI Office – Domlur

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	52.8	6.2	9.1	53	53	8	11
2012	53.2	6.1	8.9	53	53	8	11
2013	43.9	4.9	7.2	44	44	6	9
2014	58.1	6.6	10.5	58	58	8	13
2015	58.3	5.7	11.5	58	58	7	14

Table – 4.100 : Monthly Air Quality Data / Indices for the Study Pocket: Banasawadi Police Station

Year Monitored : 2011

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	69	9.5	21.0	69	69	12	13
February	-	-	-	-	-	-	-
March	115	11.0	25.8	110	110	14	32
April	111	11.5	24.3	107	107	14	30
May	88	11.8	21.6	88	88	15	27
June	73	10.7	20.4	73	73	13	26
July	62	11.5	20.3	62	62	14	25
August	64	10.6	23.4	64	64	13	25
September	65	12.4	25.7	65	65	16	32
October	65	9.7	25.2	65	65	12	32
November	89	11.6	23.5	89	89	15	29
December	101	12.3	23.8	101	101	15	30

Table – 4.101 : Monthly Air Quality Data / Indices for the Study Pocket: Banasawadi Police Station

Year Monitored : 2012

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	73	10.2	21.4	73	73	13	27
February	84	10.8	23.5	84	84	14	29
March	118	11.2	26.4	112	112	14	33
April	115	11.8	25.2	110	110	15	32
May	92	12.4	22.7	92	92	16	28
June	74	11.2	21.6	74	74	14	27
July	65	13.5	22.4	65	65	17	28
August	67	11.1	24.5	67	67	14	31
September	63	13.5	26.2	63	63	17	33
October	64	10.3	27.3	64	64	13	34
November	88	12.5	24.2	88	88	16	30
December	103	13.5	23.9	102	102	17	30

Table – 4.102 : Monthly Air Quality Data / Indices for the Study Pocket: Banasawadi Police Station

Year Monitored : 2013

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January							
February							
March	119	11.6	27.2	34	34	15	34
April	113	11.4	26.2	33	33	14	33
May	87	11.2	23.3	88	88	14	33
June	71	11.3	22.9	72	72	14	29
July	64	10.8	22.4	64	64	14	28
August	62	10.6	22.7	62	62	13	28
September	70	11.1	24.8	70	70	14	31
October	66	10.9	24.4	66	66	14	31
November	86	11.4	24.6	86	86	14	31
December	104	11.1	24.9	103	103	14	31

Table – 4.103 : Monthly Air Quality Data / Indices for the Study Pocket: Banasawadi Police Station

Year Monitored : 2014

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	84.3	11.2	25.1	181	181	14	31
February	83.4	11.7	25.2	178	178	15	32
March	119	11.6	27.0	34	-	15	34
April	96	10.8	25.0	220	220	14	31
May	74	10.4	25.3	74	74	13	32
June	84	10.3	25.7	84	84	13	32
July	70	9.9	24.8	70	70	12	31
August	85	10.3	25.5	83	83	13	32
September	77	10.3	25	77	77	13	31
October	95.8	10.8	25.6	96	96	14	32
November	91	10.2	24.8	91	91	13	31
December	79.8	9.8	24.5	80	80	12	31

Table – 4.104 : Monthly Air Quality Data / Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2015

Month of the Year	Average Monthly Concentration (µg/m^3) of the parameter stated			AQI for the Month	Monthly AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
January	81	10.2	24.6	81	81	13	31
February	82	10.1	24.8	82	82	13	31
March	88	9.3	24.5	88	88	12	31
April	98	11.2	27	98	98	14	34
May	75	11.5	26.2	75	75	14	33
June	87	10.5	26.4	87	87	13	33
July	73	10.3	25.1	73	73	13	31
August	90	11.0	28.3	90	90	14	31
September	102	11.2	26.3	101	101	14	35
October	97	11.5	27.5	97	97	14	34
November	103	11.3	23.4	102	102	14	29
December	95	10.2	26.7	95	95	13	33

Table – 4.105 : Seasonal Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2011

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	86.3	11.1	22.8	86	86	14	29
Summer (Mar to Jun)	96.8	11.4	23	97	97	14	29
Monsoon (July to Oct)	64	11.0	23.7	64	64	14	29

Table – 4.106 : Seasonal Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2012

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	87	11.8	23.3	87	87	15	29
Summer (Mar to Jun)	99.8	11.7	24.0	100	100	15	30
Monsoon (July to Oct)	64.8	12.1	25.1	65	65	15	31

Table – 4.107 : Seasonal Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2013

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	86.8	10.9	23.3	87	87	14	29
Summer (Mar to Jun)	83.8	11.5	24.9	84	84	14	29
Monsoon (July to Oct)	65.5	10.9	23.6	66	66	14	30

Table – 4.108 : Seasonal Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2014

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	84.6	10.7	24.9	85	85	13	31
Summer (Mar to Jun)	93.3	10.8	25.8	93	93	14	32
Monsoon (July to Oct)	82	10.3	25.2	82	82	13	32

Table – 4.109 : Seasonal Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2015

Season of the Year	Average Seasonal Concentration (µg/m^3) of the parameter stated			Seasonal AQI	Seasonal AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
Winter (Nov to Feb)	90.3	10.5	24.9	90	90	13	31
Summer (Mar to Jun)	83.8	10.6	25.9	87	87	13	32
Monsoon (July to Oct)	90.5	11	26.8	91	91	14	34

Table – 4.110 : Yearly Air Quality Indices for the Study Pocket:

Banasawadi Police Station

Year Monitored : 2011 – 2015

Season of the Year	Average Annual Concentration (µg/m^3) of the parameter stated			Annual AQI	Annual AQI for the parameter stated (Sub Index)		
	PM_{10}	SO_2	NO_2		PM_{10}	SO_2	NO_2
2011	82	11.2	23.2	82	82	14	29
2012	83.8	11.8	24.1	84	84	15	30
2013	70.5	9.3	20.3	70	70	12	35
2014	86.4	10.5	25.10	86	86	13	31
2015	83.5	9.9	24.6	84	84	12	31

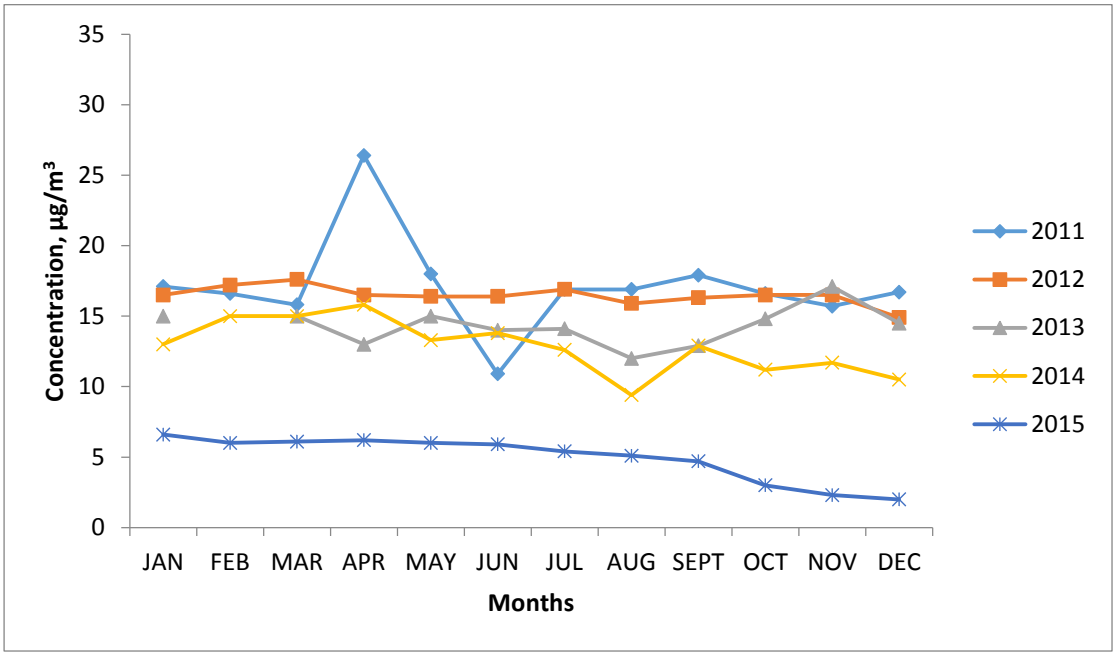


Fig. 4.47 : Monthly Variation of SO_2 During the Study Period (Station : C)

