Atmospheric toxic gases and their probable impacts on public health and crop production.

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CERTIFICATE

We have the pleasure to certify that the thesis entitled "Atmospheric toxic gases and their probable impacts on public health and crop production" is an original research work carried by Sharmeen Jahan in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the department of Soil, Water and Environment. Sharmeen jahan has successfully completed her course works and carried out her field experiments during the session 2009-2010. To the best of my knowledge, this is the researcher's won achievement and not a conjoint work. The thesis or there of the part of it has not been submitted to any other university for any degree.

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Abstract

Bangladesh ranked fourth among 91 countries with the worst urban air quality in the latest air pollution monitoring report by the World Health Organization. Data from the National Institute of Diseases of the Chest and Hospital shows that nearly seven million Bangladeshis suffer from asthma and more than half of them are children. In Dhaka alone, an estimated 15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality. Experiences from other countries of the world suggest that plants exposed to air pollution over an extended period grow at a slower rate, produce fewer blossomless and are more susceptible to disease and insect damage. In addition to physiological damage, ground level ozone may cause reduced resistance in crop plants to fungi bacteria, viruses and insects, reducing growth and inhibiting yield and reproduction. Chlorossis (yellowing) and a gradual bleaching of the surrounding tissues fairly common in crop plants. Bangladesh is lacking systematic ambient air quality measurements and time series data though the reports based on sporadic analysis indicate worsening air pollution in particular, in cities with heavy traffic movement and congestion, industrial and brick-kiln actives and solid waste management practices. The level of air pollution and the effects on human health and crop plants were however, not assessed to that extant. With this background atmospheric toxic gas concentrations namely, O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 in the ambient air were measured in some selected hot spots in Dhaka city between 2009 and 2011. The results were compared with some selected peri-urban, semi-urban, rural areas and St. Martin's Island at the Bay of Bengal as base-line. Among the toxic gases concentration of CO 14818 $\mu g/m^3$, NO 178 $\mu g/m^3$ and NO_2 264 $\mu g/m^3$ and SO_2 239 $\mu g/m^3$ were measured at different hot spots in Dhaka city appeared to be very high and exceeded the limit values suggested by the WHO, 2005 (CO 5000 $\mu g/m^3$), SO_2 (80 $\mu g/m^3$), NO and NO_2 (120 $\mu g/m^3$). The highest level of CO 14818 $\mu g/m^3$, TVOC 15881 $\mu g/m^3$, NO 178 $\mu g/m^3$ and NO_2 264 $\mu g/m^3$ were measured for Farm gate; SO_2 239 $\mu g/m^3$, H_2S 113 $\mu g/m^3$, NH_3 121 $\mu g/m^3$, PH_3 118 $\mu g/m^3$ were also measured for Amin Bazaar in Dhaka city during three consecutive years. Elevated concentrations of O_3 47 $\mu g/m^3$ were also measured in Dhaka city however, still within the safe limit WHO, 2005 (100 $\mu g/m^3$). Significant positive correlation were obtained ($r = 0.65$) between CO and NO and ($r = 0.84$) between CO and PH_3 in the present investigation. A strong negative correlation ($r = - 0.72$) between O_3 and TVOC, ($r = - 0.70$) between NO and TVOC and ($r = - 0.50$) between TVOC and SO_2 were obtained in the present investigation. Significant level of diurnal and seasonal variations of toxic gases were also observed. A survey on human health and damages on crop plants and/or trees

using structured questionnaire reveal that the people in Dhaka city are experiencing health problems like breathing problem, eye-irritation, cough, asthma, vomiting, headache in particular, women and children appears to be the mostly affected. More than 40 percent women and children interviewed in Dhaka city reported to have been suffering from eye-irritation, cough, asthma, vomiting, headache and other respiratory problem. Regarding damages on crop plants and/or trees, 60 percent of the people interviewed reported that they are having damages on crop plants in the form of chlorosis of leaves, crop damages, top dying of tree species, spotted fruits (guava), small size fruits and reduction in yield (20% for rice, 25% for fruits) and loss of leaves on road-side trees. No direct relationship to the damages on crops or effects on human health with any of the particular toxic gases measured could be established.

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1. Introduction

The atmosphere is a thin blanket of air which envelops earth sustaining life in it and protecting it from the adverse effects of outer space. It contains a large amount of N_2 and O_2, smaller amounts of Ar and CO_2 as well as traces of other gases such as He, Ne, CH_4, H_2S, O_3, NH_3, CO, VOCs etc. On an average about 50 Ibs of air are required per person per day to meet O_2 requirement. Clean air is necessary for healthy environment and to sustain biodiversity *(ADB, 2006).* Unfortunately, atmosphere is used as a dumping site for varieties of toxic organic and inorganic gases, particulate matter and aerosols etc. which contaminate the atmosphere.

The atmospheric air pollution is known to have a range of effects, including those on human health, crop production, soil acidification, visibilities and corrosion of materials and received priority among environment issues in Asia, as well as other parts of the world (*Faiz et. al., 1996*). Burning of fossil fuels in industries, power installations, automobiles, domestic and business centers for heating, cooking, production of bricks etc. causes air pollution and the effects on public health and crop production (*Azad and Kidata, 1998*). Air pollution has become a worldwide crisis and emerged as a big problem where industrialization has taken place without prior planning (*Williams et. al., 2011).* The problem appears to be acute in Dhaka being the capital of the country and also the hub of commercial activity. The ambient atmospheric air quality has been reported to be progressively deteriorated due to the unprecedented growth in numbers of motor vehicles and continuous housing and industrial development. Faulty vehicles, especially diesel run vehicles, brick-kilns, and dust from roads and construction sites and toxic fumes from industries are reported to contributing air pollution in Dhaka city (*ADB, 2006*). The number of automobiles have been increasing in Dhaka city at the rate of at least 10 percent annually, which has been contributing to air pollution on one hand and traffic congestion on the other (*Agarwal et. al., 1991*). Although existing air quality , monitoring data is limited, it has been clearly shown that the average ambient concentrations of suspended particulate matter (SPM) in Dhaka city is higher than the Bangladesh National Ambient Air Quality Standard (200 $\mu g/m^3$) and much higher than the WHO guidelines (120 $\mu g/m^3$).The concentrations of some of the other gases like NOx 100 $\mu g/m^3$, SOx 120 $\mu g/m^3$ and CO 5000 $\mu g/m^3$ are also reported to be increasing in an alarming way (*EPA, 2009*). The essential raw ingredients for ozone (O_3) are nitrogen oxides (NOx), hydrocarbons, also called volatile organic compounds (VOCs) and carbon monoxide (CO). They are produced primarily when fossil fuels like gasoline, oil or coal are burned or when some chemicals, like solvents, evaporate. NOx is emitted from power plants, motor vehicles and other sources of high-heat combustion. Volatile organic compounds (VOCs) are emitted from motor vehicles, chemical plants, refineries, factories, gas stations, paint and other sources. Carbon monoxide (CO) is also primarily emitted from motor vehicles (*EPA, 2013*).The main air pollution problem in both developed and rapidly industrializing countries has typically been high levels of SO_2 emitted following the combustion of sulphur-containing fossil fuels such as coal that is used for domestic and industrial purposes,

Carbon monoxide (CO), Oxides of nitrogen (NOx),Total Volatile Organic Compounds (TVOC), O_3, NH_3, H_2S and PH_3 emitted from petrol and diesel-engine motor vehicles (*Williams et. al., 2011*).

Bangladesh ranked fourth among 91 countries with the worst urban air quality in the latest air pollution monitoring report by the World Health Organization. Data from the National Institute of Diseases of the Chest and Hospital shows that nearly seven million Bangladeshis suffer from asthma and more than half of them are children. In Dhaka alone, an estimated 15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality, according to the Air Quality Management Project, funded by the government and the World Bank (*Haque et. al., 2014).* Reports on the effects of air pollution on crop plants and tree species in Bangladesh are scanty. However, experiences from other countries of the world suggest that plants exposed to air pollution over an extended period grow at a slower rate, produce fewer blossoms and are more susceptible to disease and insect damage. The worst pollutants for plants are ground –level Ozone (O_3) and sulphur dioxide (SO_2). A 120 µg/m^3 seasonal average of 7- hour mean ground level Ozone concentrations have been reported to lead to reductions in crop yields in the range of 16-35% for cotton, 0.9-51% for wheat, 5.3-24% for soybeans and 0.3-5.1% for corn (*NRC, 1991).* In addition to physiological damage, ground level ozone may cause reduced resistance to fungi bacteria, viruses and insects, reducing growth and inhibiting yield and reproduction. Chlorossis (yellowing) and a gradual bleaching of the surrounding tissues fairly common in crop plants in the USA *(WHO, 2012) are reported* to be associated with growth suppression, reduction in yield and heavy defoliation. A tan to reddish brown, dieback or banding of tree species are also reported (*Heagle, 1998*). The degree of injury increases as both the concentrations of sulferdioxide and the length of exposure increase. Sensitive plants are injured by exposures of 0.5 ppm for 4 hours or 0.25 ppm for 8 to 24 hours. The factor that govern the extent of damage in the region where air pollution is a problem are the concentration of pollutants to a distance from the source length of exposure, plant species exposed and its stage of development and meteorological conditions (*Heck et. al., 1986*). Bangladesh is lacking systematic ambient air quality measurements and time series data though the reports based on sporadic analysis indicate worsening air pollution, in particular, in cities with heavy traffic movement and congestion, industrial and brick-kiln actives and solid waste management practices. The level of air pollution and the effects on human health and crop plants however, not assessed to that extant. The present research was initiated in order to investigate level of toxic gases in the ambient air in some selected hot spots of Dhaka city and surrounding areas and to find out any link to human health problems and crop damages.

1.1 Objectives of the research

This research was carried out with the following objectives:

a) To investigate the level of atmospheric toxic gases such as O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 in some hot spots and surrounding areas of Dhaka city and compare the concentrations with toxic gases measured in some selected rural spots as base line or less affected.

b) To determine any diurnal variations of the gases and the factors controlling.

c) To identify any Seasonal variations in concentration of toxic gases.

d) To find out any link of the toxic gases to human health problems and crop damages.

e) To make a future projection of the level of toxic gases (based on the data) generated using model ARIMA (0, 1, 0) and ARIMA (0, 2, 2) *(Asteriou et. al., 2011)*.

1.2 Limitations of the study

1. The probes (TG- 501 and TG-502) used for the determination of toxic gases measured gas concentrations in a shaded area on the road-side spots and the data generated represents a combined indoor and outdoor air quality.

2. The probes and the PC connected were battery operated and could function 5-6 hours at full charge and therefore, required recharging as and when required. The gases measured at times exclude time required for recharging.

1.3 Hypothesis

The generation of atmospheric toxic gases in Dhaka city is increasing and that, the level is enough to induce damaging effects on human health and crop plants.

2. Review of Literature

Toxic gas means a compressed gas or vapour that has a median lethal concentration (LC50) in air of 200 parts per million (ppm) by volume, or 2 milligrams per litre of mist, fume, or dust, when administered by continuous inhalation for one hour (or less if death occurs within one hour) to albino rats weighing between 200 and 300 grams each *(Acgih, 2009).* Bangladesh ranked fourth among 91 countries with worst urban air quality in the recent air pollution monitoring report of World Health Organisation *(WHO, 2014)*. Moreover, three Bangladeshi cities have been put among the top 25 cities with poorest air quality. The effects of toxic gases on atmosphere, climate, public health and crop are among the central topics in current environmental research. Bangladesh is a developing country in South-East Asia with a rapid growing population of more than 160 million. Air Pollution in some areas particularly, in cities is a major problem in Bangladesh threatening environmental quality ecosystem. Soil and air pollution problem is particularly serious in the rapidly urbanized and industrialized cities of South and East Asia especially in the mega cities *(Faiz and Sturm, 2000)*. Concerning the air pollutants measurement either urban or rural sites of Bangladesh, a little work is found. Some measurements were reported from South East Asia urban and background sites e.g. *(Venkataramam et. al., 2002).*

Diesel engines, an attractive alternative to petrol powered motor vehicles in some developing countries, have the advantages that they produce virtually no hydrocarbons that can take part in photochemical reactions and no carbon monoxide is evolved. Unless correctly maintained, however, they can produce smoke, odor and noise (*WHO, 1969).*

Petrol, a mixture of liquid compounds of carbon and hydrogen, called hydrocarbons burns very fast in an engine. Due to short time availability for burning, incomplete combustion of petrol takes place and some carbon monoxide and some unburned carbon particles are produced. The carbon monoxide and carbon particles go into the air and pollute it. The incomplete combustion of petrol also produces some alcohols and acids, which escape into the air *(Trivedi and Raj, 1992).*

When petrol burns in a car engine, a very high temperature is produced. At this high temperature, nitrogen and oxygen of air combine to yield nitrogen oxides like NO and NO_2 that are emitted into the air in car exhaust. Tetraethyl lead compounds, which are used as antiknock agent with the petrol or diesel to get a smooth ride, give rise to lead compounds in the car exhausts. From the air, these lead compounds are also absorbed by soil and plants and hence may enter into food chain *(Trivedi and Raj, 1992).*

Aerosols play an important role in the atmosphere with regard to health, climate, visibility impairment, and atmospheric chemistry. Large number of clinical and epidemiological studies have indicated the cause and effect of associations between respiratory- related mortality and morbidity *(Adler and Fischer, 1994).* Airborne particulate matters have important implications through the inhalation of fine particle fractions (<PM_{10}), which can be deposited in the tracheobronchial and alveolar regions of the lung *(Hileman, 1981*). Over the last decade's atmospheric pollution by suspended particulate matters has gained considerable attention, due to the public health risk associated with fine particles *(Kendall et. al., 2001).* Heavy metal pollution and toxic gaseous pollutions also cause serious public health problems *(Smith et. al., 1996)*

Effects of aerosol particles on climates depend upon their chemical composition. Aerosols can modify the climate forcing directly by altering the radioactive heating of the planet *(Coakley, 1985; Charlson et. al., 1991)* indirectly by altering cloud properties e.g. acts as Cloud Condensation Nuclei (CCN) *(Albrecht, 1989; Rosenfeld, 2000)* and semi directly by evaporating the clouds *(Hansen et. al., 1997*). The composition of atmospheric aerosol particulate is mainly carbonaceous materials, soluble ions (inorganic and organic), mineral dust and aerosol humidity (*Puxbaum et. al., 2000).* Anthropogenic activities increased atmospheric aerosol concentrations by emitting particulate matters (fly ash, dust and elemental carbon) and aerosol precursor gases (SO_2, NO_x, TVOC), which form secondary aerosol particles through gas to particle conversion *(Schwartz, 1996).*

2.1. Air

Air, the most integral part of the physical environment, sustains life of both plant and animal kingdoms including human beings. Animals take in the major constituent, oxygen from the air giving out carbon dioxide, and plants take in carbon dioxide, giving out oxygen during photosynthesis. Both land and aquatic ecosystems are naturally interrelated through direct participation of air, an invisible ocean. Degradation of the quality of the environment, including that of the air due to anthropogenic activities has now emerged as a major concern all over the world. It is for this reason that 113 nations and other stakeholders from developed and developing world joined in the first conference on environment -- The United Nations Conference on Human Environment – to discuss the common environmental issues in Stockholm in 1972, which was later named as the "Stockholm Spirit of Compromise" *(WHO, 1996).*

2.1.1. Air Pollution

The growth of mega cities in Asia-Pacific region, air pollution has come at the top of the key environmental issues in the region. Additional environmental impacts of air pollution include damage to buildings and structures, agricultural crops, vegetation and forests, ecosystem, livestock and reduced visibility (*WHO, 2014).* Contaminations of the atmosphere caused by the discharge, accidental or deliberate of a wide range of toxic substances. The major sources of air pollution are transportation engines, power and heat generations, industrial processes and the burning of solid waste. A new source of air pollution is an increasing 'hole' in the ozone layer in the atmosphere above Antarctica, coupled with growing evidence of global ozone depletion. Air pollution has also long been known to have an adverse effect on human beings, plants, livestock and aquatic ecosystem through acid rain *(Novakovet et. al., 2000).*

The air pollution problem is widespread throughout the world and the elimination of the risks to human health is of paramount importance. Air pollutants increase the risk of infections of the respiratory tract, affect the cardiac and pulmonary system, lead to allergies, affect asthmatics and may also act as cancer precursors. Increased level of inhalable particles and carbon monoxide seriously cause respiratory diseases and also affect people with cardiovascular disease *(Dockery et. al., 1993).*

Recent studies indicate that motor vehicles are a major source of toxic air pollutants including 1.3-butadiene, benzene and a number of carcinogens, associated with particulate matter. As the vehicle fleet continues to grow, motor vehicle emissions and the products of their transformation in the atmosphere are becoming increasingly important contributors to nearly every major air pollution problem facing the world today (*DOE, 2010*).

Table 2.1: Types of air pollution

Gaseous substances	Gases, vapors, SOx, NOx, CO, O_3, NH_3
Particulate matter	Dust, fly ash, smoke, shoot, droplets, mist, fog, fumes, aerosol

Source: (Khaliquzaman, 1998).

The eight classes of air pollutants are: oxides of carbon, sulphur and nitrogen, volatile organic compounds, suspended particulate matter, photochemical oxidants, radioactive substances and hazardous air pollutants.

2.1.2. Sources of air pollution

Anthropogenic sources

- Stationary sources-
- Power plant
- Manufacturing factories
- Waste incinerators
- Fuel-burning

Mobile sources

- Motor vehicles
- Marine vessels
- Aircraft.
- Fumes from paint, aerosol sprays, varnish and other solvents.
- Waste deposition in landfills.
- Toxic gases
- Nuclear weapons
- Germ warfare
- Rocketry etc

Natural sources

- Dust from natural sources
- Radon gas from radioactive decay.
- Smoke and CO from wildfires.
- Volcanic activity which produce sulfur, chlorine and ash particulates.

Recently as in other parts of the world, air pollution has received priority among environmental issues in Asia. This problem is acute in Dhaka, the capital of Bangladesh and also the hub of commercial activity. Basically, there are two major sources of air pollution, industrial emissions and vehicular emissions. The industrial sources include brick kilns, fertiliser factories, sugar, paper, jute and textile mills, spinning mills, tanneries, garment, bread and biscuit factories, chemical and pharmaceutical industries, cement production and processing factories, metal workshops, and wooden dust from saw mills and dusts from ploughed land, and salt particles from ocean waves near the offshore and coastal lands. These sources

produce enormous amount of smokes, fumes, gases and dusts, which create the condition for the formation of fog and smog. Certain industries such as tanneries at Hazaribag emit hydrogen sulphide, ammonia, chlorine, and some other odorous chemicals that are poisonous and cause irritation and public complaints. This may cause headache and other health problems *(DOE, 2010).*

The number of vehicles is also increasing rapidly, and contributing to more and more air pollution. The Department of Environment *(DOE, 2010)* and other related organizations has identified overloaded, poorly maintained and very old trucks and mini-buses and small vehicles are plying the city streets emitting smokes and gases. In fact about 90% of the vehicles that ply Dhaka's streets daily are faulty, and emit smoke far exceeding the prescribed limit. Diesel vehicles emit black smoke, which contain unburned fine carbon particles.

During the last century the increasing emissions of gases and aerosol particles, due to human activities, have changed the composition of the atmosphere *(IPCC, 2007*). The increase of aerosol particle concentration is visible to the human eye as haze layers (atmospheric brown clouds) that can be seen even from space over populated areas around the world. This haze with sometimes a brownish appearance consists mainly of inorganic salts, organic compounds, soot and crustal material. Primary effect of the aerosols is impact on the atmospheric radiation balance *(Ramanathan et. al., 2005).* Secondary effects are increased health problems and effects on the hydrological cycle that can influence the availability and quality of fresh water (*WHO, 2006).* In order to predict the effects of these brown clouds knowledge is needed about their sources and sinks.

The ability of soot particles to act as a Cloud Condensation Nucleus (CCN) depends on the size and the chemical nature of the surface of the particle. The hydrophobic property of freshly emitted soot suggests that it is not likely to act as a CCN. During its residence time in the atmosphere soot can undergo coagulation and condensation (mass transfer of a gas phase compounds to the aerosol particle), and thereby alter the chemical nature of the surface of soot from hydrophobic to more hydrophilic. Given a more hydrophilic nature soot can be activated to form cloud droplets. Repeated cycling in and out of cloud droplets can promote a build up of water-soluble material on the soot particles, through liquid phase reactions *(Ogren and Charlson, 1983).*

2.1.3. Effects of toxic gases on ecosystems, livestock, agriculture and soil

Environmental pollution is any discharge of material or energy into water, land, or air that causes or may cause acute (short-term) or chronic (long-term) detriment to the Earth's ecological balance or that lowers the quality of life. Pollutants may cause primary damage, with direct identifiable impact on the environment, or secondary damage in the form of minor perturbations in the delicate balance of the biological food web that are detectable only over long time periods.

Air pollution is the process which the substances and the energy forms are not present in normal atmospheric composition reach the atmosphere, or are present but in much lower concentrations. Air pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or cause damage to the natural environment or built environment, into the atmosphere.

More than 3,000 substances that are not part of the atmospheric composition, falling in the atmosphere can be considered air pollutants (*Khallaf, 2011).* Some substances that are normally present in the atmosphere in a certain concentration can be considerate pollutants because their concentration is much higher than usual concentration. Also certain substances that are normally present in certain layers of the atmosphere (e.g. ozone in the stratosphere), once arrived in the troposphere is pollutant. Some gases, such as oxides of nitrogen may have beneficial effect on vegetation, after hydration may affect the leaf fertilizer *(Khallaf, 2011)*.

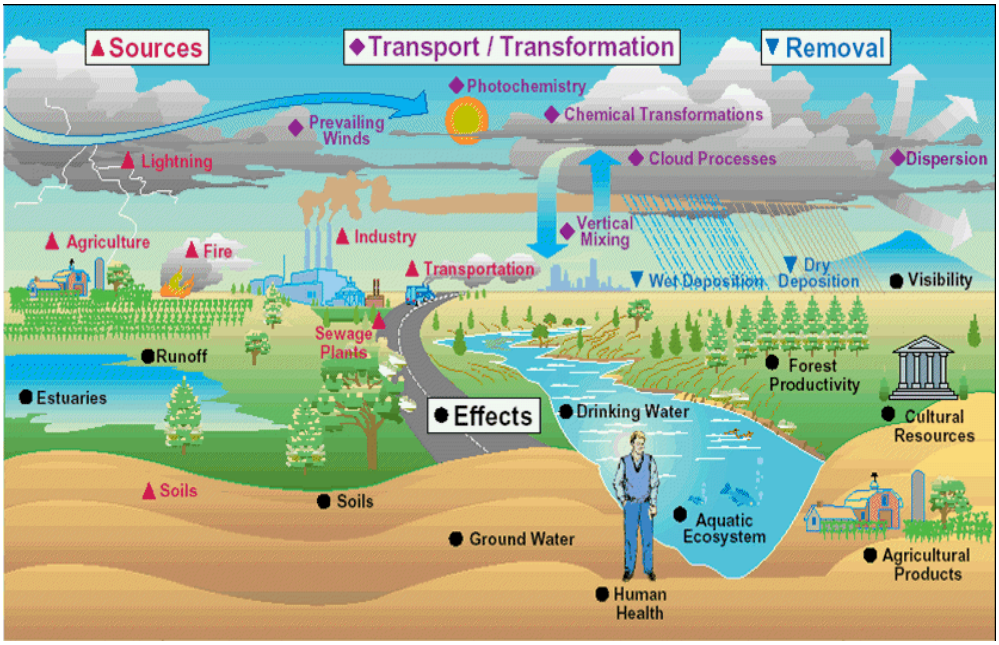


Fig 2.1: Global pollutants circuit.

Source: (http://www.cleartheair.nsw.gov.au, 2011).

Pollutants describe a global circuit; they are produced by different sources, are transported and transformed into atmosphere, some of them being removed, another part is reaching the earth having different effects on different biogenesis of ecosystems. An analysis done at the global level revealed a diversification of pollutants agents and sources of air pollution. This diversification and increasing concentrations are in strict correlation with industrialization and the increasing of amounts use as fossil energy (non-renewable sources). At the beginning, the pollution has been felt in urban areas and the forms of relief that favored the accumulation of pollutants and long stay (depressions, closed valleys, etc.). Currently, air pollution has become a larger area, sometimes to disperse across multiple continents *(Khallaf, 2011*). Air pollution can be analyzed on three spatial scales: global pollution, regional pollution and local pollutants. The global pollution is the result of cumulative effects of various sources, located on the entire surface of the globe, manifested by global effects: the stratospheric ozone depletion; greenhouse effect - emission of greenhouse gases (CO_2, CH_4, CFCs) formation of aerosols *(EPA, 2011).*

The regional pollution is in part the result of local air pollution--including that produced by individual sources, such as automobiles - that has spread out to encompass areas of many thousands of square kilometers. Meteorological conditions and landforms can greatly influence air-pollution concentrations at any given place, especially locally and regionally. For example, cities located in bowls or valleys over which atmospheric inversions form and act as imperfect lids are especially likely to suffer from incidences of severe smog. Oxides of sulfur and nitrogen carried long distances by the atmosphere and then precipitated in solution as acid rain, can cause serious damage to vegetation, waterways, and buildings. The local pollutants (smog) can be loosely defined as a multi-source, widespread air pollution that occurs in the air of cities. Smog, a contraction of the words smoke and fog, has been caused throughout recorded history by water condensing on smoke particles, usually from burning coal.

In terms of the effects, pollutants can be acidifying agents - sulphur dioxide (SO_2), nitrogen oxides (NOx) ammonia (NH_3) fluoride and Cl_2, hydrogen chloride (HCl) - and oxidizing agents - carbon monoxide (CO), PAN (peroxyacetylnitrate-$CH_3CO.O_2.NO_2$), ozone (O_3).(*EPA, 2011*).

2.2. Air Pollutants

The following nine pollutants have been identified as most widespread and seriously affecting environment particularly human health.

2.2.1 Carbon monoxide (CO)

Carbon monoxide poisoning occurs after enough inhalation of carbon monoxide (CO). Carbon monoxide is a toxic gas, but, being colorless, odorless, tasteless, and initially non-irritating, it is very difficult for people to detect *(Ernst and Zibrak, 1998).*

Carbon monoxide is a product of incomplete combustion of organic matter due to insufficient oxygen supply to enable complete oxidation to carbon dioxide (CO_2). It is often produced in domestic or industrial settings by older motor vehicles and other gasoline-powered tools, heaters, and cooking equipment. It is toxic to all forms of aerobic life and absorbed through lungs *(Ernst and Zirak, 1998)*. Exposures at 100 ppm or greater can be dangerous to human health (*Prockop et. al., 2007).* Symptoms of mild acute poisoning include light-headedness, confusion, headaches, vertigo, and flu-like effects; larger exposures can lead to significant toxicity of the central nervous system and heart, and even to death. Following acute poisoning, long-term squeal often occur. Carbon monoxide can also have severe effects on the fetes of a pregnant woman. Chronic exposure to low levels of carbon monoxide can lead to depression, confusion, and memory loss. Carbon monoxide mainly causes adverse effects in humans by combining with haemoglobin to form carboxyhemoglobin (HbCO) in the blood. This prevents oxygen binding to hemoglobin, reducing the oxygen-carrying capacity of the blood, leading to hypoxia. Additionally, myoglobin and mitochondrial cytochrome oxidase are thought to be adversely affected. Carboxyhemoglobin can revert to hemoglobin, but the recovery takes time because the HbCO complex is fairly stable.

Treatment of poisoning largely consists of administering 100% oxygen or providing hyperbaric oxygen therapy, although the optimum treatment remains controversial (*Prockop and Chichkova, 2007).* Oxygen works as an antidote as it increases the removal of carbon monoxide from haemoglobin, in turn providing the body with normal levels of oxygen. The prevention of poisoning is a significant public health issue. Domestic carbon monoxide poisoning can be prevented by early detection with the use of household carbon monoxide detectors. Carbon monoxide poisoning is the most common type of fatal poisoning in many countries (*Omaye, 2002).* Historically, it was also commonly used as a method to commit suicide, usually by deliberately inhaling the exhaust fumes of a running car engine. Modern cars with electronically controlled combustion and catalytic converters produce so little carbon monoxide that this is much less viable. Carbon monoxide poisoning has also been implicated as the cause of apparent haunted houses. Symptoms such as delirium and hallucinations have led people suffering from poisoning to think they have seen ghosts or to believe their house is haunted *(Donnay, 2004).*

Table 2.2: Carbon monoxide (CO) emissions by SRES world regions, current legislation and maximum technically feasible reduction scenarios (million tons CO). Emissions from biomass burning, international shipping and aircrafts are not included.

			Current legislation (CLE)			Maximum feasible reductions (MFR)		
Region	1990	2000	2010	2020	2030	2010	2020	2030
Sub-Saharan Africa	54.6	73.8	82.5	89.0	81.4	52.7	54.7	45.3
Centrally Planned Asia and China	75.0	85.1	80.2	69.1	69.1	47.4	44.9	44.8
Central and Eastern Europe	7.9	7.6	6.0	5.9	6.3	3.6	4.0	4.2
Latin America and Caribbean	68.6	51.6	36.9	30.8	23.1	22.3	19.3	13.2
Middle East and North Africa	10.7	12.0	6.3	6.5	7.3	2.9	3.4	3.8
North America	88.2	80.0	62.3	72.0	75.9	23.9	28.1	25.4
Newly Independent States	33.2	20.6	19.5	18.1	20.0	8.9	10.0	10.8
Pacific OECD	10.1	9.6	8.3	8.0	7.4	4.5	4.4	4.1
Other Pacific Asia	29.1	36.1	30.5	27.5	29.4	18.0	17.3	19.1
South Asia	59.1	59.0	57.2	55.9	56.4	38.4	35.8	34.7
Western Europe	54.7	35.2	22.6	20.0	20.6	15.4	15.9	16.4
World Total	491.7	470.4	412.2	402.9	397.0	237.9	237.6	221.6

Source: Nakicenovic et. al., 2000.

2.2.2. Signs and symptoms of CO

Inhaling even relatively small amounts of the gas can lead to hypoxic injury, neurological damage, and even death. Different people and populations may have a different carbon monoxide tolerance level *(Raub et. al., 2000)*. In the United States, the OSHA limits long-term workplace exposure levels to less than 50 ppm averaged over an 8-hour period *(Kao, 2006).* In addition, employees are to be removed from any confined space if an upper limit of 100 ppm is reached. Carbon monoxide exposure may lead to a significantly shorter life span due to heart damage (*Henry et. al., 2006*). The carbon monoxide tolerance level for any person is altered by several factors, including activity level, rate of ventilation, a pre-existing cerebral or cardiovascular disease, cardiac output, anaemia, sickle cell disease and other haematological disorders, barometric pressure, and metabolic rate *(Struttmann et. al., 1998).*

Table 2.3: The acute effects produced by carbon monoxide in relation to ambient concentration in parts per million

Concentration	Symptoms
35 ppm (0.0035%)	Headache and dizziness within six to eight hours of constant exposure
100 ppm (0.01%)	Slight headache in two to three hours
200 ppm (0.02%)	Slight headache within two to three hours; loss of judgment
400 ppm (0.04%)	Frontal headache within one to two hours
800 ppm (0.08%)	Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours
1,600 ppm (0.16%)	Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours
3,200 ppm (0.32%)	Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes.
6,400 ppm (0.64%)	Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes.
12,800 ppm (1.28%)	Unconsciousness after 2-3 breaths. Death in less than three minutes.

Source : Goldstein, 2008 ; Struttmann et. al., 1998.

2.2.3. Effects on human body

Carbon monoxide is dangerous because it inhibits the blood's ability to carry oxygen to vital organs such as the heart and brain. Inhaled *CO* combines with the oxygen carrying hemoglobin of the blood and forms carboxyhemoglobin (*COHb*) which is unusable for transporting oxygen.

Table 2.4 Health effects of various concentration of carbon monoxide

Exposure (hours)	*CO* Concentration (*ppm*)[1]		
	Perceptible	Sickness[3)]	Deadly[4)]
0.5	600	1000	2000
1	200	600	1600
2	100	300	1000
4	50	150	400
6	25	120	200
8	25[2)]	100	150

[1)] ppm - parts per million - is defined as the mass of the component in solution divided by the total mass of the solution multiplied by 10^6 (one million)

[2)] The maximum exposure allowed by OSHA in the workplace over an eight hour period is *35 ppm*.

[3)] Typical sickness symptoms are mild headache, fatigue, nausea and dizziness.

[4)] A *CO* concentration of *12-13.000 ppm* is deadly after *1-3 minutes*. A CO concentration of *1600 ppm* is deadly after *one hour*.

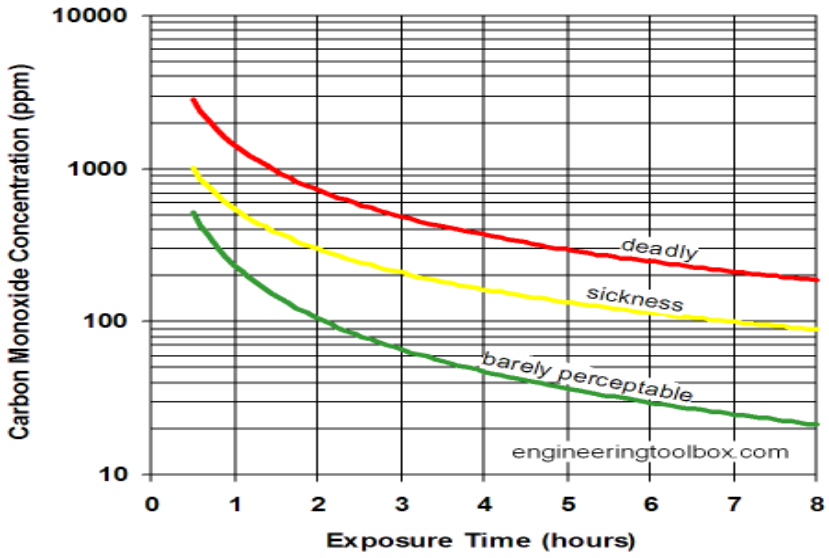


Fig.2.2Health effects of various concentration of carbon monoxide

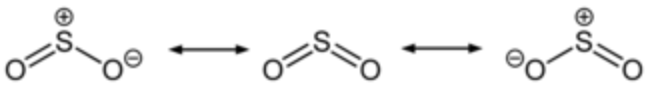
Ref. Engineering Tool Box.com

2.3: SO_2 (Sulfur dioxide)

Sulfur dioxide is the chemical compound with the formula SO_2. It is a poisonous gas with a pungent, irritating smell that is released by volcanoes and in various industrial processes. Since coal and petroleum often contain sulfur compounds, their combustion generates sulfur dioxide unless the sulfur compounds are removed before burning the fuel. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain Sulfur dioxide emissions are also a precursor to particulates in the atmosphere. Both of these impacts are the causes of concern over the environmental impact of these fuels (*Holleman, 2001).*

2.3.1. Structure and bonding

SO_2 is a bent molecule with C_{2v}symmetry point group. In terms of counting formalism, the sulfur atom has an oxidation state of +4 and a formal charge of 0. It is surrounded by 5 electron pairs and can be described as a hypervalent molecule. From the perspective of molecular orbital theory, most of these valence electrons are engaged in S–O bonding.



Three resonance structures of sulfur dioxide

2.3.2 Production of SO_2

Sulfur dioxide is the product of burning of sulfur or materials containing sulfur:

$$S_8 + 8\ O_2 \rightarrow 8\ SO_2$$

Sulfur dioxide is typically produced in significant amounts by the burning of common sulfur-rich materials including wool, hair, rubber, and foam rubber such as are found in mattresses, couch cushions, seat cushions, and carpet pads, and vehicle tires. Ferrous metals such as steel exposed to sulfur dioxide combustion fumes are rapidly oxidized and sulfidated. In house fires, this sometimes produces apparently molten steel comprising iron oxides and iron sulfide. The most common example of this phenomenon is “apparently melted steel” bedsprings that are found by fire investigators. The burning foam rubber in the mattress produces sulfur dioxide which reacts with the hot metal, further heating it until the oxide/sulfide melts, giving the appearance of “melted bed springs”. After the foam rubber burns away, a further heating of the apparently melted bedsprings in the presence of an excess of oxygen, re-releases the sulfur dioxide:

$$4\ FeS_2 + 11\ O_2 \rightarrow 2\ Fe_2O_3 + 8\ SO_2$$

The combustion of hydrogen sulfide and organ sulfur compounds proceeds similarly.

$$2\ H_2S + 3\ O_2 \rightarrow 2\ H_2O + 2\ SO_2$$

The roasting of sulfide ores such as pyrite, sphalerite, and cinnabar (mercury sulfide) also releases SO_2:

$$4\ FeS_2 + 11\ O_2 \rightarrow 2\ Fe_2O_3 + 8\ SO_2$$

$$2\ ZnS + 3\ O_2 \rightarrow 2\ ZnO + 2\ SO_2$$

$$HgS + O_2 \rightarrow Hg + SO_2$$

$$4\ FeS + 7O_2 \rightarrow 2Fe_2O_3 + 4SO_2$$

A combination of these reactions is responsible for the largest source of sulfur dioxide, volcanic eruptions. These events can release millions of tones of SO_2.

Sulfur dioxide is a by-product in the manufacture of silicate cement: $CaSO_4$ is heated with coke and sand in this process:

$$2\ CaSO_4 + 2\ SiO_2 + C \rightarrow 2\ CaSiO_3 + 2\ SO_2 + CO_2$$

The action of hot sulfuric acid on copper turnings produces sulfur dioxide.

$$Cu + 2\ H_2SO_4 \rightarrow CuSO_4 + SO_2 + 2\ H_2O$$

2.3.3 Effects of SO_2

2.3.4 Acid rain

Acid rain" is a popular term referring to the deposition of wet (rain, snow, sleet, fog, cloud water, and dew) and dry (acidifying particles and gases) acidic components. Distilled water, once carbon dioxide is removed, has a neutral pH of 7. Liquids with a pH less than 7 are acidic, and those with a pH greater than 7 are alkaline. “Clean” or unpolluted rain has a slightly acidic pH of over 5.7, because carbon dioxide and water in the air react together to form carbonic acid, but unpolluted rain also contains other chemicals. A common example is nitric acid produced by electric discharge in the atmosphere such as lightning **(***Lied, 2006).* Carbonic acid is formed by the reaction

$$H_2O\ (l) + CO_2\ (g) \rightleftharpoons H_2CO_3\ (aq)$$

Carbonic acid then can ionize in water forming low concentrations of hydronium and carbonate ions:

$$H_2O\ (l) + H_2CO_3\ (aq) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$$

Acid deposition as an environmental issue would include additional acids to H_2CO_3

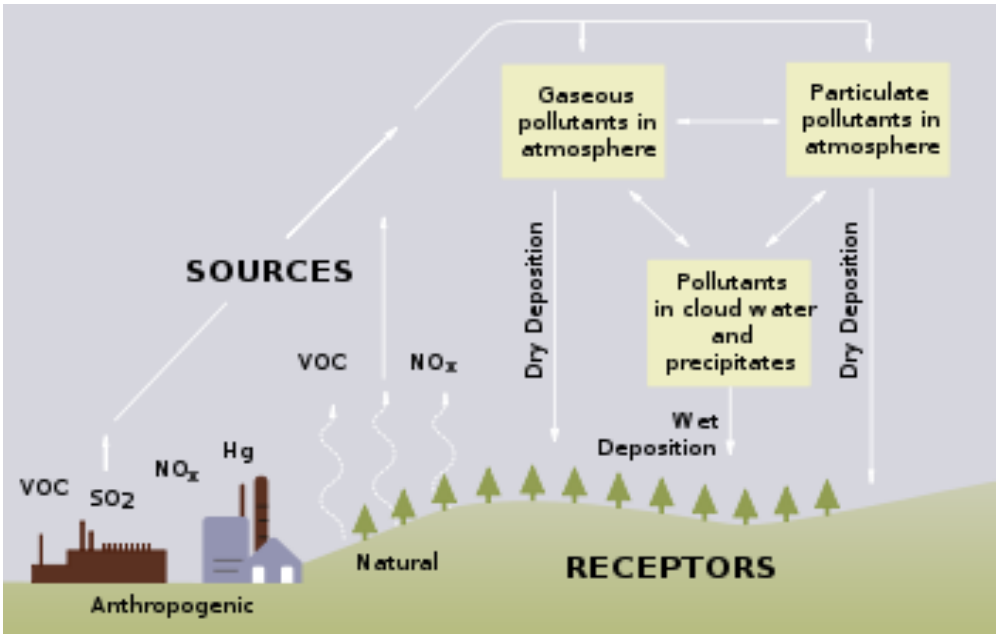


Fig. 2.3: Sources of air pollutants.

Source: EPA, 2009.

2.3.5: Reduction of SO_2 in U.S.A. with time.

Sulphur dioxide is a noticeable component in the atmosphere, especially following volcanic eruptions *(Hoffman, 1990)*. According to the United States Environmental Protection Agency (as presented by the *2002 World Almanac* or in chart form the following amount of sulphur dioxide was released in the U.S. per year:

Table 2.5: Amount of SO_2 was released in the U.S. per Year

Year	SO_2 (thousands of short tons)
1970	31,161
1980	25,905
1990	23,678
1996	18,859
1997	19,363
1998	19,491
1999	18,867

Sulfur dioxide has significant impacts upon human health. In addition the concentration of sulfur dioxide in the atmosphere can influence the habitat suitability for plant communities as well as animal life). Sulfur dioxide emissions are a precursor to acid rain and atmospheric particulates. Due largely to the US EPA's Acid Rain Program, the U.S. has witnessed a 33 percent decrease in emissions between 1983 and 2002. This improvement resulted in part from flue-gas desulphurization, a technology that enables SO_2 to be chemically bound in power plants burning sulfur-containing coal or oil. In particular, calcium oxide (lime) reacts with sulfur dioxide to form calcium sulfite:

$$CaO + SO_2 \rightarrow CaSO_3$$

Aerobic oxidation of the $CaSO_3$ gives $CaSO_4$, anhydrite. Most gypsum sold in Europe comes from flue-gas desulphurization.

Sulfur can be removed from coal during the burning process by using limestone as a bed material in Fluidized bed combustion (2006). Sulfur can also be removed from

fuels prior to burning the fuel. This prevents the formation of SO_2 because there is no sulfur in the fuel from which SO_2 can be formed. Fuel additives, such as calcium additives and magnesium oxide, are being used in gasoline and diesel engines in order to lower the emission of sulfur dioxide gases into the atmosphere.

Table: 2.6: SO_2 emissions by SRES world regions, current legislation and maximum technically feasible reduction scenarios (million tons SO_2). Emissions from biomass burning, international shipping and aircrafts are not included.

			Current legislation (CLE)			Maximum feasible reductions (MFR)		
Region	1990	2000	2010	2020	2030	2010	2020	2030
Sub-Saharan Africa	4.8	5.4	4.9	5.2	5.8	1.3	1.3	1.3
Centrally Planned Asia and China	22.0	28.4	30.9	31.1	29.4	6.7	6.6	6.4
Central and Eastern Europe	11.1	5.9	4.1	2.6	2.3	0.8	0.6	0.6
Latin America and Caribbean	6.7	6.2	6.8	5.8	5.3	1.8	1.8	1.7
Middle East and North Africa	3.1	5.0	3.5	2.8	2.4	0.8	0.7	0.7
North America	24.4	18.5	16.4	15.9	17.5	2.9	3.2	3.3
Newly Independent States	19.5	11.1	7.8	6.0	6.3	1.8	1.7	1.7
Pacific OECD	2.7	2.6	2.8	2.1	1.5	0.6	0.5	0.5
Other Pacific	5.1	4.3	5.4	6.9	8.7	1.5	1.8	2.0

Asia								
South Asia	4.8	7.6	11.0	17.3	22.5	1.9	2.6	3.3
Western Europe	17.9	7.9	3.8	3.1	2.9	1.4	1.3	1.2
World Total	122.1	102.9	97.4	98.9	104.5	21.5	22.2	22.7
SRES B2 (Message)	130	126	120	111	109			
SRES A2 (Message)	130	126	125	1486.3	177			

Source: Nakicenovic et. al., 2000.

2.3.6: Guideline values for SO_2

The ambient air quality guideline values (*DoE, 2002*) for SO_2 are:

- 350 µg/m^3 (one-hour average)
- 120 µg/m^3 (24-hour average).

Previously, the 1994 ambient air quality guideline values for New Zealand included a 10-minute average SO_2 guideline value of 500 µgm^3

2.3.7 Health effects of sulphur dioxide

Sulphur dioxide causes its irritant effects by stimulating nerves in the lining of the nose and throat and the lung's airways. This causes a reflex cough, irritation, and a feeling of chest tightness, which may lead to narrowing of the airways. This latter effect is particularly likely to occur in people suffering from asthma and chronic lung disease, whose airways are often inflamed and easily irritated *(DoE, 1995).*

Asthmatics are generally considered the most sensitive group in the community to concentrations of SO_2. Other sensitive groups include those exercising. This is because SO_2 is very reactive and consequently the distribution of SO_2 along the conductive airways of the respiratory tract is non-uniform, depending on breathing volumes and types. For nasal breathing with low to moderate volumes the penetration into the lungs is negligible. For oral inhalation and larger volumes, doses may reach the segmental bronchi *(WHO, 2000).*

The health effects of concentrations of SO_2 have been studied in a number of ways including exposure of volunteers to sulphur dioxide in the air they are breathing in a laboratory situation and by examination of the effects on members of the population who have been exposed to episodes of atmospheric pollution. In the controlled laboratory situation, acute responses occur within the first few minutes of exposure and further inhalation does not increase effects.

Short-term (less than 24-hour exposure) guideline values for SO_2 have been developed based on the minimum concentrations associated with adverse effects in asthmatic patients exercising in a laboratory situation (*WHO, 2000*). Thus the guideline values represent a protective level for vulnerable groups within the community. Information on the effects of exposure for longer periods (e.g. 24-hour) is obtained from epidemiological studies, which show associations between contaminants such as SO_2 and health impacts in communities and selected panels. In evaluating the health evidence relating to SO_2 exposure for the New Zealand ambient air quality guideline values (*Dennison et. al., 2002*) concludes that because of the correlations between SO_2 and other contaminants in the air it is difficult to confidently attribute the observed effects in the epidemiological studies to SO_2 alone. Experimental studies were therefore used to derive the dose-response relationships underpinning the ambient air quality guideline values for SO_2 for New Zealand.

2.3.8 Effects of Sulphur Dioxide on plants

Sulfur dioxide enters the leaves mainly through the stomata (microscopic openings) and the resultant injury is classified as either acute or chronic. Acute injury (*Figure 2.4*) is caused by absorption of high concentrations of sulfur dioxide in a relatively short time. The symptoms appear as 2-sided (bifacial) lesions that usually occur between the veins and occasionally along the margins of the leaves. The color of the necrotic area can vary from a light tan or near white to an orange-red or brown depending on the time of year, the plant species affected and weather conditions. Recently expanded leaves usually are the most sensitive to acute sulfur dioxide injury, the very youngest and oldest being somewhat more resistant.

Fig. 2.4. Acute sulfur dioxide injury to raspberry. The injury occurs between the veins and the tissue nearest the vein remains healthy.

Chronic injury is caused by long-term absorption of sulfur dioxide at sub-lethal concentrations. The symptoms appear as a yellowing or chlorosis of the leaf, and occasionally as a bronzing on the under surface of the leaves *(Napoli et. al., 2006).*

2.4 Ozone (O_3) Pollution

Ozone (O_3) is positive or negative present in our atmosphere, depending on where it is found. The atmosphere of the earth is divided into four layers, defined by their distance above the planet's surface, with ozone important in the two lower levels - the stratosphere and the troposphere. In the troposphere - the level that contains the air we breathe - ozone is a damaging pollutant. In the stratosphere - 15-50 kilometres above the ground - ozone forms a protective layer which filters out the harmful rays of the sun.

2.4.1 Troposphere ozone

Ozone (O3) occurs naturally in the troposphere (the lowest layer of our atmosphere - 8-16km above the surface of the earth) and the stratosphere (the second layer of the atmosphere - 12-50km above the earth). The background level of tropospheric, or ground level, ozone is 10-30ppb. However, in Europe it is thought to be increasing by 1-2% a year due to the effects of pollution. Higher concentrations of ozone can be damaging to plants, animals and materials. Tropospheric ozone is also a greenhouse gas, contributing to global warming.

2.4.2: Ozone pollution

Ozone is a secondary pollutant formed by the action of sunlight on primary pollutants - nitrogen oxides from vehicle emissions and industry and volatile organic compounds from vehicles, solvents, paint and industry. Nitrogen oxides react in sunlight (photochemical reaction) to form ozone -a major constituent of photochemical smog. Other constituents are PAN (peroxyacetylnitrate) and aldehydes.

2.4.3: Ozone Formation

The atmospheric chemistry involved in ozone formation is complex. Ultraviolet (uv) radiation from the sun breaks down nitrogen di oxide (NO_2) into nitrogen oxide and atomic oxygen -

NO_2 + uv - NO + O

Oxygen atoms combine with oxygen molecules to form ozone -

O + O_2 - O_3

However, ozone will not accumulate when nitrogen oxide is present, as the two molecules react to reform nitrogen dioxide and oxygen -

$NO + O_3 - NO_2 + O_2$

Problems occur when volatile organic pollutants (VOCs) such as hydrocarbons, react in the atmosphere to form oxygenated products such as baldheads. The oxygen in these molecules allows NO to form NO_2, without breaking down ozone, thus ozone accumulates. The build-up of ozone therefore depends upon the relative concentrations of nitrogen oxides, hydrocarbons and other pollutants, and sunlight. It takes time for the ozone to accumulate as the chemical reactions involved are quite slow - ozone builds up in polluted air masses. This takes several days and is favored by prolonged sunny weather and low wind speeds. Polluted air masses often come from continental Europe, so ozone episodes are more frequent in southern England.

The distribution and build up of ozone is also affected by air movement. Although most of the pollutants that form ozone (ozone precursors) are generated in urban areas, concentrations of troposphere ozone tend to be higher away from towns. Ozone levels are also higher on high ground and on the coast. For this reason ozone monitoring stations are situated in the countryside as well as in urban areas.

2.4.4: Guideline values for O_3

The ambient air quality guideline values *(DoE, 2002*) for O_3 are:

- 150 µg/m^3 (one-hour average)
- 100 µg/m^3 (eight-hour average).

2.4.5: Health effects of ozone

Even low levels of ozone may be deadly. A large study of 48 U.S. cities looked at the association between ozone and all-cause mortality during the summer months. Ozone concentrations by city in the summer months ranged from 16 percent to 80 percent lower than the U.S. Environmental Protection Agency (EPA) currently considers safe. Researchers found that ozone at those lower levels was associated with deaths from cardiovascular disease, strokes, and respiratory causes *(Zanobetti et. al., 2008)* .The health impacts of exposure to ozone concentrations have been widely studied using both epidemiological methods and laboratory studies *(Dennison, et. al., 2002*). summarizes the health effects associated with exposure to ozone as:

- increase in daily mortality, respiratory and cardiovascular disease
- increase in hospital admissions and emergency room visits, respiratory and cardiovascular disease
- decrease in lung function

- increase in symptoms of respiratory illness such as cough, phlegm and wheeze
- Increase in bronchodilator usage.

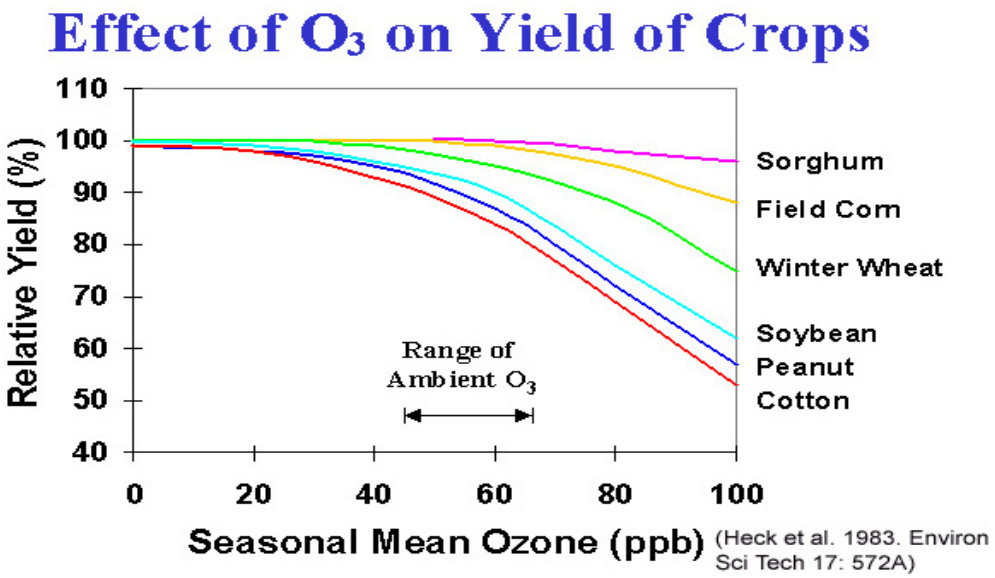
At low concentrations ozone can cause tissue injuries in the lungs and can result in significant impairment of pulmonary function. The impact of ozone on health depends on a number of factors including magnitude of concentration, duration of exposure, climate, individual sensitivity and pre-existing conditions. Those most susceptible to concentrations of ozone include children, people with pre-existing diseases, and the elderly and healthy adults exercising in the outdoors.

Although some studies have indicated the potential for a no effects threshold, the overall interpretation of the health effects literature is that there is no threshold of exposure, below which effects do not occur (*Dennison et. al., 2000*). A dose response relationship of 0.6% per 10 μgm^{-3} (eight-hour mean) for mortality and 0.7% per 10 μgm^{-3} (eight-hour mean) for hospital admissions was used to estimate the impact of ozone concentrations in the *Quantification of the Effects of Air Pollution on Health in the United Kingdom* study (*WHO, 1998).* This dose response relationship was based on studies carried out in the urban and rural areas of the United Kingdom during the summer months, prior to 1998.

2.4.6: **Effects on Plants**

Physiological and developmental processes of plants are affected by UVB radiation, even by the amount of UVB in present-day sunlight. Despite mechanisms to reduce or repair these effects and a limited ability to adapt to increased levels of UVB, plant growth can be directly affected by UVB radiation. Indirect changes caused by UVB (such as changes in plant form, how nutrients are distributed within the plant, timing of developmental phases and secondary metabolism) may be equally, or sometimes more, important than damaging effects of UVB. These changes can have important implications for plant competitive balance, herbivore, plant diseases, and biogeochemical cycles.

Fig 2.5: Injury in a pumpkin leaf.



Source: Heck et. al., 1983.

Fig. 2.6: Effects of O_3 on Yield of Crops.

The strongest evidence for significant effects of ozone on crop yield comes from NCLAN (National Crop Loss Assessment Network) studies (*Heagle, 1998).* The results show that dicot species (soybean, cotton and peanut) are more sensitive to yield loss caused by ozone than monocot species (sorghum, field corn and winter wheat) (*Bell, 2009).*

2.5: NOx (Oxides of Nitrogen)

NO_x is a generic term for mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. NOx gases are formed everywhere where there is combustion – like in an engine. In atmospheric chemistry, the term means the total concentration of NO and NO_2. NO_x react to form smog and acid rain. NO_x are also central to the formation of troposphere ozone. NO_x should not be confused with nitrous oxide (N_2O), which is a greenhouse gas and has many uses as an oxidizer, an anesthetic, and a food additive *(WHO, 2012).*

2.5.1: Formation and reactions

The oxygen and nitrogen do not react at ambient temperatures. But at high temperatures, they have an endothermic reaction producing various oxides of nitrogen. Such temperatures arise inside an internal combustion engine or a power station boiler, during the combustion of a mixture of air and fuel. In atmospheric

chemistry, the term NO_x means the total concentration of NO and NO_2. During daylight, these concentrations are in equilibrium; the ratio NO/NO_2 is determined by the intensity of sunshine (which converts NO_2 to NO) and the concentration of ozone (which reacts with NO to again form NO_2).

In the presence of excess oxygen (O_2), nitric oxide (NO) reacts with the oxygen to form nitrogen dioxide (NO_2). When NO_x and volatile organic compounds (VOCs) react in the presence of sunlight, they form photochemical smog, a significant form of air pollution, especially in the summer. Children, people with lung diseases such as asthma, and people who work or exercise outside are particularly susceptible to adverse effects of smog such as damage to lung tissue and reduction in lung function *(EPA, 2007).*

Mono-nitrogen oxides eventually form nitric acid when dissolved in atmospheric moisture, forming a component of acid rain. The following chemical reaction occurs when nitrogen dioxide reacts with water:

$$2\ NO_2 + H_2O \rightarrow HNO_2 + HNO_3$$

Nitrous acid then decomposes as follows:

$$3\ HNO_2 \rightarrow HNO_3 + 2\ NO + H_2O$$

Where nitric oxide will oxidize to form nitrogen dioxide that again reacts with water, ultimately forming nitric acid:

$$4\ NO + 3\ O_2 + 2\ H_2O \rightarrow 4\ HNO_3$$

Mono-nitrogen oxides are also involved in tropospheric production of ozone *(Fowler et. al., 1998).*

This nitric acid may end up in the soil, where it makes nitrate, where it is of use to growing plan.

2.5.2: Sources

2.5.2.1: Natural sources

Nitric oxide is produced during thunderstorms due to the extreme heat of lightning (Levine, et. al., 1984) and is caused by the splitting of nitrogen molecules. This can result in the production of acid rain, if nitrous oxide forms compounds with the water molecules in precipitation.

2.5.2.2: Biogenic sources

Agricultural fertilization and the use of nitrogen fixing plants also contribute to atmospheric NO_x, by promoting nitrogen fixation by microorganisms *(Galloway, et. al., 2004).*

2.5.2.3: Industrial sources

The three primary sources of NO_x in combustion processes:

- thermal NO_x
- fuel NO_x
- prompt NO_x

Thermal NO_x formation, which is highly temperature dependent, is recognized as the most relevant source when combusting natural gas. Fuel NO_x tends to dominate during the combustion of fuels, such as coal, which have significant nitrogen content, particularly when burned in combustors designed to minimize thermal NO_x. The contribution of prompt NO_x is normally considered negligible. A fourth source, called *feed* NO_x is associated with the combustion of nitrogen present in the feed material of cement rotary kilns, at between 300° and 800 °C, where it is also a minor contributor.

Table 2.7: NO_x emissions by SRES world regions, current legislation and maximum technically feasible reduction scenarios (million tons SO_2). Emissions from biomass burning, international shipping and aircrafts are not included.

			Current legislation (CLE)			Maximum feasible reductions (MFR)		
Region	1990	2000	2010	2020	2030	2010	2020	2030
Sub-Saharan Africa	2.6	3.7	3.7	4.8	6.7	1.1	1.2	1.4
Centrally Planned Asia and China	7.8	12.3	13.8	15.0	16.2	3.7	4.2	4.5
Central and Eastern Europe	3.5	2.8	2.0	1.7	1.8	0.6	0.6	0.7
Latin America and Caribbean	5.5	6.4	6.0	5.8	6.3	1.3	1.5	1.7
Middle East and North Africa	2.6	3.3	2.6	2.8	3.1	0.7	0.8	0.8
North America	20.4	19.9	18.3	20.8	22.2	5.7	6.3	6.8
Newly Independent States	11.2	7.2	6.7	5.9	6.7	1.5	1.6	1.8
Pacific OECD	3.7	3.7	3.4	3.2	2.8	1.2	1.1	1.0
Other Pacific Asia	2.6	6.6	5.8	6.9	8.2	1.6	2.0	2.4
South Asia	3.1	5.4	7.6	9.7	11.6	1.9	2.4	2.9
Western Europe	14.1	10.8	7.5	6.0	6.1	2.8	3.0	3.1
World Total	81.0	81.1	77.3	82.5	91.6	22.1	24.7	27.1
SRES B2 (Message)	82.0	86.0	103.0	123.0	143.0			
SRES A2 (Message)	82.0	86.0	107.0	135.0	166.0			

Source: Nakicenovic et. al., 2000.

2.5.3: Health effects

NO_x reacts with ammonia, moisture, and other compounds to form nitric acid vapour and related particles. Small particles can penetrate deeply into sensitive lung tissue and damage it, causing premature death in extreme cases. Inhalation of such particles may cause or worsen respiratory diseases such as emphysema, bronchitis it may also aggravate existing heart disease *(EPA, 2008*). NO_x reacts with volatile organic compounds in the presence of sunlight to form Ozone. Ozone can cause adverse effects such as damage to lung tissue and reduction in lung function mostly in susceptible populations (children, elderly, and asthmatics). Ozone can be transported by wind currents and cause health impacts far from the original sources. The American Lung Association estimates that nearly 50 percent of United States inhabitants live in countries that are not in ozone compliance *(Davidson and Kingerlee, 1997*). NO_x also readily reacts with common organic chemicals, and even ozone, to form a wide variety of toxic products: nitroarenes, nitrosamines and also the nitrate radical some of which may cause biological mutations. Recently another pathway, via NOx, to ozone has been found that predominantly occurs in coastal areas via formation of nitryl chloride when NOx comes into contact with salt mist.

2.6: Volatile Organic Compounds (VOCs)

Volatile Organic Compounds (VOCs) are a large group of carbon-based chemicals that easily evaporate at room temperature. While most people can smell high levels of some VOCs, other VOCs have no odor. Odor does not indicate the level of risk from inhalation of this group of chemicals. There are thousands of different VOCs produced and used in our daily lives. Some common examples include:

- Acetone
- Benzene
- Ethylene glycol
- Formaldehyde
- Methylene chloride
- Perchloroethylene
- Toluene
- Xylene
- 1,3-butadiene

2.6.1: Sources of VOCs

Many products we have in our homes release or "off-gas" VOCs. Some examples of sources of VOCs are:

Building Materials

- Carpets and adhesives
- Composite wood products
- Paints
- Sealing caulks
- Solvents
- Upholstery fabrics
- Varnishes
- Vinyl Floors

Home and Personal Care Products

- Air fresheners
- Air cleaners that produce ozone
- Cleaning and disinfecting chemicals
- Cosmetics
- Fuel oil, gasoline
- Moth balls
- Vehicle exhaust running a car in an attached garage

Behaviours

- Cooking
- Dry cleaning
- Hobbies
- Newspapers
- Non-electric space heaters
- Photocopiers
- Smoking
- Stored paints and chemicals
- Wood burning stoves

Studies have shown that the level of VOCs indoors is generally two to five times higher than the level of VOC's outdoors. VOC concentrations in indoor air depend on many factors, including the:

- Amount of VOCs in a product;
- Rate at which the VOCs are released;
- Volume of the air in the room/building;
- Ventilation rate or the area; and
- Outdoor concentrations of VOCs.

2.6.2: The health effects of VOC exposure

The risk of health effects from inhaling any chemical depends on how much is in the air, how long and how often a person breathes it in. Scientists look at short-term (acute) exposures as hours to days or long-term (chronic) exposures as years to even lifetime.

Breathing low levels of VOCs for long periods of time may increase some people's risk of health problems. Several studies suggest that exposure to VOCs may make symptoms worse in people who have asthma or are particularly sensitive to chemicals. These are much different exposures than occupational exposures to VOCs *(EPA, 2008).*

VOCs refer to a group of chemicals. Each chemical has its own toxicity and potential for causing different health effects. Common symptoms of exposure to VOCs include:

Short-Term (Acute) to high levels of VOCs

- Eye, nose and throat irritation
- Headaches
- Nausea / Vomiting
- Dizziness
- Worsening of asthma symptoms

Long-Term (Chronic) to high levels of VOCs

Increased risk of:

- Cancer
- Liver damage
- Kidney damage
- Central Nervous System damage

2.7 NH_3 (Ammonia)

Ammonia is a compound of nitrogen and hydrogen with the formula NH_3. It is a colorless gas with a characteristic pungent odor. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers. Ammonia either directly or indirectly, is also a building-block for the synthesis of many pharmaceuticals and is used in many commercial cleaning products. Although in wide use, ammonia is both caustic and hazardous. In 2006, worldwide production was estimated at 146.5 million tones. Ammonia, as used commercially, is often called *anhydrous ammonia.* Because NH_3 boils at −33.34 °C (−28.012 °F) at a pressure of 1 atmosphere, the liquid must be stored under high pressure or at low temperature. "Household ammonia" or "ammonium hydroxide" is a solution of NH_3 in water. The concentration of such solutions is measured in units

of the Baumé scale (density), with 26 degrees Baume (about 30% w/w ammonia at 15.5 °C) being the typical high-concentration commercial product (Ammonium hydroxide physical properties) Household ammonia ranges in concentration from 5 to 10 weight percent ammonia.

2.14. Synthesis and production

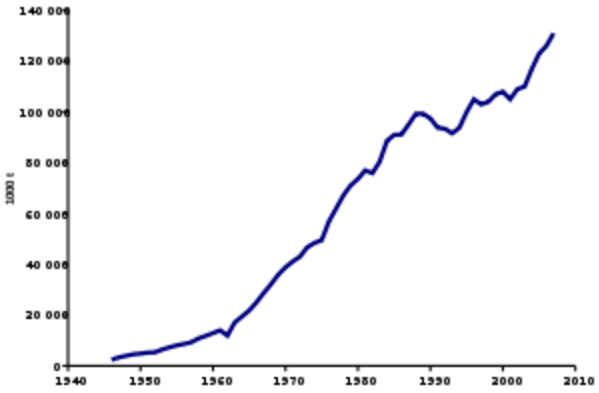


Fig. 2.7: Production trend of ammonia between 1947 and 2007.

Source: EPA, 2011.

Because of its many uses, ammonia is one of the most highly produced inorganic chemicals. Dozens of chemical plants worldwide produce ammonia. The worldwide ammonia production in 2004 was 109 million metric tons. China produced 28.4% of the worldwide production followed by India with 8.6%, Russia with 8.4%, and the United States with 8.2% (EPA, 2010).It was produced by the distillation of coal, and also by the decomposition of ammonium salts by alkaline hydroxide(Chemistry of the Group 2 Elements s) such as quicklime, the salt most generally used being the chloride (sal-ammoniac) thus:

$$2\ NH_4Cl + 2\ CaO \rightarrow CaCl_2 + Ca\ (OH)_2 + 2\ NH_3$$

Today, the typical modern ammonia-producing plant first converts natural gas (i.e., methane) or liquefied petroleum gas (such gases are propane and butane) or petroleum naphtha into gaseous hydrogen. The process used in producing the hydrogen begins with removal of sulfur compounds from the natural gas (because sulfur deactivates the catalysts used in subsequent steps). Catalytic hydrogenation converts organ sulfur compounds into gaseous hydrogen sulfide:

$$H_2 + RSH \rightarrow RH + H_2S\ (g)$$

The hydrogen sulfide is then removed by passing the gas through beds of zinc oxide where it is adsorbed and converted to solid zinc sulfide:

$$H_2S + ZnO \rightarrow ZnS + H_2O$$

Catalytic steam reforming of the sulfur-free feedstock is then used to form hydrogen plus carbon monoxide:

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

In the next step, the water gas shift reaction is used to convert the carbon monoxide into carbon dioxide and more hydrogen:

$$CO + H_2O \rightarrow CO_2 + H_2$$

The carbon dioxide is then removed either by absorption in aqueous ethanolamine solutions or by adsorption in pressure swing absorbers (PSA) using proprietary solid adsorption media.

The final step in producing the hydrogen is to use catalytic meth nation to remove any small residual amounts of carbon monoxide or carbon dioxide from the hydrogen:

$$CO + 3\ H_2 \rightarrow CH_4 + H_2O$$

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$$

$$3\ H_2 + N_2 \rightarrow 2\ NH_3$$

Hydrogen required for ammonia synthesis could also be produced economically using other sources like coal or coke gasification, less economically from the electrolysis of water into oxygen + hydrogen and other alternatives that are presently impractical for large scale. At one time, most of Europe's ammonia was produced from the Hydro plant at Vendors, via the electrolysis route. Various renewable energy electricity sources are also potentially applicable *(EPA, 2011).*

2.7.1 Environmental Impacts

When in gaseous form, ammonia has a short atmospheric lifetime of about 24 hours and usually deposits near its source (the majority of gaseous ammonia is deposited within 700 -1000 m of feedlot parameters; 29). In particulate form ammonia can travel much further impacting a larger area. Both gaseous and particulate ammonia contribute to eutrophication of surface waters, soil acidification, fertilization of vegetation, changes in ecosystems (5),and smog and decreased visibility in cities and pristine areas. Since ammonia is one of the only basic species in the atmosphere, it readily reacts with strong acidic species in the atmosphere such as nitric and sulfuric acids, which are byproducts of combustion process including vehicle and industrial sources, to form ammonium salts, also known as fine particulate matter or PM2.5.

Due to their small diameter (less than 2.5 microns (μm)) and increased atmospheric lifetime of 15 days, these particulates are able to travel long distances before being dry or wet deposited to the ground surface. This allows them to travel from rural areas to urban locations where they mix and build up in the atmosphere leading to smog or transportation to other areas. In Colorado transport of these particulates from urban areas to pristine mountain regions, such as Rocky Mountain National Park, has been documented. Deposition of these enrich particulates in the Park has caused changes in the Park's vegetation, lakes, and natural ecosystems.

Soil Acidification

When ammonia reaches the soil surface, it usually reacts with water in the soil and is converted into its ionic form. Ammonium (NH4+) and absorbs to the soil. The ammonium in the soil eventually disassociates or is nitrified into nitrite (NO_2-) or nitrate (NO3-) by nitrifying bacteria, releasing H+ ions into the soil (3, 4). If not taken up by biomass and converted to methane, the surplus H+ ions eventually lead to the formation of an acidic soil environment. The nitrogen left over in the soil will either be taken up by plants, stored in the soil, returned to the atmosphere, or will be removed from the soil in runoff or leaching .

Fertilization of Vegetation

Fertilization of vegetation by ammonia occurs in much the same way as applying fertilizer to the soil; however, in this case ammonia gas from the air deposits on the leaf or soil surface at the base of the plant and is taken up by the plant. Changes in plant growth can then occur, similar to those resulting from fertilization. In a grass plains environment, changes may be subtle; however, in natural or mountain areas, changes in plant species may be more obvious, promoting weedy plants while choking out native plants and wild flowers or promoting grasses and sages.

Changes in Ecosystems

An ecosystem is a natural system consisting of plants, animal, and other microorganisms functioning together in a balanced relationship. Changes in ecosystems due to ammonia deposition occur through a combination of all the above mentioned processes. When changes in ecosystems occur, the natural balance of a system is disrupted and fragile plant and animal species can be replaced by non-native or N-responsive species. The disruption of an ecosystem can cause it to adapt by changing (positive or negative outcome), or a disruption may lead to the extinction of the ecosystem.

2.8: H_2S (Hydrogen sulphide)

Hydrogen sulphide (British English: *hydrogen sulphide*) is the chemical compound with theformulaH_2S. It is a colorless, very poisonous, flammable gas with the characteristic foul odor of rotten eggs. It often results from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps and sewers; this process is commonly known as anaerobic digestion. It also occurs in volcanic gases, natural gas, and some well waters. The human body produces small amounts of H_2S and uses it as a signalling molecule.

2.8.1: Production of SO_2

Hydrogen sulfide is most commonly obtained from sour gas, which is natural gas with high content of H_2S. It can also be produced by reacting hydrogen gas with molten elemental sulfur at about 450 °C. Hydrocarbons can replace hydrogen in this process. Sulfate-reducing (resp. sulfur-reducing) bacteria generate usable energy under low-oxygen conditions by using sulfates (resp. elemental sulfur) to oxidize organic compounds or hydrogen; this produces hydrogen sulfide as a waste product *(WHO, 2012).*

2.8.2: Effects on human body

Hydrogen sulfide is considered a broad-spectrum poison, meaning that it can poison different systems in the body, although the nervous system is most affected. The toxicity of H_2S is comparable with that of hydrogen cyanide. It forms a complex bond with iron in the mitochondrialcytochromeenzymes, thus preventing cellular respiration *(Belley et. al., 2005).*

Since hydrogen sulfide occurs naturally in the body, the environment and the gut, enzymes exist in the body capable of detoxifying it by oxidation to (harmless) sulfate (*Ramasamy et. al., 2006).* Hence, low levels of hydrogen sulfide may be tolerated indefinitely.

At some threshold level, believed to average around 300–350 ppm, the oxidative enzymes become overwhelmed. Many personal safety gas detectors, such as those used by utility, sewage and petrochemical workers, are set to alarm at as low as 5 to 10 ppm and to go into high alarm at 15 ppm *(Hsue et. al., 1987).* An interesting diagnostic clue of extreme poisoning by H_2S is the discoloration of copper coins in the pockets of the victim. Treatment involves immediate inhalation of amyl nitrite, injections of sodium nitrite, inhalation of pure oxygen, administration of bronchodilators to overcome eventual bronchospasm, and in some cases hyperbaric oxygen therapy (HBO). HBO therapy has anecdotal support and remains controversial *(Gerasimon et. al., 2007*). Exposure to lower concentrations can result in eye irritation, a sore throat and cough, nausea, shortness of breath, and fluid in the lungs. These effects are believed to be due to the fact that hydrogen sulfide combines with alkali present in moist surface tissues to form sodium sulfide, a caustic (*Lewis, 1996*).These symptoms usually go away in a few weeks. Long-term, low-level exposure may result in fatigue, loss of appetite, headaches, irritability, poor memory, and dizziness. Chronic exposure to low level H_2S (around 2 ppm) has been implicated in increased miscarriage and reproductive health issues among Russian and Finnish wood pulp workers (*Hemminki, 1982),* but the reports have not (as of circa 1995) been replicated.

- 0.0047 ppm is the recognition threshold, the concentration at which 50% of humans can detect the characteristic odor of hydrogen sulfide, normally described as resembling "a rotten egg".
- Less than 10 ppm has an exposure limit of 8 hours per day.
- 10–20 ppm is the borderline concentration for eye irritation.
- 50–100 ppm leads to eye damage.
- At 100–150 ppm the olfactory nerve is paralyzed after a few inhalations, and the sense of smell disappears, often together with awareness of danger.[18][19]
- 320–530 ppm leads to pulmonary edema with the possibility of death.
- 530–1000 ppm causes strong stimulation of the central nervous system and rapid breathing, leading to loss of breathing.
- 800 ppm is the lethal concentration for 50% of humans for 5 minutes exposure (LC50).
- Concentrations over 1000 ppm cause immediate collapse with loss of breathing, even after inhalation of a single breath.

Hydrogen sulfide was used by the British Army as a chemical agent during World War I. It was not considered to be an ideal war gas, but, while other gases were in short supply, it was used on two occasions in 1916 *(Foulkes et. al., 2001).*

2.9: PH_3 (Phosphine)

Phosphine is a colorless, flammable highly toxic gas with a fishy or garlic-like odor. Phosphine acts on the central nervous system and lungs leading to pulmonary enema. Symptoms like faintness, vomiting, headache, tightness in the chest may appear rapidly after exposure. Even a short exposure to an acute amount of phosphine can lead to chronic neurological problems. It should also be recognized that phosphine is highly flammable and may spontaneously ignite in air or even explode when mixed with oxygen. Phosphine coming in contact with oxidizers, halogenated hydrocarbons, or even aluminum and copper may cause the same. It is for this reason that extreme care must be adhered to whenever working with or around phosphine.

Table 2.8: Effects of Various PH_3 Levels

Phosphine Level in ppm	**Resulting Conditions on Humans**
0.3	OSHA Permissible Expo sure Limit (PEL).
1	OSHA Short Term Exposure Limit (STEL).
35	Diarrhoea, nausea, respiratory distress.
500	Lethal after 45 minutes.
2000	Lethal after 1-3 minutes.

Source: AIHA, 2006.

2.9.1: Effects on plant life

Seeds :

There is considerable evidence from studies so far conducted that phosphine in insecticidal treatments does not, under normal conditions, affect the germination of seeds. Strong and Lindgren (1960) tested cereal, sorghum and small legume seeds with one or two (repeat) fumigations at comparatively high concentrations (*Berstlief and Alexandrescu, 1964)* confirmed these findings for wheat sod maize under

Rumanian conditions and de Matos (1961) for the germination of groundouts. When a third fumigation was done with phosphine found no ill effect on the germination of some varieties of tomatoes, sweet melons, cucumbers, peas and beans, but one variety of broad beans was slightly affected. However, the growth and yield of plants grown from seeds subjected to repeated fumigations with phosphine may be significantly reduced reported a reduction in total yield of maize grown from seed fumigated twice sod three times with phosphine (*Fam et. Al., 1974*)

Living Plants :

There is little information on the tolerance of growing plants to the vapors of phosphine found that 15 varieties of glasshouse plants were tolerant to concentrations which were completely toxic to the postembryonic life stages of the mealybug Plannococcuscitri (Risso), but the eggs were not killed. The nematode Meloidopynehapla may be controlled in potted rose plants with phosphine applied to the soil, without apparent injury to the plants *(Faber, 1966).*

Effect on plant production:

Phosphine has been used for many years to control insects in a wide range of plant products throughout the world. To date there has been no report of appreciable adverse effects from recommended treatments concluded that normal fumigation with phosphine has no effect on vitamins, particularly vitamins A and B_2 (riboflavin), in a group of important foods which are a regular dietary source of these vitamins. Fumigation of wheat with phosphine under normal conditions has no adverse effect on the baking quality of flour made from it. Phosphine can also be used to control insects in dried fruit (*Nelson et.al., 1970).*Tests on fresh fruit and vegetables show that insects such as fruit flies can be controlled using gas generated from a magnesium phosphide preparation without injury to the produce found no injury on papaya, tomato, bell pepper, eggplant or banana fumigated with dosages that eliminated eggs and larvae of the fruit flies Dacus dorsal Hendl and Ceratitiscapitata Wied. Ten varieties of avocado, although not injured by the treatment, did ripen more quickly than unfumigated avocados. Grapefruit and tomatoes have also been fumigated without injury at concentrations sufficient to kill fruit flies (*Windeguth et. al., 1977).*

2.10: Effects of Humidity

Humidity is a term for the amount of water vapor in the air, and can refer to any one of several measurements of humidity. Formally, humid air is not "moist air" but a mixture of water vapor and other constituents of air, and humidity is defined in terms of the water content of this mixture, called the absolute humidity In everyday usage, it commonly refers to relative humidity, expressed as a percent in weather forecasts and on household humidistat's; it is so called because it measures the current absolute humidity *relative* to the maximum. Specific humidity is a ratio of the water vapor content of the mixture to the total air content (on a mass basis). The water vapor content of the mixture can be measured either as mass per volume or as a partial pressure, depending on the usage. In meteorology, humidity indicates the likelihood of precipitation, dew, or fog. High relative humidity reduces the effectiveness of sweating in cooling the body by reducing the rate of evaporation of moisture from the skin. This effect is calculated in a heat index table, used during summer weather (*Wyer, 1906)*.

Animals and plants

Humidity is one of the fundamental biotic factors that defines any habitat, and is a determinant of which animals and plants can thrive in a given environment (*Michael et. al., 2010).*

The human body dissipates heat by a perspiration and evaporation. Heat convection to the surrounding air and thermal radiation are the primary modes of heat transport from the body. Under conditions of high humidity, the rate of evaporation of sweat from the skin decreases. Also, if the atmosphere is as warm as or warmer than the skin during times of high humidity, blood brought to the body surface cannot dissipate heat by conduction to the air, and a condition called hyperpyrexia results. With so much blood going to the external surface of the body, relatively less goes to the active muscles, the brain, and other internal organs. Physical strength declines and fatigue occurs sooner than it would otherwise. Alertness and mental capacity also may be affected, resulting in *heat stroke* or hyperthermia.

Human comfort

Humans are sensitive to humid air because the human body uses evaporative cooling as the primary mechanism to regulate temperature. Under humid conditions, the *rate* at which perspiration evaporates on the skin is lower than it would be under arid conditions. Because humans perceive the rate of heat transfer from the body rather than temperature itself, we feel warmer when the relative humidity is high than when it is low.

Some people experience difficulty breathing in high humidity environments. Some cases may possibly be related to respiratory conditions such as asthma, while others may be the product of anxiety. Sufferers will often hyperventilate in response, causing sensations of numbness, faintness, and loss of concentration, among others *(WHO, 2011).* Air conditioning reduces discomfort in the summer not only by reducing temperature, but also by reducing humidity. In winter, heating cold outdoor air can decrease relative humidity levels indoor to below 30%, leading to discomfort such as dry skin and excessive thirst.

2.11. Limit Values

National Ambient Air Quality Standards (NAAQS) were updated for Bangladesh in 2005 through the national S.R.O. No 220-Law. The standards set for NO_2, SO_2, and O_3 are mostly based on the US-EPA's ambient AQ standards, where Bangladesh is the only country in South Asia which set a standard for PM2.5 (CAI-ASIA, 2006). These standards are not as stringent as the European Union (EU) limit values or the World Health Organization (*WHO, 2011)* air quality guidelines (AQG), although impacts to human health are a major driving force in developing NAAQS. Adverse effects on human health (and ecosystems) occur for both short-term and long-term exposure, so different standard values are valid for different averaging periods (1 hour, 8 hours, 24 hours, 1 year etc (*WHO, 2011).*

2.11.1. SO_2 (Sulphur dioxide)

Sulphur dioxide (SO_2) is an air pollutant which at certain levels and durations poses a human health risk. Elevated SO_2 concentrations can affect the respiratory system, and can also be harmful to ecosystems at very high concentrations. The primary contributor of anthropogenic SO_2 is the combustion of sulphur-containing fossil-fuels (mainly coal and heavy oils used in industrial and vehicular sources).

A summary of the SO_2 standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA are shown below:

Annual limit values for the protection of ecosystems are also given, where these values are most relevant for more remote areas.

Table 2.9: Annual limit values for the protection of ecosystems

Effect	Averaging period	Bangladesh (standards)[a]	EU (limit values)[b]	WHO (guidelines)[c]	US-EPA (standards)[d]
Health	10 min	-	-	500 µg/m^3	-
Health	1 hour	-	350 µg/m^3 (1)	-	212 µg/m^3
Health	24 hours	365 µg/m^3	125 µg/m^3 (2)	20 µg/m^3	365 µg/m^3
Health/Ecosystem	Annual	80 µg/m^3	20 µg/m^3	-	78 µg/m^3

[a]NAAQS (CAI-Asia, 2006)
[b](EU, 2008)
[c]AQG (WHO, 2005)
[d]NAAQS (US-EPA, 2010)
(1) not to be exceeded more than 24 times a calendar year
(2) not to be exceeded more than 3 times a calendar year

2.11.2. NO_2 (Nitrogen Dioxide)

Nitrogen Dioxide (NO_2) is a highly reactive gas within the nitrogen oxide (NOX) group that has human health effects to the respiratory system, as well as to ecosystem. NOX emissions are generated mainly from anthropogenic combustion sources such as vehicles and power plants. NO emissions interact with O_3 to form NO_2, and also contribute to fine particle pollution.

A summary of the NO_2 standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA are shown below:

Table 2.10: A summary of the NO_2 standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA.

Effect	Averaging period	Bangladesh (standards)[a]	EU (limit values)[b]	WHO (guidelines)[c]	US-EPA (standards)[d]
Health	1 hour	-	200 µg/m^3 (1)	200 µg/m^3	200 µg/m^3
Health	Annual	100 µg/m^3 (2)	40 µg/m^3	40 µg/m^3	100 µg/m^3

[a]NAAQS (CAI-Asia, 2006)
[b](EU, 2008)
[c]AQG (WHO, 2005)
[d]NAAQS (US-EPA, 2010)
(1) not to be exceeded more than 18 times a calendar year
(2) Limit value only available for NO_x, no specific limit value for NO_2.

2.11.3. O_3 (Ozone)

Ozone (O_3) is a toxic gas and photochemical oxidant which has effects upon the ecosystem and is linked to health problems associated with the respiratory system, including rise in human inflammatory responses and decreases in lung function. O3 is formed through the action of short wavelength solar radiation on NOx, and in the presence of VOCs, it produces even higher levels of ozone. In this regard, the primary sources of O3 are the same as the NO_2 sources, with the addition of sunlight to produce the gas.

A summary of the O_3 standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA are shown in Table 2.11.

Table 2.11: A summary of the O_3 standards for Bangladesh, limit values from the EU, guideline values from the WHO, and standards for the US-EPA.

Effect	Averaging period	Bangladesh (standards)[a]	EU (limit values)[b]	WHO (guidelines)[c]	US-EPA (standards)[d]
Health	1 hour	235 µg/m^3	180 µg/m^3	-	235 µg/m^3
Health	8 hours	157 µg/m^3	120 µg/m^3	100 µg/m^3	157 µg/m^3

[a]NAAQS (CAI-Asia, 2006)
[b](EU, 2008), (EU, 2002)
[c]AQG (WHO, 2005)
[d]NAAQS (US-EPA, 2010)

(EPA, 2010) has developed and air quality index (AQI) for toxic gasses to delineated the levels of severity on human health and in the environment, which is presented below:

Table 2.12: Air Quality Index

Air Quality Index Levels of Health Concern	Numerical Value µg/m3	Meaning
Good	0 to 50	Air quality is considered satisfactory.
Moderate	51 to 100	Air quality is acceptable.

Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects.
Unhealthy	151 to 200	Everyone may begin to experience health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Hazardous	301 to 500	Health warnings of emergency conditions.

Source: EPA, 2010.

Table 2.13: Air quality standard of Bangladesh

Area	SPM	SO2	CO	NO_x
Industrial & mixed	500 µg/m3	120 µg/m3	5000 µg/m3	100 µg/m3
Commercial & mixed	400 µg/m3	100 µg/m3	5000 µg/m3	100 µg/m3
Residential & Rural	200 µg/m3	80 µg/m3	2000 µg/m3	80 µg/m3
Sensitive	100 µg/m3	30 µg/m3	1000 µg/m3	30 µg/m3

Source: DoE, 2009.

Table 2.14: National Ambient Air quality standards (NAAQS) given by: put table index

Pollutants	Time weighted average	Industrial area	Residential rural and other area	Sensitive area
Sulphur dioxides	Annual average	80 µg/m3	60 µg/m3	15 µg/m3
Oxides of Nitrogen (NO_2)	Annual average	80 µg/m3	60 µg/m3	15 µg/m3
Carbon monoxides	8 hours	5.0 mg/m3	2.O mg/m3	1. 0 mg/m3

Source: EPA, 2010.