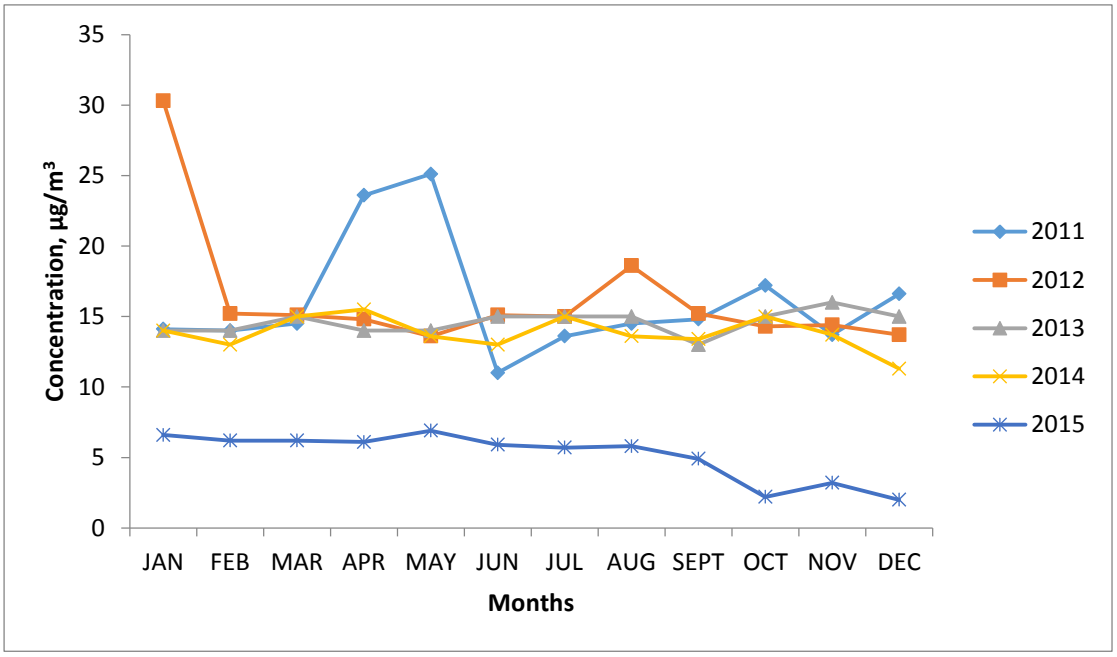


Fig. 4.48 : Monthly Variation of SO_2 During the Study Period (Station : D)

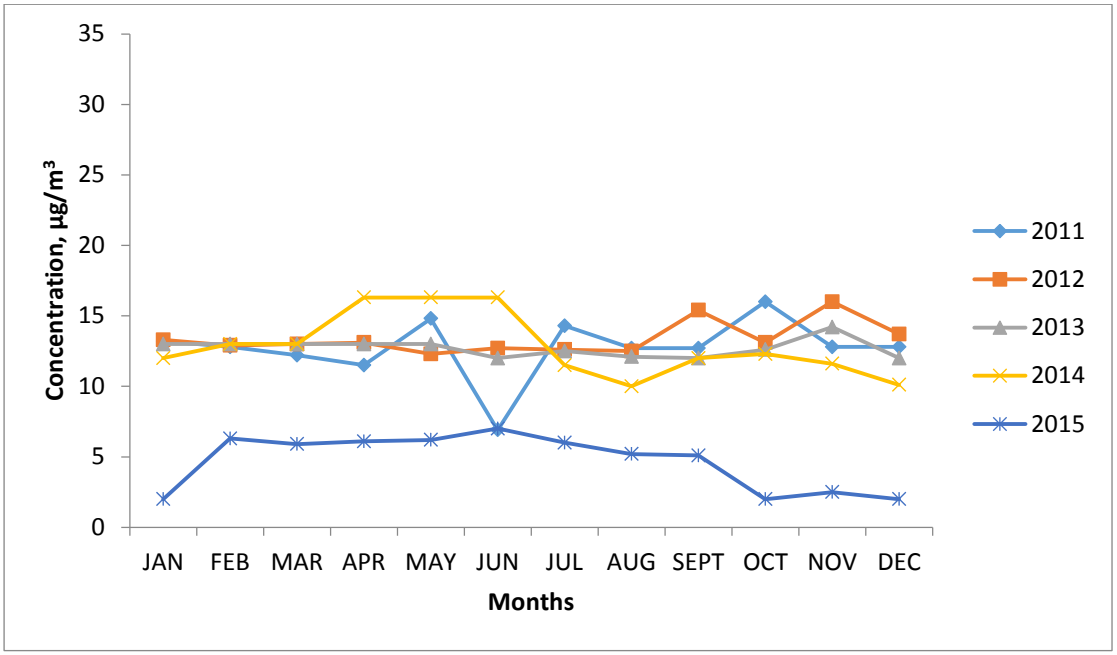


Fig. 4.49 : Monthly Variation of SO_2 During the Study Period (Station : E)

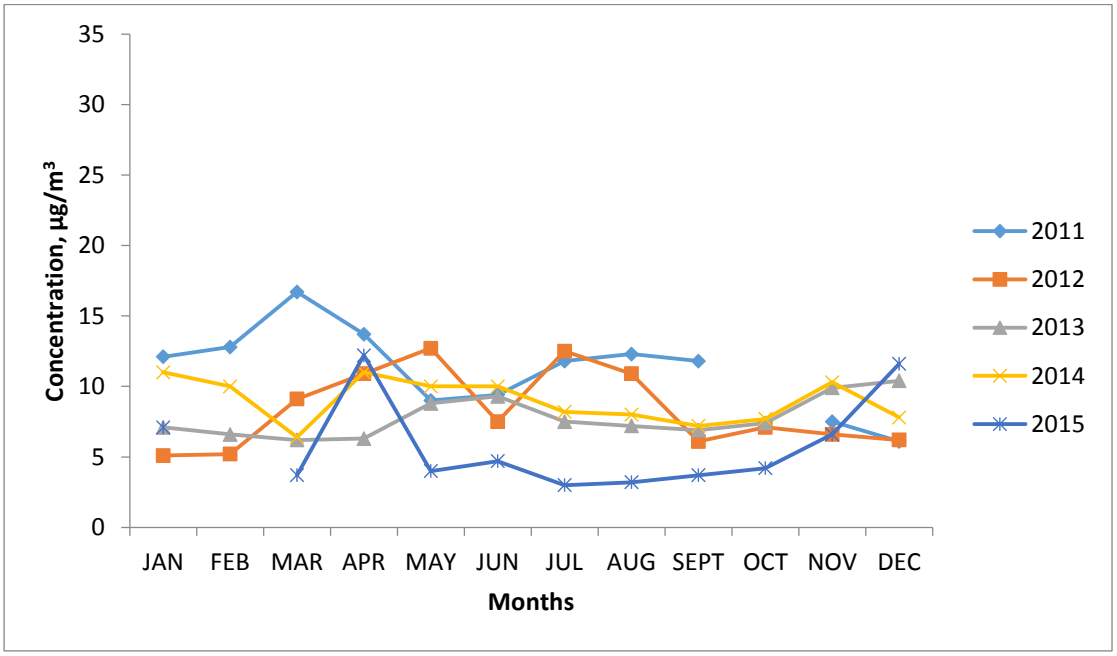


Fig. 4.50 : Monthly Variation of SO_2 During the Study Period (Station : F)