2.12: Types of Vehicles Operating in the City and its Growth

The Bangladesh Road Transport Corporation (BRTC) is the state-owned transport corporation of Bangladesh. It was established under the Government Ordinance No.7 of 1961 dated 4 February 1961. Following the independence of Bangladesh in 1971, it assumed its current name (*BRTA, 2015).* BRTC operates three international bus services (Dhaka to Kolkata, Agartala, and Siliguri in India). Inside Bangladesh, it operates inter-district bus services through its bus depots in Chittagong, Bogra, Comilla, Pabna, Rangpur, Barisal, and Sylhet. It also operates intra-city bus services in many major cities of the country .The metropolitan area of the city has several precincts – old city, newly developed areas, developing areas, satellite towns etc. with their own characteristics including social and cultural tradition and income disparity. These lead to a variation of demand for transport services and subsequently proliferate different types of vehicles. The bottom income group mostly depends on the low cost transportation including non-motorized vehicles. The development of mass transit was limited to bus operation, which has failed to cope with the rapidly increasing demand for transportation in the metropolis. The government own public transport (bus operation) deteriorated steadily both in quality and quantity since its formation in the pre-independence era because of management and maintenance problems. The private sector bus operators also were unable to provide required public transport facilities due to fragmentation of ownership, lack of coordinated control, poor maintenance, traffic congestion, and excessive overcrowding etc. causing undue wear and tear and premature failure *(Faiz, 1996).*

In order to meet growing transport demand of the middle-income and low-income group of the metropolis, both motorized and non-motorized Para transit as an inevitable alternative proliferated in the city. Auto-rickshaw, two-stroke three-wheeler, with seating capacity of 3 passengers rapidly expanded in 1980s and Tempo with 8-10 seating capacity came into operation in the latter half of the decade. In the first half of 1990s, Tempo mode expanded rapidly at the rate of more than 100 percent per annum and the expansion of the three-wheeler Auto-rickshaw operation become slower. With further growth of population including floating population and sprawling of the city with increased commercial activities and growth of secondary and tertiary industries, the demand for transport was accelerating at a very high rate while the public transport system (bus operation) could hardly be developed. In this context, para-transit penetrated deeply and quickly in the public transport system. A convoy of small passenger vehicles, four-stroke four-wheeler, with passenger capacity ranging from 10 to 15 started coming in operation from the beginning of the last decade.

The economically well off city dwellers have their own vehicles including car, jeep, station wagon, microbus as means of their transportation. It is revealed from the transport registration department that on an average about 5000 cars and 1600 microbuses per annum are entering into city. There is a declining trend of registration of Auto-rickshaw and Tempo in the metropolis due to discouraging policy of the government. Table 2 presents annual registration of different vehicles in the metropolis *(Mahadi, 2013).*

Table 2.15 Modes of transport in Bangladesh

Sectors	%
Road	60
Waterways	14
Railways	12
Airways	<0.5

Source: BRTA, 2012.

Table 2.16 Number of Registered vehicles in Dhaka city.

Upto2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
303215	21471	26779	33963	36942	48137	56778	61578	69587	81457

Source: BRTA, 2012.

Table 2.17 Number of Registered vehicles in Bangladesh.

Upto 2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
73740	49202	65818	80306	121272	144419	150213	161254	169457	188467

Source: BRTA, 2012.

Table 2.18 Contribution of vehicles to pollution in Dhaka city

Toxic gases	Cars (%)	Bus/Truks(%)		Auto-Richshaw(%)		Others (%)
CO	65	12		22		5
HC	35	6		50		10
Nox	12	85		7		2
PM	15	45		42		4

Source: BRTA, 2012.

2.12.1Contribution of urban transport system to Dhaka's air pollution

Air pollution in Dhaka is serious due to increasing population and associated motorization. Although existing air quality monitoring data is limited, it has been clearly shown that the average ambient concentrations of suspended particulate matter (SPM) and airborne lead are higher than the Bangladesh national ambient air quality standards and much higher than the WHO guidelines. The city's average SPM levels are about 2 times higher than the Bangladeshi standard of 200 µg/m^3 in residential areas and are more than 10 times higher than the WHO guidelines of 120 µg/m3 (24hours) in commercial areas. Lead levels are also high compared to other cities in the world. Although there is a lack of time-series data, the ambient air quality measurements available for 1990 and 1996 onward indicate that the air pollution is worsening *(Mahadi, 2013).*

2.12.2 Diesel vehicles found causing 80 percent of air pollution in city

Diesel-run vehicles account for more than 80 per cent of the air pollution in Dhaka as most of them fail to comply with the approved emission standard, said a recently published survey report.

About 60 per cent of the city dwellers consider motor vehicles as the main source of air pollution, about 55 per cent consider diesel-run buses to be most polluting the air and 22 per cent feel that diesel-run trucks cause the air pollution (*Mahadi, 2013).*

Nearly 60 per cent of the dwellers said they contract diseases because of air pollution and 88 per cent believed smoke and dust are the most important air pollutants. The public perception of air pollution was revealed in the survey, Stakeholders Perception on Air Pollution by Diesel Vehicles in Dhaka City, conducted by the Air Quality Management Project of the Department of Environment and the World Bank.

The air quality project director, Mohammad Nasiruddin, said in 2004, they conducted a study, Roadside Vehicle Emission Testing Programme in Dhaka, where they surveyed 2,140 vehicles of all types to identify the principal contributors to air pollution.' At the end of the study, we found 90 percent of human haulers followed by 60 percent diesel-run minibus have failed to comply with the approved emission standard, as their smoke capacity is higher than 80 Hart ridge Smoke Units (HSU),' he said, The study suggested asset of recommendations that included retirement of old-technology vehicles following a time-bound road map, introduction of low sulphur diesel, imposition of a total ban on the import of all types of old vehicles and switchover to natural gas as the main source of transport fuel. The visible signs of

ambient air quality of Dhaka are indicating an upward trend in gross emissions in recent years. Motor vehicles, especially the two strokes engine vehicles (TSEV) are responsible for the increase in emissions of both local pollutants and green house gases due to the rapid growth in the number and use of motor vehicles. Data shows that number of registered vehicles in Dhaka has grown by 60% from 1990 to 1996.TSEVs have outgrown all other types of vehicles. The following table shows the vehicle population by type, utilization, and fuel economy *(Mahadi, 2013*).

Table 2.19: Vehicle population, utilization, and fuel economy in Dhaka, 1996.

	Vehicle Population	Annual Utilization (km/yr)	Total Annual Vehicles kms (millions)	Fuel economy (km/l)
Cars & Taxis	42,000	19,200	806.4	8.0
Jeep, Station Wagon, Micro Bus	12,000	19,200	230.4	8.0
Diesel bus	4,000	57,600	230.4	4.8
Diesel Truck	5,000	64,000	320.0	2.4
3-wheeler Vehicle	14,500	38,400	556.8	2.4
2-wheeler Vehicle	73,500	10,000	735.0	35.0

Source: EEC, 1996.

Initial estimates reveal that motor vehicles annually emit 3,700 tons of particulate matters (PM10), 8,550 tons of nitrogen oxides, 50,700 tons of carbon dioxide, etc. TSEVs (mainly 3-wheeler baby taxis) are the significant contributors.

Table 2.20: Baseline vehicular emissions inventory in Dhaka, 1996; Unit: 1,000 tons.

	Particulate matter (PM10)	Hydrocarbons	Carbon Monoxide	Nitrogen oxides	Lead	Carbon dioxide	Methane
Light duty vehicles	0.26	3.70	24.91	1.63	0.012	309	0.04
Mini bus	0.21	0.12	0.30	0.58	0.003	115	0.02
Diesel bus	0.64	0.42	1.40	2.65	0	324	0.02
Diesel truck	1.11	0.74	1.91	3.61	0	563	0.03
3-wheeler	0.93	13.52	16.37	0.07	0.011	147	0.19
2-wheeler	0.55	3.31	5.81	0.02	0.011	50	0.11
Total	3.70	21.80	50.70	8.55	0.037	1507	0.40

Source: EEC, 1996.

Two strokes engine baby taxis pollute intensively in terms of per vehicle per kilometre driven. A typical baby taxi is driven 100-120 kms. per day. Thus, in 360 days of a year, Dhaka's 30,000 strong baby taxis (<17% of total vehicles) are responsible for 25% of total vehicular PM10, 62% of hydrocarbons, and 32% of carbon mono oxide. The health related economic cost is US$ 360 per vehicle per year. The transport sector is an increasingly important Green House Gas (GHG) contributor. Bangladesh emitted 20million tons of carbon dioxide in 1995 *(IEA, 1995)*. But, public health impact of transport system is more compared to its impact on global warming.

Table 2.21: Motorized Vehicles by Type on Road in Greater Dhaka.

Year	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Annual Growth (%)
Type													
Motor Car	16557	17997	19563	21265	22966	24806	26376	28486	30764	33225	35883	38753	8
Jeep + Station Wagon + Microbus	8943	9732	10590	11525	12446	13442	14336	15501	16761	18123	19604	21211	8.1
Taxi	1053	1145	1219	1297	1375	1457	1531	1623	1720	1824	1934	2059	6
Bus	3525	3751	4078	4257	4470	4693	4792	4993	5202	5426	5670	5936	4.2
Minibus	2354	2585	2838	3116	3428	3771	3946	4297	4682	5103	5562	6063	8.9
Truck	7157	7590	8049	8536	9048	9591	9961	10518	11107	11729	12385	13252	5.7
Auto-Rickshaw	6959	8092	9410	10943	14849	15815	18744	20895	23506	26561	30279	34820	14
Motor Cycle	13306	15121	17184	19528	21676	24060	26058	29184	30143	34664	39343	45637	12
Others	667	690	713	737	770	789	804	832	861	895	939	985	3.2
Total	60521	66703	73644	81203	91028	98424	106548	116329	124746	137550	151599	168716	8.6

Source: BRTA, 2001.

Table 2.22: Motor Vehicles Registered in Dhaka city are presented bellow from 1995 to 2001.

Types of Vehicles	1995	1996	1997	1998	1999	2000	2001	Total
Motor Car	6,923	8,386	6,528	4,984	4,330	3,153	3,468	37,772
Auto Rickshaw/Auto Tempo	7,301	4,615	1,902	1,689	682	258	54	16,501
Jeep/St. wagon/Micro Bus	1,556	1,387	1,492	1,438	1,371	1,912	2,053	11,209
Human Hauller, Microbus (rental)	46	15	105	175	198	278	336	1,153

Bus	145	73	58	184	224	309	439	1,432
Truck	802	615	834	1,681	855	525	547	5,859
Others	878	828	310	196	1,392	74	2,078	5,756
Total	17,651	15,919	11,229	10,347	9,052	6,509	8,975	79,682

Source: BRTA, 2006.

2.12.3 Consumption of Fuels

A survey on fuel consumption by the small passenger vehicles operating in the Dhaka city has been carried out during the month of June and July 2002 by South North project. The survey has been carried out on 171 small passenger vehicles having different brand names such as Tempo, Maxi, Navana, Laguna etc., with different seating capacities ranging from 12 to 16 passengers (*Azad, 2005).* The survey result revealed that some of the small passenger vehicles are gasoline driven and some are diesel driven. The average fuel consumption per kilometre varies with the types of vehicles ranging from 4.5 to 9.0 km/litre. Apart from the engine and seating capacity the variation in fuel consumption varies due to poor maintenance and variation of traffic congestion with respect to route. Table 3 and 4 presents energy consumption by type of vehicles.

Table: 2.23. Average Fuel Consumption by Type of Vehicles

Brand Name of Small Passenger Vehicles	Average Consumption of Fuel (litre/day)	Type of Fuel (litre/day)			Average Travel Distance (Km/day)	AverageTravel Distance (Km/litre)
		Average Consumption of Petrol	Average Consumption of Diesel	Average Consumption of Octane		
Tempo	16.06	15.57	0.49	-	116	7.22
Maxi	30.17	-	30.17	-	233	7.72
Suzuki	21.57	9.46	-	12.11	197	9.13
Emma	21.48	10.85	-	10.63	166	7.73
Leguna	25.33	12.79	-	12.54	203	8.01
Navana	28.5	-	28.5	-	215	7.54
Goti	21.09	-	21.09	-	159	7.54
Niloy	11.57	-	11.57	-	51	4.41

Source: SSN, 2002.

2.12.4 Vehicular Pollution

Fossil fuel consumption by the road transport sector in Bangladesh shows an increasing trend, with the increase of greenhouse emission. It is found that greenhouse gas emission of the road transport sector has increased on an average 8 per cent per annum from 1995 to 2000. The total greenhouse gas emission of the road transport sector was about 2845 Gg CO_2 equivalent and 4050 Gg CO_2 equivalent in 1995 and 2000 respectively (*DOE, 2002).*About 80 percent of car, jeep and station wagon of Bangladesh ply in the Dhaka metropolis. About 60 percent of total auto-rickshaw, tempo and other small passenger vehicles are operating in the Dhaka Metropolis, which is the main mode of transport for low-income and middle-income group. Percentage of different vehicles as Bangladesh total has been provided below:

Table 2.24: Vehicles of Dhaka as percentage of Bangladesh Total

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Car/Jeep/St. Wagon	84	80	80	80	80	80	79
Auto rickshaw/Tempo/Others	63	67	63	61	60	57	57
Buses and Minibus	29	31	30	30	30	30	28

Source: BRTA 2006.

Due to rapid and unplanned urbanization the total number of vehicles has increased enormously. Most of the cars, jeeps, auto-rickshaws, motorcycles, etc., ply in the cities. This has really led to a deterioration of air quality. Although the percentage of two stroke auto-rickshaws is around 8%, some recent studies have shown that they contribute around 40% of PM10 and 50% of hydrocarbon (HC) in Dhaka City. The second largest polluters are trucks and buses, although they constitute only 10% of the total automotive vehicles in Dhaka. These cause about 44% of the PM10 pollution (*UNEP, 2001).*

2.12.5 Traffic Congestion

Traffic congestion in the metropolis is getting worse due to increased density of motorized and non-motorized vehicles, poor management of traffic, operation of different types and speed vehicles in the same road, narrow road infrastructure etc. Moreover, the sprawling of the city along with the construction of high-rise commercial and residential buildings took place in an unplanned way paying little consideration to the transport need *(Azad, 2005)*

Fig. 2.8: Traffic congestion in the metropolis.

One basic weakness of the traffic system of the city is poor traffic behaviour of the road users. The tendency to violate traffic rules is high among them. All types of road users have varying degrees of involvement in traffic offences, which impede traffic movement and thus create traffic congestion and healthy growth of traffic system. Some common examples are rush and careless driving, wrong and illegal parking practices, unauthorized encroachments on the road and sidewalks etc *(DOE, 2012).*

2.13: Air pollution making Dhaka city inhospitable

The volume of poisonous particles in the city air has reached far beyond the permissible level for human body in recent years.

The Dhaka city dwellers are always at a serious health risk due to the highly polluted air, warned health experts.

The increasingly high concentration of toxic elements in the air is causing a foggy blanket in the city sky at present, according to the experts of Air Quality Management Project (AQMP) under the Department of Environment (DoE).

The AQMP, which has been monitoring the air quality of the city since 2002, has recently launched a website to inform the people about the air quality on daily basis.

The website reveals that the air quality of the city is lethal for human body especially during winter and post winter.

The AQMP advised the city dwellers to stay indoors as much as possible during this time to avoid health hazards from the pollution.

According to the website, poisonous carbon monoxide, sulphur dioxide, nitrogen dioxide, suspended particulate matter (PM-10) and particulate matter (PM-2.5) exist in Dhaka's air beyond permissible level for human body.

Due to increase of PM-10 and PM-2.5, people lose lung function and suffer from chronic respiratory and cardiovascular diseases while nitrogen dioxide increase risks of bronchitis and pneumonia. Nitrogen dioxide causes respiratory infection.

Carbon monoxide reduces delivery of oxygen into the human body, creates severe headache and decreases visual perception and manual dexterity.

Permissible limit of PM-10 is 65 micrograms per cubic metre and for PM-2.5 it is 150micrograms per cubic metre.

The implementation of the ban on two-stroke three-wheelers in 2003 made some temporary progress in reducing toxic elements from the air but has been marred by the functioning of old motorized vehicles and the brick kilns around the city.

Faulty vehicles are the largest source of air pollution. Only the diesel-run vehicles contribute about 60 per cent of such particles in the air, surveys of the AQMP revealed.

At least 70 per cent of the diesel-run vehicles, mainly buses and trucks, are emitting toxic particles beyond the permissible limit. Brick kilns in the northern edge of the city contribute at least 20 per cent to the air pollution.

There are 4,000 brick kilns around the city, which use tyres, wood and low-quality coal, emitting poisonous particles into the air. But no initiative has been taken yet to measure quantity of poisonous particles emitting from brick kilns.

The chimneys of the brick kilns made higher than 120-feet is not a solution to reducing the air pollution, said the AQMP officials.

The government banned running of buses more than 20 years old in the city but failed to keep those vehicles out of the city.

The height of brick kiln chimneys has been increased to reduce air pollution but the initiative failed as the government failed to ensure quality of fuel used in the kilns (*Mahadi, M., 2014).*

2.13.1 Air pollution in developing countries

Limited resources for the development of transport facilities, coupled with the rapid rise in transport demand, existence of a huge number of non-motorized vehicles on roads, lack of application of adequate and proper traffic management schemes are producing severe transport problems in the developing countries. In mega cities in many developing countries due to rise in motor vehicle air quality has deteriorated and has severe effects human health and mortality. Acute respiratory disease is responsible for some 4 million deaths a year of children under five in developing countries, second only to infant diarrhoea in its impact on mortality. There are countries such as Bangladesh, where leaded gasoline is the only alternative. The lead in exhaust fumes may be inhaled directly or may settle on food, water, or any items that are put in the mouth, can cause mental retardation, learning disabilities in children. High blood pressure in adults was found to be correlated with high levels of lead in the blood. The major source of this wide spread contamination was leaded gasoline. Many countries have elimination of leaded gasoline and the concentration of lead in the environment has dramatically reduced.

Emissions of pollutants in Mexico city, hourly ozone, levels of 600 mgm-3, SO_2 levels 80-200 mgm-3, suspended particulate matter 100-500 mgm-3 all exceed the WHO recommended level *(WHO, 2006).*

2.13.2: Pollutants in developed and developing countries

In developed countries, governments have fought for clean air by regulating all major and many minor sources of air pollution. Industrial emissions have been significantly reduced. As a result of new motor vehicle emission standards introduced in 1988, new vehicles in developed nations are 90% cleaner than those manufactured in the 1970s. Despite those substantial efforts, we continue to be plagued with air pollution problems. For developing nations, however, pollution severity occur due to the high content of lead in gasoline, big number of high polluting vehicles, impure fuel, inefficient land use, and overall poor traffic

management *(Karim et. al., 1997*). Even though the pollutants regulated by developed and developing nations should differ, it is possible to make gross generalizations. The pollutants of concern for developed countries would be volatile organic compounds, nitrogen oxides, and carbon monoxide; whereas leaded fuel, particulate matter, dust and sulphur dioxide would be targeted by developing nations.

2.13.3: The Quality of Air in World Megacities

Results of the WHO / UNEP study of megacities show that the most severe air pollution is monitored in cities in developing countries, but that air pollution is a widespread problem in megacities with at least one major air pollutant exceeding health guidelines in all of the 20 megacities studied.

2.25: Air Quality in 20 Megacities

Megacity	Country	Population in 2000 (million)	Ranking (population)	SO_2	SPM	Lead	CO	NO_2	O_3
Bangkok	Thailand	10.26	19	*	***	**	*	*	*
Beijing	China	11.47	16	***	***	*	-	*	**
Bombay	India	15.43	6	*	***	*	*	*	-
Buenos Aires	Argentina	13.05	9	-	**	*	-	-	-
Cairo	Egypt	11.77	13	-	***	***	**	-	-
Calcutta	India	15.94	5	*	***	*	-	*	-
Delhi	India	12.77	12	*	***	*	*	*	-
Jakarta	Indonesia	13.23	8	*	***	**	**	*	**
Karachi	Pakistan	11.57	14	*	***	***	-	-	-
London	UK	10.79	18	*	*	*	**	*	*
Los Angeles	USA	10.91	17	*	**	*	**	**	***
Manila	Philippines	11.48	15	*	***	**	-	-	-
Mexico City	Mexico	24.44	1	***	***	**	***	**	***
Moscow	Russia	10.11	20	-	**	*	**	**	-
New York	USA	16.10	4	*	*	*	**	*	**
Rio de Janeiro	Brazil	13.00	10	**	**	*	*	-	-
Sâo	Brazil	23.60	2	*	**	*	**	**	***

Paulo									
Seoul	S. Korea	12.97	11	***	***	*	*	*	*
Shanghai	China	14.69	7	**	***	-	-	-	-
Tokyo	Japan	21.32	3	*	*	-	*	*	***

*** Serious problem, WHO guidelines exceeded by more than a factor of two.

** Moderate to heavy pollution, WHO guidelines exceeded by up to a factor of two (Short term guidelines exceeded on a regular basis at certain locations)

* Low pollution, WHO guidelines are normally met. (short term guidelines may be exceeded occasionally)

- No data available or insufficient data for assessment.

Source: WHO, UNEP, 1992.

2.13.4 Status of Air Quality in Dhaka

Economic, industrial and demographic growths are driving urbanization in Bangladesh as it is in the other developing countries. Emergence of urban conurbation of extremely high population density is affecting the quality of life in many different ways. Uncontrolled emissions from motor vehicles and other economic activities give rise to air and other forms of pollution. High levels of emission of air pollutants in a small area exceed the processes of dilution and dispersal, leading to severe episodes of ambient air pollution *(Biswas et. al., 2004)*. The worst affected areas in Dhaka city include: Hatkhola, Manik Mia Avenue, Tejgaon, Farmgate, Motijheel, Lalmatia, and Mohakhali. Surveys conducted between January 1990 and December 1999 showed that the concentration of suspended particles goes up to as high as 3,000 $\mu g/m^3$ although the allowable limit is 400$\mu g/m^3$. The sulphur dioxidein the air near Farmgate was found to be 385 $\mu g/m^3$, where as the maximum permissible limit is 100 micrograms per cubic meter. Similarly, in the Tejgaon Industrial Area the maximum concentration of suspended particles was 1,849$\mu g/m^3$ as opposed to the allowable limit of 500$\mu g/m^3$. Usually the maximum concentration of air pollution in Dhaka is during the dry months of December to March. Dust pollution is causing many respiratory diseases, including asthma. Recently, 200 organic compounds are detected by analyzing four air samples collected from the Shewrapara area of the city. As far as the VOC is concerned the following worst affected areas are identified: Hatkhola, Manik Mian Avenue, Tejgaon, Farm Gate, Motijheel, Lalmatia, and the inter-district bus terminals. Surveys conducted between December 1996 and June 1997 showed that the concentration of suspended particles went up to as high as 2,465 $\mu g/m^3$ as against the allowable

limit of 400 µg/m^3 at Farm gate. In Tejgaon Industrial Area, on the other hand, the maximum concentration of suspended particles was 630 micrograms as against the allowable limit of 500 µg/m^3 *(Mahadi, 2010).*

Following rapid industrialization the environmental scenario in Bangladesh changed dramatically. The Ministry of Environment and Forest and the Department of Environment were created in 1989 and the Environment Policy of 1992 was introduced.

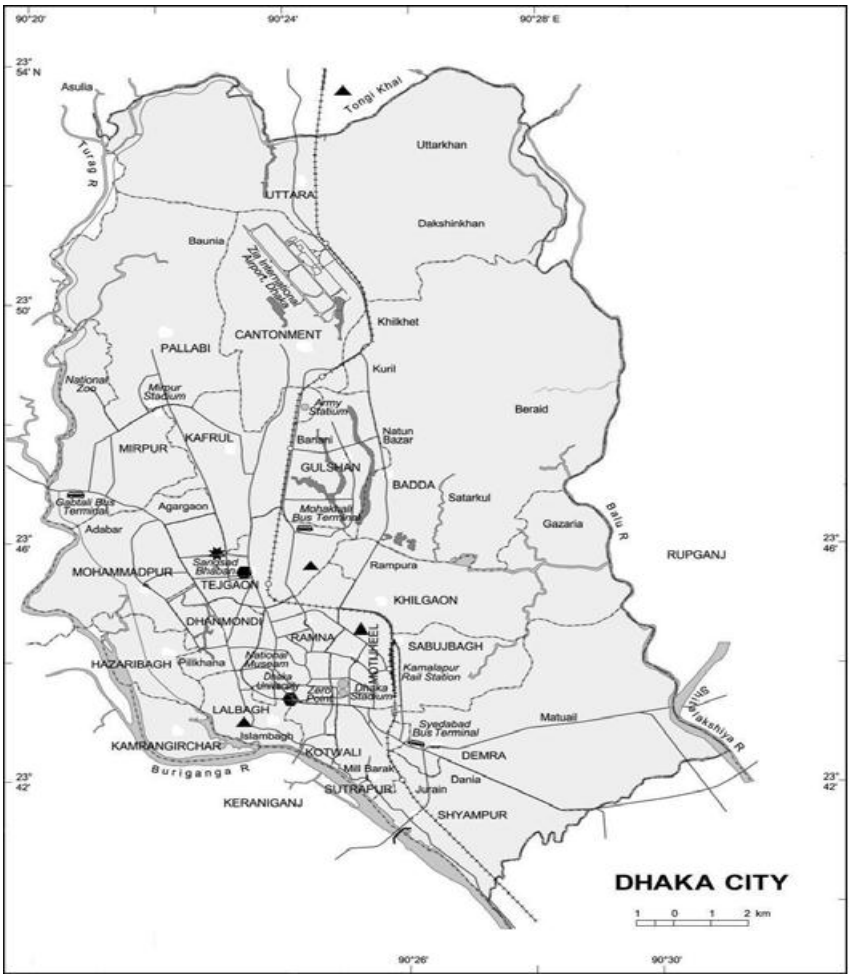


Fig. 2.9: Map of Dhaka City.

Further, the Environmental Conservation Act, 1995, and the Environment Conservation Rules, 1997, were approved by the Bangladesh National Assembly to restrict and mitigate ever-growing environmental problems in the country. The main pollutant of concern in Dhaka is particulate matter. Both PM10 and PM2.5 levels are extremely high, being much above the proposed standard. The NO_2 levels are also now close to the limit and may become a concern in the future. The levels of other

pollutants are still low and thus are not important from health point of view. Lead (Pb) concentration is not shown in the table. The Pb level is now sufficiently low (i.e., around 100 ng/m3) and therefore airborne lead is no longer considered a health issue (*Biswas et. al, 2003).* However, blood lead levels in children are still high (Kaiser et al, 2001) indicating that other sources of lead may exist. Investigation using the receptor-modelling approach to identify sources of particulate air pollution has been reported (*Begum, et. al., 2005*). Seven components have been found in the coarse PM (PM2.2-10µ) and six components have been found in the fine (PM2.2µ) particulate matter. The major sources are motor vehicle emission, re-suspended, road dust, biomass burning, and construction and fugitive sources. The fugitive sources probably include industrial emissions. In the PM2.2 fraction about 50% of the contributions come from motor vehicles. The economic valuation of the air pollution revealed that between US$ 121 to 353 million per year (2003 estimate) can be saved in Dhaka as health cost if the PM10 pollution level is reduced by a modest 20% of the current level and to the proposed national standard *(Khan, 2005*).

The absolute number of motorized 3-4 wheel vehicles plying on the city street is not large, being only about two hundred thousand. However, the emissions from the vehicles are substantial due to low technology of the vehicle fleet, weak maintenance culture, overloading and over-fuelling of heavy duty vehicles among other causes. Most of the private operator fleets consist of highly polluting old vehicles. These transport companies have limited resources for operation and maintenance. Poor maintenance coupled with poor fuel quality, congestion and poor transport infrastructure exacerbate the vehicular air pollution in the city. As pointed out earlier, the main pollutants of concern in Dhaka are the particulate matter and motor vehicles are major contributors to PM pollution. Most of the vehicular PM pollution (> 80%) comes from the diesel vehicles in Dhaka. This is also the situation for NOx and SO_2. Thus major policy decisions in respect of diesel vehicle pollution control are imperative. The gasoline vehicles contribute more to CO and HC pollution. The ambient concentrations of these pollutants are still low and thus gasoline vehicle pollution management is not yet a major issue. The major gain in PM pollution reduction from the baby-taxi ban in January 2003 is being progressively lost due to increasing pollution from diesel vehicles (*Mehedi, 2011*). However, the government has taken several initiatives and policy decisions to update the existing environmental acts, rules and regulations for environmental improvement in general and air quality improvement in particular.

Dhaka has rapidly grown into a busy city of more than 10 million people with an area of 815 km2. Dhaka has extremely serious air pollution, which has increased with the growth of the population, traffic and employment in industry. Economic benefit of transport in Dhaka are well recognized, but the negative and environmental effects caused by accidents, air pollution and noise are most severe and are not truly

realised. Dhaka city has heterogeneous traffic flows. A substantial part of total traffic is non-motorised vehicles enhance severe congestion and pollution problem. It is estimated that the popular two stroke engine, baby-taxi, though suitable for Dhaka city due to its small size, emit 30 times more pollution than normal cars (*Karim, 1997).* According to preliminary evaluation the daily total emissions are estimated using the daily fuel consumption and total traffic flows in Dhaka city.

Estimated daily emissions are 42, 39, 314, 14, and 42 tons/day for NOx, HC, CO, PM, and SOx, respectively (*Karim et. al., 1997*). High share of SOx emissions from automobiles is due to the high content of sulphur in petroleum products and extensive use of diesel. Bangladesh has the highest lead pollution in the world for a part of the year, according to the observations of the scientists at the Bangladesh Atomic Energy Commission, BAEC, BAEC scientists detected 463 monogram of lead in air over Dhaka, during the dry months. In Bangladesh, all vehicles use leaded fuel because the country's only refinery is not able to produce lead-free fuel. A study on emission source inventory performed in winter 1995 at Dhaka estimated total emissions for SO_2 and NO_2 to values 70 and 72 ton/day, respectively (*Azad and Kitada, 1996*). A recent study to estimate yearly emission of pollutants found that in the year 1996 a total of 59770 t of CO, 27119 t of HC, 5902 t of NOx, 5133 t of PM, and 1680 t of SO_2 emitted from automobiles in Dhaka City (*Khan, 2007).* At the moment, there are very limited data that describe the current and historic situation of air quality in the cities in Bangladesh. This makes it difficult to develop an appropriate air quality monitoring system and to define mitigation measures for zones of high air pollution. There are no detail air quality regulations based on which Environmental Impact Assessment could be done.

2.13.5 Causes for air pollution in Dhaka city

1. Motor vehicle emission is the major cause for air pollution around Dhaka. As per Bangladesh Road Transport Authority law, trucks, buses and minibuses that are older than 10 years are not allowed to be driven in the city limit. However, BRTA estimates that there are presently 13,778 such buses and trucks plying the streets of the capital out of 5,62,851 registered vehicles while 80,615, including private car, bus and trucks, have no fitness certificates. According to a report published by International Fuel Quality Center, the sulfur level in diesel sold in Bangladesh is well over 1000 PPM, whereas sulfur level in diesel sold in the USA is 15 PPM (The appendix shows the sulfur in diesel for various countries). Most of the sulfur in fossil fuel is converted to sulfur dioxide, but a small amount is also converted to sulfuric acid. In the atmosphere, gaseous sulfur dioxide can also be converted to sulfuric acid and sulfate-containing particles. Thus, atmospheric concentrations of sulfur dioxide

are often highly associated with acidic particles, sulfuric acid particles and sulfate particle concentrations. Sulfur dioxide is a very water-soluble gas; and therefore, most of the sulfur dioxide that is inhaled is absorbed in the upper respiratory tract and does not reach the lung's airways. However, the small amount of sulfur dioxide that does penetrate into the airways can provoke important health effects, primarily in individuals with asthma. Burning fuel with higher level of nitrogen yields toxic nitrous oxides. Motor vehicle emissions are throwing about 4 thousand tons of fine particles into the atmosphere of Dhaka City every year causing serious health effects *(Mehedi, 2010).* Motor vehicle emission is also the major cause for green house gases around Dhaka. Gases that trap heat in the atmosphere are often called greenhouse gases. The principal greenhouse gases that enter the atmosphere because of human activities are:

Carbon Dioxide (CO_2): Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions and industrial emissions. At the same time carbon dioxide is also removed from the atmosphere when it is absorbed by plants as part of the biological carbon cycle.

Methane (CH_4): Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills.

Nitrous Oxide (N_2O): Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

Fluorinated Gases: Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes.

2. The other major source of toxic gases in Dhaka is burning bricks in and around the city. Very low quality coal with high sulfur content is used to burn bricks in the open atmosphere resulting in large amount of toxic gas production. Modern closed burning system can be adopted for brick production to reduce air pollution in Dhaka.

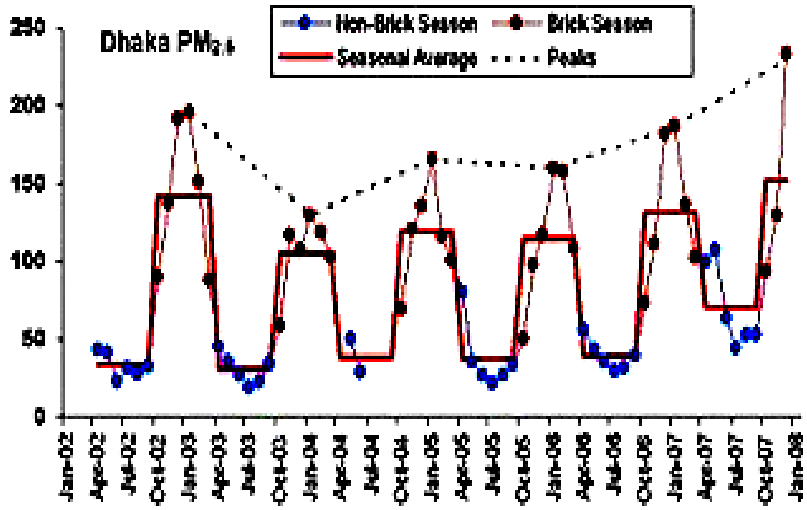


Fig.2.10: Monthly average PM2.5 measurements in Dhaka city (*Guttikunda, 2009).*

3. There are many industries in and around Dhaka polluting the air. Though there is a law to control industrial emissions, it is not enforced. So, toxic gases are thrown into the air in and around Dhaka through these industries.

4. Municipal waste is dumped at various spots around the city in open areas. This waste generates toxic gases like carbon dioxide, methane and nitrous oxide.

5. There are still many open toilets in and around the city producing gases like methane and nitrous oxide.

6. Reduced watershed around the Dhaka city is a factor for increased carbon dioxide, because water body reduces carbon dioxide through absorption.

7. We have seen deforestation around Dhaka City through housing construction and other developments that is one of the contributing factors for air pollution.

2.13.6 Control of air pollution

The approaches to combat air pollution can be divided into three categories:

1. Source control.

2. Enforcement of regulations and

3. Public awareness building.

2.13.6.1 Source Control

1. Reduction of sulfur content in diesel would be a major step in source control.

2. Installation of catalytic converter in all types of vehicles would reduce toxic emissions.

3. Reduction of nitrogen in diesel and gasoline would help reduce NO_2.

4. Developing mass transit system would help reduce motor vehicles in Dhaka.

5. Modern closed burning system can be adopted for brick production.

6. Modern closed waste management system needs to be adopted for municipal waste.

7. The toxic waste from industries can be controlled through installation of scrubbers.

8. The dust from numerous construction sites should be controlled with spraying of water.

9. In an effort to comply with increasingly stringent diesel exhaust emissions standards, diesel engine manufacturers have invented a technology known as selective catalytic reduction (SCR)-a method of converting harmful diesel oxides of nitrogen emissions, by catalytic reaction, into nitrogen gas and water.

2.13.6.2 Enforcement of regulations

1. Regulation of removing older buses and trucks should be enforced.
2. All motor vehicles should be inspected yearly for emissions.

3. No motor vehicle should be allowed without fitness certificate.
4. Number of private cars should be regulated.
5. Use of cleaner fuel should be mandatory.
6. Regulation for controlling construction dust should be developed.
7. Regulation for controlling toxic industrial emission should be strictly enforced.
8. Law of conservation of water bodies needs to be enforced.
9. Uncontrolled dumping of municipal waste should be punishable offence.
10. Tree preservation law should be enforced.

2.13.6.3 Public Awareness Building

1. Media can play a vital role in building public awareness of the severe health effects of air pollution.

2. Health care professionals can build public awareness through seminars and talk shows.

3. People need to be educated of adverse effects of dumping waste.

4. Adverse effects of open toilet should be communicated to general poor people.

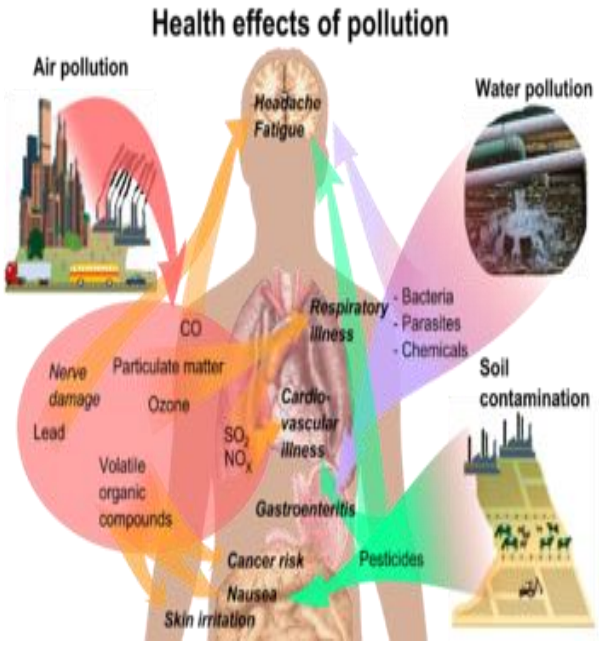


Fig. 2.11: Effects of pollutions on human health.

Source: ***WHO, 2010.***

Overview of main health effects on humans from some common types of pollution. (*Kallman et. al., 2009*). Adverse air quality can kill many organisms including humans. Ozone pollution can cause respiratory disease, cardiovascular disease, throat inflammation, chest pain, and congestion. Water pollution causes approximately 14,000 deaths per day, mostly due to contamination of drinking water by untreated sewage in developing countries. An estimated 700 million Indians have no access to a proper toilet, and 1,000 Indian children die of diarrhoeal sickness every day (*WHO, 2008*) Nearly 500 million Chinese lack access to safe drinking water 656,000 people die prematurely each year in China because of air pollution. In India, air pollution is believed to cause 527,700 fatalities a year. Studies have estimated that the number of people killed annually in the US could be over 50,000 (*David et. al., 2010*) spills can cause skin irritations and rashes. Noise pollution induces hearing loss, high blood pressure, stress, and sleep disturbance. Mercury has been linked to developmental deficits in children and neurologic symptoms. Older people are majorly exposed to diseases induced by air pollution. Those with heart or lung disorders are under additional risk. Children and infants are also at serious risk. Lead and other heavy metals have been shown to cause neurological problems. Chemical and radioactive substances can cause cancer and as birth (*WHO, 2009).*

2.13.6.4 Key Environment Issues

Nine key environmental issues have been identified by the stakeholders at the inception workshop and the national stakeholder consultation meeting. These are air, water, land, noise, solid waste management, sewage management, slums and squatters, environmental health and natural disaster. This section provides in depth analysis of each of the issues mentioned above. On top of that, air pollution is worsening. Bangladesh was ranked fourth among 91 countries with the worst urban air quality in the latest air pollution monitoring report by the World Health Organization. Data from the National Institute of Diseases of the Chest and Hospital shows that nearly seven million Bangladeshis suffer from asthma and more than half of them are children. In Dhaka alone, an estimated 15,000 premature deaths, as well as several million cases of pulmonary, respiratory and neurological illness are attributed to poor air quality, according to the Air Quality Management Project, funded by the government and the World Bank (*Haque et. al, 2014).*

2.13.6.5: Recent Policy Decision of the Government

• Introduction of Compressed Natural Gas (CNG) which has tremendously helped reduce the air pollution of Dhaka city

• Introduction of unleaded gasoline from 1st July of 1999

• Notification of lubricant standards on 1st January, 2001

• Banning of buses older than 20 years and trucks older than 25 years from 2002

• Banning of two-stroke engines three wheeler vehicles from 1st January, 2003

• Banning of imported reconditioned cars older than 5 years.

• Reduction of number of NMVs (Non- Motorized Vehicles) and by restriction of movement of such vehicles within certain areas of the city and during specific periods of the day.

• Banning of operation of commercial trucks in Dhaka city during day time (8 am to 10 pm)

Enforcement of all the environmental laws and regulations remains a major issue to be tackled in the future. Some of the policies and laws are as follows:

• Environment Conservation Act, 1995 (amended in 2000 and 2002).

• Environment Court Act, 2000 (amended in 2002).

• Environment Conservation Rules, 1997.

• Motor Vehicle Ordinance, 1983 (amended in 1988).

• Dhaka Métropolitain Police Act, 1976.

• Environnent Policy, 1992.

Besides laws, policies and guidelines, the government has taken a few other initiatives to improve and better transport and traffic management. The noteworthy initiatives are:

• Dhaka Integrated Transport Study (DITS) conducted during 1991-1992 to determine the transport status of Dhaka.

• Dhaka Transport Coordination Board (DTCB) established in 2001 to develop an innovative transport policy and guidelines for the improvement of transport status of Dhaka city.

• DTCB is currently preparing Strategic Transport Plan (STP), which will provide a long-term strategic vision for transport system in Dhaka.

• Updating and installation of new traffic signals.

• Construction of road dividers and parking facilities.

• Construction of bypasses and flyovers.

• Decision for amendment of the Motor Vehicles Ordinance, 1983 to provide serious punishment for reckless and drunk driving, illegal parking, using fake driving licenses and other transport related crimes (The Daily Star, 28 March 2005).

• Air Quality Management Program (AQMP) of the DOE is currently conducting a study on policy options to control diesel vehicle PM pollution, and

• Construction of a City Centre in Motijheel area for car parking.

3. Research Methodology

3.1. Sample collection

Atmospheric toxic gases – O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 were measured in Dhaka city, Mymensingh, Jamalpur, Chittagong, Teknaf and St. Martin Island. In these areas temperature and humidity were also recorded along with the above gases with the help of TG- 501 and TG-502 probes (Fig.3.3). These probes were activated with batteries (Duracell plus, D) and were connected with pocket PC for monitoring and storing measured data with dates, locations and time intervals. Measurements of toxic gases, temperature and humidity were carried out at 15, 30, 60 minutes and 8 hour intervals throughout the year starting from 2009 to 2011 to ascertain the air quality and assess diurnal, seasonal and yearly changes of the concentrations of O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 . The concentrations of the atmospheric toxic gases were determined at different locations of Dhaka, Mymensing, Jamalpur, Chittagong, Teknaf and St. Martin Island to see the difference among the cities and towns and areas classified as urban, semi-urban, rural, island etc. The cities were generally considered to be the most polluted areas and thus compared with non-polluted areas. Measurements were also done at Teknaf and St. Martin's Island (Fig. 3.1).

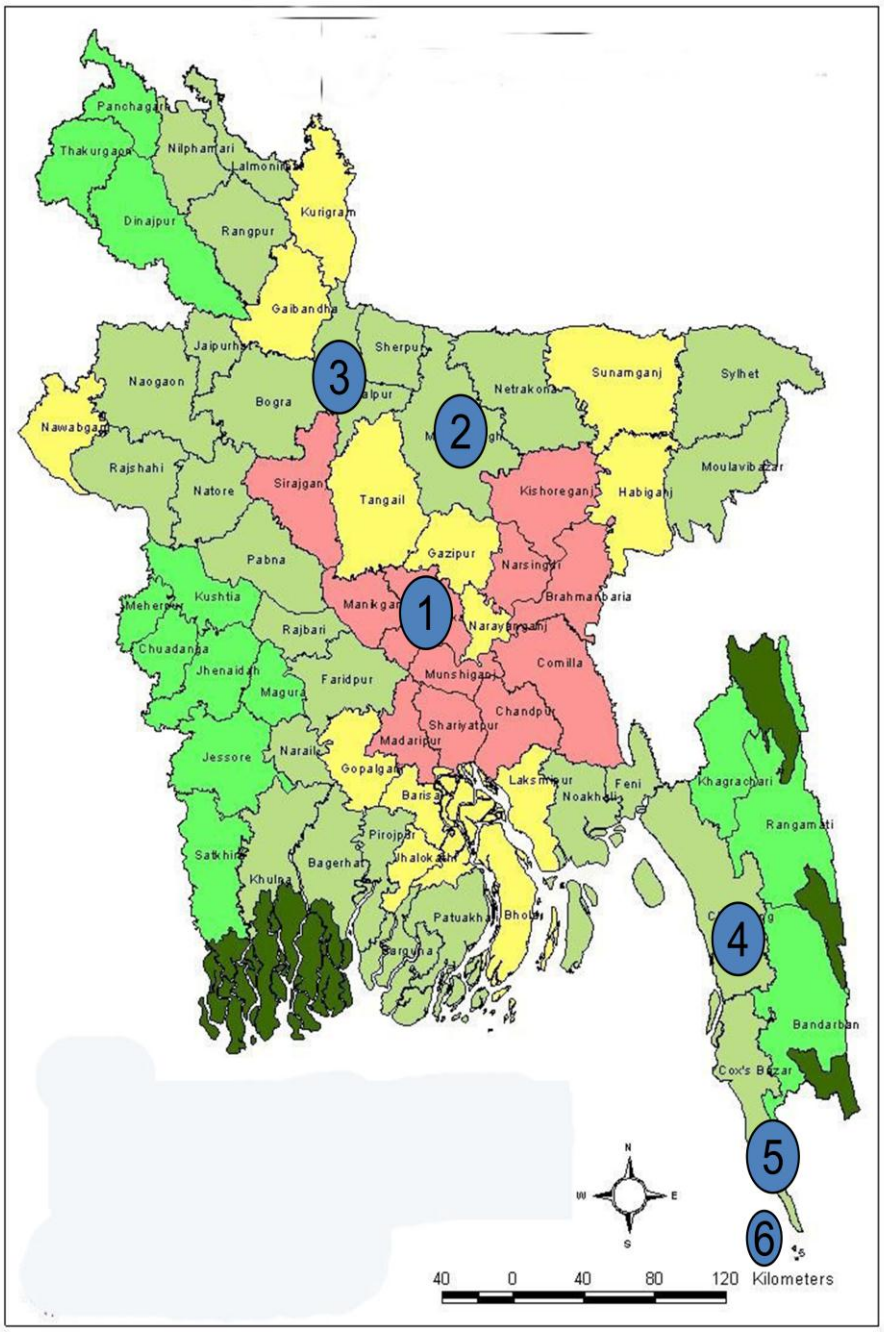


Fig. 3.1: Map of Bangladesh showing the sampling locations.

The concentrations of the atmospheric toxic gases were determined in Dhaka city at heavily, moderately and less trafficked areas and residential areas (Fig.3.2)

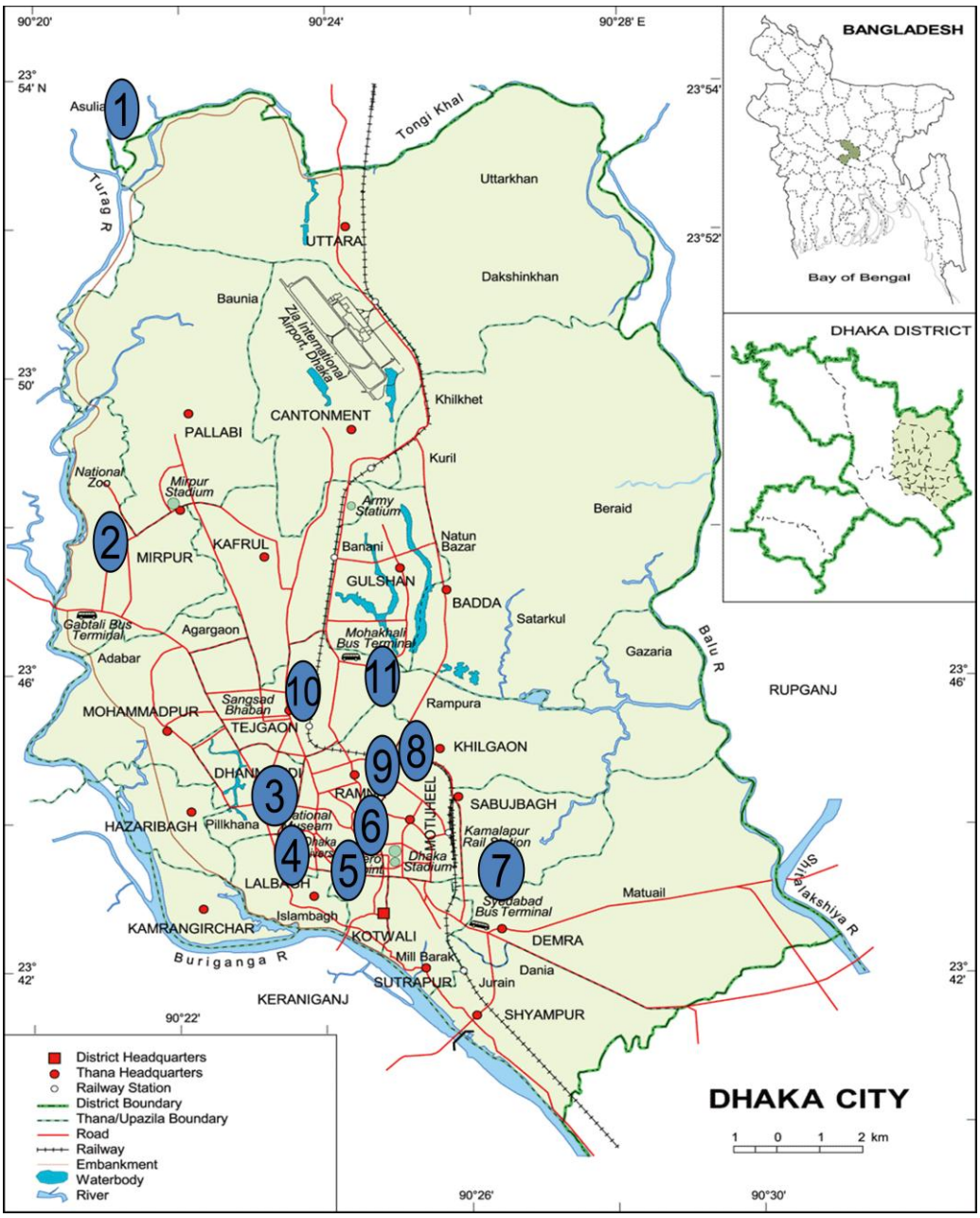


Fig. 3.2: Map of Dhaka city showing the sampling locations.

Fig. 3.3: Toxic gas (TG- 501 and TG-502 probes) monitoring equipment.

3.1.1 Effects on Crops and Plants

Effects of toxic gases on crops and plants exposed were investigated following interview with the farmers, workers and senior citizens on selected spots using a structured questionnaire (See Appendix, Ques. 4.26). These were verified and/or compared with the statements were made by the scientists or researchers in different institutes or organizations. The farmers views were the cross- matched with the toxic gas concentrations measured at the same location for the establish any link. Data on effects on crop yield like rice, vegetables, fruits etc. were collected from different locations such as Amin Bazar, Ashulia, Gazipur, Dhaka- Mymensing high-way, Dhaka-Chittagong high-way, Tangail and the unpolluted rural areas. Yield data was also collected from Kashimpur agricultural farm cultivating different crops, jack-fruits, mango, guava, banana, blackberry, papaya etc. and also from Bangladesh Agricultural Research Institute (BARI) at Joydevpur.

3.1.2 Survey on Human health

Effects on human health were investigated following interview with matured males, females at selected areas. Females, children, traffic polices, drivers and physicians at different hospitals through a structured questionnaire (See Appendix Ques. 4.27). Data were collected from the hospitals (Dhaka Medical College hospital, Community hospital, Holy family hospital, Apollo hospital etc). The data collected from traffic police, drivers, children, males, females, city dwellers were verified and/or compared with the statements were made by the doctors or physicians. People are reported to be suffering from eye-irritations, skin problem, respiration problems, bronchitis, asthma, inhalation, lung- cancer and other pulmonary diseases due to the emission of vehicular and industrial toxic gases.

3.2. Sampling Period

Meteorologically, the year of Bangladesh is divided into four seasons, pre-monsoon (March–May), Monsoon (June-September), post-monsoon (October-November) and winter (December-February). Toxic gases were collected in the months of January to December in 2009-2011. During the sampling period, the average temperature varied from 20^0C -31^0C. Moderately higher temperatures 31 ^{0}C were observed in the afternoon. Sunny days, rainy days, cloudy days, fogy days were observed during the investigations (*BMD, 2011).*

3.3. Description of the locations

Dhaka city

Dhaka is the capital of Bangladesh and one of the major cities of South Asia. Dhaka, along with its metropolitan area, had a population of over 16 million in 2011, making it the largest city in Bangladesh (Bangladesh Bureau of Statistics, 2008). It is not only the capital of Bangladesh but also the centre of commerce and industry of Bangladesh. It is located in central Bangladesh at 23°42’0”N 90°22’30”E, on the eastern banks of the Buriganga River (Fig. 3.2).

The city is congested with a large number of motor vehicles, including both public and private transportation. Moreover, construction of roads and buildings are taken place continuously throughout the city. The sampling spots were selected to reflect

different influences form mobile sources in the highly populated central part of Dhaka. The spots were Giasuddin R/S, Curzon Hall (Dhaka University Campus), Topkhana, Saidabad, Mouchak, Ramna, park, Mohakhali, Farmgate, Science lab, Amin bazaar, Ashulia in Dhaka city.

Giasuddin Residential Area

Giasuddin R/A is a part of Dhaka University and close to Newmarket and Nilkhet in the west and palashi in the south. It is located between 23º43'33.62'' N longitude and 90º24'16.43'' E latitude. It is close to National Sahid Minar from the east and a quarter km away from Shahbag. The area has the influence of vehicles. Buses, auto rickshaws, tempos, cars and other types of motor vehicles. Motor vehicles passing through the roads for almost twenty-four hours.

Curzon hall

The location of the sampling site was Curzon Hall which is a part of the school of science of the University of Dhaka. It is located between 23º43'33.62'' N longitude and 90º24'16.43'' E latitude. Dwell Chattar is in front of the Curzon Hall. Bangladesh Shishu Academy is straightforward to Curzon Hall. Motsho Bhaban and Press club are in the right corner of this place. It is only about 500 yards close to Chankharpul from the east and a quarter km away from Shahbag. Although too much vehicles are not allowed in this place but three roads beside the Curzon Hall are running to press club, Chankharpul and Bangabazar have moderate load of vehicles. Buses, auto rickshaws, tempos, cars and other types of motor vehicles pass through these roads for almost twenty-four hours.

Science lab

The sampling site was Science lab, located between 23º44'47.27'' N latitude and 90º22'33.64'' E longitude. It has been traditionally known as a residential area. However, nowadays it is more of a commercial area than a residential area. The increasing number of commercial establishments, such as schools, universities, hospitals, restaurants and shopping centres has given rise to a tremendous amount of traffic congestion, especially during the mornings and afternoons. Different types of vehicles such as cars, auto rickshaws, buses, mini-buses and other types of motor vehicles pass through the roads of Science lab.

Farm gate

Farm gate an important place of Dhaka was the sampling site. It is located between 23º45'21.99'' N longitudes and 90º23'13.91'' E latitude. This is one of the busiest and most crowded areas of Dhaka city. From the early 1990s, the area has seen massive building and construction boom. Consequently, the area has got commercial importance and nowadays it has become one of the major transportation hubs of Dhaka from where anyone can travel all other parts of the city as well as throughout the country. Today Farm gate has become a more commercial area than a residential area. Neighbouring places of Farmgate are Kawran Bazar, Pantapath, National Parliament, Rajabazar etc. As a transportation hub of Dhaka, the area is most often remains crowded and thousands of cars, rickshaws, minibus, bus, trucks remain stranded for even hours in the roads and streets of Farm gate.

Mohakhali

The sampling site was Mohakhali. It is an important and busy area of Dhaka city. It is located between 23º46'39.46'' N longitudes and 90º24'19.62'' E latitude. Many important offices and institutions are based in Mohakhali. Mohakhali Bus terminal is one of the most important terminals of Dhaka city. Every day thousands of people, particularly from greater Mymensingh region, travel by this bus terminal. It also has several gas stations. On its north there is Banani. On its south, there is Moghbazaar. The area is most often remains crowded and thousands of cars, rickshaws, minibus, bus, trucks remain stranded for even hours in the roads and streets of Mohakhali.

Saidabad

Saidabad an important place of Dhaka was the sampling site. It is located between 23º45'21.99'' N longitudes and 90º23'13.91'' E latitude. This is one of the busiest and most crowded areas of Dhaka city. From the early 1990s, the area has seen massive building and construction boom. Consequently, the area has got commercial importance and nowadays it has become one of the major transportation hubs of Dhaka from where anyone can travel all other parts of the city as well as throughout the country. Today Saidabad has become a more commercial area than a residential area.. As a transportation hub of Dhaka, the area is most often remains crowded and thousands of cars, rickshaws, minibus, bus, trucks remain stranded for even hours in the roads and streets of Saidabad.

Mouchak

The sampling site was Mouchak. It is located at 23º45'48.46'' N longitude and 90º22'06.47'' E latitude. Though initially Mouchak has grown as a residential area, nowadays many commercial places can be found here. It is connected to both Malibag and Rampura. Because of its position in the Dhaka city, it is now becoming busier area day by day and this gives rise to the pollution of the environment of that are. Until now, this area has moderate traffic load in comparison to other sites of Dhaka. Different types of vehicles such as cars, auto rickshaws, buses, mini-buses and other types of motor vehicles pass through the roads of Mouchak.

Topkhana

The sampling site was Topkhana. It is located at 23º45'48.46'' N longitude and 90º22'06.47'' E latitude. Though initially Topkhana has grown as a residential area, nowadays many commercial places can be found here. It is connected to both Secretariat Bhoban and GPO. Because of its position in the Dhaka city, it is now becoming busier area day by day and this gives rise to the pollution of the environment of that are. Until now, this area has moderate traffic load in comparison to other sites of Dhaka. Different types of vehicles such as cars, auto rickshaws, buses, mini-buses and other types of motor vehicles pass through the roads of Mouchak.

Ramna park

Ramna Park is a large park and recreation area situated at the heart of Dhaka, the capital city of Bangladesh. This park is one of the most beautiful areas in Dhaka with lots of trees and a lake near its centre. Ramna Park now protects an area of 68.50 acres (277,200 m^2), of which the lake covers 8.76 acres (35,500 m^2). Ramna Park now grows 71 species of flowering trees shrubs, perennials, and annuals, 36 species fruit bearing plant, 33 species medicinal plant and 41 species of forestry and 11 other species. Walkways inside park have been widened and five new gates built for entry from different sides. The Park features many beautiful and modern venues for relaxation.

Amin bazaar

The sampling site was Amin Bazaar. It is to the north- west of Dhaka city and is surrounded highly brick fields, where huge gases particularly CO_2, CO, SO_2, NO, NO_2 along with black carbon and elemental carbon are being emitted. Amin Bazaar and its neighbouring areas undergo serious air pollution affecting crop production and human health. Besides huge number of vehicles are plying through this area to the western and southern parts of Bangladesh.

Ashulia

The sampling site was Ashulia. It is to the north- west of Dhaka city and is surrounded highly brick fields, Industries where huge gases particularly CO, SO_2, NO, NO_2, TVOC, NH_3 along with black carbon. Ashulia and its neighbouring areas undergo serious air pollution affecting crop production and human health. Besides huge number of vehicles are plying through this area to the western and southern parts of Bangladesh. There is a huge number of bamboo trees, Jack-fruit trees etc.

Mymensing

The University campus, with an area of 4.85 km², is in scenic rural surroundings on the western bank of the old Brahmaputra River, 3 km south of the district town of Mymensingh and 120 km north from Dhaka, the capital city of Bangladesh. The campus is made up of a series of academic, administrative and residential buildings and a number of experimental farms, gardens and other related facilities. Besides, two national research institutes, Bangladesh Institute of Nuclear Agriculture (BINA) and Bangladesh Fisheries Research Institute (BFRI) are housed in this campus. The climate of Mymensingh is moderate, much cooler than Dhaka, as it is closer to the Himalayas. The monsoon starts in May or June and continues till August. It rains heavily and sometimes for days and weeks. During the monsoon, the temperature varies between 15 and 20 degrees. The temperature falls below 15 °C (59 °F) in winter which is spread over December and January and may well include November and February. The highest temperature is felt during April–May period, when the temperature may be as high as 40 °C (104 °F). High humidity causes heavy sweating during this period.

Chittagong (BFRI)

Under the Koppen climate classification, Chittagong has a tropical monsoon climate. Chittagong is located on the banks of the Karnaphuli River. It has a total area of 157 square kilometers (61 sq mi). The city is known for its vast hilly terrain that stretches throughout the entire district and eventually into India. Chittagong does not contain any natural lakes, but it does have artificial lakes and the sampling site was $22^{O}21^{/}08.76^{//}$ N to $91^{O}48^{/0}2.87^{//}$.

Jamalpur (SRID)

This place is situated at Jamalpur Zilla in Dhaka Division. The climate of Jamalpur is moderate, much cooler than Dhaka, as it is closer to the Himalayas. The monsoon starts in May or June and continues till August. It rains heavily and sometimes for days and weeks. During the monsoon, the temperature varies between 16 and 22 degrees. The temperature falls below 16 °C in winter which is spread over December and January and may well include November and February. The highest temperature is felt during April–May period, when the temperature may be as high as 40 °C (104 °F). High humidity causes heavy sweating during this period.

St. Martin

St. Martin's Island is the south-eastern most point of Bangladesh about 8 km west of the Myanmar coast. It covers 5.9 km^2 and has five physiographic areas, plus an extensive marine zone and the sampling sites was $20^O38'07.10''$ N to $92^O19'25.12''$E. Although it lies within the tropical belt, the climate of the Island is heavily influenced by the subtropical monsoonal climate that prevails over Bangladesh. From October to February the weather is mild with low rainfall. The hot season extends from March to May, and the monsoon during which most rains are concentrated extends from June to September *(Paul et. al., 2010).*

Teknaf

Located in the far south-eastern corner of Bangladesh with latitude between 20^o - 21^o N and a longitude of 92^o E, the site generally lies along the western coastal zone of the Teknaf Peninsula. The total area of the site as calculated from GIS records is 10,465 ha (DoE, 1999) and the sampling sites was $20^O51'52.81''$ N to $92^O18'00.52''$E near natural park. The site's northern, western and southern boundaries are delineated by waterways – the northern boundary by the Moheshkhali Channel from the Bay of Bengal up the channel as far as Ghorokghata; the western boundary by the beach along the Bay of Bengal; and the southern boundary by the tip of the Peninsula bordered by both the Bay and the Naaf River Estuary. The site's eastern boundary follows Mouza lines and incorporates the Mouzas of Kurushkul and Jhilwanja (Cox's Bazar Upazila). The boundaries of the Shilkhali, Baradail, Lengurbil and Teknaf Mouza are shared with the adjacent Teknaf Reserve Forest or Teknaf Game Reserve. While most Mouza share boundaries with adjacent Mouza, the Sabrang and Shahparir Dip Mouza share boundaries with the Naaf River estuary.The

NCSIP-1 Survey of Fauna *(Moef, 2001b*) describes the climate as moist tropical maritime with high rainfall concentrated during monsoon (usually June-September) and a dry period of 4-5 months .The plant bio-diversity of teknaf is so good (*Mannan, 2006).*

3.4. Measuring Toxic gases

3.4.1 Description of Gray Wolf Toxic Gas monitoring Units

Atmospheric toxic gases (SO_2, CO, NO, NO_2, O_3, TVOC, NH_3, H_2S and PH_3) , temperature and humidity were measured mostly at ground level with the help of two probes TG- 501 (SO_2, CO, NO, NO_2, O_3, temperature and humidity) and TG-502 (TVOC, NH_3, H_2S and PH_3, temperature and humidity) one containing 5 and another containing 4 sensors. They also contained temperature and humidity sensors. These probes were battery operated and connected to a PC through the USB port. Pocket PC has been provided with a rechargeable battery, which can function 5-6 hours at full charge. A pocket PC running Wolf sense (TM) application software takes the reading of air quality, toxic gases, air-speed, moisture and other parameters.

For the measurements of SO_2, CO, NO, NO_2, O_3, TVOC, NH_3, H_2S, PH_3, temperature and percent relative humidity, a PC was connected with the sensors installed in the probes 501 and 502 through serial ports. Inputs such as locations, time, dates, months, year, units of measurements, interval of measurements and the parameters to be measured. An in-built data logger stored the data generated with PC/data logger. Before starting toxic gas monitoring all the units were checked for its proper functioning, particularly, with respect to batteries, display of parameters and units of measurement.

Sometimes PC required to be installed by touching the readjustment knobs. The sensors were calibrated every 2 months to obtain better performances and proper functioning of the instruments as well as the processes. Any changes of locations of measurements, time, interval, dates, months, years, etc. was rein put in the PC.

3.4.2 Data transfer

Data on atmospheric toxic gases were transferred to the desktop for further analysis and data processing.

3.4.3 Basic Formulae

3.4.3.1: Calculation of the volume of air sample:

Volume of air sample = Sample flow rate x sample time.

3.4.3.2: Conversion of PPm (Parts per million) to µg/m^3 (micrograms):

µg/m^3 = PP^m x (molecular weight * / 24)

3.4.3.3: Calculation of time weighted average (TWA):

To determine an 8 hour TWA from one more than one sample within any 24 hour period:

TWA = (C1 x T1) + (C2 x T2) + (C3 x T3) + … + (Cn x Tn) /8

Where, C is the occupational exposure and T is the time for that exposure.

3.4.3.4: Time Series Analysis

Future predictions were made following time series analyses *(Hyndman, 2015).* ARIMA is used to generate an autoregressive integrated moving average using ARIMA model. These models are fitted to time series data either to better understand the data or to predict future points in the series (forecasting). They are applied in some cases where data show evidence of non-stationary, where an initial differencing step (corresponding to the "integrated" part of the model) can be applied to reduce the non-stationary.

Non-seasonal ARIMA models are generally denoted $ARIMA(p,d,q)$where parameters *p*, *d*, and *q* are non-negative integers, p is the order of the Autoregressive model, $d$is the degree of differencing, and $q$is the order of the Moving-average model. Seasonal ARIMA models are usually denoted $ARIMA(p,d,q)(P,D,Q)_m$, where $m$refers to the number of periods in each season, and the uppercase P,D,Q refer to the autoregressive, differencing, and moving average terms for the seasonal part of the ARIMA model . ARIMA models form an important part of the Box-Jenkins approach to time-series modelling *(Asteriou et.al. 2011).*

When two out of the three terms are zeros, the model may be referred to base on the non-zero parameter, dropping "AR", "I" or "MA" from the acronym describing the model. For example, ARIMA (1,0,0) is AR(1), ARIMA (0,1,0) is I(1), and ARIMA(0,0,1) is MA(1).

In this research work we use an ARIMA (0, 1, 0) model, an ARIMA (0, 2, 2) model are given by

- An ARIMA (0, 1, 0) model (or I(1) model) is given by $X_t = X_{t-1} + \varepsilon_t$ – which is simply a random walk.
- An ARIMA (0, 1, 0) with a constant, given by $X_t = c + X_{t-1} + \varepsilon_t$ – which is a random walk with drift.
- An ARIMA (0,2,2) model is given by $X_t = X_{t-1} + X_{t-2} + (\alpha + \beta - 2)\varepsilon_{t-1} + (1 - \alpha)\varepsilon_{t-2} + \varepsilon_t$ – which is equivalent to Holt's linear method with additive errors.

  The data generated was put in the time – series model based on the consecutive months starting from Jan, 2009 - Dec, 2011. Based on this model the prediction of gas concentrations for the next 48 consecutive months (till Aug, 2015) was made.

3.1: Correlations among the Toxic gases, Temperature^{0}C and Relative humidity (%) in 2011 in Dhaka city.

Parameter	SO_2	CO	O_3	NO	NO_2	Temp^{0}C	TVOC	H_2S	PH_3	NH_3	RH%
SO_2	1.000	**0.919****	**0.814****	**0.729***	0.379	0.579	-0.506	**0.875****	**0.882****	**0.655***	**0.754****
CO		1.000	0.558	**0.652***	0.316	0.423	-0.235	**0.737****	**0.845****	**0.629***	**0.698***
O_3			1.000	0.643*	0.352	**0.694***	**-0.727***	**0.796****	**0.689***	0.471	**0.646***
NO				1.000	0.152	**0.795****	**-0.702***	**0.768****	**0.753****	0.504	0.543
NO_2					1.000	0.024	0.006	0.275	0.456	**0.794****	0.163
Temp ^{0}C						1.000	**-0.917****	**0.793****	**0.728***	0.267	0.744**
TVOC							1.000	**-0.776****	-0.568	-0.233	-0.580
H_2S								1.000	**0.842****	**0.648***	**0.758****
PH_3									1.000	**0.654***	**0.839****
NH_3										1.000	0.280
RH%											1.000

**Correlation is significant at the 0.01 level.

*Correlation is significant at the 0.05 level.

4. Results and discussion

4.1: Ground level O_3 Concentrations ($\mu g/m^3$) measured for Dhaka City during 2009 -2011.

The ground-level O_3 concentrations ($\mu g/m^3$) measured for Dhaka city at different hot spots during 2009 to 2011 presented in tables 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations. The concentrations varied from 31 $\mu g/m^3$ to 47 $\mu g/m^3$ in the hot spots. Among the hot spots the maximum concentrations were measured for Farmgate 47 $\mu g/m^3$ in 2011 followed by Amin bazar 46 $\mu g/m^3$, Ashulia 45 $\mu g/m^3$, Science Laboratory 41 $\mu g/m^3$, Topkhana 41 $\mu g/m^3$, Mouchak 40 $\mu g/m^3$, Curzon Hall 39 $\mu g/m^3$. No ground level O_3 however, was detected in any of the spots between 9 hours to 17 hours. The concentrations of O_3 measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of O_3 in Dhaka city for three consecutive years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 29 $\mu g/m^3$ to 45 $\mu g/m^3$. The highest level 45 $\mu g/m^3$ was measured in the month of November (in winter) and the lowest 29 $\mu g/m^3$ in the month of June (rainy season) with an average 36 $\mu g/m^3$ (Table: 4.17).

The registered average natural background concentrations of ground-level O_3 are around 30-100 $\mu g/m^3$. Short-term (one-hour) mean ambient concentrations in urban areas may exceed 300-800 $\mu g/m^3$ (*WHO, 1979).* The ground-level O_3 measured for Dhaka city and the exposure level is within the limit values set by WHO guidelines 100 $\mu g/m^3$ (Eight hours), 2005 and Bangladesh standards 157 $\mu g/m^3$ (*DoE, 2005*).

Both natural and anthropogenic sources contribute to the ground-level O_3 precursors, and the composition of emissions sources may show large variations across locations. Volatile Organic Compounds (VOCs) occurring naturally due to emissions from trees and crop plants may account for as much as two thirds of ambient VOCs in some locations (*USEPA, 1986*). Ground-level O_3 is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of ground-level O_3 precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Tables 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the O_3 precursors. Ozone (O_3) concentrations are influenced by the intensity of solar radiation, the absolute concentration of NOx and VOCs, and the ratio of NOx and VOCs. A strong negative correlation ($r = -0.98$) between O_3 and TVOC, positive correlation ($r = 0.99$) between O_3 and NO and negative correlation ($r = -0.92$) between O_3 and NO_2 obtained in the present investigation. That is O_3 concentration increased with a concomitant decrease in TVOC and NO_2. Whereas, the concentration increased with increasing concentration of NO. The

variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which O_3 is converted to O_2 during day time period. The O_3 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for O_3 and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level O_3 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak ground-level O_3 concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level O_3 rarely last longer than two to three hours *(WHO, 1979).*

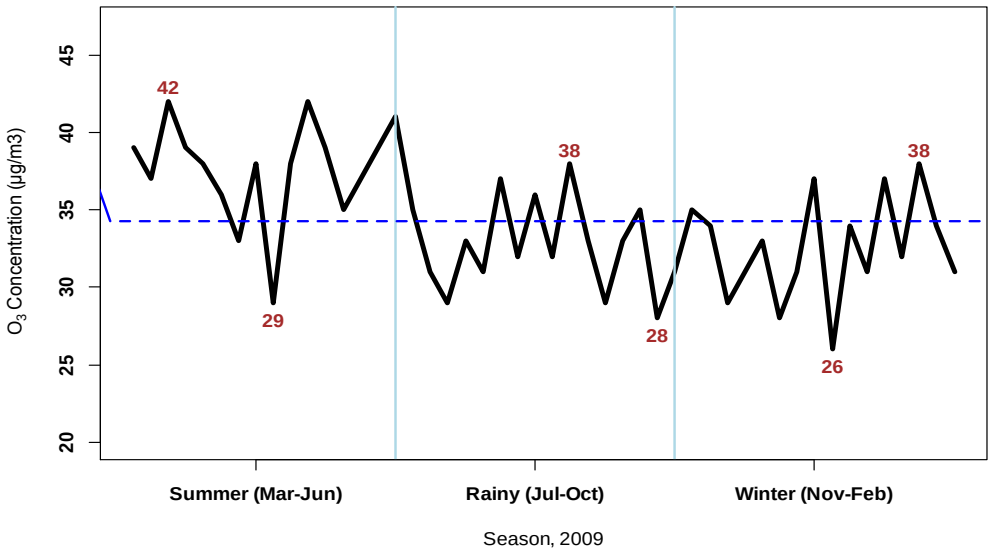


Fig.4.1.1: O_3 Concentrations (µg/m^3) in 2009 in Dhaka City.

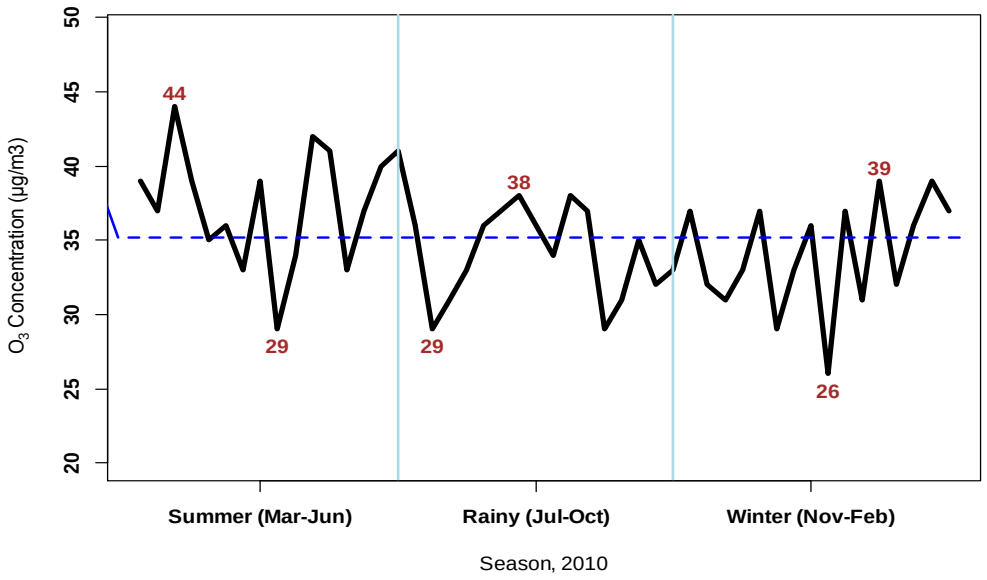


Fig. 4.1.2: O_3 Concentrations (µg/m^3) in 2010 in Dhaka City.

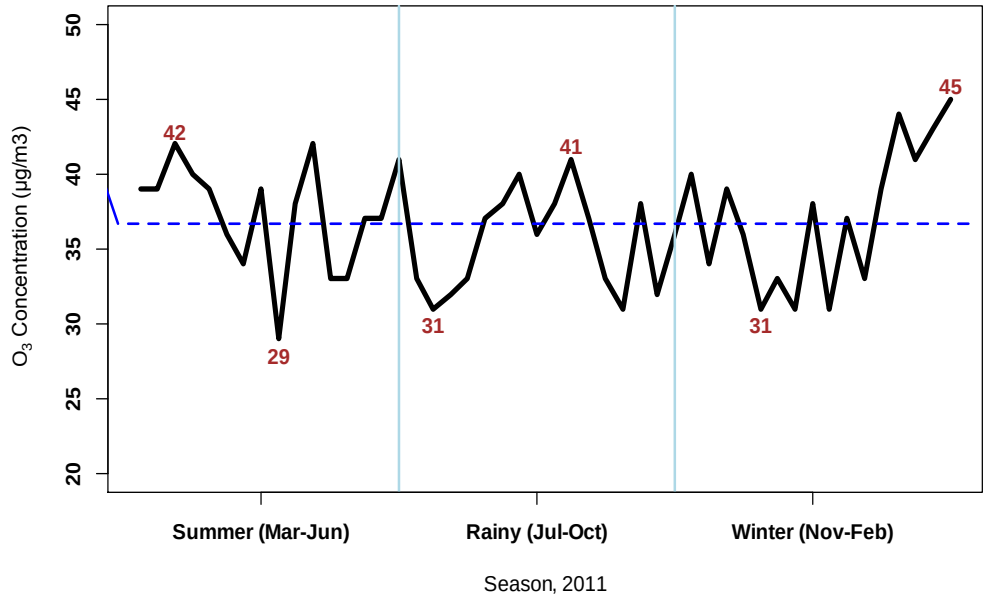


Fig.4.1. 3: O_3 Concentrations (µg/m^3) in 2011 in Dhaka City.

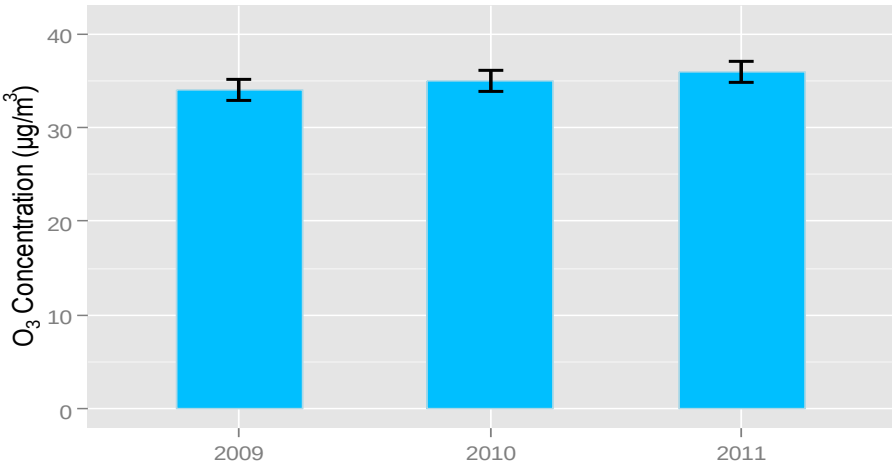


Fig.4.1.4: Yearly variations in O_3 Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

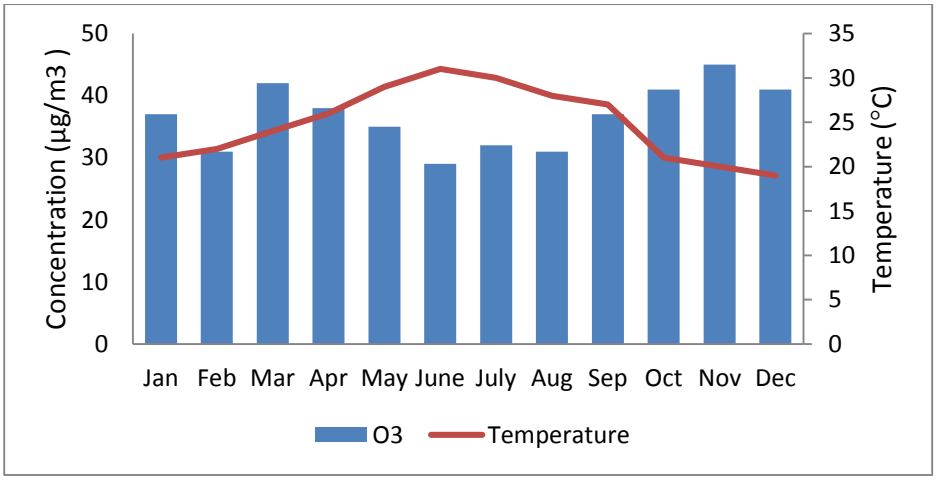


Fig. 4.1.5: O_3 variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition, there was also a seasonal variation in O_3 concentrations in summer, rainy and winter season. The Figs. 4.1.1, 4.1.2, 4.1.3 show that the highest O_3 concentration was measured in winter followed by summer and rainy season respectively.

It can be seen from Fig. 4.1.4 that there is an increasing trend in average O_3 concentration from year 2009 to 2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are overlapped.

It is also evident from the results presented in Fig. 4.1.5 that O_3 levels decreased with increasing day temperature in particular during month of April to September.

The atmospheric chemistry involved in ozone formation is complex. Ultraviolet (uv) radiation from the sun breaks down nitrogen dioxide (NO_2) into nitrogen oxide and form atomic oxygen -

NO_2 + uv - NO + O

Oxygen atoms combine with oxygen molecules to form ozone -

O + O_2 - O_3

However, ozone will not accumulate when nitrogen oxide is present, as the two molecules react to reform nitrogen dioxide and oxygen -

NO + O_3 - NO_2 + O_2

When volatile organic compounds (VOCs) such as hydrocarbons, react in the atmosphere to form oxygenated products the oxygen in these molecules allows NO to form NO_2, without breaking down ozone, thus ozone accumulates (*WHO, 2009*). The build-up of O_3 therefore, depends upon the relative concentrations of nitrogen oxides, hydrocarbons and other pollutants and sunlight. It takes time for the ozone to accumulate as the chemical reactions involved are quite slow - ozone builds up in polluted air masses.

Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of O_3. An air mass trajectory analysis using HYSPLIT model (NOAA, 2012) showed that a substantial amount of O_3 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

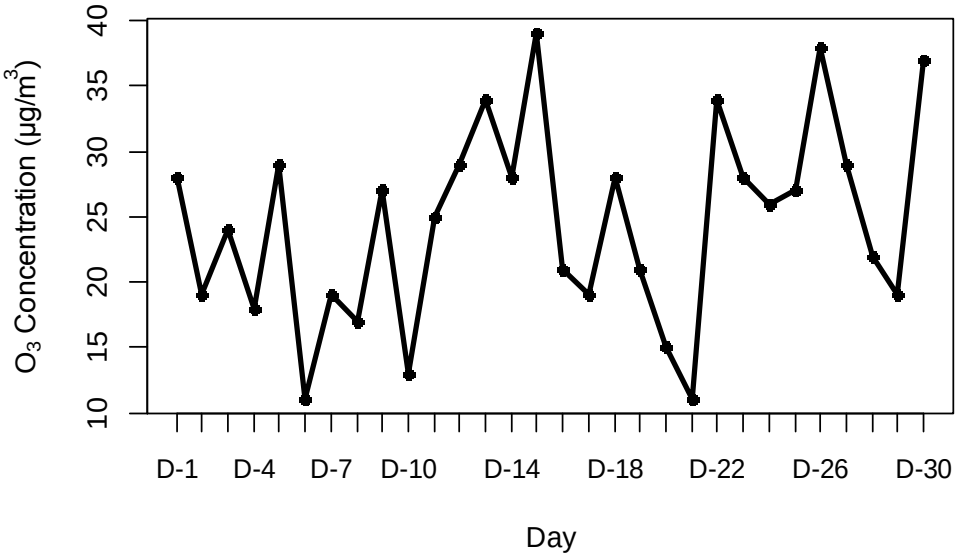


Fig. 4.1.6: Monthly variations in O_3 Concentrations (µg/m^3) in Dhaka city (June, 2011).

Ozone (O_3) concentrations (µg/m^3) measured for 30 days in June, 2011 in Dhaka city (presented in Fig 4.1.6) shows that the concentrations varied significantly from 1st June to 30th June. The highest concentration was 39 µg/m^3 in 15th June and the lowest concentration was 11 µg/m^3 in 6th and 21th June respectively (Table: 4.5). The reason behind the variation can be explained by the vehicular emissions of O_3 precursors during the holiday, rainy day, cloudy day in this time period. The average value is significantly different as the 95% confidence level between 6th, 21th June and 15th June. The lowest value was found in 6th and 21th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of O_3 were low than the other days. It can also be explained by the photo-chemical dissociation of $O_3 = O_2 + O$. A significant level of spatial variations was observed in 0_3 concentrations in Dhaka city. The highest concentration 39 µg/m^3 was measured on 15th June and the lowest concentration 11 µg/m^3 on 6th and 21th June, 2011. These variations can be explained by the vehicular movement on the roods and emissions obtained during holidays, rainy days, cloudy days. There are less traffic movements in the holidays in Dhaka city and the rainy and cloudy days generally affect fluctuations in diurnal changes that occur during each day.

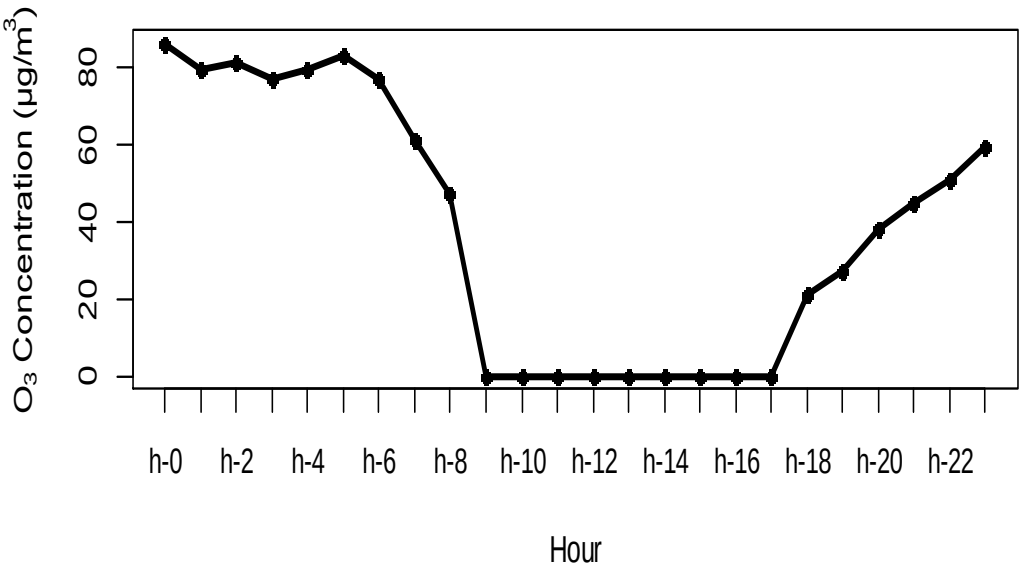


Fig. 4.1.7: Diurnal variation in O_3 Concentrations (µg/m³) in Dhaka city (3 June, 2011).