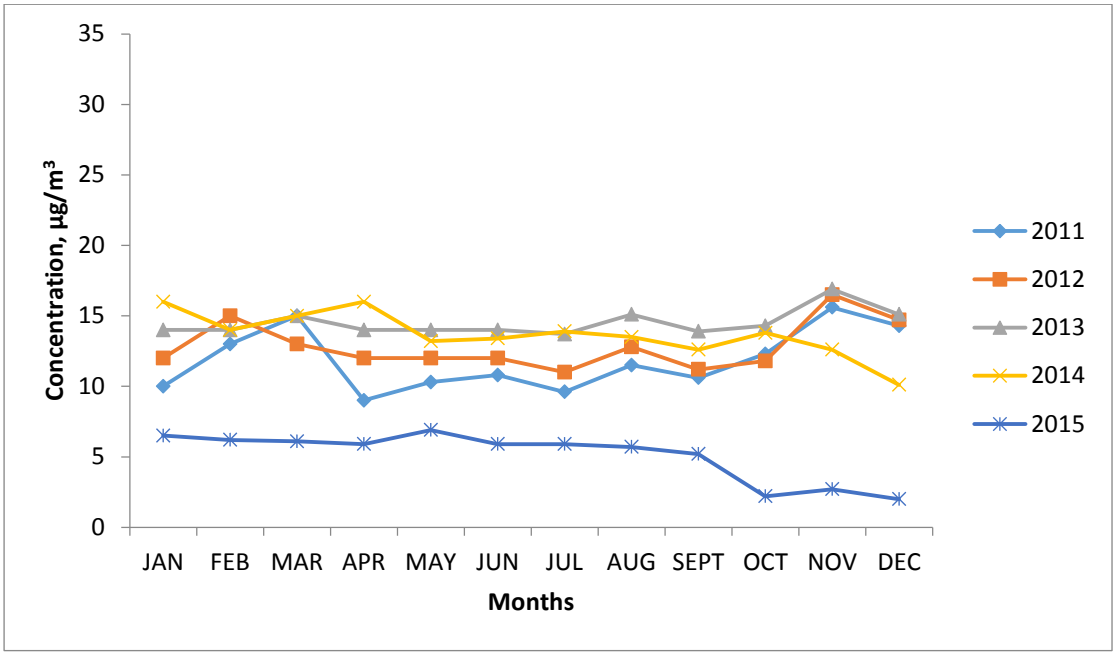


Fig. 4.51 : Monthly Variation of SO_2 During the Study Period (Station : G)

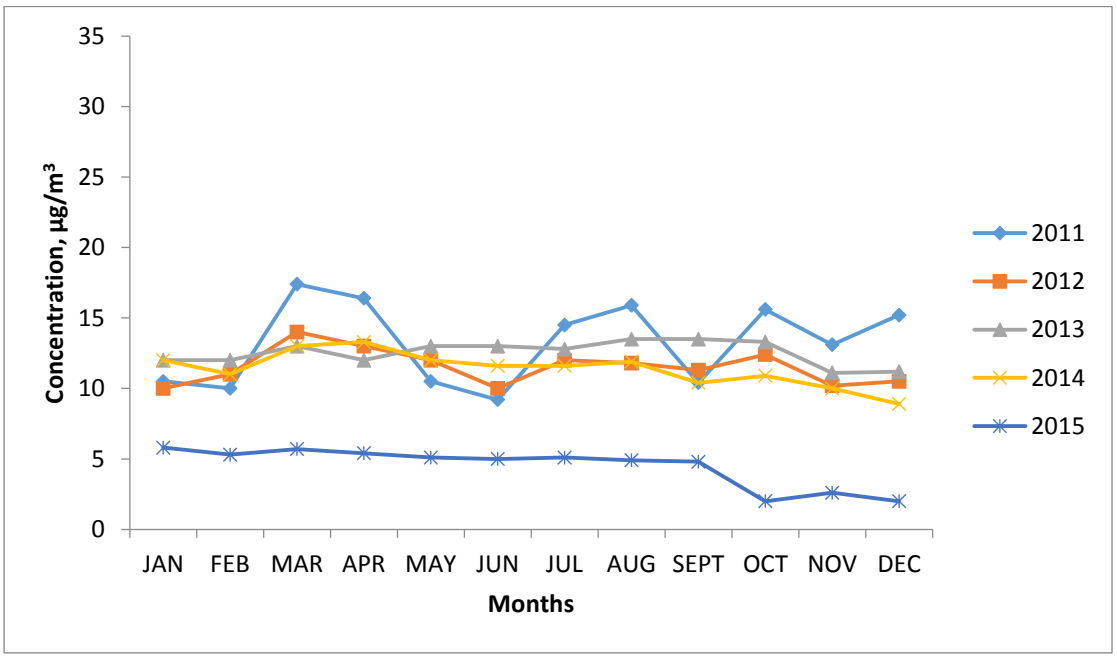


Fig. 4.52 : Monthly Variation of SO_2 During the Study Period (Station : H)

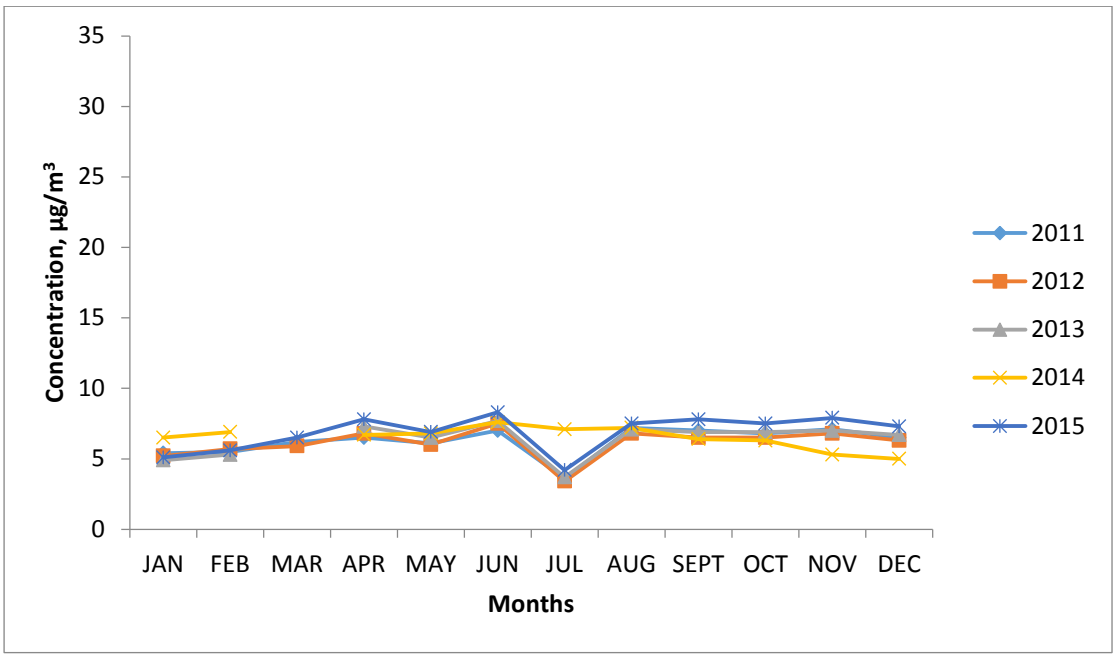


Fig. 4.53 : Monthly Variation of SO_2 During the Study Period (Station : I)