Diurnal variation in O_3 concentrations (µg/m³) measured on 3 June, 2011 are presented in Fig. 4.1.7 shows that the concentrations varied significantly from 0 hour to 24 hours. The concentration measured between 0 to 6 hours were 86 µg/m³, 79 µg/m³, 81 µg/m³, 77 µg/m³, 79 µg/m³, 83 µg/m³, 77 µg/m³ , 61 µg/m³, 47 µg/m³ (Table 4.6) and then declined to 0 µg/m³ concentrations between 9h -17h and then again regained the concentrations slowly increasing between 18h -24h. The highest O_3 level 86 µg/m³ was recorded at 0 hour and the lowest 0 µg/m³ between 9 and 17 hours .The reason behind the variation can be explained by the presence of sunlight and the photochemical reaction O_3 is converted to O_2 during day time period. The O_3 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698 %) was obtained for O_3 and relative humidity. O_3 concentrations increase with increasing hydrocarbons and decrease with increasing NOx. It can be seen in Fig 4.1.7 that the concentrations varied significantly from hour to hour. The average value was significantly different as the 95% confidence level in 24 hours.

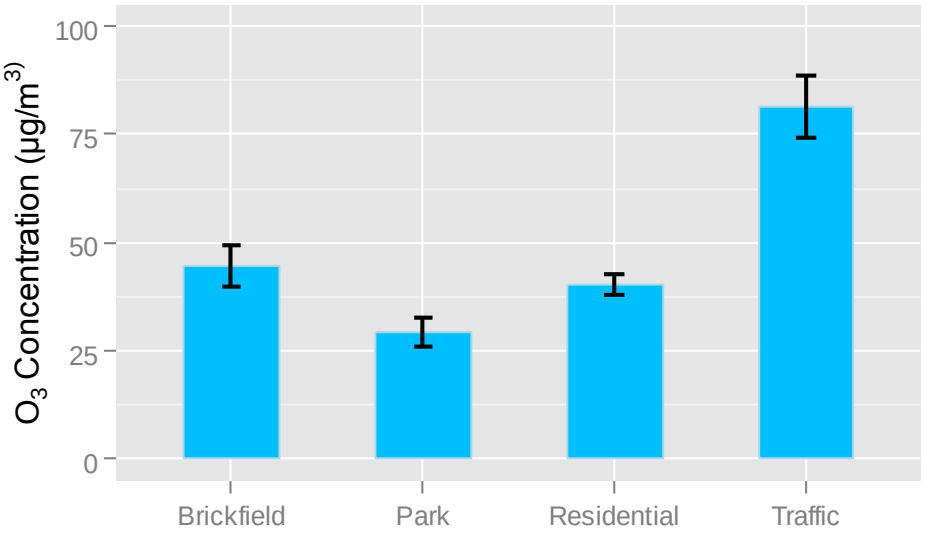


Fig. 4.1.8: Comparison of O_3 Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Ozone (O_3) concentrations determined at residential, traffic, park, brick-field areas to observe the locational variations presented in Fig 4.1.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in traffic area 81 µg/m^3 followed by brick-field 44 µg/m^3, residential area 40 µg/m^3 and park area 29 µg/m^3 (Table 4.7) .The O_3 concentration measured for traffic areas were significantly higher than that measured for park and residential areas at 95% confidence level. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of O_3. Huge number of running vehicles, long time traffic jam produce O_3 resulting in an air pollution. To use low quality coal, wood in brick-kilns are also related to the production O_3. Oxygen atoms combine with oxygen molecules to form ozone - $O + O_2 - O_3$. *(WHO, 2009).*

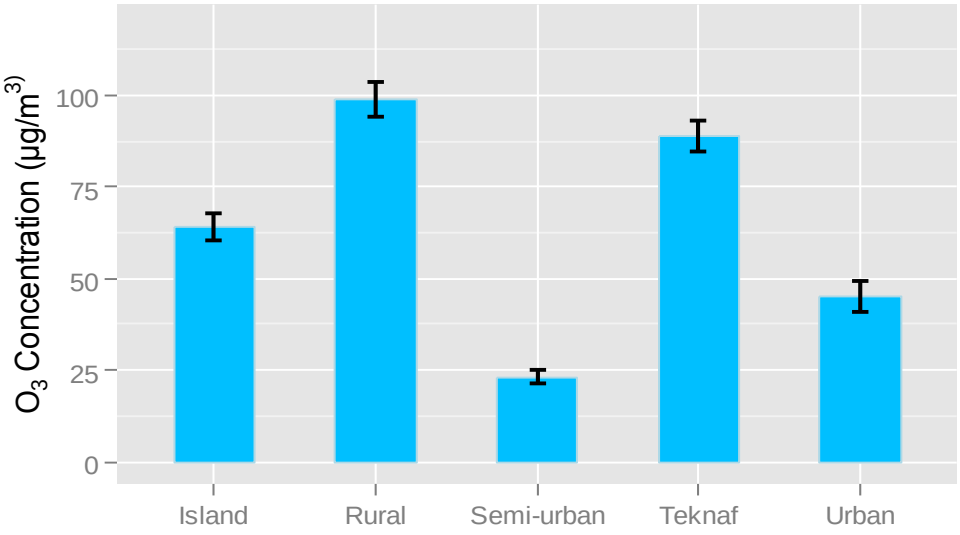


Fig. 4.1.9: Comparison of O_3 Concentrations ($\mu g/m^3$) measured for different locations in Bangladesh (December, 2009-2011).

Ozone (O_3) concentrations determined in Urban, Semi-urban, Rural, St. Martin's Island, Teknaf areas (to observe spatial variations) presented in Fig.4.1.9 shows that the concentrations varied significantly from place to place.The highest level of O_3 concentrations 99 $\mu g/m^3$ was measured in Jamalpur(rural areas) followed by 89 $\mu g/m^3$ in Teknaf, 64 $\mu g/m^3$ in St. Martin's island and 45 $\mu g/m^3$ in Urban and 23 $\mu g/m^3$ in Semi-Urban areas (Table 4.16). The O_3 concentration measured for rural areas was significantly higher than that measured for urban and semi-urban areas at 95% confidence level. High levels of O_3 concentrations measured for rural and teknaf compared to urban areas like Dhaka city in the present investigation relates well with vegetations, less photochemical reaction between NO and O_2.

4.2 CO Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Carbon monoxide (CO) concentrations (µg/m$^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented tables: 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations. The concentrations varied from 7978 µg/m^3 to 14818 µg/m^3 in the hot spots. Among the hot spots the maximum concentrations were measured for Farm gate 14818 µg/m^3 in 2011 followed by Science laboratory 14945 µg/m^3, Mohakhali 14145 µg/m^3, Mouchak 14712 µg/m^3, Topkhana 14548 µg/m^3 Amin bazaar 13645 µg/m^3, Ashulia 12745 µg/m^3,Curzon hall 11257 µg/m^3. The concentrations of CO measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of CO in Dhaka city for three consecutive years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 7387 µg/m^3 – 12534 µg/m^3. The highest level 12534 µg/m^3 was measured in the month of January (in Winter season) and the lowest level 7387 µg/m^3 in the month of June (in rainy season) with an average 9969 µg/m^3 (Table: 4.17).

The average natural background concentrations of CO are around 2000-5000 µg/m^3. Short-term (one-hour) mean ambient concentrations in urban areas may exceed 5000 µg/m^3 (*EPA, 2002).* Inhaling even relatively small amounts of the gas can lead to hypoxic injury, neurological damage, and even death. Different people and populations may have a different carbon monoxide tolerance level *(Raub et. al., 2000).* Carbon monoxide exposure may lead to a significantly shorter life span due to heart damage *(Henry et. al., 2006).* The CO measured for Dhaka city and the exposure level is very high compared to the limit values set by *EPA, 2002* and Bangladesh standards 5000 µg/m^3 *(DoE, 2002).*

Both natural and anthropogenic sources contribute to CO precursors, and the composition of emissions sources may show large variations across locations (*WHO, 2012*). One of the major anthropogenic sources of CO precursors is the motor vehicles. It is possible that the increasing number of motor vehicles (Tables 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in to CO precursors. Carbon monoxide is a product of incomplete combustion of organic matter due to insufficient oxygen supply to enable complete oxidation to carbon dioxide (CO_2). A strong negative correlation (r = - 0.23) between CO and TVOC, positive correlation (r = 0.65) between CO and NO and positive correlation (r = 0.84) between CO and PH_3 obtained in the present investigation. It is often produced in domestic or industrial settings by older motor vehicles and other gasoline-powered tools, heaters, and cooking equipment. The reason behind the variation can be explained by the vehicular emissions of CO during this time period. It is evident from the daily traffic movement on the street that the number of vehicles significantly increase during the day time especially between 9am – 10pm .The CO concentrations also varied with relative humidity. A significant negative correlation (r = 0.698 %) was obtained for CO and relative humidity. It is evident from the results that CO concentrations increased with increasing relative humidity

and supported by *EPA, 2009.* The diurnal and seasonal variations occur in response to changes in sunlight. Peak CO concentrations are measured in the day time.

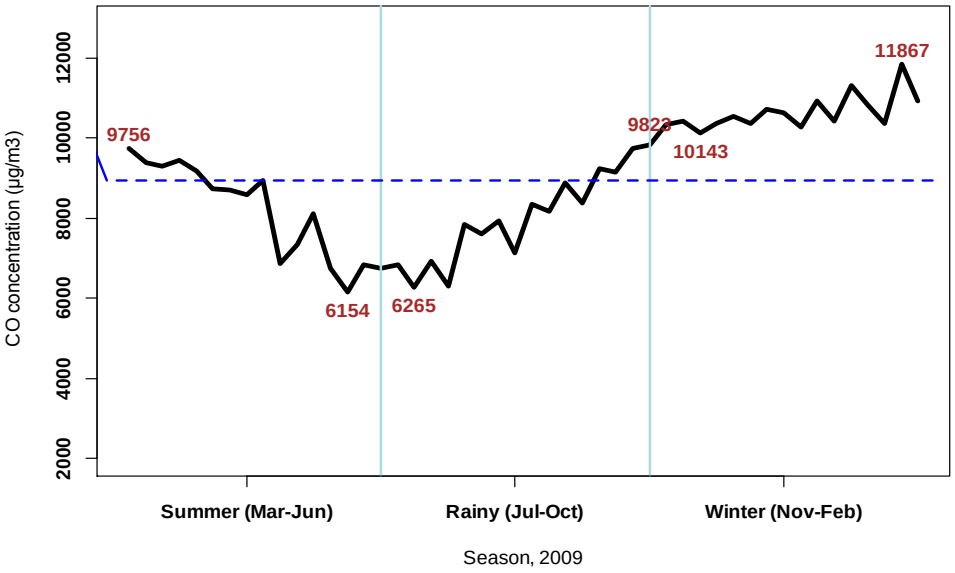


Fig. 4.2.1: CO Concentrations (µg/m^3) in 2009 in Dhaka City.

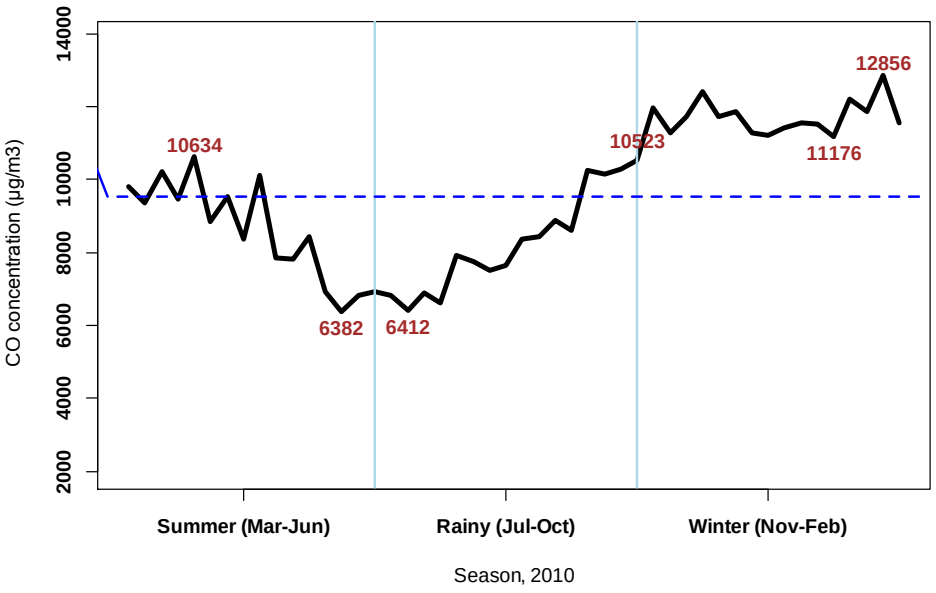


Fig. 4.2.2: CO Concentrations (µg/m^3) in 2010 in Dhaka City.

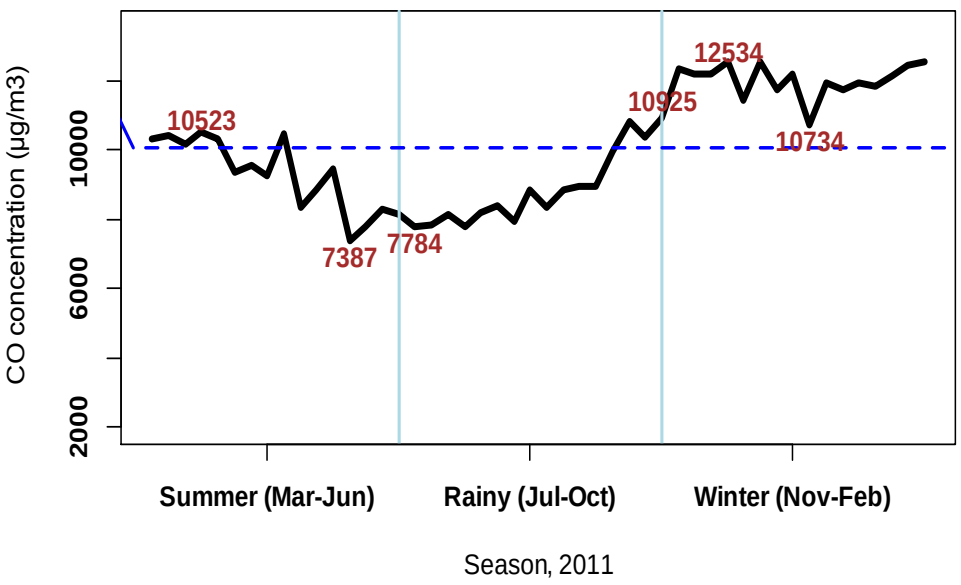


Fig. 4.2.3: CO Concentrations (µg/m³) in 2011 in Dhaka City.

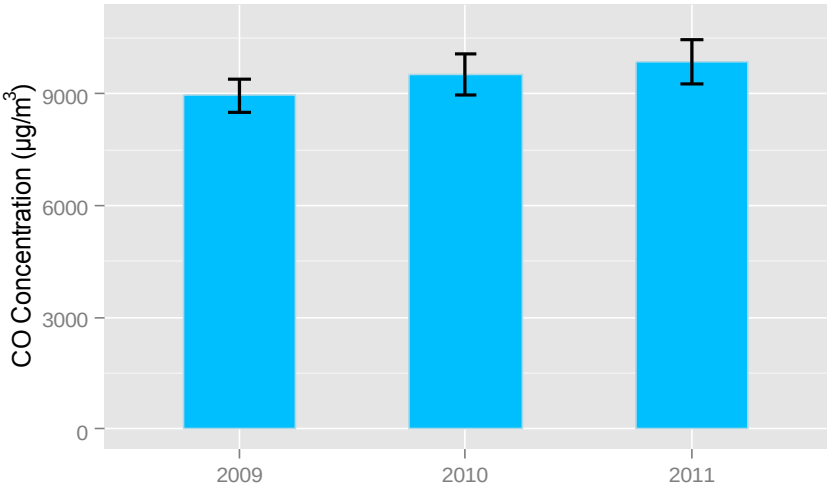


Fig.4.2.4: Yearly variations in CO Concentrations (µg/m³) in 2009, 2010 and 2011 in Dhaka City.

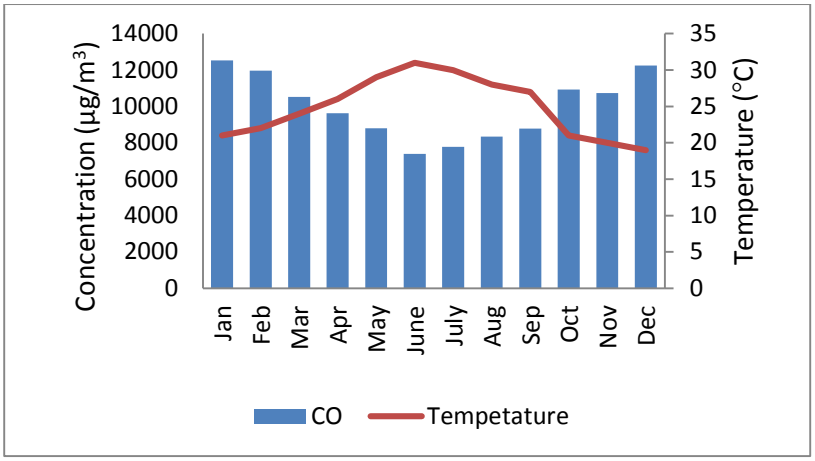


Fig. 4.2.5: CO variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition, there was also seasonal variation in CO concentration. The Figs. 4.2.1, 4.2.2, 4.2.3 shows that the CO concentration was highest in winter season followed by summer and rainy season.

It is also evident from Fig. 4.2.4 that there is an increasing trend in average concentration of CO from year 2009-2011 and the difference between the average values for the years is significantly different at 95% confidence level.

The concentrations of CO decreased as the temperature increased between April and September (Fig. 4.2.5). When the temperature starts decreasing the value of CO is increasing in October to March. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of CO. A air mass trajectory analysis using HYSPLIT model (NOAA, 2012) showed that a substantial amount of CO are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2). Carbon and oxygen combine to form two gases. When combustion of carbon is complete, *i.e*. in the presence of plenty of air, the product is mainly carbon dioxide (CO_2). Sources of carbon include; coal, coke, charcoal. When combustion of carbon is incomplete, *i.e*. there is a limited supply of air, only half as much oxygen adds to the carbon, and instead forms carbon monoxide (CO). Carbon monoxide is also formed as a pollutant when hydrocarbon fuels (natural gas, petrol and diesel) are burnt. The relative amount of CO produced depends on the efficiency of combustion *(EPA, 2009*).

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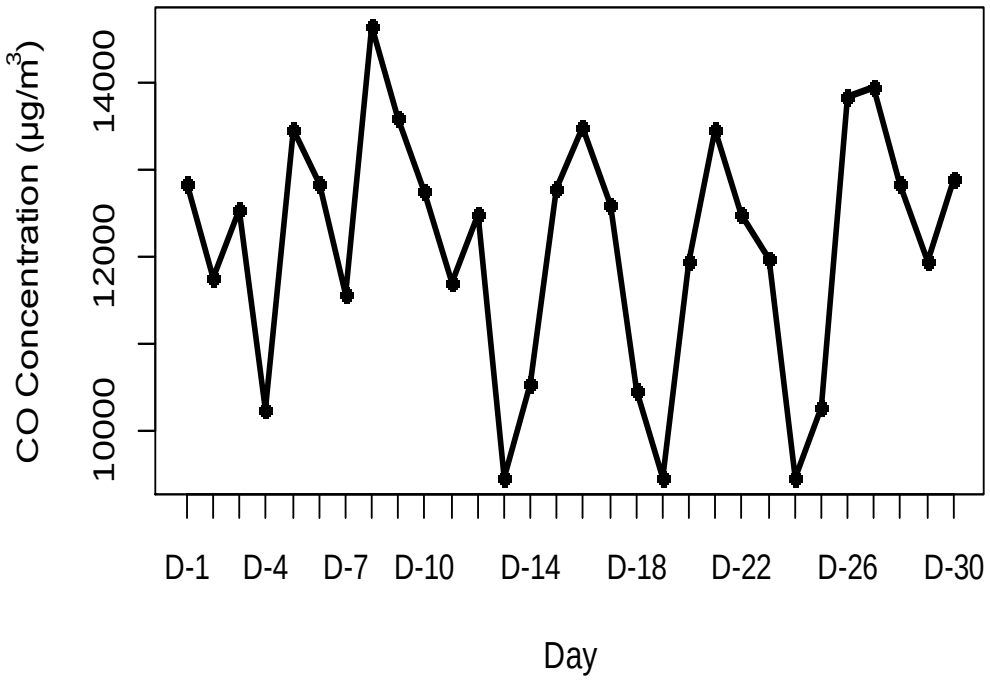


Fig. 4.2.6: Monthly variations in CO Concentrations (µg/m^3) in Dhaka city (June, 2011).

Carbon monoxide (CO) concentrations (µg/m^3) measured for 30 days in June, 2011 in Dhaka city presented in Fig 4.2.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 12845 µg/m^3, 11745 µg/m^3, 12547 µg/m^3,10245 µg/m^3, 13451 µg/m^3,12845 µg/m^3 respectively (table 4.5). The highest value was 13942 µg/m^3 measured on 27th June and the lowest 9456 µg/m^3 on 13th June .The reason behind the variation can be explained by the vehicular emissions of CO during the holiday, rainy day, cloudy day in this time period . The average value is significantly different at 95% confidence between 27th June and 13th June. The lowest values were recorded on 13th and 24th June and the days were rainy day. The 3rd, 10th, 17th, 24th June were holidays and for these reason the concentrations of CO were lower than the other days.

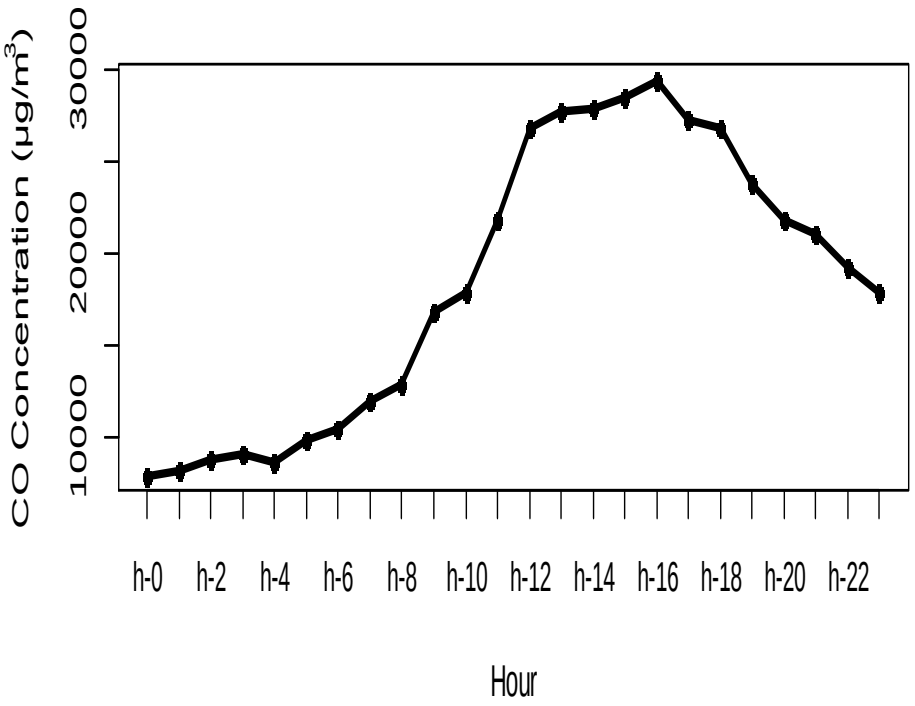


Fig. 4.2.7: Diurnal variation in CO Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Carbon monoxide (CO) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city presented in Fig.4.2.7 shows that the concentrations varied significantly from 0 hour to 24 hours. The peak concentrations measured between 15 hour and 16 hour were 28547 µg/m^3, 29467 µg/m^3 (Table 4.6) .The highest value 29467 µg/m^3 was measured at 16 hour and the lowest value 7956 µg/m^3 at 0 hour. The reason behind the variation could possibly be conversion of CO to other gases by the presence of sunshine, sunlight and the photochemical reaction. It is evident from the daily traffic movement on the streets that the number of vehicles significantly increase during the day time especially between 11 am – 18 PM .The CO concentrations also varied with relative humidity.

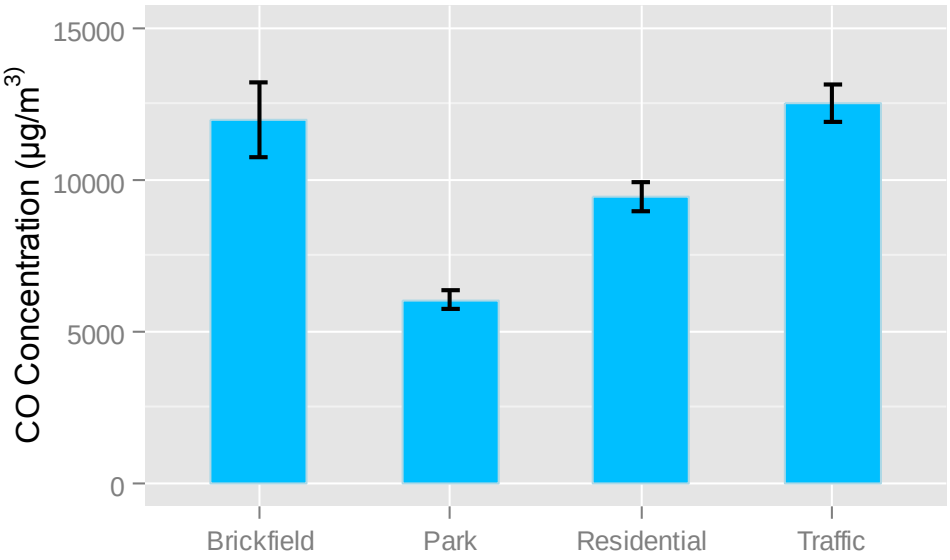


Fig. 4.2.8: Comparison of CO Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Carbon monoxide (CO) concentrations (µg/m^3) determined at residential area, traffic area, park, brick-field etc. to see the locational variations presented in Fig 4.2.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in traffic area 15834 µg/m^3 followed by brick-field 16845 µg/m^3, residential area 11976 µg/m^3 and park area 7612 µg/m^3 (Table 4.8). The CO concentration measured for traffic areas were significantly higher than that measured for park and residential areas at 95% confidence level. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. Produce a huge amount of CO. The number of running vehicles, long time traffic jam produce CO resulting in a air pollution. Use of low quality coal, wood in brick-kilns also produce a huge amount of CO (*WHO, 2009).*

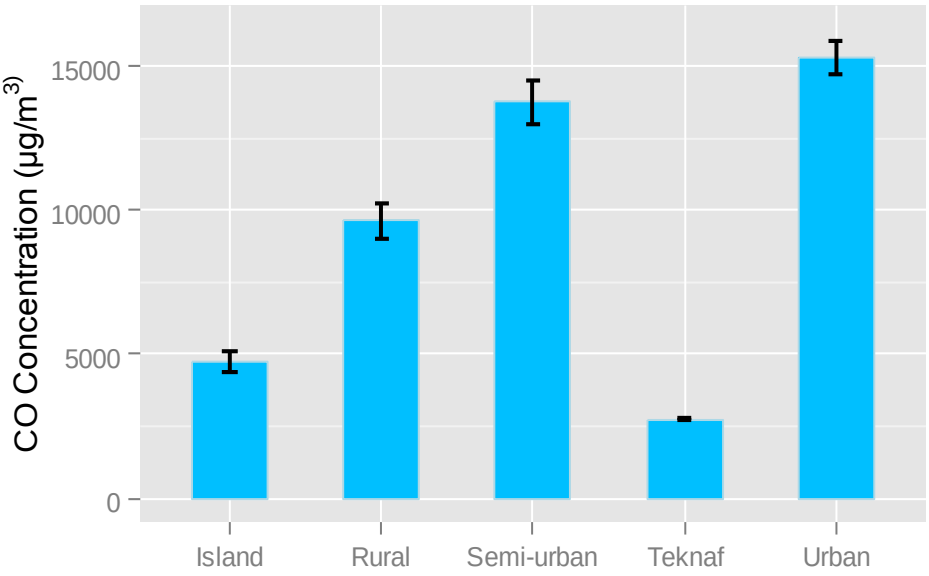


Fig.4.2.9: Comparison of CO Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Carbon monoxide (CO) concentrations determined in Urban, Semi-urban, Rural, St. Martin's Island, Teknaf areas to see any spatial variations presented in Fig 4.2.9 shows that the concentrations varied significantly from place to place. The highest level of CO concentrations 15324 µg/m^3 was measured in urban sites, 13756 µg/m^3 in semi- urban, 9645 µg/m^3 in rural, 4756 µg/m^3 in St. Martin Island and 2745 µg/m^3 in Teknaf(Peri –rural) (Table 4.16). The CO concentration measured for urban and semi- urban areas were significantly higher than that measured for rural, St. Martin's Island and Teknaf areas at 95% confidence level. Low levels of CO concentrations measured for St. Martin Island and Teknaf compared to urban areas like Dhaka city in the present investigation relates well with vehicular and industrial emissions and other anthropogenic activities.

4.3 SO_2 Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Sulphur dioxide (SO_2) concentrations (µg/m^3) measured for Dhaka city at different hot spots during 2009 to 2011 are presented in tables 4.4.1, 4.4.2 and 4.4.3. The tables show a significant level of spatial and temporal variations in SO_2. The concentrations varied from 99 µg/m^3 to 239 µg/m^3 in the hot spots. Among the hot spots the maximum concentrations 239 µg/m^3 was measured at Amin bazar in 2011 followed by Ashulia 237 µg/m^3 , Farmgate 161 µg/m^3, Mohakhali 151 µg/m^3 Science laboratory 149 µg/m^3,Topkhana 133 µg/m^3, Mouchak 141 µg/m^3 and Curzon hall 121 µg/m^3. No SO_2 however, was detected in any of the spots between 9 hours to 18 hours. The concentrations of SO_2 measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of SO_2 in Dhaka city for three years from 2009 to 2011(January – December) and a generalized analysis of the data depict that the concentration varied from 106 -136 µg/m^3. The highest level 136 µg/m^3 was measured in the months of December (in winter) and the lowest level 106 µg/m^3 in the month of October with an average of 122 µg/m^3(Table: 4.17).

The registered average natural background SO_2 concentration is around 80-120 µg/m^3. Short-term (one-hour) mean ambient concentrations in urban areas may exceed 350 µg/m^3 (*DoE, 2002).* The SO_2 measured for Dhaka city and the exposure level is high and passed the limit values set by *EPA, 2002* and Bangladesh standards 80 µg/m^3 *(DoE, 2002).*

Both natural and anthropogenic sources contribute to the ground-level SO_2 precursors, and the composition of emissions sources may show large variations across locations. VOCs occurring naturally due to emissions from trees and crop plants may account for as much as two thirds of ambient SO_2 in some locations (*USEPA, 1986*). Sulphur dioxide (SO_2) is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of SO_2 precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the SO_2 precursors. A strong negative correlation (r = - 0.50) between SO_2 and TVOC, positive correlation (r = 0.91) between SO_2 and CO and positive correlation (r = 0.81) between SO_2 and O_3 obtained in the present investigation. That is SO_2 concentration increased with a concomitant decrease in TVOC. Whereas, the concentrate in increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which SO_2 is converted to SO_3 during day time period. The SO_2 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for SO_2 and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level SO_2 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Mean concentrations are generally highest in the winter. Peak concentrations of SO_2 rarely last longer than two to three hours *(WHO, 1979).* This is because SO_2 is very reactive and consequently the distribution of SO_2 along the conductive airways of the respiratory tract is

non-uniform, depending on breathing volumes and types. For nasal breathing with low to moderate volumes the penetration into the lungs is negligible. For oral inhalation and larger volumes, doses may reach the segmental bronchi *(WHO, 2000).*

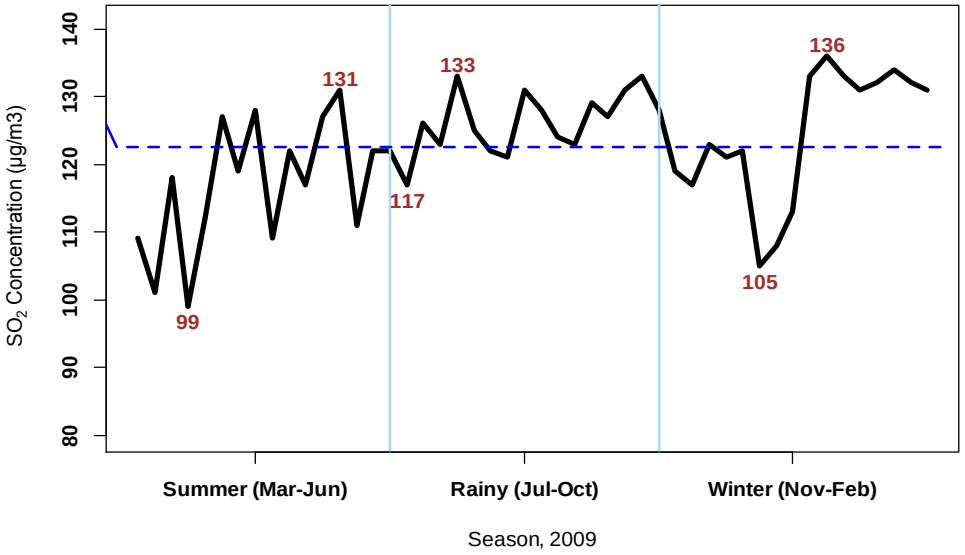


Fig. 4.3.1: SO_2 Concentrations (µg/m³) in 2009 in Dhaka City.

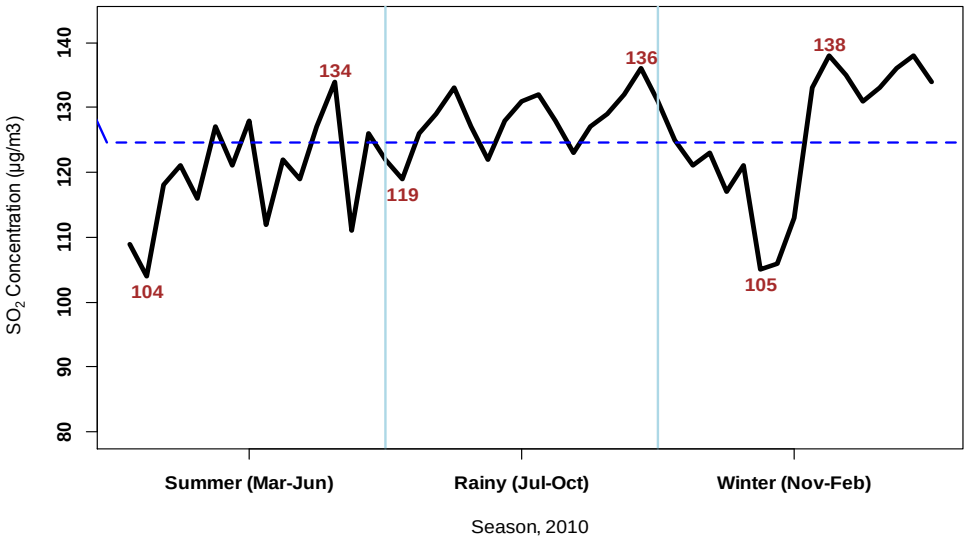


Fig. 4.3.2: SO_2 Concentrations (µg/m³) in 2010 in Dhaka City.

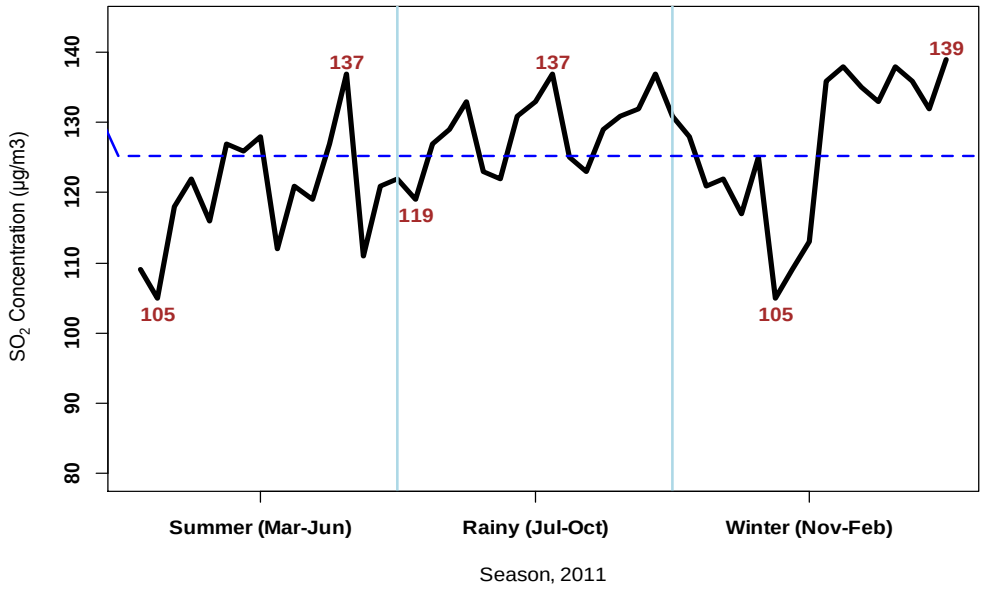


Fig. 4.3.3: SO_2 Concentrations ($\mu g/m^3$) in 2011 in Dhaka City.

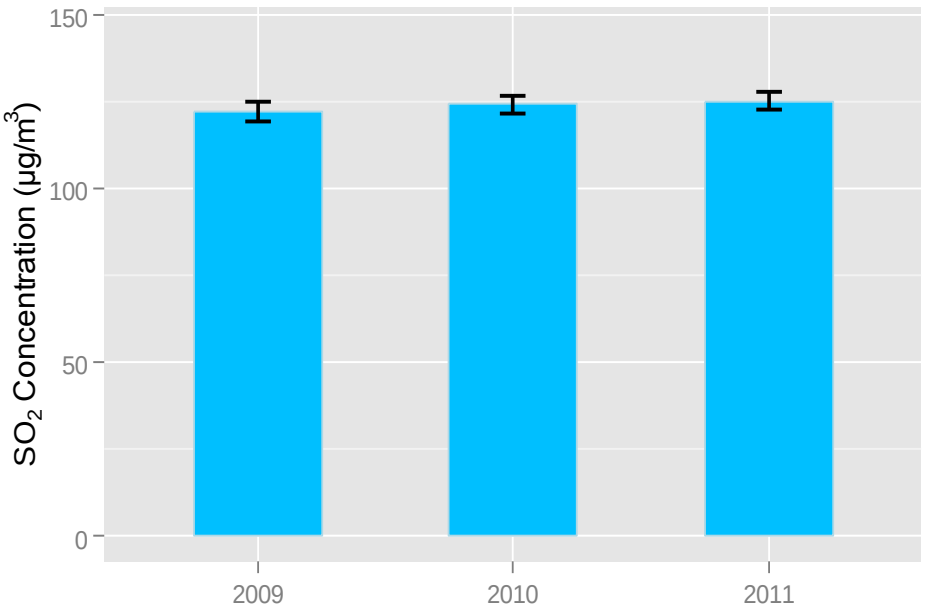


Fig.4.3.4: Yearly variations in SO_2 Concentrations ($\mu g/m^3$) in 2009, 2010 and 2011 in Dhaka City.

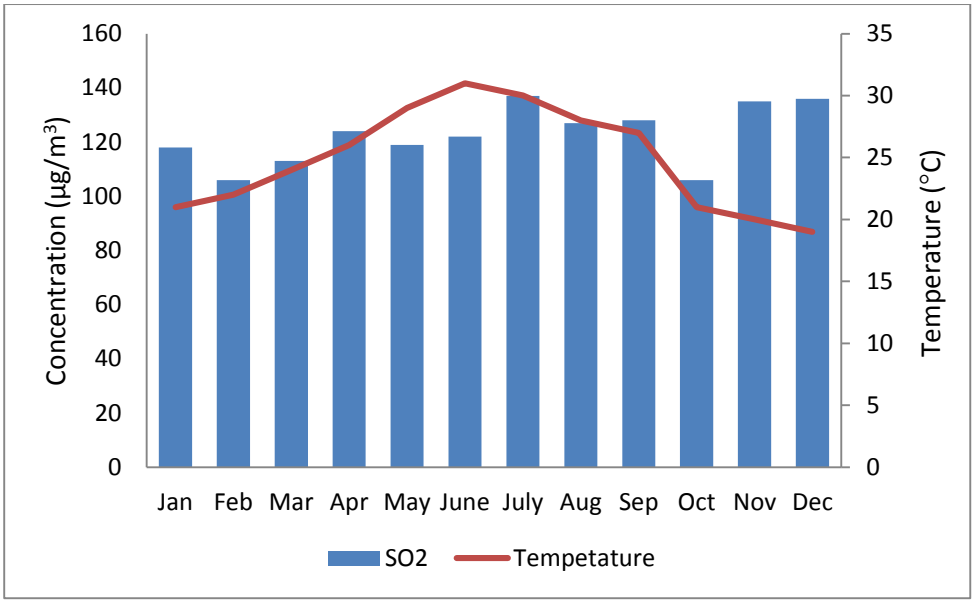


Fig. 4.3.5: SO_2 variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition, there was also a seasonal variation in SO_2 concentrations in summer, rainy and season winter. The Figs. 4.3.1, 4.3.2, 4.3.3 show that the highest SO_2 concentration was measured in winter followed by rainy, summer season respectively.

It can be seen from Fig. 4.3.4 that there is an increasing trend in average SO_2 concentration from year 2009 to 2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are overlapped.

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction SO_2 convert to another gases during this day time period. The SO_2 concentrations also varied with relative humidity. A significant correlation(r= 0.698 %) was obtained for SO_2 and relative humidity. SO_2 concentrations increase with increasing hydrocarbons and decrease with increasing SOx .

Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of SO_2. A air mass trajectory analysis using HYSPLIT model (NOAA, 2012) showed that a substantial amount of O_3 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

Sulphur dioxide is the product of the burning of sulphur or of burning materials that contain sulphur:

$$S + O_2 \rightarrow SO_2, = -297 \text{ kJ/mol}$$

To aid combustion, liquefied sulphur (140–150 °C) is sprayed through an atomizing nozzle to generate fine drops of sulphur with a large surface area. The reaction is exothermic, and the combustion produces temperatures of 1000–1600 °C. The significant amount of heat produced is recovered by steam generation that can subsequently be converted to electricity (*Müller and Hermann, 2005).*

The combustion of hydrogen sulfide and organosulfur compounds proceeds similarly. For example:

$$2\ H_2S + 3\ O_2 \rightarrow 2\ H_2O + 2\ SO_2$$

The roasting of sulfide ores such as pyrite, sphalerite, and cinnabar (mercury sulfide) also releases SO_2 *(Shriver and Atkins, 2010).*

$$4\ FeS_2 + 11\ O_2 \rightarrow 2\ Fe_2O_3 + 8\ SO_2$$
$$2\ ZnS + 3\ O_2 \rightarrow 2\ ZnO + 2\ SO_2$$
$$HgS + O_2 \rightarrow Hg + SO_2$$
$$4\ FeS + 7O_2 \rightarrow 2\ Fe_2O_3 + 4\ SO_2$$

A combination of these reactions is responsible for the largest source of sulphur dioxide, volcanic eruptions. These events can release millions of tonnes of SO_2 (*WHO, 2010).*

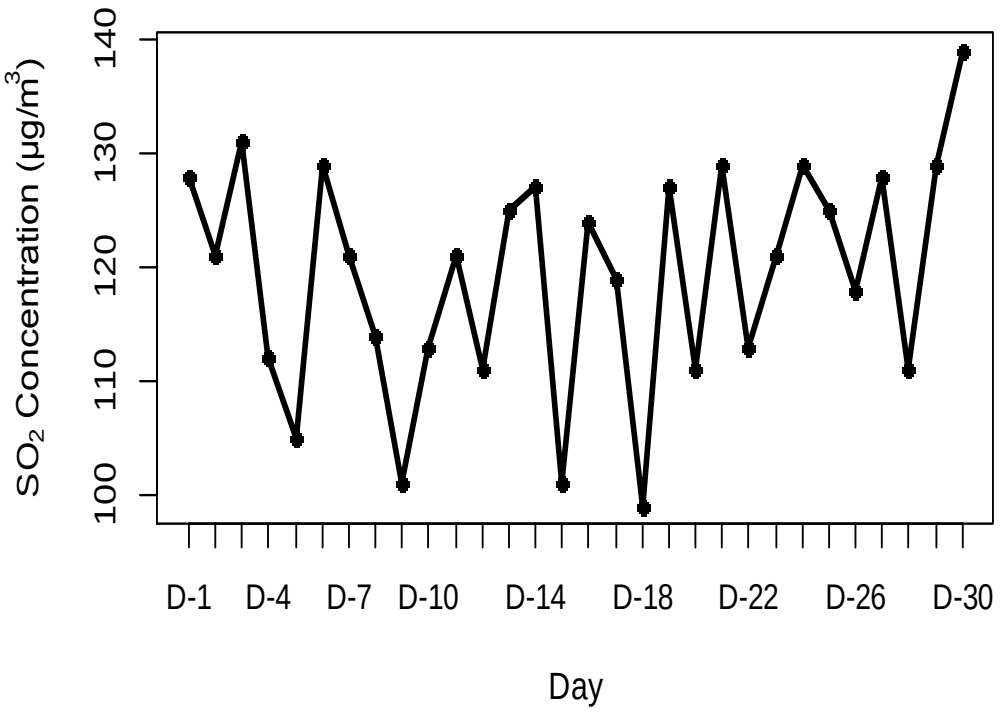


Fig. 4.3.6: Monthly variations in SO_2 Concentrations (µg/m³) in Dhaka city (June, 2011).

Sulphur dioxide (SO_2) concentrations (µg/m³) measured for 30 days in June, 2011 in Dhaka city presented in Fig 4.3.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 128 µg/m³, 121 µg/m³, 131 µg/m³,112 µg/m³, 105 µg/m³,129 µg/m³ presented table 4.5 . The highest value was 139µg/m³ in 30th June and the lowest value was 99 µg/m³ in 18th June .The reason behind the variation can be explained by the vehicular emissions of SO_2 during the holyday, rainy day, cloudy day in this time period. The average value is significantly different as the 95% confidence between 6th, 21th June and 30th June. The lowest value was found in 9th and 15th and 18th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays and for these reason the concentrations of SO_2 were low than the other days.

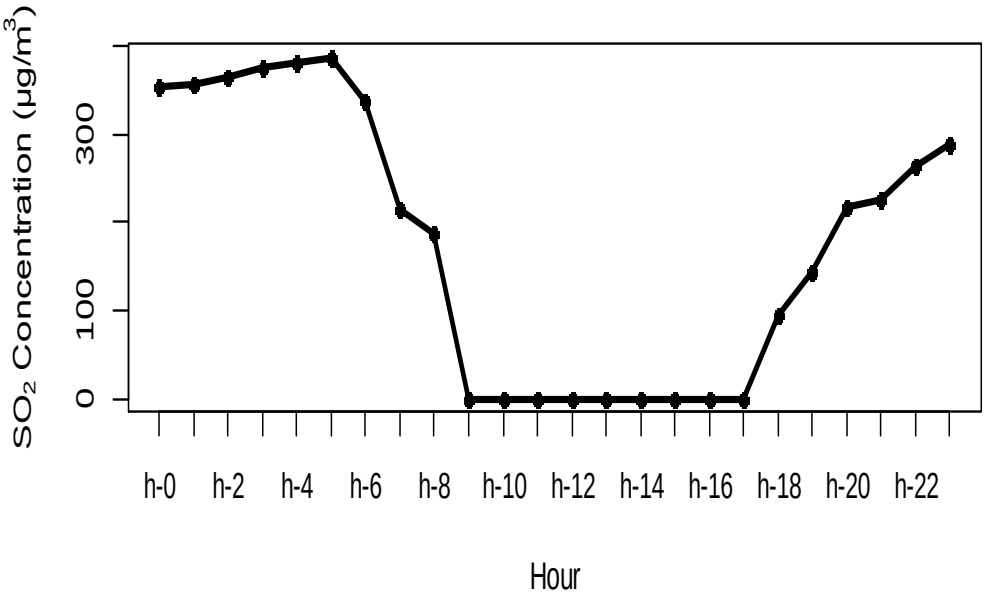


Fig. 4. 3.7: Diurnal variation in SO_2 Concentrations (µg/m³) in Dhaka city (3 June, 2011).

Sulphur dioxide (SO_2) concentrations (µg/m³) measured for 24 hours on 3 June, 2011 in Dhaka city (presented in Fig.4.3.7) shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 0 hour to 8 hour were 352 µg/m³, 356 µg/m³, 365 µg/m³, 376 µg/m³, 379 µg/m³, 386 µg/m³, 337 µg/m³ 214 µg/m³, 187 µg/m³ presented table 4.6 and then declined to 0 µg/m³ concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was 386 µg/m³ in 5 hour and the lowest value was 0 µg/m³ in 9 hour to 17 hour .The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction SO_2 is converted to SO_3 during this day time period. The SO_2 concentrations also varied with relative humidity. A significant negative correlation(r= 0.698 %) was obtained for SO_2 and relative humidity. The average value is significantly different as the 95% confidence between 0 hour to 8 hour and 9 hour to 17 hour. The average value is also significantly different as the 95% confidence between 0 hour to 8 hour and 18 hour to 23 hour.

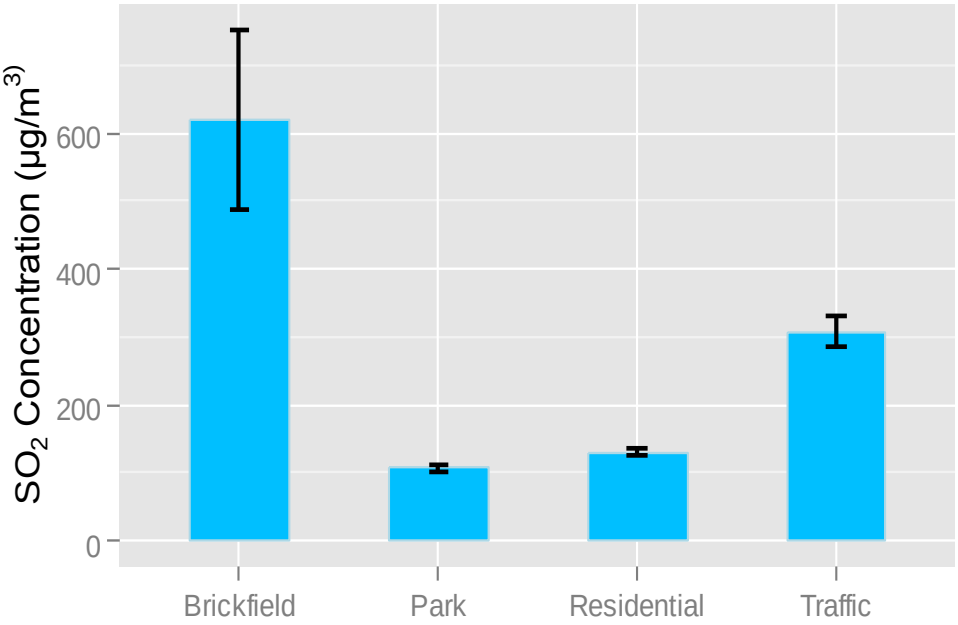


Fig. 4.3.8: Comparison of SO_2 Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Sulphur dioxide (SO_2) concentrations (µg/m^3) determined at residential area, traffic area, park, brick-field etc to observe the locational variation presented in Fig. 4.3.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in brick-field area 1243 µg/m^3 followed by traffic 423 µg/m^3, residential area 151 µg/m^3 and park area 141 µg/m^3 (Table 4.9) .The SO_2 concentration measured for brick-fields areas were significantly higher than that measured for park and residential areas at 95% confidence level. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of SO_2. Huge amount of running vehicles, long time traffic jam produced O_3 resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced SO_2 *(EPA, 2009).*

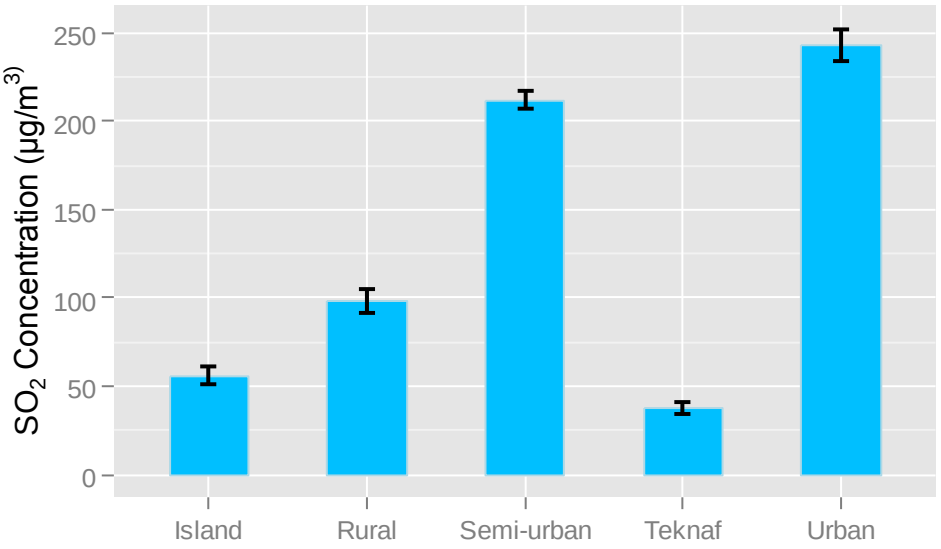


Fig.4.3.9: Comparison of SO_2 Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Sulphur dioxide (SO_2) concentrations (µg/m^3) varied significantly from urban to semi-urban, semi-urban to rural, island and teknaf. In urban - Farmgate, Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana, saidabad bus stand,Park, D.U.R/A, (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Aminbazar , Ashulia, Island- Saint Martin, Periy-rural- Teknaf in Bangladesh . The highest level of SO_2 concentrations was 243 µg/m^{3}in urban sites, 212 µg/m^3 in semi- urban, 98 µg/m^3 in rural, 56 µg/m^3 in St. Martin Island and 38 µg/m^3 in Teknaf (Peri –rural) (Table 4.16). The SO_2 concentration measured for urban areas were significantly higher than that measured for Rural, St. Martin Island, Teknaf areas at 95% confidence level.

4.4 TVOC Concentrations (µg/m^3) measured for Dhaka City during 2009 - 2011.

Total volatile organic compounds (TVOC) concentrations (µg/m$^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented tables: 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations in TVOC. The concentrations varied from 10548 µg/m^3 to 15881 µg/m^3 in the hot spots. Among the hot spots the maximum concentrations were measured for Farmgate 15881 µg/m^3 in 2011 followed by Science laboratory 14945 µg/m^3, Topkhana 14548 µg/m^3, Mouchak 14712 µg/m^3, Amin bazaar 13645 µg/m^3, Ashulia 12745 µg/m^3, Curzon hall 11257 µg/m^3. Breathing low levels of VOCs for long periods of time may increase some people's risk of health problems. Several studies suggest that exposure to VOCs may make symptoms worse in people who have asthma or are particularly sensitive to chemicals. These are much different exposures than occupational exposures to VOCs *(EPA, 2008*). The TVOC measured for Dhaka city and the exposure level is very much high. The concentrations of TVOC measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Both natural and anthropogenic sources contribute to the TVOC precursors, and the composition of emissions sources may show large variations across locations. VOCs occurring naturally due to emissions from trees and crop plants may account for as much as two thirds of ambient VOCs in some locations (*USEPA, 1986*). TVOC is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of ground-level TVOC precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the TVOC precursors. Total Volatile Organic Compounds (TVOC) concentrations are influenced by the intensity of solar radiation, the absolute concentration of NOx and VOCs, and the ratio of NOx and VOCs. A strong negative correlation (r = - 0.72) between O_3 and TVOC, negative correlation (r = - 0.70) between NO and TVOC and negative correlation (r = - 0.50) between TVOC and SO_2 obtained in the present investigation. That is TVOC concentration increased with a concomitant decrease in NO and O_3. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which TVOC is converted to O_3 during day time period. The TVOC concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for TVOC and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, TVOC accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak TVOC concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level TVOC rarely last longer than two to three hours *(WHO, 1979).*

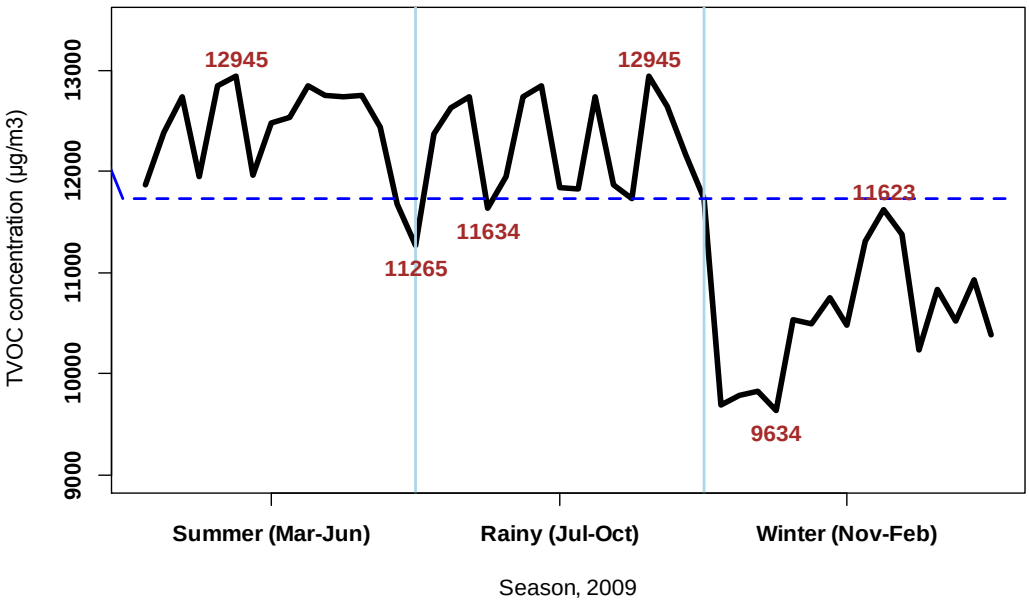


Fig. 4. 4.1: TVOC Concentrations (µg/m³) in 2009 in Dhaka City.

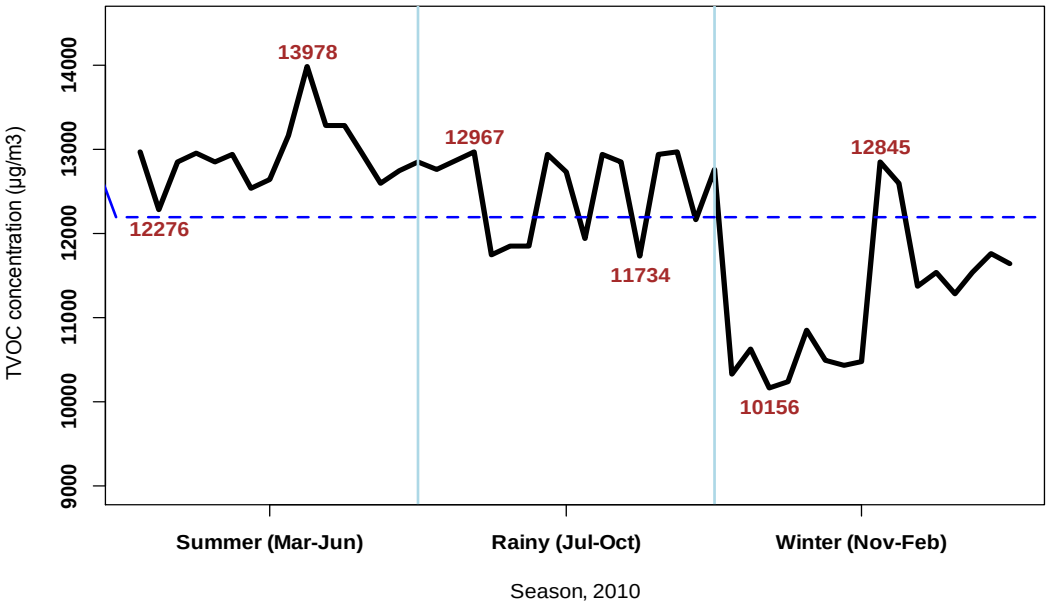


Fig. 4.4.2: TVOC Concentrations (µg/m³) in 2010 in Dhaka City.

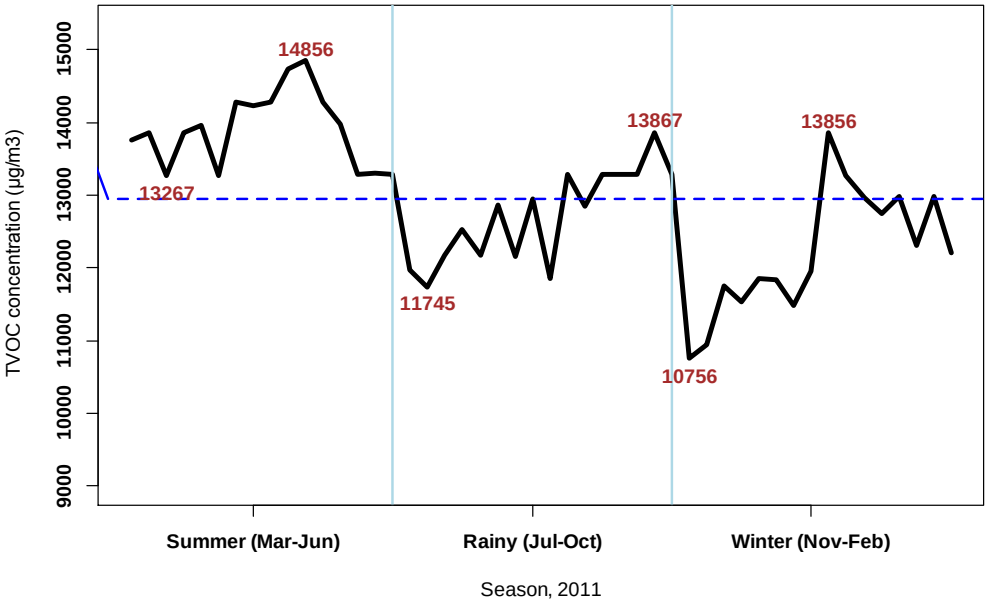


Fig. 4.4.3: TVOC Concentrations (µg/m^3) in 2011 in Dhaka City.

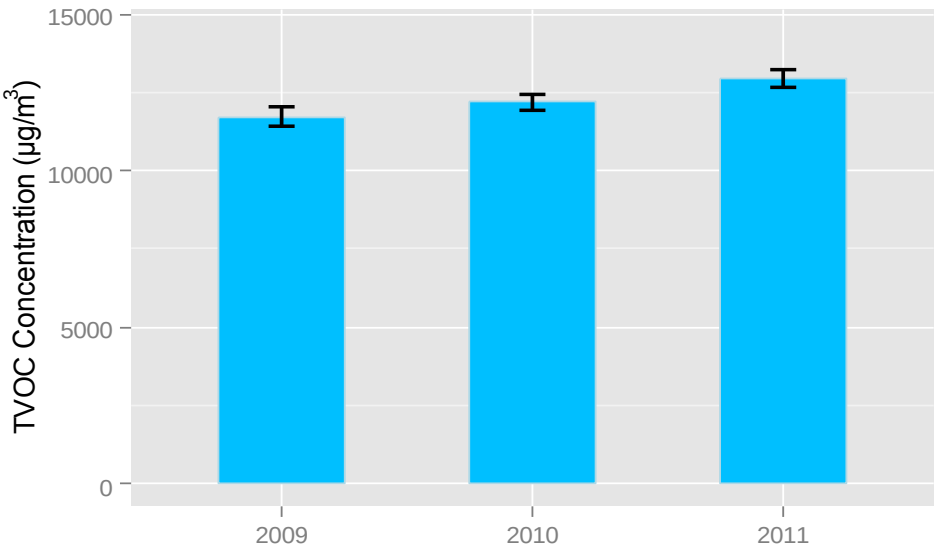


Fig. 4.4.4: Yearly variations in TVOC Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

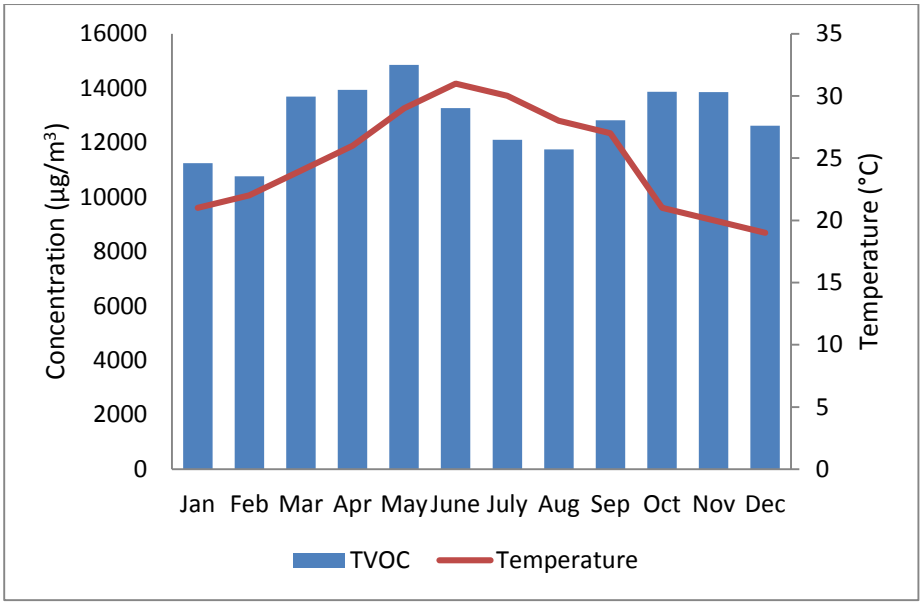


Fig. 4.4.5: TVOC variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition, there was also a seasonal variation in TVOC concentrations in summer, rainy and season winter. The Figs. 4.4.1, 4.4.2, 4.4.3 show that the highest TVOC concentration was measured in summer followed by rainy and winter season respectively.

It can be seen from Fig. 4.4.4 that there is an increasing trend in average TVOC concentration from year 2009 to 2011. Although the difference between the averages values for the years is significantly different as the 95% confidence.

It is often produced in domestic or industrial settings by older motor vehicles and other gasoline-powered tools, heaters, and cooking equipment. The reason behind the variation can be explained by the vehicular emissions of co during this time period. It is evident from the daily traffic movement on the street that the number of vehicles significantly increase during the day time especially between 9am – 17pm .The TVOC concentrations also varied with relative humidity. A significant correlation (r = 0.698 %) was obtained for TVOC and relative humidity. It is evident from the results that TVOC concentrations increased with increasing relative humidity. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of TVOC. A air mass trajectory analysis using HYSPLIT model (NOAA, 2012) showed that a substantial amount of TVOC are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

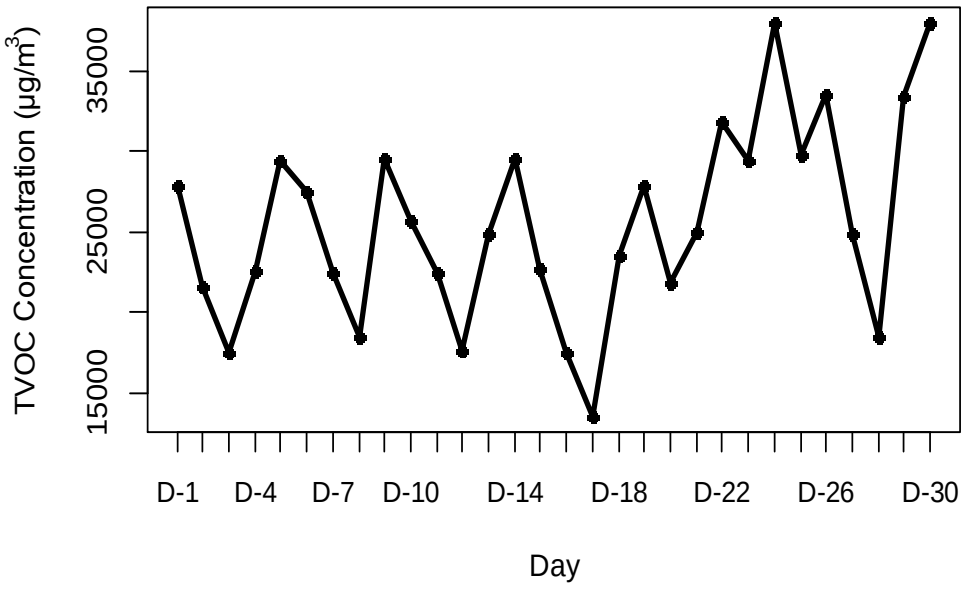


Fig. 4.4.6: Monthly variations in TVOC Concentrations (µg/m³) in Dhaka city (June, 2011).

Total Volatile Organic Compounds (TVOC) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city presented in Fig 4.4.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 27845 µg/m^3, 21548 µg/m^3, 17458 µg/m^3, 22548 µg/m^3, 29458 µg/m^3, 27451 µg/m^3 (Table 4.5) . The highest value was 37945 µg/m^3 in 24th June and 30th June and the lowest value was 17458µg/m^3 in 3th June .The reason behind the variation can be explained by the vehicular emissions of TVOC during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 3th June and 30th June. The lowest value was found in 2th and 3th, 12th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of TVOC were low than the other days.

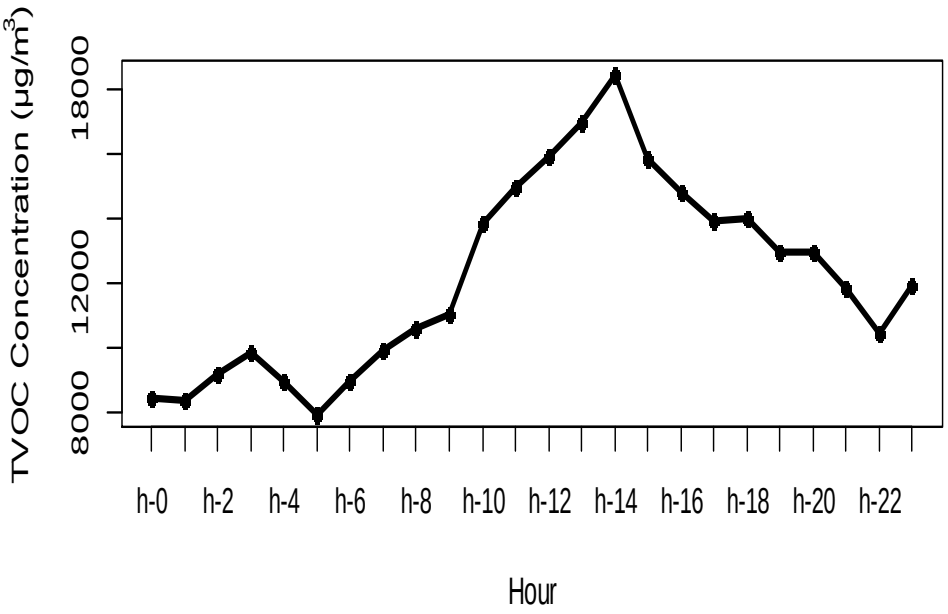


Fig. 4.4.7: Diurnal variation in TVOC Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Total Volatile Organic Compounds (TVOC) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city presented in Fig.4.4.7 shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 11 hour to 18 hour were 14978 µg/m^3, 15945 µg/m^3, 16956 µg/m^3, 18454 µg/m^3, 15845 µg/m^3, 14834 µg/m^3, 13956 µg/m^3, 13978 µg/m^3 (Table 4.6).The highest value was 18454 µg/m^3 in 14 hour and the lowest value was 8385 µg/m^3 in 1 hour. The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction convert to another gases during this day time period. The reason behind the variation can be explained by the vehicular emissions of TVOC during this time period. It is evident from the daily traffic movement on the street that the number of vehicles significantly increase during the day time especially between 11 am – 18 pm .The TVOC concentrations also varied with relative humidity. Fig. 4.4.7 that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence level in 24 hours.

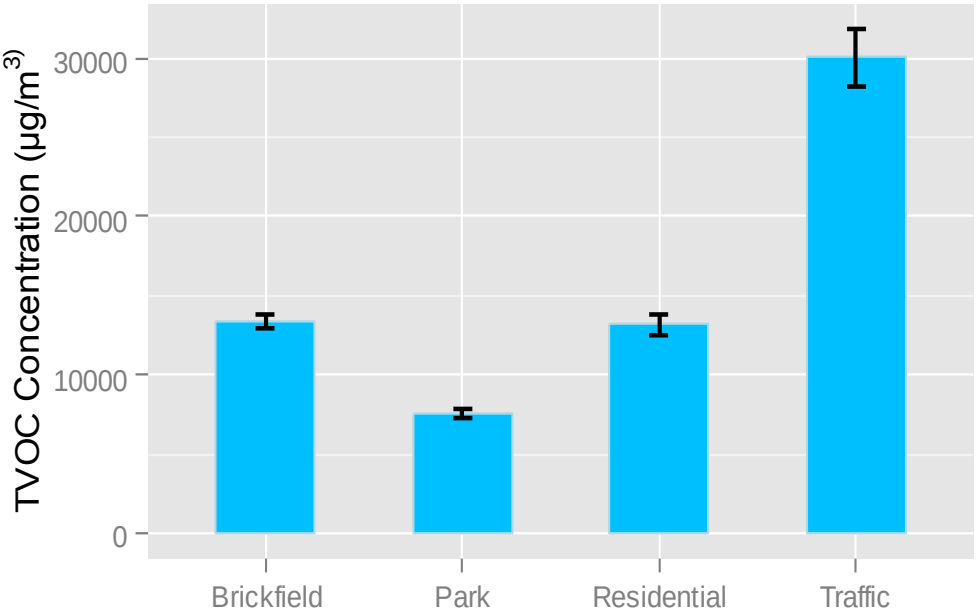


Fig. 4.4.8: Comparison of TVOC Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Total Volatile Organic Compounds TVOC concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation. Presented in Fig 4.2.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in traffic area 29678 µg/m^3 in 2010 followed by brick-field 15634 µg/m^3 in 2011, residential area 16857 µg/m^3 in 2011and park area 8974 µg/m^3 in 2011 (Table 4.10) . Although the difference between traffic and residential area, the average value is significantly different as the 95% confidence. The average value is significantly different as the 95% confidence between brickfield and park. The average value is significantly different as the 95% confidence between traffic and park. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of TVOC. Huge amount of running vehicles, long time traffic jam produced TVOC resulting in a air pollution. To use low quality coal, wood in brick-kilns to produce a huge amount of TVOC *(EPA, 2009).*

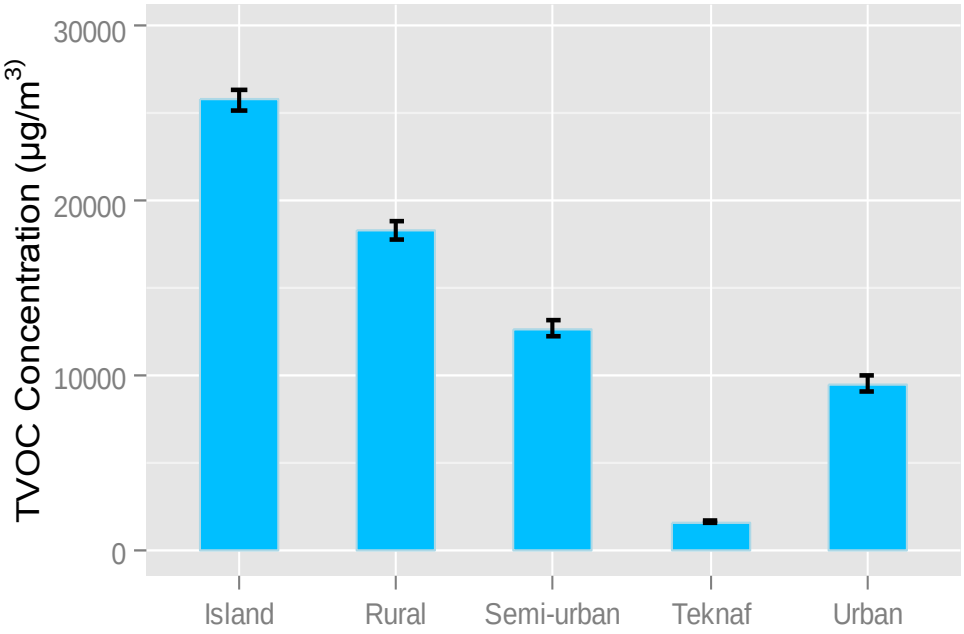


Fig.4.4.9: Comparison of TVOC Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Total Volatile Organic Compounds TVOC concentrations varied significantly from urban to semi-urban, semi-urban to rural, island and teknaf. In urban - Farmgate , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana,saidabad bus stand,Park, D.U.R/A, (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Aminbazar , Asholia, Island- Saint Martin, Periy-rural- Teknaf in Bangladesh. The highest level of TVOC concentrations 25768 µg/m^3 was measured in St. Martin Island areas followed by 18290 µg/m^3 in rural, 12645 µg/m^3 in semi-urban (Table 4.16). The TVOC concentrations measured for St. Martin Island area was significantly higher than that measured for urban and Teknaf areas at 95% confidence.

4.5 NO Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Nitric oxide (NO) concentrations (µg/m$^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented in tables 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations in ground level NO. The concentrations varied from 124 µg/m^3 to 178 µg/m^3 in the hot spots. Among the hot spots the maximum concentrations were measured for Farm-gate 178 µg/m^3 in 2011 followed by Ashulia 167 µg/m^3, Amin bazar 166 µg/m^3, Mouchak 159 µg/m^3, Science laboratory 155 µg/m^3, Topkhana 144 µg/m^3, Curzon hall 141 µg/m^3. NO nitric oxide (NO) however, was detected in any of the spots between 9 hours to17 hours.The concentrations of NO measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of NO in Dhaka city for three years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 101- 135 µg/m^3. The highest levels 135 µg/m^3 was measured in the month of January (in winter) and the lowest level was 101 in the month of June (in rainy season) with an average 121 µg/m^3 (Table: 4.17).

NO_x is a generic term for mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. NOx gases are formed everywhere where there is combustion – like in an engine. In atmospheric chemistry, the term means the total concentration of NO and NO_2. NO_x react to form smog and acid rain. NO_x are also central to the formation of troposphere ozone. NO_x should not be confused with nitrous oxide (N_2O), which is a greenhouse gas and has many uses as an oxidizer, an anesthetic, and a food additive *(WHO, 2012).*

Both natural and anthropogenic sources contribute to the ground-level NO precursors, and the composition of emissions sources may show large variations across locations. VOCs occurring naturally due to emissions from trees and crop plants may account for as much as two thirds of ambient VOCs in some locations (*USEPA, 1986*). NO is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs) which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of NO precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the NO precursors. Nitric oxide concentrations are influenced by the intensity of solar radiation, the absolute concentration of NOx and VOCs, and the ratio of NOx and VOCs. A strong negative correlation (r = - 0.70) between NO and TVOC, positive correlation (r = 0.76) between NO and H_2S and positive correlation (r = 0.81) between NO and O_3 obtained in the present investigation. That is H_2S concentration increased with a concomitant decrease in TVOC. Whereas, the concentrate in increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which NO are converted to O_2 during day time period. The NO concentrations also varied with relative humidity. A significant positive

correlation (r = 0.698) was obtained for NO and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level NO accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Mean concentrations are generally highest in the summer. Peak concentrations of ground-level NO rarely last longer than two to three hours *(WHO, 1979).*

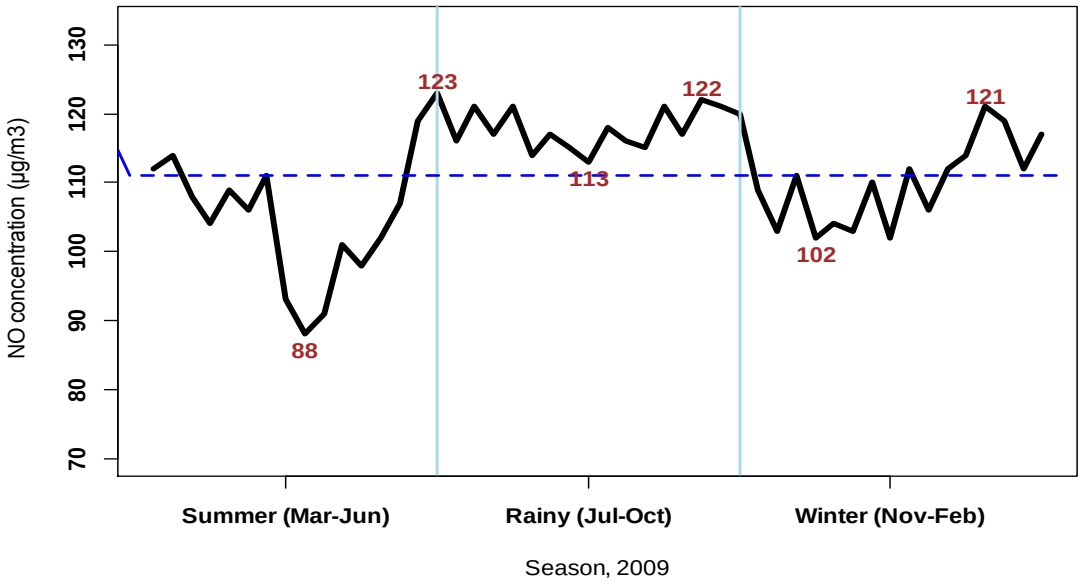


Fig. 4. 5.1: NO Concentrations (µg/m^3) in 2009 in Dhaka City.

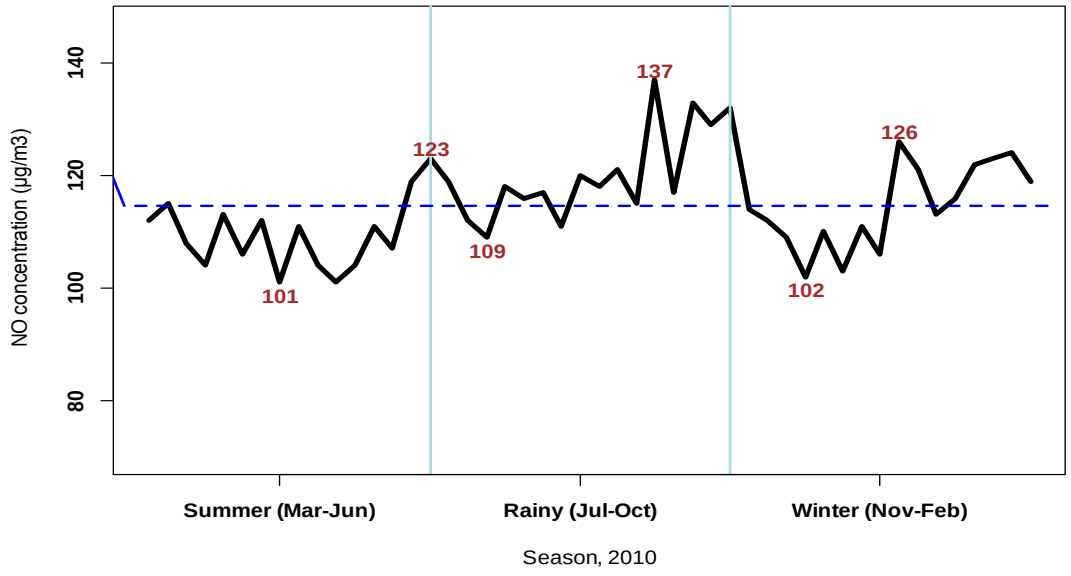


Fig. 4. 5.2: NO Concentrations (µg/m^3) in 2010 in Dhaka City.

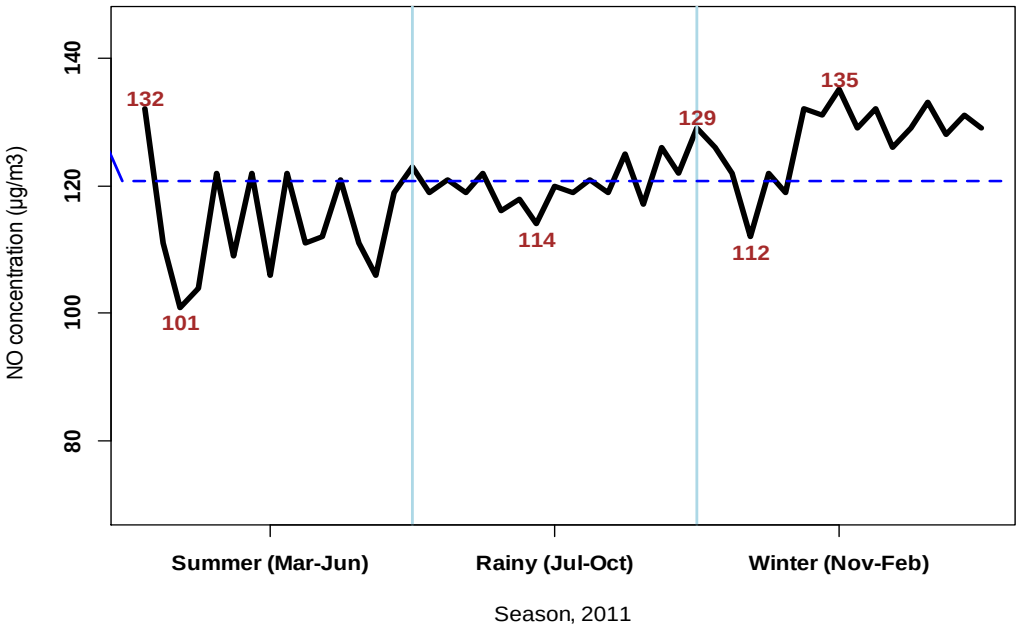


Fig. 4. 5.3: NO Concentrations (µg/m^3) in 2011 in Dhaka City.

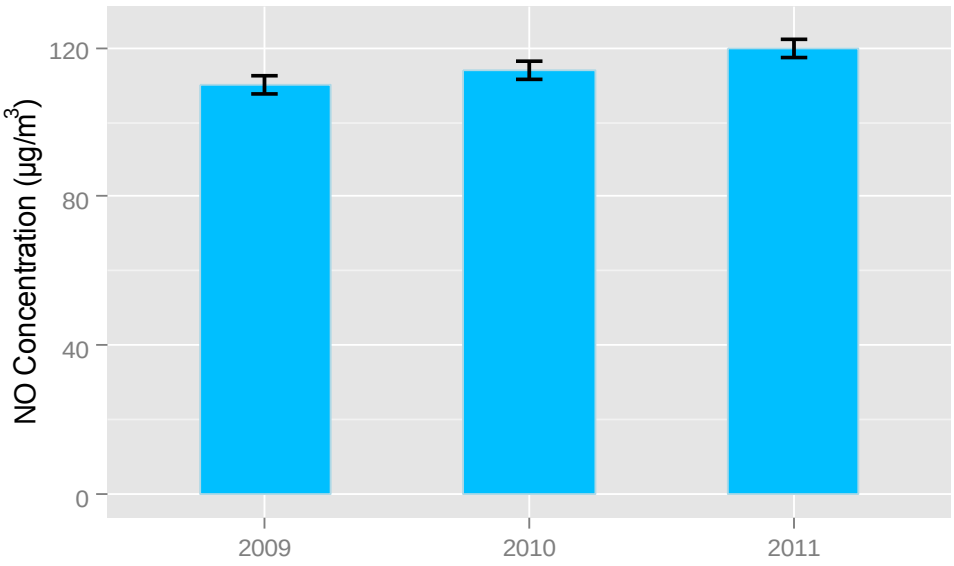


Fig. 4.5.4: Yearly variations in NO Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

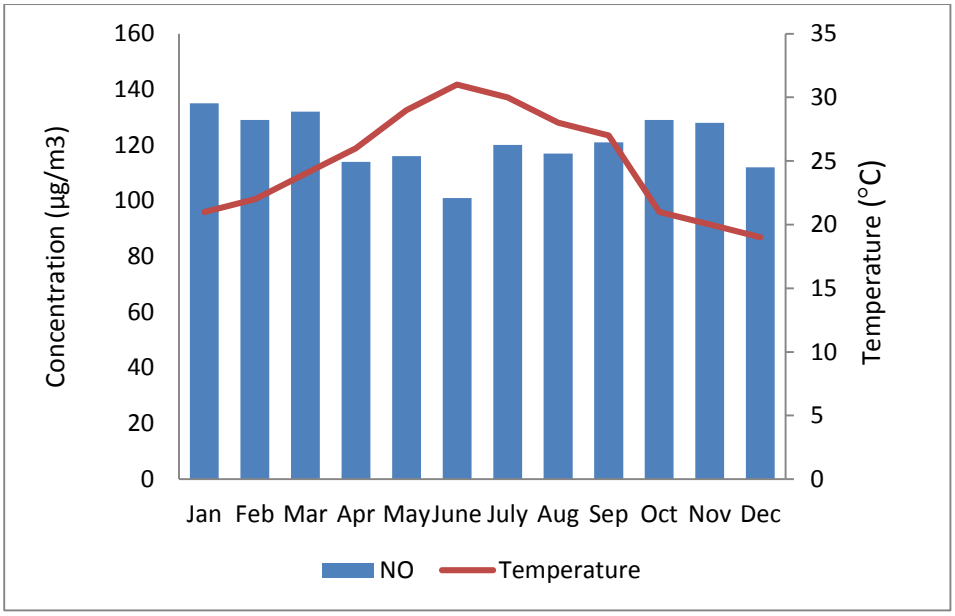


Fig. 4.5.5: NO variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition there was also seasonal trend where in summer, rainy and winter season. The Fig. 4.5.1, 4.5.2, 4.5.3 shows that the NO concentration was highest value in winter season followed by rainy and summer season.

From Fig. 4.5.4 shows that there is a increasing trend in average concentration of NO from year 2009-2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are over lapped.

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO convert to another gases during this day time period. The NO concentrations also varied with relative humidity. A significant correlation(r= 0.698 %) was obtained for NO and relative humidity. NO concentrations increase with increasing hydrocarbons and decrease with increasing NOx.

It is evident from the results that NO concentrations increased with increasing relative humidity. The atmospheric chemistry involved in ozone formation is complex. Ultraviolet (uv) radiation from the sun breaks down nitrogen dioxide (NO_2) into nitrogen oxide and atomic oxygen -

$NO_2 + uv - NO + O$

Oxygen atoms combine with oxygen molecules to form ozone -

$O + O_2 - O_3$

However, ozone will not accumulate when nitrogen oxide is present, as the two molecules react to reform nitrogen dioxide and oxygen -

$NO + O_3 - NO_2 + O_2$

The oxygen in these molecules allows NO to form NO_2, without breaking down ozone, thus ozone accumulates. When exposed to oxygen, NO is converted into nitrogen dioxide.

$2\ NO + O_2 \rightarrow 2\ NO_2$

This conversion has been speculated as occurring via the ONOONO intermediate. In water, NO reacts with oxygen and water to form HNO_2 or nitrous acid. The reaction is thought to proceed via the following stoichiometry:

$4\ NO + O_2 + 2\ H_2O \rightarrow 4\ HNO_2$

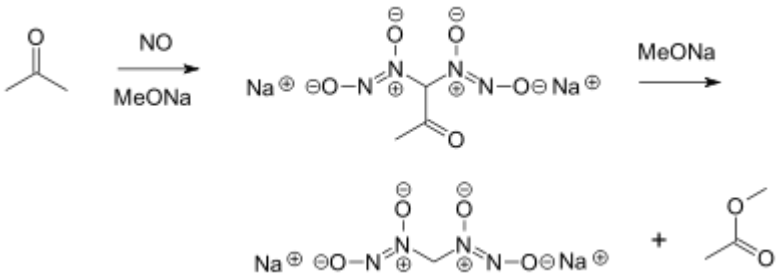
NO will react with fluorine, chlorine, and bromine to form the XNO species, known as the nitrosyl halides, such as nitrosyl chloride. Nitrosyl iodide can form but is an extremely short-lived species and tends to reform I_2.

$2\ NO + Cl_2 \rightarrow 2\ NOCl$

Nitroxyl (HNO) is the reduced form of nitric oxide.

Nitric oxide dimer N_2O_2 is formed when nitric oxide is cooled.

Nitric oxide reacts with acetone and an alkoxide to a *diazeniumdiolate* or *nitrosohydroxylamine* and methyl acetate (*Traube and Wilhelm , 1898).*



This reaction was discovered around 1898, and remains of interest today in NO prod rug research. Nitric oxide can also react directly with sodium meth oxide, forming sodium format and nitrous oxide *(Derosa et.al., 2008).*

Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of NO. A air mass trajectory analysis using HYSPLIT model (*NOAA, 2012)* showed that a substantial amount of NO are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

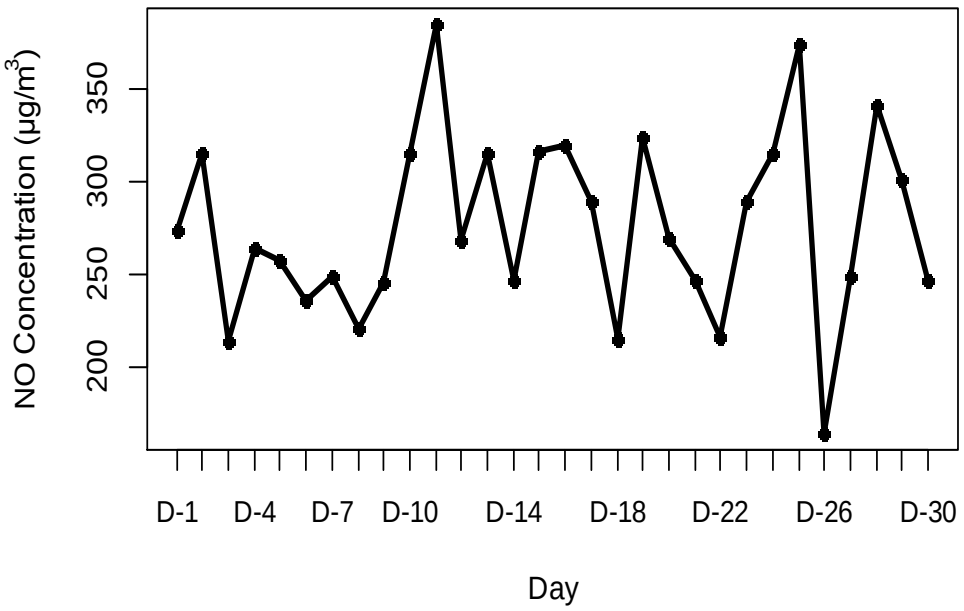


Fig. 4. 5.6: Monthly variations in NO Concentrations (µg/m^3) in Dhaka city (June, 2011).

Nitric oxide (NO) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city presented in Fig 4.5.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 274 µg/m^3, 315 µg/m^3, 214 µg/m^3,264 µg/m^3, 258 µg/m^3,236 µg/m^3 (Table 4.5) . The highest value was 384 µg/m^3 in 11th June and the lowest value was 164 µg/m^3 in 26th June .The reason behind the variation can be explained by the vehicular emissions of NO during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 26th, 11th June and 5th June. The lowest value was found in 26th and 3th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of NO were low than the other days.

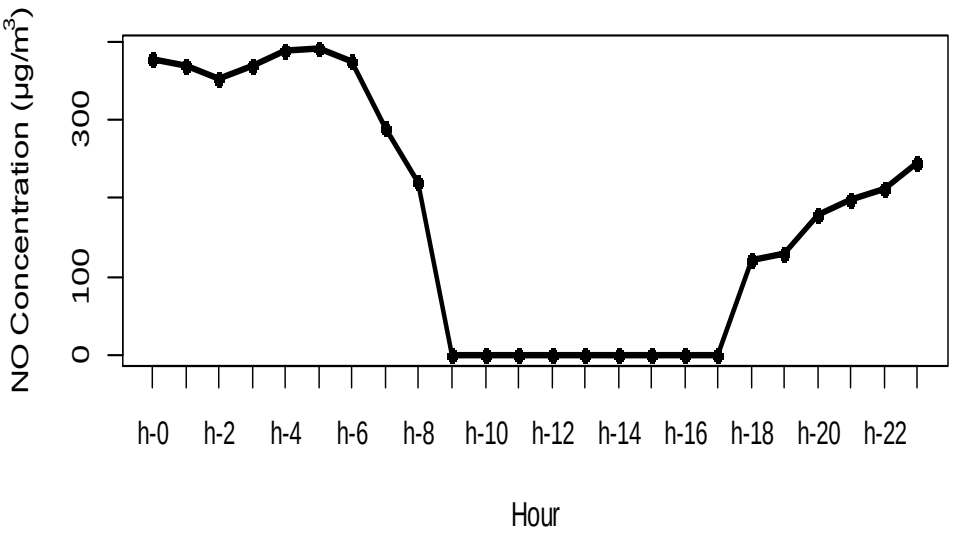


Fig. 4.5.7: Diurnal variation in NO Concentrations (µg/m³) in Dhaka city (3 June, 2011).

Nitric oxide (NO) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city (presented in Fig.4.5.7) shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 0 hour to 8 hour were 378 µg/m^3, 368 µg/m^3, 352 µg/m^3, 368 µg/m^3, 389 µg/m^3, 391 µg/m^3, 373 µg/m^3, 289 µg/m^3, 219 µg/m^3 (Table 4.6) and then declined to 0 µg/m^3 concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was 378 µg/m^3 in 0 hour and the lowest value was 0 µg/m^3 in 9 hour to 17 hour .The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO convert to another gases during this day time period. The NO concentrations also varied with relative humidity. A significant negative correlation(r = 0.698 %) was obtained for NO and relative humidity. NO concentrations increase with increasing hydrocarbons and decrease with increasing NOx. Presented in Fig 4.5.7 shows that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence between 0 hour to 8 hour and 9 hour to 17 hour. The average value is also significantly different as the 95% confidence between 0 hour to 8 hour and 18 hour to 23 hour.

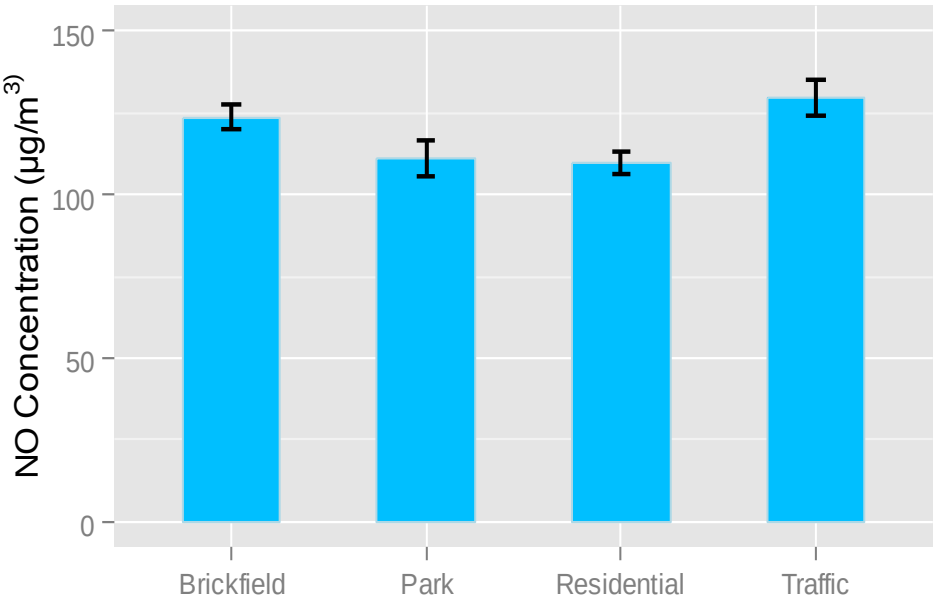


Fig. 4.5.8 Comparison of NO Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Nitric oxide (NO) concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation. Presented in Fig 4.5.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in traffic area 171 µg/m^3 followed by brick-field 139 µg/m^3, residential area 122 µg/m^3 and park area 138 µg/m^3 (Table 4.11). Although the difference between traffic and residential area, the average value is significantly different as the 95% confidence. The average value is significantly different as the 95% confidence between brickfield and park. The average value is significantly different as the 95% confidence between traffic and park. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of NO. Huge amount of running vehicles, long time traffic jam produced NO resulting in a air pollution. To use low quality coal, wood in brick-kilns to produced NO.

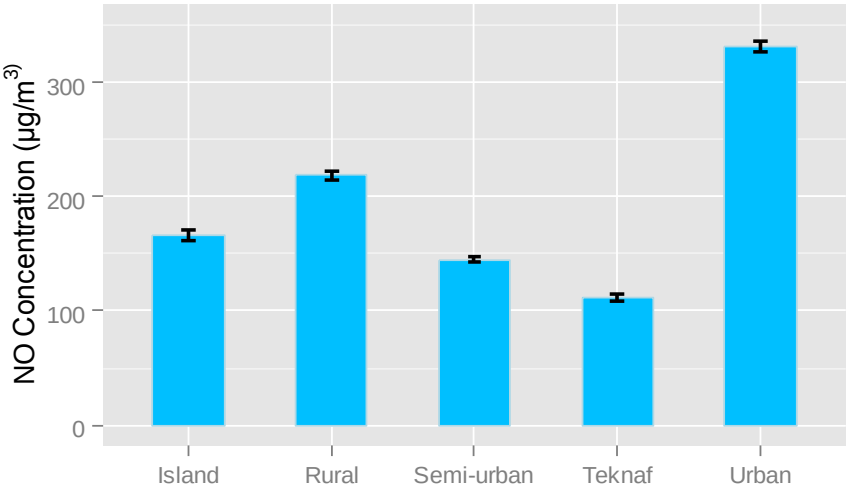


Fig.4.5.9: Comparison of NO Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Nitric oxide (NO) concentrations varied significantly from urban to semi-urban, semi-urban to rural, island and teknaf. In urban - Farm gat , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana, saidabad bus stand,Park, D.U.R/A, (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Aminbazar , Asholia, Island- Saint Martin, Periy-rural- Teknaf in Bangladesh .The average concentrations of NO was 332 µg/m^{3}in urban sites, 145 µg/m^3 in semi- urban, 219 µg/m^3 in rural, 167µg/m^3 in Saint. Martin island and 112 µg/m^3 in Teknaf (Periy –rural) (Table 4.16).The Fig. 4.7.9 shows that the highest NO was found in Urban area followed by rural, teknaf , Island due to vegetations, vehicles emissions , photochemical reaction between NO and O_2 . The average value is significantly different as the 95% confidence between urban and semi-urban, semi-urban and rural, teknaf and urban, semi-urban and Island.

4.6 NO_2 Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Nitrogen di oxide (NO_2) concentrations (µg/$m^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 (Table: 4.4.1, 4.4.2 and 4.4.3). The tables show a significant level of spatial and temporal variations in ground level NO_2. The concentrations varied from 157 µg/m^3 to 264 µg/m^3 in the spots. Among the hot spots the maximum concentrations were measured for Farmgate 264 µg/m^3 in 2011 followed by Amin bazaar 261 µg/m^3, Ashulia 257 µg/m^3, Science laboratory 257µg/m^3, Mohakhali 259 µg/m^3, Mouchak 244 µg/m^3, Topkhana 229 µg/m^3, Curzon hall 155 µg/m^3. NO nitrogen di oxide (NO_2) however, was detected in any of the spots between 0 hours to 5 hours. The concentrations of NO_2 measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of NO_2 in Dhaka city for three years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 104- 149 µg/m^3. The highest levels 149 µg/m^3 was measured in the month of May (in summer season) and the lowest level was 104 in the month of January (in winter season) with an average 126 µg/m^3 (Table: 4.17).

NO_x is a generic term for mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. NOx gases are formed everywhere where there is combustion – like in an engine. In atmospheric chemistry, the term means the total concentration of NO and NO_2. NO_x react to form smog and acid rain. NO_x are also central to the formation of troposphere ozone. NO_x should not be confused with nitrous oxide (N_2O), which is a greenhouse gas and has many uses as an oxidizer, an anesthetic, and a food additive *(WHO, 2012).*

Both natural and anthropogenic sources contribute to the NO_2 precursors, and the composition of emissions sources may show large variations across locations. VOCs occurring naturally due to emissions from trees and crop plants may account for as much as two thirds of ambient VOCs in some locations (*USEPA, 1986*). NO is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of NO precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the NO_2 precursors. A strong negative correlation (r = - 0.70) between NO_2 and TVOC, positive correlation (r = 0.81) between NO_2 and O_3 and negative correlation (r = 0.27) between H_2S and NO_2 obtained in the present investigation. That is NO_2 concentration increased with a concomitant decrease in TVOC and NO_2. Whereas, the concentrate in increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which NO_2 is converted to O_2 during day time period. The NO_2 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for NO_2 and

relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level NO_2 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak ground-level NO_2 concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level NO_2 rarely last longer than two to three hours *(WHO, 1979).*

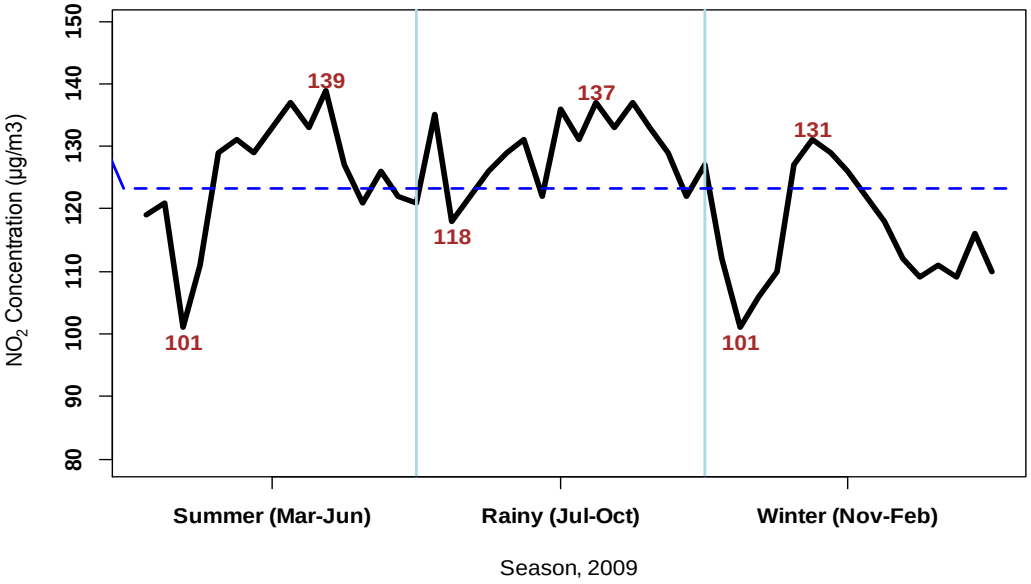


Fig. 4. 6.1: NO_2 Concentrations (µg/m^3) in 2009 in Dhaka City.

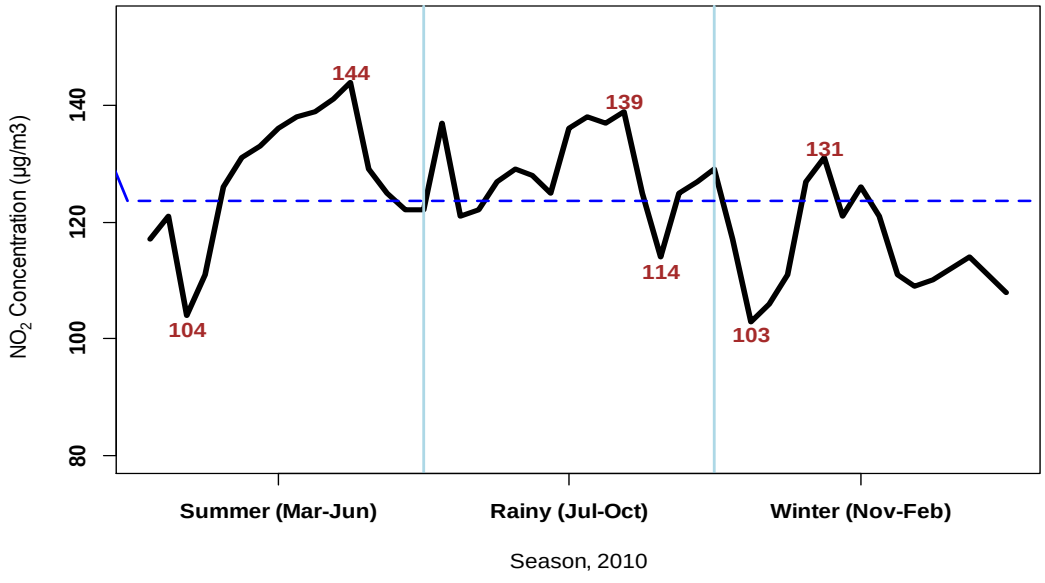


Fig. 4. 6.2: NO_2 Concentrations (µg/m^3) in 2010 in Dhaka City.

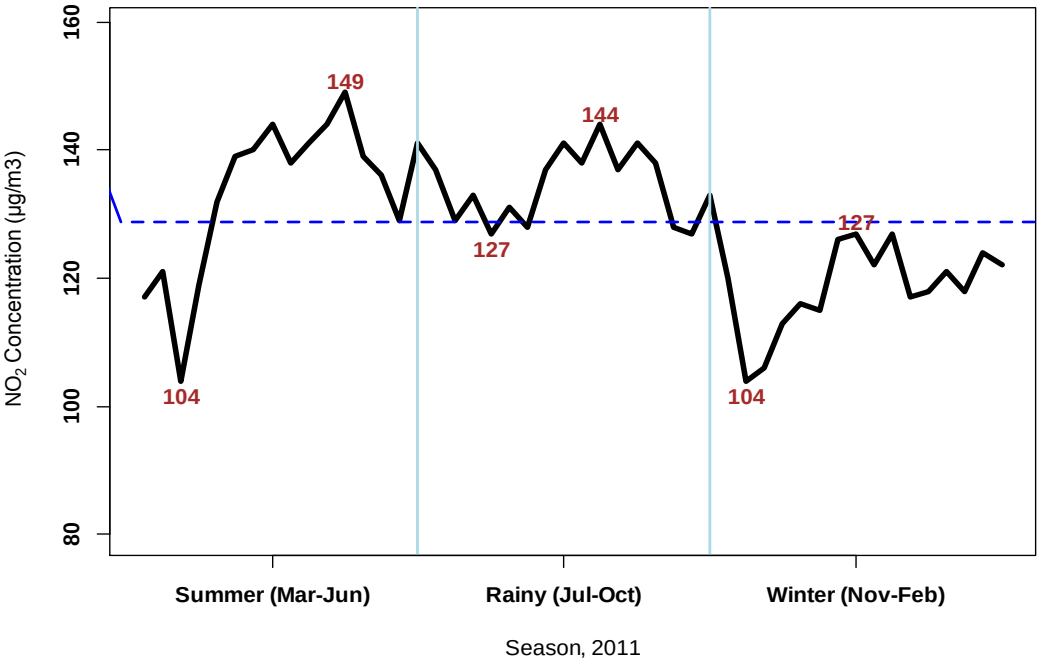


Fig. 4. 6.3: NO_2 Concentrations (µg/m^3) in 2011 in Dhaka City.

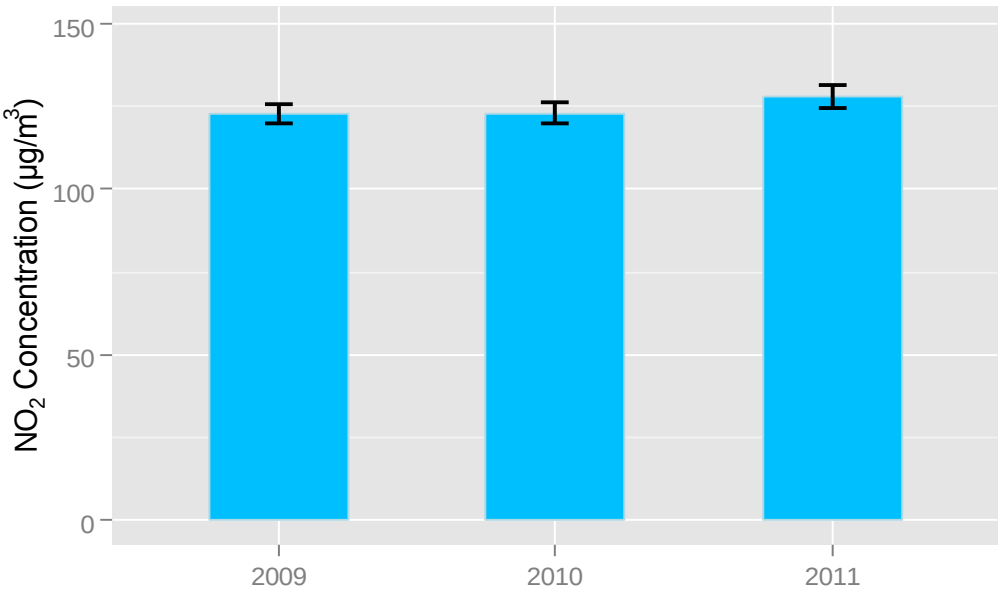


Fig. 4.6.4 : Yearly variations in NO_2 Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

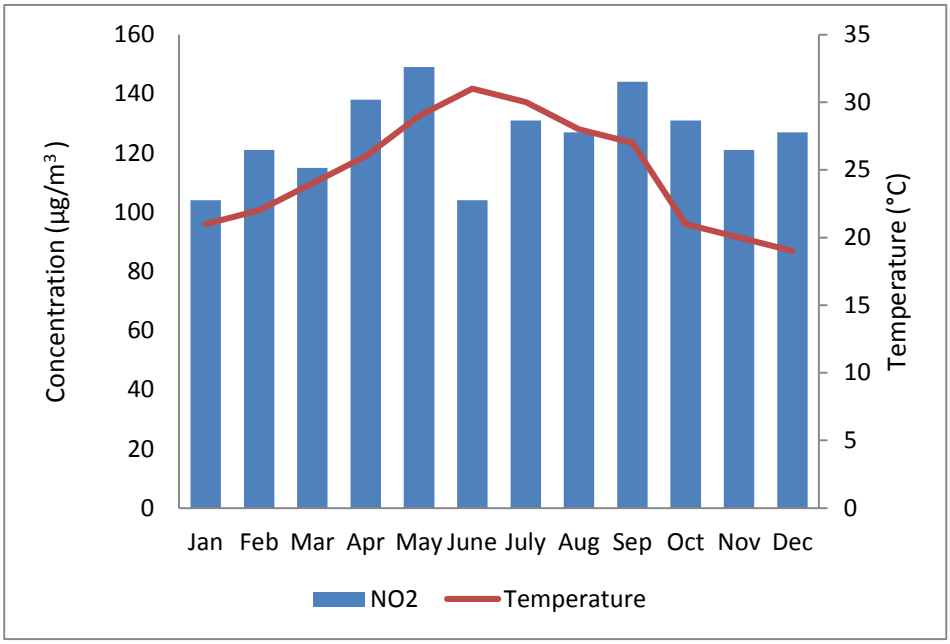


Fig. 4.6.5: NO_2 variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition there was also seasonal trend where in summer, rainy and winter season. The Fig. 4.6.1, 4.6.2, 4.6.3 shows that the NO_2 concentration was highest value in summer season followed by rainy and winter season.

From Fig. 4.6.4 shows that there is an increasing trend in average concentration of NO_2 from year 2009-2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are over lapped.

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO_2 convert to another gases during this day time period. The NO_2 concentrations also varied with relative humidity. A significant correlation(r= 0.698 %) was obtained for NO_2 and relative humidity. NO_2 concentrations increase with increasing hydrocarbons and decrease with increasing NOx .

It is evident from the results that NO_2 concentrations increased with increasing relative humidity. The atmospheric chemistry involved in ozone formation is complex. Ultraviolet (uv) radiation from the sun breaks down nitrogen dioxide (NO_2) into nitrogen oxide and atomic oxygen -

NO_2 + uv - NO + O

Oxygen atoms combine with oxygen molecules to form ozone -

O + O_2 - O_3

However, ozone will not accumulate when nitrogen oxide is present, as the two molecules react to reform nitrogen dioxide and oxygen -

$NO + O_3 - NO_2 + O_2$

Problems occur when volatile organic pollutants (VOCs) such as hydrocarbons, react in the atmosphere to form oxygenated products such as baldheads. The oxygen in these molecules allows NO to form NO_2, without breaking down ozone, thus ozone accumulates. The build-up of ozone therefore depends upon the relative concentrations of nitrogen oxides, hydrocarbons and other pollutants, and sunlight. It takes time for the ozone to accumulate as the chemical reactions involved are quite slow - ozone builds up in polluted air masses *(Joel et. al., 1984).*

Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of NO_2. A air mass trajectory analysis using HYSPLIT model (NOAA, 2012) showed that a substantial amount of NO_2 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

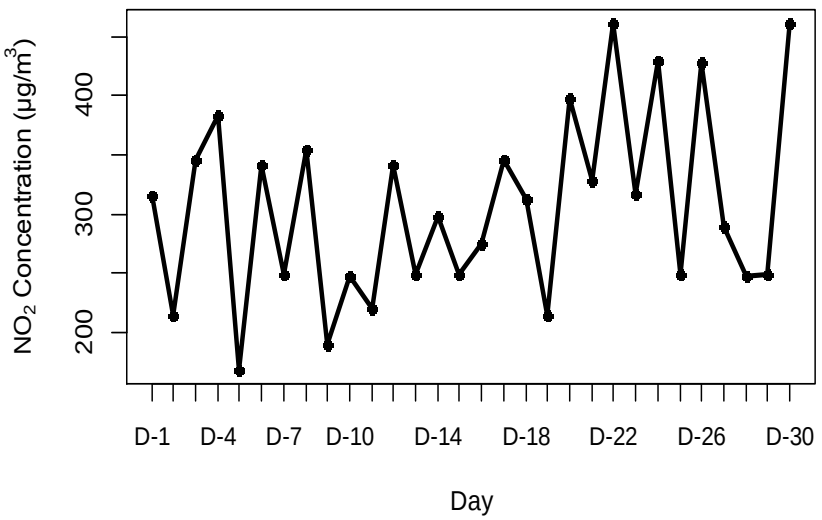


Fig. 4.6.6: Monthly variations in NO_2 Concentrations (µg/m^3) in Dhaka city (June, 2011).

Nitrogen di oxide (NO_2) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city (presented in Fig 4.5.6 shows that the concentrations varied significantly from 1st

June to 30thJune. The Concentrations measured on 1st, 2th, 3th ,4th,5th,6th June were 315 µg/m^3, 214 µg/m^3, 345 µg/m^3, 384 µg/m^3, 167 µg/m^3, 341 µg/m^3 (Table 4.5) . The highest value was 461 µg/m^3 in 30th June and the lowest value was 167µg/m^3 in 5th June .The reason behind the variation can be explained by the vehicular emissions of NO_2 during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 26th, 11th June and 5th June. The lowest value was found in 26th and 3th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of NO_2were low than the other days.

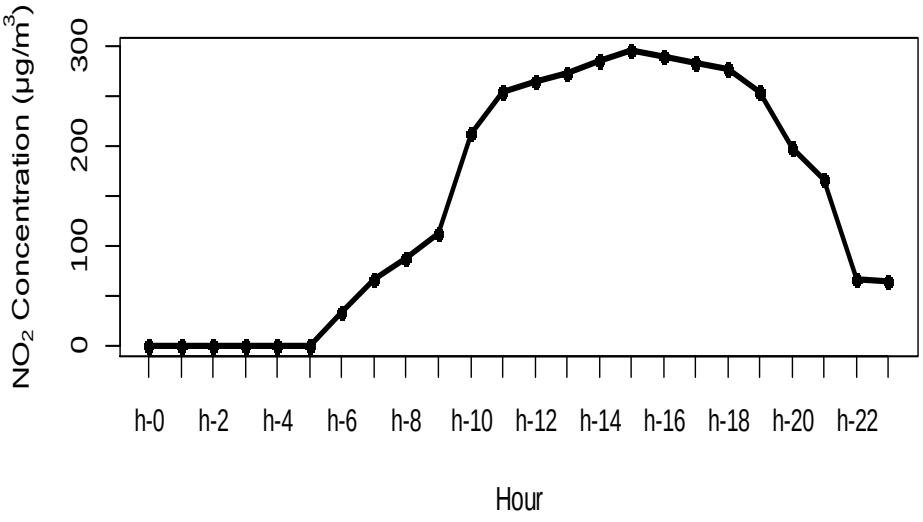


Fig. 4.6.7: Diurnal variation in NO_2 Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Nitrogen di oxide (NO_2) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city (presented in Fig.4.6.7) shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 10 hour to 18 hour were 213 µg/m^3, 254 µg/m^3, 265 µg/m^3, 272 µg/m^3, 286 µg/m^3, 296 µg/m^3, 289 µg/m^3, 283 µg/m^3, 278 µg/m^3 (Table 4.6) and then declined to 0 µg/m^3 concentrations between 9h -17h and then again regain concentrations slowly increasing 18h -24h. The highest value was 296 µg/m^3 in 15 hour and the lowest value was 0 µg/m^3 in 0 hour to 5 hour .The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NO_2 convert to another gases during this day time period. The NO concentrations also varied with relative humidity. A significant correlation (r= 0.698 %) was obtained for $NO_2$and relative humidity. NO_2 concentrations increase with increasing hydrocarbons and decrease with increasing NOx. Presented in Fig 4.6.7 shows that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence between 0 hour to 9 hour and 10 hour to 23 hour. The average value is also significantly different as the 95% confidence between 0 hour to 18 hour and 18 hour to 23 hour.

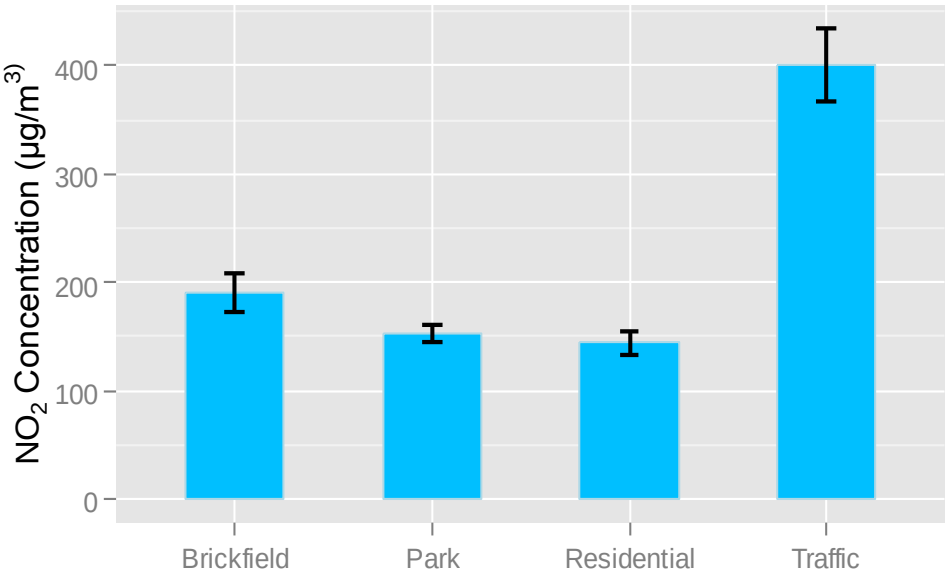


Fig. 4. 6.8: Comparison of NO_2 Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Nitrogen di oxide (NO_2) concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation. Presented in Fig 4.6.8 shows that the concentrations varied significantly from place to place. The highest concentrations measured in traffic area 542 µg/m^3 followed by brick-field 295 µg/m^3, residential area 217 µg/m^3 and park area 198 µg/m^3 (Table 4.12). Although the difference between traffic and residential area, the average value is significantly different as the 95% confidence. The average value is significantly different as the 95% confidence between brickfield and park. The average value is significantly different as the 95% confidence between traffic and park. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of NO_2. Huge amount of running vehicles, long time traffic jam produced NO_2 resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced NO_2.

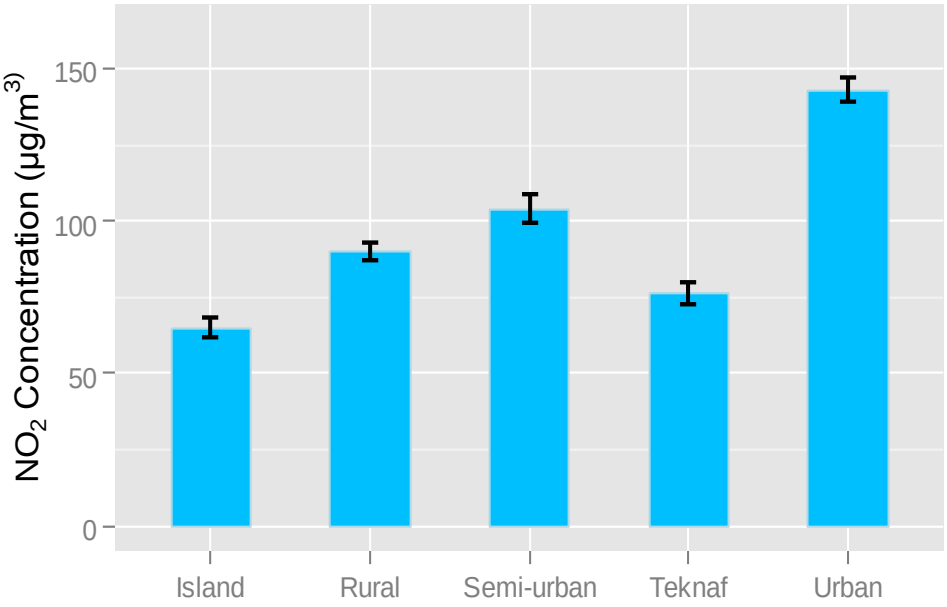


Fig.4.6.9: Comparison of NO_2 Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Nitrogen di oxide (NO_2) concentrations varied significantly from urban to semi-urban, semi-urban to rural, island and teknaf. In urban - Farm gat , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana,saidabad bus stand,Park, D.U.R/A, (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Aminbazar , Asholia, Island-Saint Martin, Periy-rural- Teknaf in Bangladesh .The average concentrations of NO_2 was 143 µg/m^3in urban sites, 104 µg/m^3 in semi- urban, 90 µg/m^3 in rural, 65 µg/m^3 in Saint. Martin island and 76 µg/m^3 in Teknaf (Periy –rural) (Table 4.16).The Fig.4.6.9 shows that the highest NO_2 was found in Urban area followed by semi- urban, rural, teknaf , Island due to vegetations, vehicles emissions , photochemical reaction between NO_2 and NO. The average value is significantly different as the 95% confidence between urban and semi-urban, semi-urban and rural, teknaf and urban, semi-urban and Island.

4.7 PH_3 Concentrations ($\mu g/m^3$) measured for Dhaka City during 2009 -2011.

Phosphine (PH_3) concentrations ($\mu g/m^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented in tables 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations in ground level PH_3. The concentrations varied from 68 $\mu g/m^3$ to 118 $\mu g/m^3$ in the spots. Among the hot spots the maximum concentrations were measured for Amin bazar 118 $\mu g/m^3$ in 2011 followed by Ashulia 115 $\mu g/m^3$, Farmgate 99 $\mu g/m^3$, Science laboratory 97 $\mu g/m^3$, Mohakhali 94 $\mu g/m^3$, Topkhana 89 $\mu g/m^3$, Mouchak 83 $\mu g/m^3$ and Curzon hall 81 $\mu g/m^3$. The concentrations of PH_3 measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of PH_3 in Dhaka city for three years from 2009 to 2011(January – December) and a generalized analysis of the data depict that the concentration varied from 93- 139 $\mu g/m^3$. The highest levels 139 $\mu g/m^3$ was measured in the months of December (in winter) and the lowest level was 93 $\mu g/m^3$ in the month of June (rainy season) with an average 114 $\mu g/m^3$ (Table: 4.17).