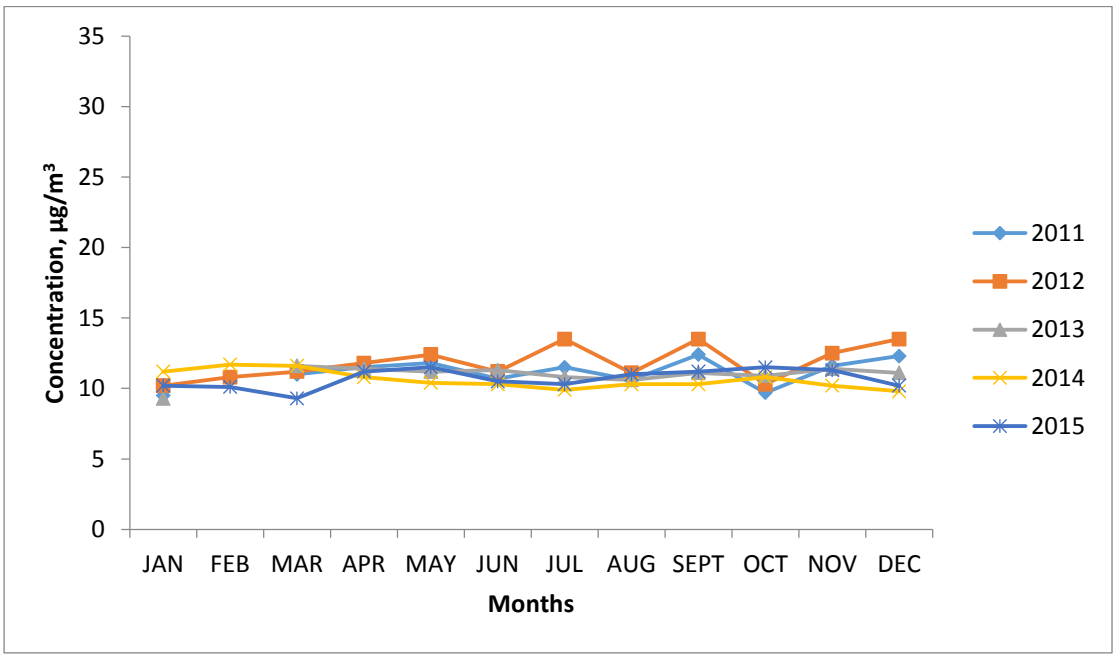


Fig. 4.54 : Monthly Variation of SO_2 During the Study Period (Station : J)

4.6 COMPARATIVE EVALUATION OF AIR QUALITY AT STUDY POCKETS

Air quality status of Ten Pockets studied in the present research work is discussed in the above sections 4.1 to 4.5. Here in this section, comparative evaluation of air quality at these ten study pockets is documented. The discussions are made here with, based on seasonal and annual AQIs of these pockets (fig. 4.26 to 4.45).

The industrial pockets A and B were found to be suffering from severe air pollution. The commercial pockets viz. C, D, F and G are also found to be suffering from Heavy to severe air pollution, majority of the times and/or otherwise few observations indicated Light to major air pollution. On the other hand the rural and background pockets namely H, I and J were found to be experiencing moderate to heavy air pollution. It was astonishing to note that even sensitive hospital pocket (Pocket 'E') is experiencing Heavy to severe air pollution.

Thus in total, the author opine that, the industrial and commercial pockets are becoming bowls of air pollutants and demands immediate action to mitigate air pollution. Even the rural and background pockets are not spared. Declining ambient air quality at these rural and background pockets has been observed.

4.7 EXCEEDENCE FACTOR AND AIR QUALITY

Exceedence factor values calculated for various pollutants at study pockets during the study period are documented in the Table 4.111. Also the Table 4.112 take stock of pollution status of study pockets based on exceedence factor. Interrelationship between exceedence factor and air pollution rating are discussed in section 3.10 of this report. Based on these guidelines the observations made are listed as below.

- As per the rate scale documented, EF: 0 to 0.5 (Low pollution), EF: 0.5 to 1.0 (Moderate pollution), EF: 1.0 to 1.5 (High pollution) and EF: 1.5 and above (Critical pollution) were adopted to draw inferences.

- Exceendence factor calculated for PM_{10}, found to exceed 1.5, majority of the times at industrial and commercial pockets (1.8 to 3.1). Thus it was inferred that these industrial and commercial pockets are critically polluted.
- On the other hand, at rural and background pockets (H, I and J). The EF almost ranging between 1.0 to 1.4 (PM_{10}) has been observed. This is an indicative of high pollution.
- Even the sensitive hospital area (Pocket 'E') was found to be experiencing critical air pollution to moderate air pollution (PM_{10}: 0.9 to 2.2).
- EF calculated with reference to pollutant NO_2 indicated that the industrial commercial and sensitive pockets are moderately polluted and rural and background pockets are low to moderately polluted.
- However the pockets studied were found to be low polluted with reference to SO_2 contents (EF: 0 to 0.5).
- Percentage times the stated pollution rate for the parameter mentioned at various study pockets (Table 4.112) also confirmed the critical pollution of industrial, commercial and sensitive area w.r.t PM_{10}, within the statistical limitations. While rural and background areas are moderately and highly polluted with respect to PM_{10}. On an average EE for NO_2 indicated that, the pockets are moderately polluted except Pocket 'H' (Highly polluted). However the EF for SO_2 indicated the low air pollution of the pockets studied.
- Thus in a nutshell, it was inferred that the main culprit pollutant is PM_{10} followed by NO_2 and SO_2, and no pockets considered for study are free from pollution.

4.8 TRAFFIC CENSUS AT / NEAR STUDY POCKETS

Yearly (2011 to 2015) Traffic census details pertaining to study pockets considered are collected from transportation department and are presented in Tables 4.113 to 4.117. Census details documented include vehicle types (Two wheeler, Auto, Cars/ Jeeps/ Vans, Buses, Trucks / Tractors), No of vehicles passing an intersection and there by the percentage of particular type of vehicles. Number of vehicles passing each intersection ranged from 59036 to 231593 (2011), 66066 to 259893 (2012), 72400 to 285755 (2013), 79824 to 316934 (2014) and 89674 to 346980 (2015).

These figures clearly speak the increase in vehicles number from year to year. At an any given time, maximum and minimum number of vehicles passed at intesections near to Pocket – A and Pocket – I respectively are 231593 to 346980 and 59036 to 89674. Percentage and number of vehicles passing the intersection reflected that the traffic composition is dominated by Cars/ Jeeps/ Vans followed by Two wheelers. The traffic flow at the intersections of study pockets was found to be one of the culprit for ambient air pollution. However the relationship between magnitude of pollution and traffic flow could not be established in the present study because of time constraint and lack of information about other pollution sources and meteriological factors which could not be accounted for in the present work.

4.9 SUMMARY

Based on the discussions made, inferences drawn and documented in the sections above, it was inferred that, all the study pockets are suffering from Heavy to serious air pollution. Industrial and commercial pockets are more polluted compared to Rural and background pockets. Out of the three pollutants studied, PM_{10} was found to be the critical pollutant responsible for ambient air pollution, followed by NO_2 and SO_2.

The author could not establish a relationship between season of a year and AQIs with the observations made in the present study. However suggested, in depth studies in duplicate and triplicate in future to arrive at such a relationship. Author opined that the vehicular movement is also one of the major problem resulting in ambient air pollution. Further it is opined that, there is a urgent need to initiate the measures to mitigate the pollution of ambient air to make the life of human beings in this capital of the state more tolerable and sustainable.

Table – 4.111: Computed Exceedence Factor Values for Various Pollutants at Study Pockets

Year	Pollutant	Exceedence Factor Values (EF) at Pockets Stated									
		A	B	C	D	E	F	G	H	I	J
		EF	EF	EF	EF	EF	EF	EF	EF	EF	EF
2011	SO_2	0.4	0.4	0.4	0.3	0.6	0.2	0.2	0.3	0.1	0.2
	NO_2	0.8	0.8	0.8	0.8	0.8	2.1	0.7	0.6	0.2	0.6
	PM_{10}	1.8	3.0	2.1	1.1	0.9	0.9	2.7	1.3	0.9	1.4
2012	SO_2	0.3	0.3	0.1	0.3	0.7	0.2	0.3	0.2	0.1	0.2
	NO_2	0.8	0.8	0.6	0.8	1.0	0.7	0.7	0.7	0.2	0.6
	PM_{10}	2.4	3.0	1.8	2.2	2.2	1.7	2.6	1.2	0.9	1.4
2013	SO_2	0.3	0.3	0.3	0.3	0.6	0.2	0.3	0.3	0.1	0.2
	NO_2	0.7	0.7	0.5	0.7	1.0	0.7	0.7	0.7	0.2	0.5
	PM_{10}	2.3	2.3	1.8	2.8	1.7	1.3	2.6	1.2	0.7	1.2
2014	SO_2	0.3	0.3	0.2	0.3	0.7	0.2	0.3	0.2	0.1	0.2
	NO_2	0.9	0.7	0.8	0.8	1.0	0.5	0.8	0.7	0.3	0.6
	PM_{10}	3.5	1.8	2.0	3.7	2.2	1.0	3.0	1.1	1.0	1.4
2015	SO_2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2
	NO_2	0.5	0.4	0.5	0.5	0.8	1.1	0.5	0.4	0.3	0.6
	PM_{10}	3.0	2.1	2.1	2.3	2.1	1.6	3.1	1.2	1.0	1.4

Table - 4.112 : Pollution Status of Study Pockets, During the Study Period, Based on Exceedence Factor

Station	Percentage Times the Stated Pollution Rate for the Parameter Mentioned											
	Low Pollution			Moderate Pollution			High Pollution			Critical Pollution		
	SO_2	NO_2	PM_{10}	SO_2	NO_2	PM_{10}	SO_2	NO_2	PM_{10}	SO_2	NO_2	PM_{10}
A	100	-	-	-	100	-	-	-	-	-	-	100
B	100	20	-	-	80	-	-	-	-	-	-	100
C	100	-	-	-	100	-	-	-	-	-	-	100
D	100	-	-	-	100	-	-	-	20	-	-	80
E	20	-	-	80	33	-	-	67	20	-	-	80
F	100	-	-	-	60	20	-	20	40	-	20	40
G	100	-	-	-	100	-	-	-	-	-	-	100
H	100	-	-	-	20	-	-	80	100	-	-	-
I	100	100	-	-	-	60	-	-	40	-	-	-
J	100	-	-	-	100	-	-	-	100	-	-	-

Table – 4.113 : Number and Percentage Share of Each Vehicular Group At Study Intersections (2011)

Station Code	Intersection Name	Distance between station & survey location (Km)	Two Wheelers	Auto	Cars/ Jeeps/ Vans	Buses	Trucks/ Tractor	Total (100%)
A	KR Puram Bridge Junction	7.8	77946 (33.6)*	14425 (6.2)	102850 (44.4)	14250 (6.2)	22122 (9.6)	231593
B	Hebbal Junction	7.8	62750 (30)	13170 (6.3)	109985 (52.2)	9650 (3.3)	15980 (8.2)	210000
C	New BEL	1.7	24810 (39)	8740 (13.6)	25465 (40)	1995 (3.1)	2762 (4.3)	63772
D	Bapuji Nagar Junction	0.2	50144 (51)	12324 (12.8)	24012 (24.5)	5216 (5.5)	5879 (6.4)	97575
E	Town Hall Junction	2.3	35135 (39.3)	12098 (13.5)	29215 (32.7)	7865 (8.8)	5112 (5.7)	89425
F	KR Circle	2.4	50987 (48)	11867 (11.2)	35114 (33.0)	6150 (5.8)	2110 (2)	106228
G	Silk Board Junction	0.1	72168 (35)	15965 (7.7)	85014 (41.2)	17672 (8.7)	15314 (7.4)	206133
H	Entrance	-	-	-	-	-	-	-
I	Lower Agarwal Junction	4.1	27360 (46.3)	6010 (10.2)	21472 (36.4)	1698 (2.9)	2496 (4.2)	59036
J	Hennur Road Junction on ORR	1.5	45216 (32.3)	21410 (15.3)	61540 (43.9)	4385 (3.1)	7632 (5.4)	140183

( )*Percentage

Table – 4.114 : Number and Percentage Share of Each Vehicular Group At Study Intersections (2012)

Station Code	Intersection Name	Distance between station & survey location (Km)	Two Wheelers	Auto	Cars/ Jeeps/ Vans	Buses	Trucks/ Tractor	Total (100%)
A	KR Puram Bridge Junction	7.8	88158 (33.9)*	15865 (6.1)	116960 (45)	16460 (6.3)	22450 (8.6)	259893
B	Hebbal Junction	7.8	70156 (31)	15432 (6.8)	114460 (50)	8215 (3.7)	19260 (8.5)	227523
C	New BEL	1.7	27900 (38.2)	10150 (14)	29676 (40.7)	2260 (3.0)	3010 (4.1)	72996
D	Bapuji Nagar Junction	0.2	57960 (51.3)	13810 (12.2)	27185 (24)	6934 (6.2)	7147 (6.3)	113036
E	Town Hall Junction	2.3	40567 (39.7)	13648 (13.3)	33102 (32.4)	9068 (8.9)	5864 (5.7)	102249
F	KR Circle	2.4	56347 (47.1)	13460 (11.2)	40278 (33.7)	7014 (5.8)	2586 (2.2)	119685
G	Silk Board Junction	0.1	82014 (34.8)	18312 (7.8)	97610 (41.4)	20060 (8.5)	17710 (7.5)	235706
H	Entrance	-	-	-	-	-	-	-
I	Lower Agarwal Junction	4.1	30425 (46.1)	6995 (10.6)	23841 (36.1)	2042 (3.1)	2763 (4.1)	66066
J	Hennur Road Junction on ORR	1.5	51430 (33)	23860 (15.3)	68750 (44)	5010 (3.2)	7186 (4.5)	156236

( )*Percentage

Table – 4.115 : Number and Percentage Share of Each Vehicular Group At Study Intersections (2013)

Station Code	Intersection Name	Distance between station & survey location (Km)	Two Wheelers	Auto	Cars/ Jeeps/ Vans	Buses	Trucks/ Tractor	Total (100%)
A	KR Puram Bridge Junction	7.8	97032 (34)*	17227 (6)	131230 (46)	18395 (6.4)	21871 (7.6)	285755
B	Hebbal Junction	7.8	78244 (30.5)	17310 (6.8)	127120 (50)	9680 (3.8)	22577 (8.9)	254931
C	New BEL	1.7	30781 (38)	10620 (13.1)	33832 (41.7)	2506 (3.1)	3354 (4.1)	81093
D	Bapuji Nagar Junction	0.2	65676 (51.2)	15307 (12)	30161 (23.5)	8684 (6.8)	8433 (6.5)	128261
E	Town Hall Junction	2.3	45961 (40)	15337 (13.3)	36922 (3.2)	10288 (9)	6747 (5.7)	115255
F	KR Circle	2.4	62821 (46.8)	14909 (11.1)	45745 (34.1)	7815 (5.8)	2916 (2.2)	134206
G	Silk Board Junction	0.1	91385 (34.4)	20744 (7.8)	110817 (41.7)	22781 (8.6)	1982 (7.5)	265552
H	Entrance	-	-	-	-	-	-	-
I	Lower Agarwal Junction	4.1	33998 (47)	7879 (10.9)	26117 (36.0)	2388 (3.3)	2018 (2.8)	72400
J	Hennur Road Junction on ORR	1.5	57272 (33.2)	26480 (15.3)	75244 (43.6)	5726 (3.3)	7859 (4.6)	172581

( )*Percentage

Table – 4.116 : Number and Percentage Share of Each Vehicular Group At Study Intersections (2014)

Station Code	Intersection Name	Distance between station & survey location (Km)	Two Wheelers	Auto	Cars/ Jeeps/ Vans	Buses	Trucks/ Tractor	Total (100%)
A	KR Puram Bridge Junction	7.8	106629 (33.6)*	18931 (6)	144209 (45.5)	20215 (6.4)	26950 (8.5)	316934
B	Hebbal Junction	7.8	86219 (30.4)	19075 (6.7)	140077 (49.3)	10665 (3.8)	27935 (9.8)	283971
C	New BEL	1.7	34297 (38)	11833 (13.0)	37696 (24.6)	2791 (3.0)	3984 (4.4)	90601
D	Bapuji Nagar Junction	0.2	71777 (52.4)	16730 (12.2)	32962 (24.0)	5959 (4.4)	9528 (7)	136956
E	Town Hall Junction	2.3	51497 (39.8)	17184 (13.3)	41370 (32)	11528 (8.9)	7741 (6)	129320
F	KR Circle	2.4	69646 (46.8)	16529 (11.1)	50715 (34.1)	8663 (5.8)	3243 (2.2)	148796
G	Silk Board Junction	0.1	101258 (34.2)	22985 (7.8)	122789 (41.6)	25242 (8.5)	23242 (7.9)	295516
H	Entrance	-	-	-	-	-	-	-
I	Lower Agarwal Junction	4.1	37464 (47)	8682 (10.9)	28780 (36.0)	2633 (3.3)	2265 (2.8)	79824
J	Hennur Road Junction on ORR	1.5	62456 (33.1)	28877 (15.3)	82055 (43.5)	6244 (3.3)	9046 (4.8)	188678

( )*Percentage

Table – 4.117 : Number and Percentage Share of Each Vehicular Group At Study Intersections (2015)

Station Code	Intersection Name	Distance between station & survey location (Km)	Two Wheelers	Auto	Cars/ Jeeps/ Vans	Buses	Trucks/ Tractor	Total (100%)
A	KR Puram Bridge Junction	7.8	117822 (34)*	20918 (6)	159347 (46)	22337 (6.4)	26556 (7.6)	346980
B	Hebbal Junction	7.8	95534 (30.7)	21135 (6.8)	155210 (49.9)	11818 (3.8)	27565 (8.8)	311262
C	New BEL	1.7	38002 (38)	13111 (13.1)	41769 (41.7)	3092 (3.1)	4140 (4.1)	100114
D	Bapuji Nagar Junction	0.2	80648 (52.5)	18797 (12.2)	37036 (24.2)	6695 (4.4)	10355 (6.7)	153531
E	Town Hall Junction	2.3	56590 (40)	18884 (13.3)	45461 (32)	12668 (8.9)	8308 (5.8)	141911
F	KR Circle	2.4	76534 (46.8)	18163 (11.1)	55731 (34.1)	9520 (5.8)	3552 (2.2)	163500
G	Silk Board Junction	0.1	112509 (34.4)	25539 (7.8)	136432 (41.7)	28048 (8.6)	24408 (7.5)	326936
H	Entrance	-	-	-	-	-	-	-
I	Lower Agarwal Junction	4.1	42094 (47)	9755 (10.9)	32337 (36)	2958 (3.3)	2530 (2.8)	89674
J	Hennur Road Junction on ORR	1.5	69012 (33.2)	31908 (15.3)	90668 (43.6)	6900 (3.3)	9467 (4.6)	207955

( )*Percentage

CHAPTER - V

MITIGATION METHODS AND POLICIES SUGGESTED

CHAPTER – V

MITIGATION METHODS AND POLICIES SUGGESTED

Systems existing for management of air pollution at centre and state levels are briefed in this chapter. This chapter also includes the suggestions for air pollution management in Bangalore City.

5.1. NATIONAL LEVEL AIR POLLUTION MANAGEMENT SYSTEM

The Indian air pollution management model is unique and developed to operate within the constraints of Indian executive system. The states are the basic enforcement units for almost all air quality rules and laws. The air quality planning process involves : Goal setting, emissions inventory development and use, ambient air quality monitoring, and assessment, three air quality modelling controls identification, implementation, evaluation of effectiveness and modification controls as necessary. It may be noted that, air quality planning plays a major role in the entire air quality management process (AQM) and therefore, the key to successful AQM system is good planning which inturn depends on accurate data. The Indian AQM process as explained by Singh (2002) consists of mainly enforcement units and is shown in fig.5.1.

5.2 BANGALORE AIR QUALITY MANAGEMENT SYSTEM (BAQMS)

Bangalore's air pollution problem is a result of combination of forces - economic, administrative social legal, cultural - at play. Industrial activity, fossil fuel combustion (petrol, diesel, kerosene) in motor vehicles and stationary engines,- adulteration of fuels, re-suspended road dust, extensive construction activity poor city maintenance (dusty roads, unpaved sidewalks, parks without green cover and uncovered playfields) and refuse burning are some of the sources that are responsible for air pollution in Bangalore, in addition to poor appreciation of the problem by the people, archaic governmental edifice that is unable to deal with the modern science problem of air pollution and lack of capacity in the governmental departments and agencies.

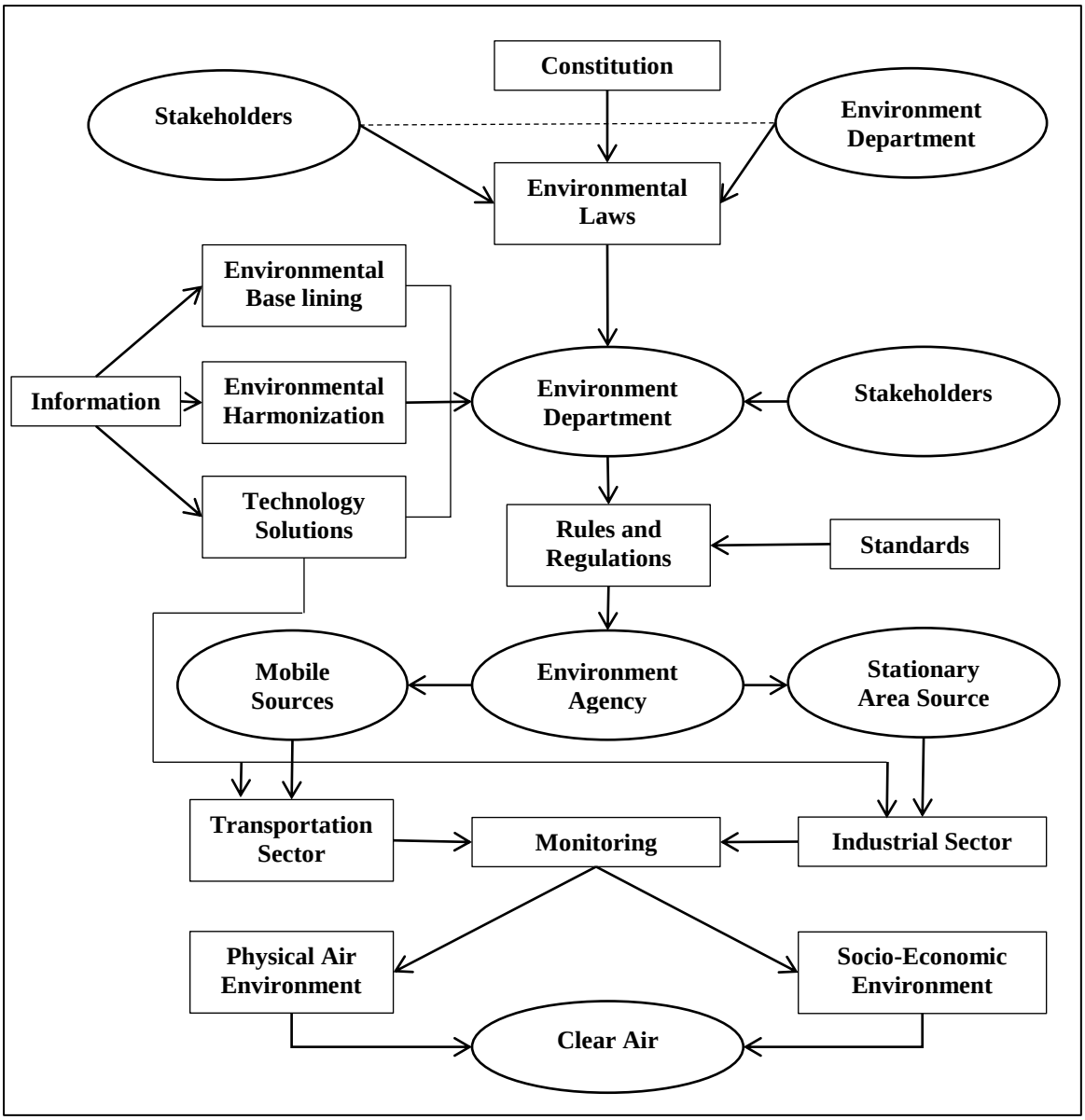


Fig. 5.1 Indian Air Quality Management System

The organisational chart of BAQMS (fig.5.2) shows the various department agencies and short term offices of the Karnataka government that are involved in the task of controlling air pollution.

The Task Force for Control of Pollution in Bangalore City, headed by the Additional Chief Secretary to Government of Karnataka, a second-from-top bureaucrat of the state, is, therefore, is placed at top of the chart. It is a need-based entity and, therefore, is placed in a dashed-line box. The dashed lines from the Task Force shows the organizations it plans and coordinates with to deal with the air pollution menace. The KSFCB, as the name suggests, is the agency to control, prevent and abate pollution. The Transport Department controls automobile pollution. The Bangalore - City Police works to ease traffic congestion and ensure smooth flow of traffic and catching Pollution Under Control certification (PUC) violators. The KSRTC and BMTC are state owned road transport corporations that are good Samaritan polluters. The Department of Food. Civil Supplies and Consumer Affairs fights adulteration of auto fuels. The Bangalore Development Authority is an urban planning agency that plans land use for Bangalore and NGQ's are either environmental action groups or provide technical assistance to the various agencies.

The Bangalore air pollution problem has not been characterized in its entirety. Yet, several measures are being tried out. Switching to LPG, restricting vehicular movement within the downtown area, easing congestion, creating one-way systems, redesigning the roads are some of the measures that have been enforced. Yet the PM_{10} revels are above the INAQQS. Sensitivity analyses of the implemented and proposed measures cannot be conducted for lack of data and therefore, the managers are not certain if the implemented mitigation measures will take the city toward cleaner air.

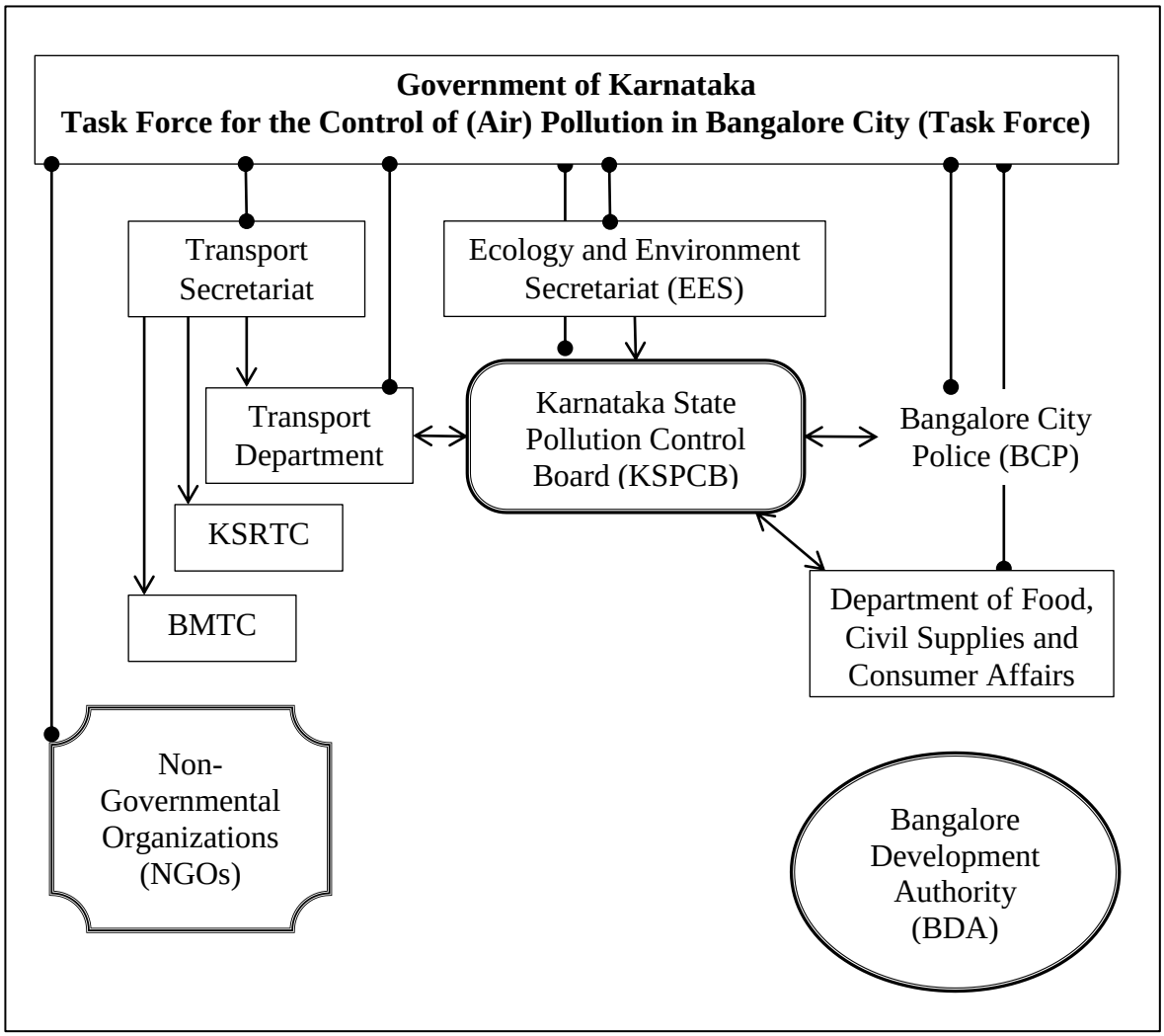


Fig. 5.2 : Graphical Depiction of the Bangalore Air Quality Management System

Legend:

1. Single Arrow: Indicates power structure.
2. Double Arrow: Indicates need-based cooperation between agencies.
3. Dashed Line: Indicates need-based, short-term cooperative relationship.
4. Dashed Box: Indicates a need-based, short-term entity.
5. KSRTC: Karnataka State Road Transport Corporation
6. BMTC: Bangalore Metropolitan Transport Corporation

Further individual agencies like Ecology and Environment Secretariat, Karnataka Pollution Control Board (KSPCB), KSRTC, BMTC, Food and Adulteration Department, Transport Department including RTOs, BBMP, Industries Department, Department of Planning, Department of Health, CiSTUP. EMPRI, ROHC (NIOH), TERI, IISC and Universities, NGOs etc. have individual entity and work towards their goal. In the process, many research works are getting repeated, focus thus diluted. The Zonal Office of CPCB Bangalore, though interact with SPCBs, the coordination with other agencies are limited. In these circumstances for effective coordination of all air pollution related: tasks a Chapter (Group of scholars & institutions) needs to be formed with clear mandates for individual, stake holders. Financial and techno-managerial support both from these institutions and abroad may be sought to make the system work. A detailed discussion on such issues viz. Monitoring, Parameters, Location/relocating existing stations, Monitoring of Health aspects, Epidemiological analysis, Validation of Data, Dissemination of Data online/offline, Air Quality Index and Prediction etc. to be discussed and a consensus to be reached so that public will be benefited from the rich experience/outcome of these important organizations/ studies.

5.3 ACTION PLAN SUGGESTED

As documented above, poor appreciation of the problem, lack of capacity, personnel shortages, lack of continuous action a sense of resignation are few of the impediment to better air quality in Bangalore. Thus for better Bangalore air quality management, the author, based on his experience as a officer worked in BBMP, National highways, Karnataka Road Development ltd., and as a citizen, herewith suggesting some of the measures that can be taken.

5.3.1 Vehicular Pollution Control

Since vehicles contribute significantly to the total air pollution load in most urban areas, vehicular pollution control deserves top priority. A practical strategy should be devised that reduces both emissions and congestion, using a mixed set of instruments, which are dictated by command and control, and/or the market based principles. Some of the these are:

- Augmentation of public transport system.

- Mass Rapid Transport System may be considered for the fast expanding and major urban areas in the country.
- Incentives and regulations affecting vehicles with a view to reducing the rate of growth in ownership of personal vehicles.
- Traffic planning and management. Also, construction of express highways linking major urban areas should be undertaken.
- Taxes on fuels, vehicles - the revenue so generated could be used for pollution control measures.
- Further tightening of emission norms and fuel quality specifications.
- Greater promotion and use of alternative fuels such as CNG/LPG/Propane/ battery operated vehicles. Expansion of CNG dispensing facilities and increased fiscal incentives for CNG kits.
- Replacement of two-stroke engines.
- Curbing fuel adulteration –state-of-the-art testing facilities and deterrent legal action.
- Strengthening of inspection and maintenance (I and M) system: The I and M system, comprising inspection, maintenance, and certification of vehicles, is crucial for regulating pollution for the large fleet of in-use vehicles. It should include testing of various elements of safety, road worthiness and compliance to pollution norms.

5.3.2 Industrial Pollution Control

- Thrust for cleaner technologies
    - Waste minimisation technologies involving process change, raw material substitution, improved housekeeping, etc.
    - Waste utilisation technologies involving reclamation and utilisation of wastes as secondary raw material
    - Flue gas desulphurisation
    - Combustion modification for NO_x reduction
    - Incentives for the development and adoption of clean technology and emission reduction
- Database on clean technology

- Database on available technologies, their performance sources, investment required, etc, should be created, regularly updated, and widely disseminated.

- Strengthening of emission standards
  - Emission standards for various categories of industries need to be strengthened. To shift from pollution control to pollution prevention, rules related to load based standards instead of concentration based standards need to be enforced.
- Appropriate siting of high pollution potential industries/projects
- Fiscal incentives for pollution prevention and control measures.

5.3.3 Other Pollution Abatement Measures

- Strengthening of monitoring network
  - The monitoring network requires a massive quality control programme and expansion of its operations to cover new stations as well as more pollutants (e.g., RPM_{10}, $RPM_{2.5}$, O_3, Pb, CO, and hydrocarbons such as benzene and PAHs) on a regular basis.
- Information dissemination/mass aware-ness/training
  - State-of-the-art technology should be used for wider dissemination of environmental information. Transparency and access to the data to be improved. Measures such as pollution bulletins and air pollution forecasts should be started on a regular basis.
  - Massive thrust should be provided to mass awareness campaigns involving community organisations such as residents associations, students, voluntary bodies and NGOs. Strategic action plans for implementation should be devised.
  - Support measures such as training and education for the industry, governmental agencies, and the public, as well as greater coordination among institutions, are important.
- Air quality management strategy
  - A comprehensive urban air quality management strategy should be formulated that includes information related to urban planning,

ambient air quality, emission inventory, and air quality dispersion models.

  - Effectiveness of EIA as a tool and environmental audit needs to be critically assessed.
  - Systematically planned emission load mapping studies should be undertaken at regular intervals. Development of emission factors for Indian conditions should be taken up.

- Fiscal measures
  - Economic instruments need to be in place to encourage a shift from curative to preventive measures, internalisation of the cost of environmental degradation, and conservation of resources. The revenue generated may be used for enforcement, collection, treatment facilities, and research and development.
  - Incentives for environmentally benign substitute, technologies and energy conservation.
- Promotion of renewable energy sources such as hydro, wind, and solar.
- Use of cleaner fuels like LPG and kerosene for domestic consumption would reduce indoor air pollution.
- Air quality standards should be based on local dose-response relationships for which appropriate environmental epidemiological studies should be undertaken.
- Non-point sources of pollution also to be controlled such as pollution from generators, waste burning, etc.
- Increase in green cover. Appropriate design of green belts/barriers and proper selection of plant species.
- Enforcement mechanism
  - Significant improvements in the enforcement mechanism required to ensure that the policies are implemented both in letter and spirit.
  - Wherever necessary, the policies/standards need to be reformulated keeping in mind the fast-changing scenario.
  - An effective environment management plan should be devised that includes environmental strategy, regulation, institutional capacity-building, and economic incentives and penalties.

CHAPTER - VI

CONCLUSIONS, LIMITATIONS AND SCOPE FOR FURTHER STUDY

CHAPTER – VI

CONCLUSIONS, LIMITATIONS AND SCOPE FOR FURTHER STUDY

To meet the objectives of the present research work, the ambient air quality monitoring at selected ten pockets in Bangalore City covering Industrial, Commercial, Sensitive and Rural areas was carried out for a duration of five years (2011 to 2015) adopting standard procedures. Pollutants namely PM_{10}, NO_2 and SO_2 were considered for study. Monthly, Seasonal and Annual AQIs were calculated and presented in tables and also by graphs and bar charts. Exceedence factor for pollutants studied are also documented in this report. Based on the data and results obtained, discussions were made and inferences were drawn. Further the conclusions were drawn and listed as below.

- Concluded that, the air quality at all the study pockets has deteriorated and will be deteriorating at the alarming rate in days to come.
- Concluded that, the industrial and commercial pockets are more polluted compared to Rural and background pockets.
- Concluded that, within the statistical limitations, the industrial and commercial pockets are heavily and seriously/ critically polluted and wherein rural pockets are moderately to heavily polluted.
- Concluded that, out of the three pollutants considered for study, PM_{10} is the critical pollutant responsible for ambient air pollution followed by NO_2 and SO_2.
- Concluded that, the traffic flow and increase in traffic flow with time is one of the major reason for deterioration of ambient air quality in the study pockets.
- Seasonal AQIs Throughout the study period varying from 49 to 197 (during Winter), 41 to 190 (during Summer) and 46 to 168 (during Monsoon) were recorded.
- Annual AQIs ranging from 44 to 180 were recorded.

- Exceedence factor calculated varied from 0.9 to 3.5, 0.5 to 1.1 and 0.1 to 0.7 for PM_{10}, NO_2 and SO_2 respectively.
- Based on the trends of air quality deterioration of study pockets, it is concluded that, there is a urgent need to initiate measures to mitigate air pollution/ pollutant in the study pockets. The measures viz. stringent implementation of pollution control acts, mass transport system, alternate fuel for vehicles, proper traffic planning and management, cleaner technologies for industries, strengthening of monitoring network, etc. are suggested.

LIMITATIONS

The following are the limitations of the present research work and these limitations are attributed to non-availability of data, lack of infrastructure facility, time shortage, not within the perview of objectives of the present study etc.

- Assessment of air quality and thereby indexing due to many other pollutants, viz. CO, NH_3, $PM_{2.5}$, hydrocarbons etc.
- Establishment of relationship between air quality and meteorological factors, due to non availability of season wise meteorological data, specific to pockets considered for study.
- Establishment of relationship between air quality and vehicular movements.
- Source apportionment.
- Development of AQI based on opinion of experts and weighted coefficients.

SCOPE FOR FURTHER STUDY

The limitations listed above can be considered as subject matter for further study.

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