Both natural and anthropogenic sources contribute to the PH_3 precursors, and the composition of emissions sources may show large variations across locations. When a third fumigation was done with phosphine found no ill effect on the germination of some varieties of tomatoes, sweet melons, cucumbers, peas and beans, but one variety of broad beans was slightly affected. However, the growth and yield of plants grown from seeds subjected to repeat fumigations with phosphine may be significantly reduced reported a reduction in total yield of maize grown from seed fumigated twice sod three times with phosphine (Fam *et. al., 1974*). PH_3 is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of PH_3 precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the PH_3 precursors. A strong negative correlation (r = - 0.77) between PH_3 and TVOC, negative correlation (r = - 0.65) between PH_3 and NH_3 obtained in the present investigation. That is PH_3 concentration increased with a concomitant decrease in TVOC and NH_3. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which PH_3 is converted to H_2S during day time period. The PH_3 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for PH_3 and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level PH_3 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*WHO, 1989*). Peak ground-level PH_3 concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level PH_3 rarely last longer than two to three hours *(WHO, 1979).*The diurnal and seasonal variations occur in response to changes in sunlight. In addition, PH_3 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak PH_3 are measured in the night. Mean concentrations are generally highest in the winter. The nematode Meloidopynehapla may be controlled in potted rose

plants with phosphine applied to the soil, without apparent injury to the plants *(Faber, 1966).*

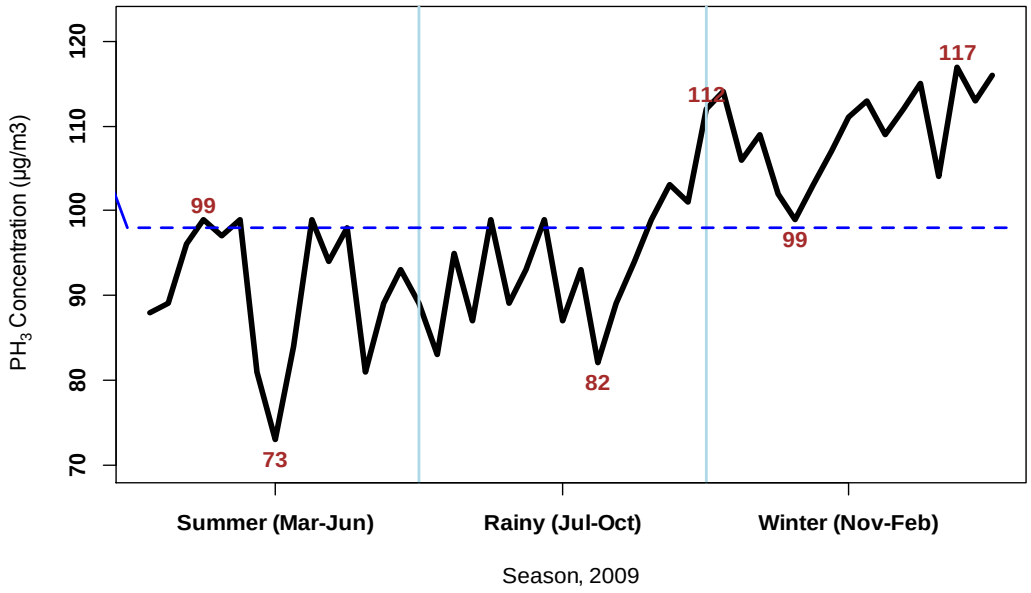


Fig. 4.7.1: PH_3 Concentrations (µg/m^3) in 2009 in Dhaka City.

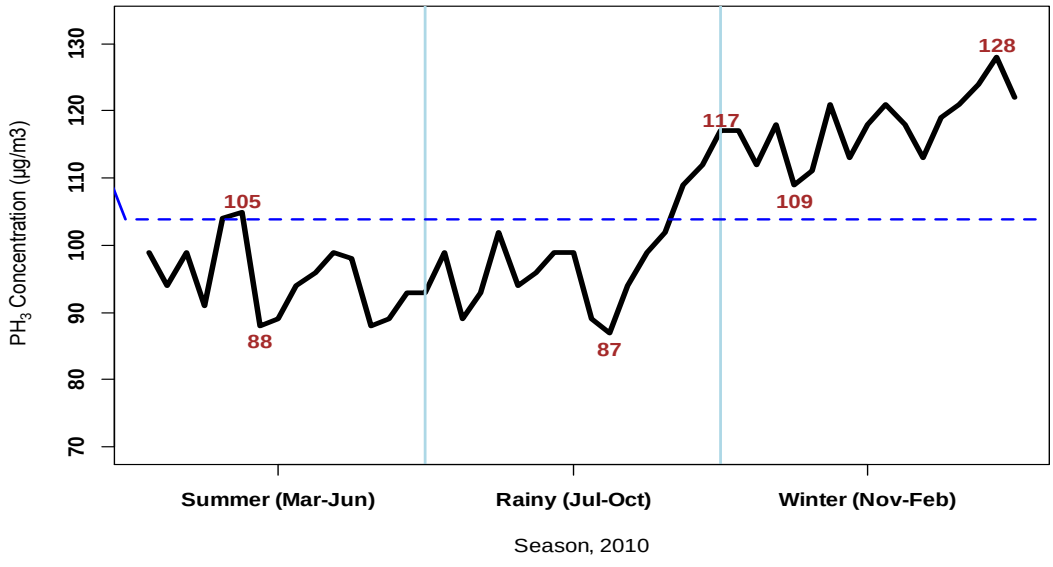


Fig. 4.7.2: PH_3 Concentrations (µg/m^3) in 2010 in Dhaka City.

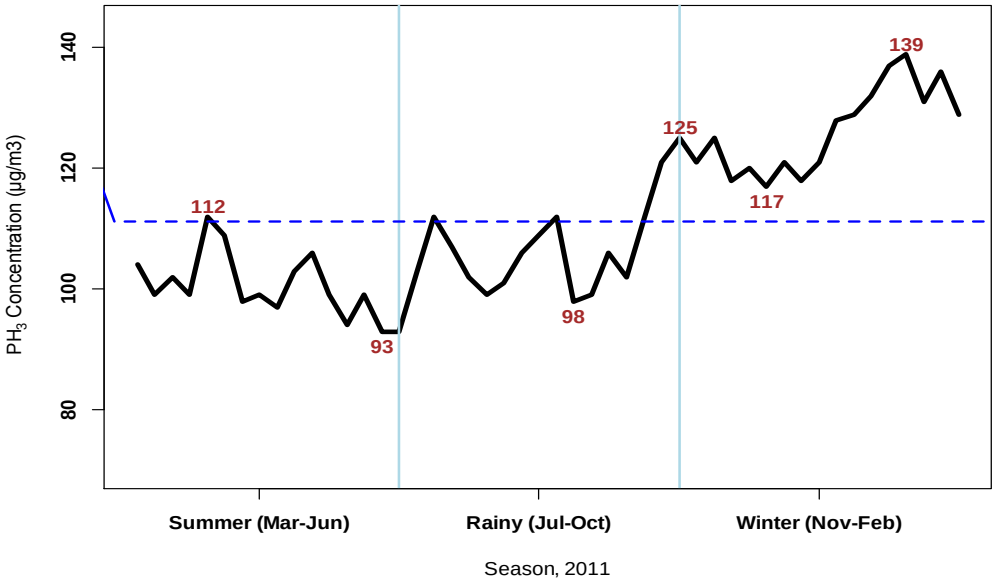


Fig. 4.7.3: PH_3 Concentrations (µg/m^3) in 2011 in Dhaka City.

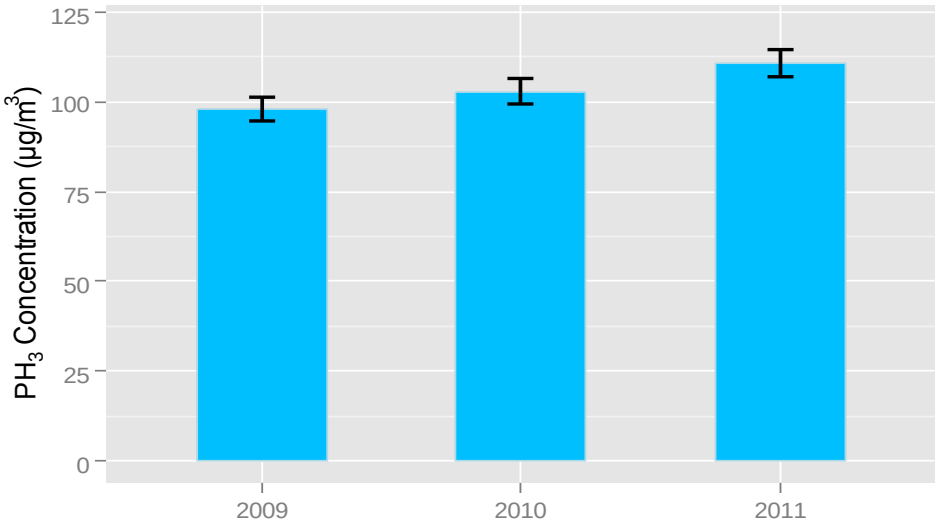


Fig.4.7.4: Yearly variations in PH_3 Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

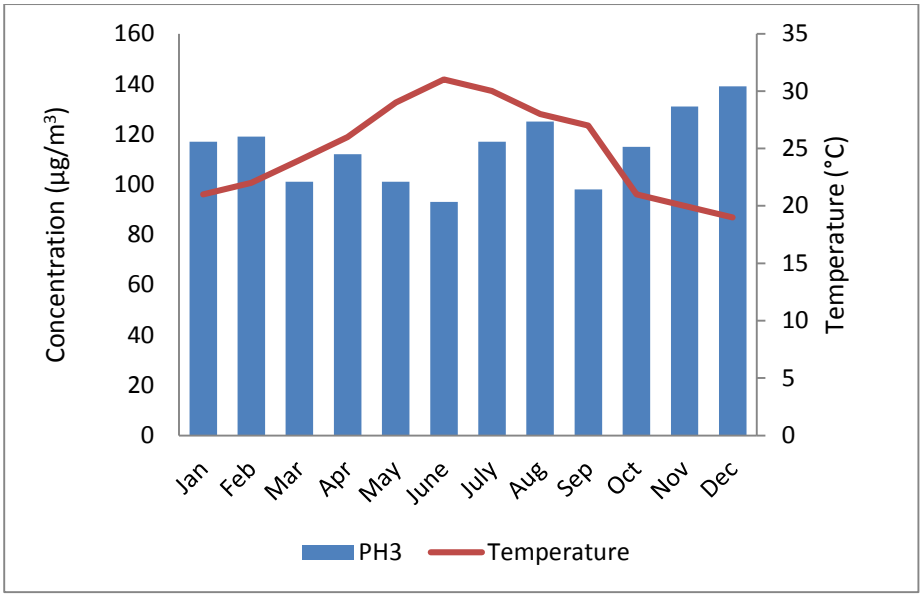


Fig. 4.7.5: PH_3 variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition there was also seasonal trend where in winter, rainy and summer season. The Fig. 4.7.1, 4.7.2, 4.7.3 shows that the PH_3 concentration was highest value in winter season followed by rainy and summer season.

From Fig. 4.7.4 shows that there is an increasing trend in average concentration of PH_3 from year 2009-2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are over lapped.

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction PH_3 convert to TVOC and NH_3 gases during this day time period. The PH_3 concentrations also varied with relative humidity. A significant correlation (r = 0.698 %) was obtained for PH_3 and relative humidity. It is evident from the results that PH_3 concentrations increased with increasing relative humidity. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are producing a huge amount of PH_3. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of PH_3. A air mass trajectory analysis using HYSPLIT model (*NOAA, 2012*) showed that a substantial amount of PH_3 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

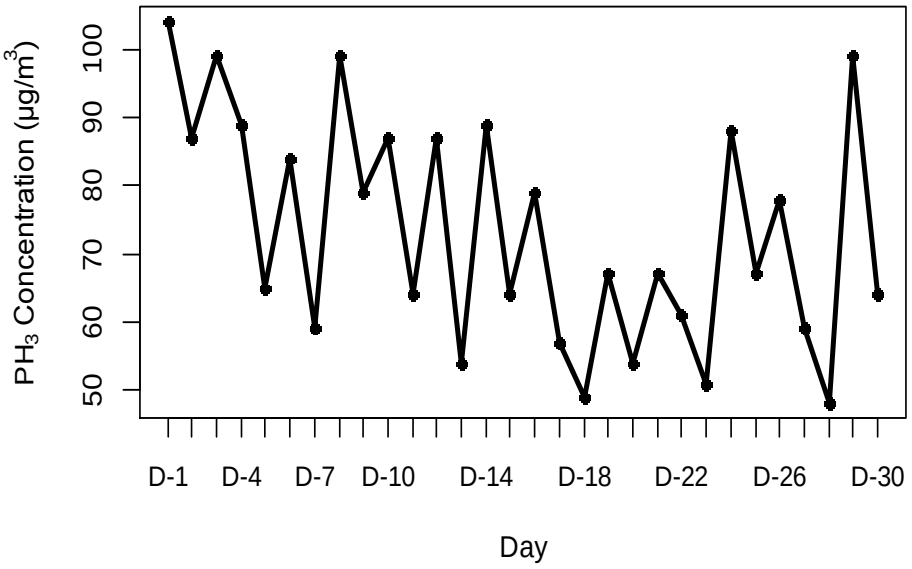


Fig. 4.7.6: Monthly variations in PH_3 Concentrations (µg/m^3) in Dhaka city (June, 2011).

Phosphine (PH_3) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city (presented in Fig 4.7.6 shows that the concentrations varied significantly from 1st June to 30th June. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 104 µg/m^3, 87 µg/m^3, 99 µg/m^3, 89 µg/m^3, 65 µg/m^3, 84 µg/m^3 (Table 4.5) . The highest value was 104 µg/m^3 in 1th June and the lowest value was 48 µg/m^3 in 28th June, 2011 .The reason behind the variation can be explained by the vehicular emissions of PH_3 during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 1th, 28th June and 5th June. The lowest value was found in 5th and 3th June because these days were rainy day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of PH_3 were low than the other days.

Fig. 4.7.7: Diurnal variation in PH_3 Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Phosphine (PH_3) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city presented in Fig. 4.7.7 shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 21 hour to 5 hour were 112 µg/m^3, 117 µg/m^3, 113 µg/m^3, 119 µg/m^3, 111 µg/m^3, 114 µg/m^3, 119 µg/m^3, 115 µg/m^3, 117 µg/m^3 , 121 µg/m^3 (Table 4.6) then declined 6h -20h. The highest value was 121 µg/m^3 in 5 hour and the lowest value was 77 µg/m^3 in 15 hour to 18 hour .The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction PH_3 convert to another gases during this day time period. The PH_3 concentrations also varied with relative humidity. A significant negative correlation (r = 0.698 %) was obtained for $PH_3$and relative humidity. PH_3 concentrations increase with increasing hydrocarbons and decrease with increasing PH_3. Presented in Fig 4.7.7 shows that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence between 0 hour to 9 hour and 10 hour to 23 hour. The average value is also significantly different as the 95% confidence between 0 hour to 10 hour and 10 hour to 23 hour.

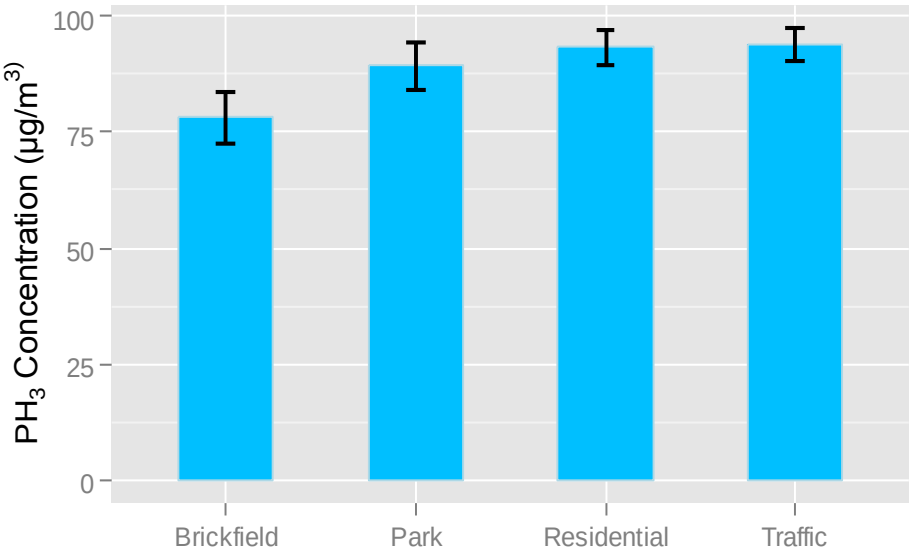


Fig. 4. 7.8 : Comparison of PH_3 Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Phosphine (PH_3) concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation presented in Fig. 4.7.8 shows that the concentrations varied not significantly from place to place. The highest concentrations measured in residential area 122 µg/m^3 followed by park 110 µg/m^3, traffic 110 µg/m^3 and brick-field 112 µg/m^3 (Table 4.12). Although the difference between traffic and residential area, the average value is not significantly different. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. are producing a huge amount of PH_3. Huge amount of running vehicles, long time traffic jam produced PH_3 resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced PH_3.

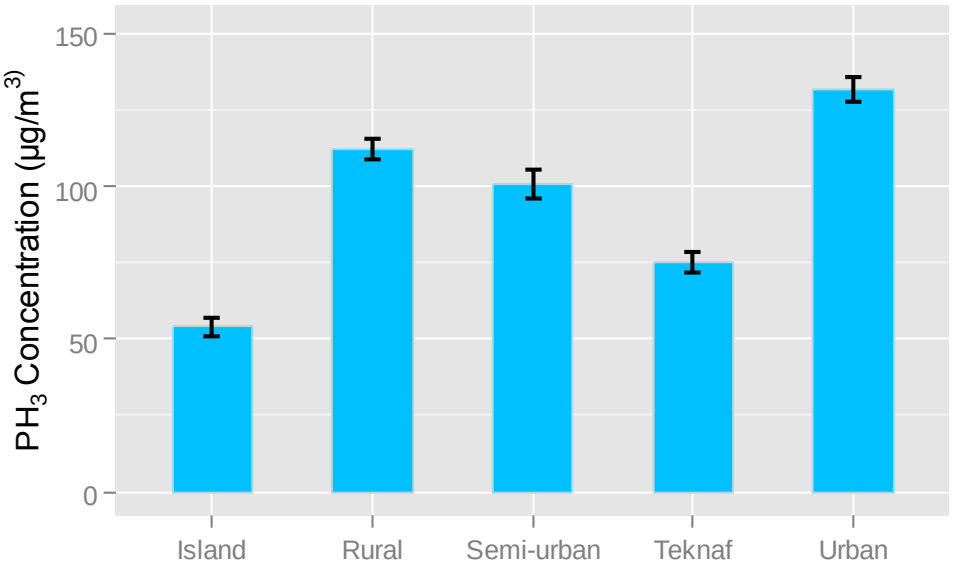


Fig. 4. 7.9: Comparison of PH_3 Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Phosphine (PH_3) concentrations varied significantly from urban to semi-urban, semi-urban to rural, island and teknaf. In urban - Farm gat , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana, saidabad bus-stand,Park, D.U.R/A (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Amin bazar , Ashulia, Island- Saint Martin, Peri-rural- Teknaf in Bangladesh .The average concentrations of PH_3 was 132 µg/m^3in urban sites, 101 µg/m^3 in semi- urban, 112 µg/m^3 in rural, 54 µg/m^3 in St. Martin's Island and 75 µg/m^3 in Teknaf (Peri –rural) (Table 4.16). The Fig.4.7.9 shows that the highest PH_3 was found in Urban area followed by semi- urban, rural, teknaf , Island due to vegetations, vehicles emissions. The average value is significantly different as the 95% confidence between urban and semi-urban, semi-urban and rural, teknaf and urban, semi-urban and Island.

4.8 NH_3 Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Ammonia (NH_3) concentrations (µg/$m^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented in tables 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations in ground level NH_3. The concentrations varied from 88 µg/m^3 to 121 µg/m^3 in the hot spots. Among the hot spots the maximum concentrations were measured for Amin bazar 121 µg/m^3 in 2011 followed by Ashulia 119 µg/m^3, Mouchak 111 µg/m^3, Farm gate 104 µg/m^3, Topkhana103 µg/m^3, Curzon hall 102 µg/m^3, Science laboratory 94 µg/m^3. The concentrations of NH_3 measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of NH_3 in Dhaka city for three years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 44 - 121 µg/m^3. The highest levels 121 µg/m^3 was measured in the month of June (in rainy season) and the lowest level was 44 µg/m^3 in the month of January (in winter season) with an average 80 µg/m^3 (Table: 4.17).

Both natural and anthropogenic sources contribute to the NH_3 precursors, and the composition of emissions sources may show large variations across locations. NH_3 is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of NH_3 precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the NH_3 precursors. The diurnal and seasonal variations occur in response to changes in sunlight. A strong negative correlation (r = - 0.50) between NH_3 and TVOC, positive correlation (r = 0.91) between NH_3 and CO and positive correlation (r = 0.88) between NH_3 and PH_3 obtained in the present investigation. That is NH_3 concentration increased with a concomitant decrease in TVOC. Whereas, the concentrate NH_3 in increased with increasing concentration of CO and PH_3. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which NH_3 is converted to H_2S during day time period. The NH_3 concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for NH_3 and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level NH_3 accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak ground-level NH_3 concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level NH_3 rarely last longer than two to three hours *(WHO, 1979).*

Peak ground-level NH_3 concentrations were measured in the night. Mean concentrations are generally highest in the rainy season followed by summer and winter seasons. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers. Ammonia either directly or indirectly, is also a building-block for the synthesis of many pharmaceuticals and is used in many commercial cleaning

products. Although in wide use, ammonia is both caustic and hazardous. In 2006, worldwide production was estimated at 146.5 million tones. Ammonia, as used commercially, is often called *anhydrous ammonia.* Because NH_3 boils at −33.34 °C (−28.012 °F) at a pressure of 1 atmosphere, the liquid must be stored under high pressure or at low temperature. "Household ammonia" or "ammonium hydroxide" is a solution of NH_3 in water. The concentration of such solutions is measured in units of the Baume scale (density), with 26 degrees Baume (about 30% w/w ammonia at 15.5 °C) being the typical high-concentration commercial product (Ammonium hydroxide physical properties) Household ammonia ranges in concentration from 5 to 10 weight percent ammonia *(WHO, 2006).*

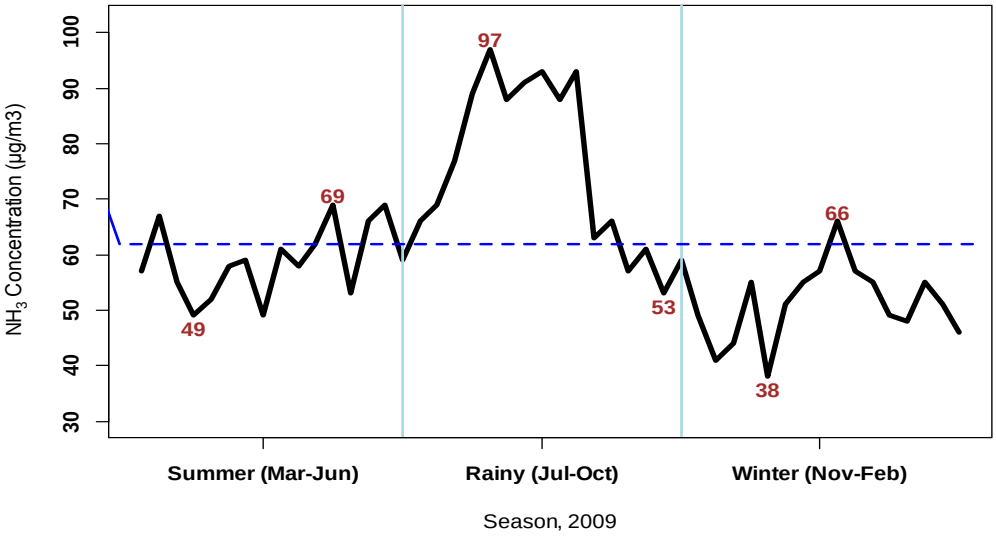


Fig. 4. 8.1: NH_3 Concentrations (µg/m^3) in 2009 in Dhaka City.

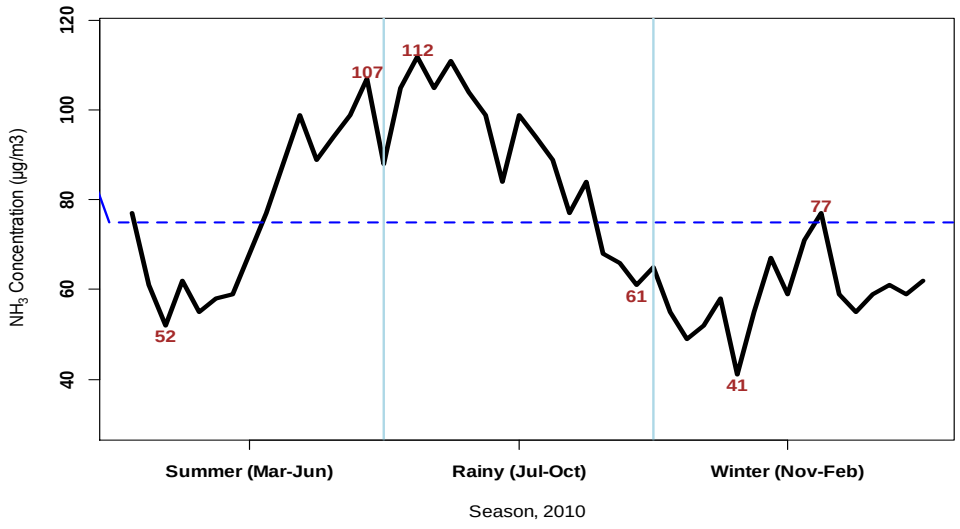


Fig. 4. 8.2: NH_3 Concentrations (µg/m^3) in 2010 in Dhaka City.

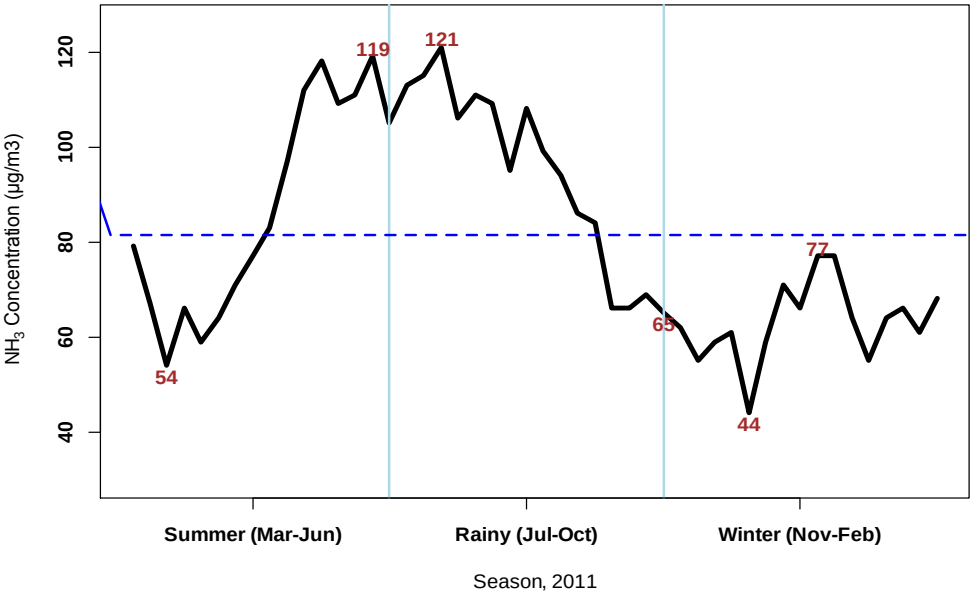


Fig. 4.8.3: NH_3 Concentrations (µg/m^3) in 2011 in Dhaka City.

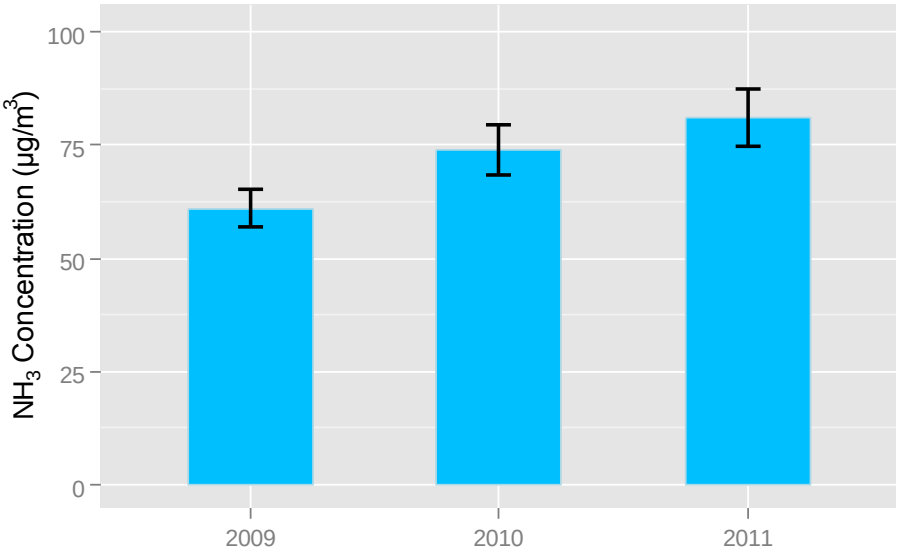


Fig. 4.8.4: Yearly variations in NH_3 Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

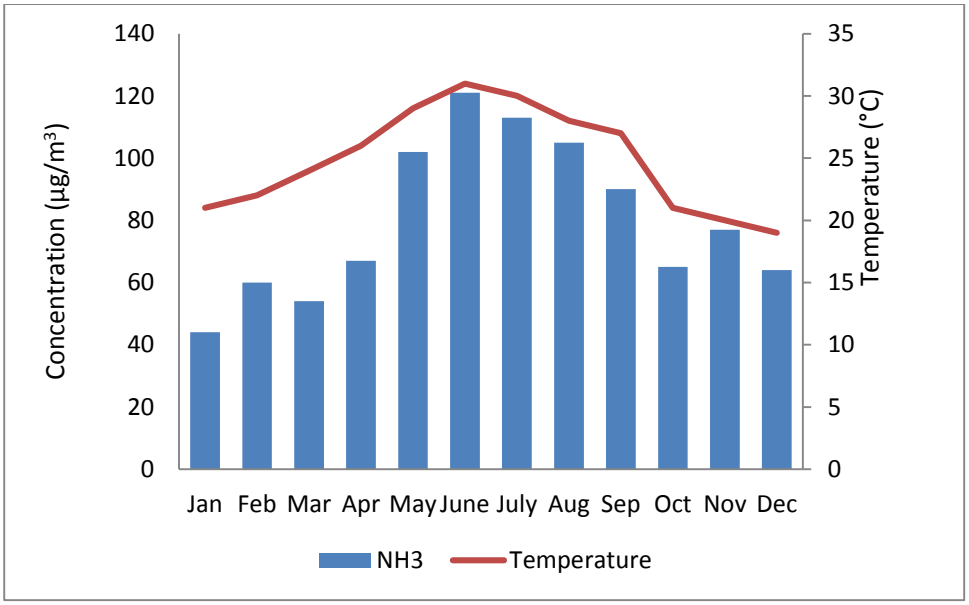


Fig. 4.8.5: NH_3 variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition there was also seasonal trend where in winter, Rainy and summer season. The Fig. 4.8.1, 4.8.2, 4.8.3 shows that the NH_3 concentrations was highest in rainy season followed by summer and winter season.

From Fig. 4.8.4 shows that there is a increasing trend in average concentration of NH_3 from year 2009-2011. Although the difference between the averages values for the years is not significantly different.

Today, the typical modern ammonia-producing plant first converts natural gas (i.e., methane) or liquefied petroleum gas (such gases are propane and butane) or petroleum naphtha into gaseous hydrogen. The process used in producing the hydrogen begins with removal of sulfur compounds from the natural gas (because sulfur deactivates the catalysts used in subsequent steps). Catalytic hydrogenation converts organ sulfur compounds into gaseous hydrogen sulfide:

$$H_2 + RSH \rightarrow RH + H_2S\ (g)$$

The hydrogen sulfide is then removed by passing the gas through beds of zinc oxide where it is adsorbed and converted to solid zinc sulfide:

$$H_2S + ZnO \rightarrow ZnS + H_2O$$

Catalytic steam reforming of the sulfur-free feedstock is then used to form hydrogen plus carbon monoxide:

$CH_4 + H_2O \rightarrow CO + 3\ H_2$

In the next step, the water gas shift reaction is used to convert the carbon monoxide into carbon dioxide and more hydrogen:

$CO + H_2O \rightarrow CO_2 + H_2$

The carbon dioxide is then removed either by absorption in aqueous ethanolamine solutions or by adsorption in pressure swing absorbers (PSA) using proprietary solid adsorption media.

The final step in producing the hydrogen is to use catalytic meth nation to remove any small residual amounts of carbon monoxide or carbon dioxide from the hydrogen:

$CO + 3\ H_2 \rightarrow CH_4 + H_2O$

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

$3\ H_2 + N_2 \rightarrow 2\ NH_3$

Hydrogen required for ammonia synthesis could also be produced economically using other sources like coal or coke gasification, less economically from the electrolysis of water into oxygen + hydrogen and other alternatives that are presently impractical for large scale. At one time, most of Europe's ammonia was produced from the Hydro plant at Vendors, via the electrolysis route. Various renewable energy electricity sources are also potentially applicable *(EPA, 2011).*

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NH_3 convert to CO and PH_3 gases during this day time period. The NH_3 concentrations also varied with relative humidity. A significant correlation (r = 0.698 %) was obtained for NH_3 and relative humidity. It is evident from the results that NH_3 concentrations increased with increasing relative humidity. Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc. produce huge amount of NH_3. A air mass trajectory analysis using HYSPLIT model *(NOAA, 2012*) showed that a substantial amount of NH_3 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution (Fig 4.11.1, 4.11.2).

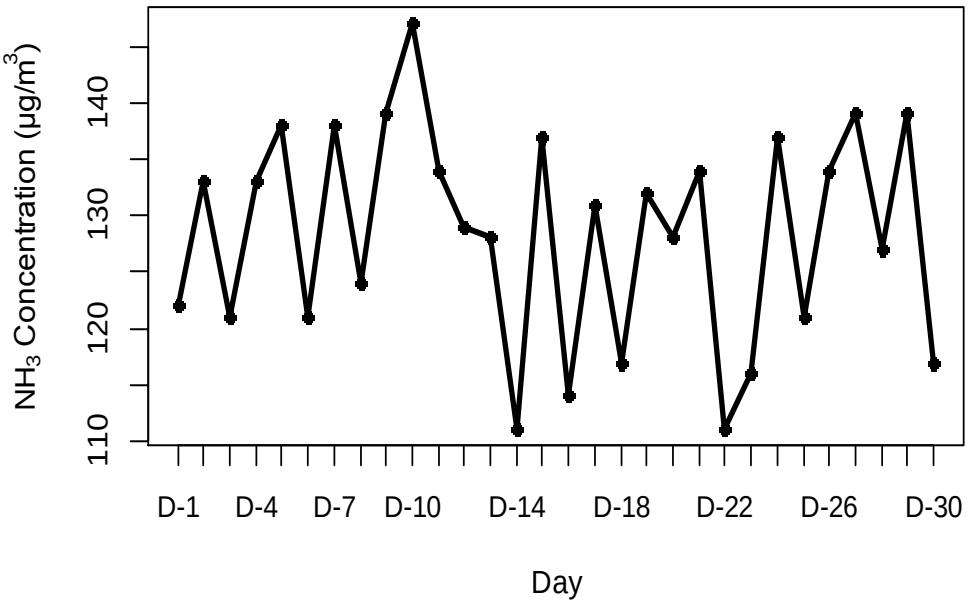


Fig. 4.8.6: Monthly variations in NH_3 Concentrations (µg/m^3) in Dhaka city (June, 2011).

Ammonia (NH_3) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city presented in Fig. 4.8.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th , 4th, 5th, 6th June were 122 µg/m^3, 133 µg/m^3, 121 µg/m^3, 133 µg/m^3, 138 µg/m^3, 121 µg/m^3 (Table 4.5) . The highest value was 139 µg/m^3 in 29th June and the lowest value was 11 µg/m^3 in 14th June, 2011 .The reason behind the variation can be explained by the vehicular emissions ofNH_3 during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 14th, 29th June and 5th June. The lowest value was found in 14th and 22th June because these days were sunny day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of NH_3 were low than the other days.

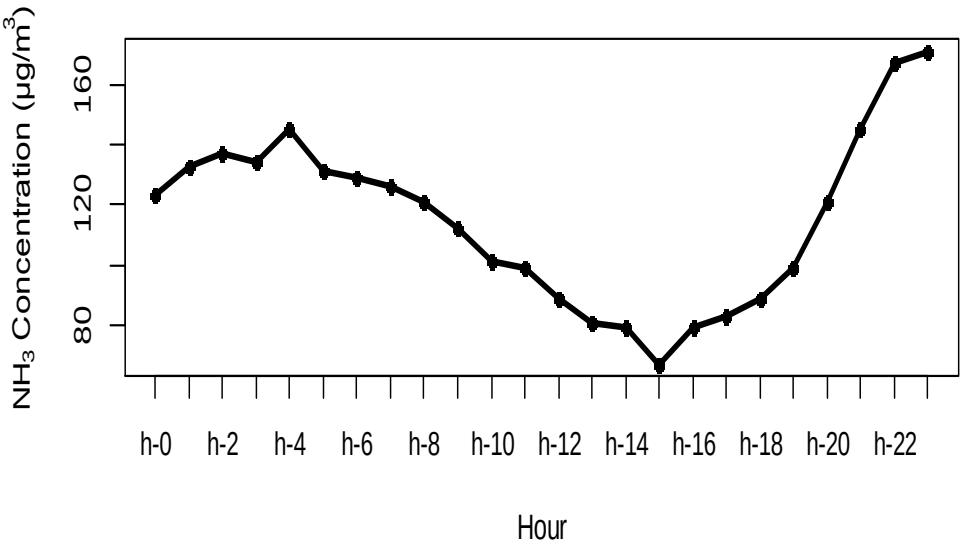


Fig. 4.8.7: Diurnal variation in NH_3 Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Ammonia (NH_3) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city (presented in Fig.4.7.7) shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 0 hour to 5 hour were 123 µg/m^3, 133 µg/m^3, 137 µg/m^3, 134 µg/m^3,145 µg/m^3, 131 µg/m^3, 129 µg/m^3, 126 µg/m^3, 121 µg/m^3 , 112 µg/m^3 (Table 4.6) and then declined 6h -19h again the highest value was seen 121 µg/m^3, 145 µg/m^3, 167 µg/m^3, 171 µg/m^3, 177 µg/m^3 in 20h – 24h. The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction NH_3 convert to CO and PH_3 gases during this day time period. The NH_3 concentrations also varied with relative humidity. A significant negativecorrelation (r = 0.698 %) was obtained for NH_3 and relative humidity. NH_3 concentrations increase with increasing hydrocarbons and decrease with increasing NH_3. Presented in Fig 4.8.7 shows that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence between 0 hour to 9 hour and 10 hour to 23 hour. The average value is also significantly different as the 95% confidence between 0 hour to 6 hour and 10 hour to 23 hour.

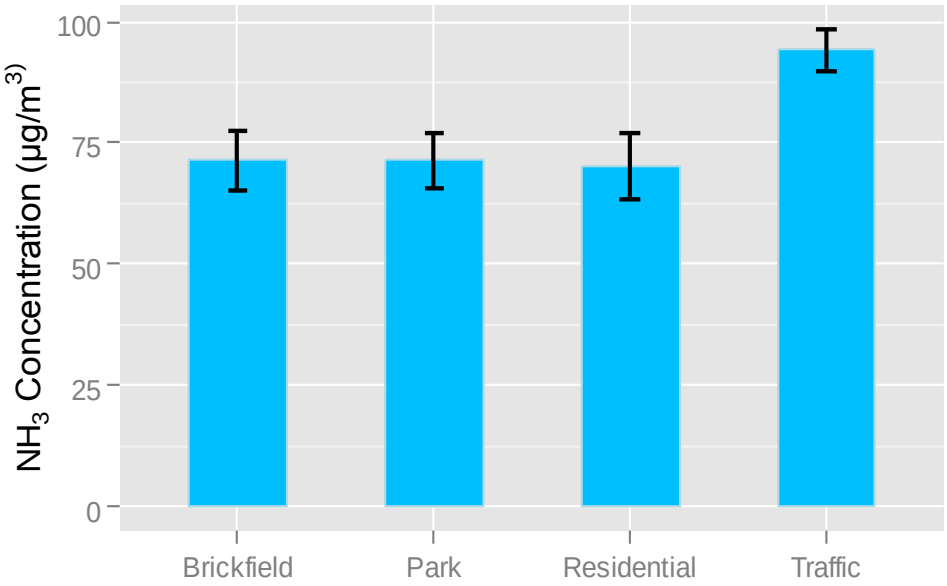


Fig. 4.8.8: Comparison of NH_3 Concentrations ($\mu g/m^3$) measured for different locations in and around Dhaka city from 2009-2011.

Ammonia (NH_3) concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation presented in Fig. 4.8.8 shows that the concentrations varied not significantly from place to place. The highest concentrations measured in traffic area 121 $\mu g/m^3$ followed by brick-field 112 $\mu g/m^3$, residential area 106 $\mu g/m^3$, and park area 99 $\mu g/m^3$ (Table 4.14). Although the difference between traffic and residential area, the average value is significantly different .Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of NH_3. Huge amount of running vehicles, long time traffic jam produced NH_3 resulting in a air pollution. To use low quality coal, wood in brick-kilns to produced NH_3.

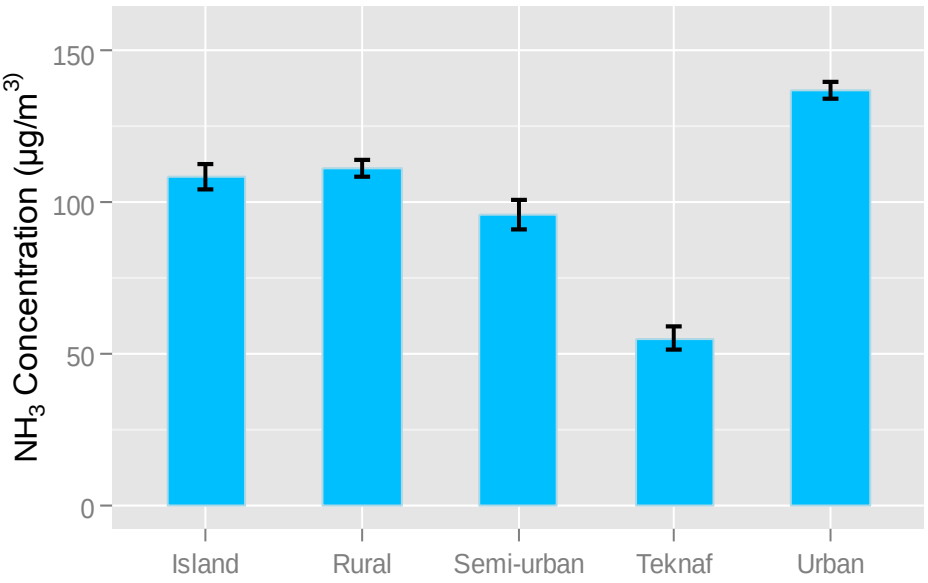


Fig.4.8.9: Comparison of NH_3 Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Ammonia (NH_3) concentrations varied significantly from urban to semi-urban,semi-urban to rural, island and teknaf. In urban - Farm gat , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana,saidabad bus stand,Park, D.U.R/A (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Aminbazar , Asholia, Island-Saint Martin, Periy-rural- Teknaf in Bangladesh .The average concentrations of NH_3 was 137 µg/m^3in urban sites, 96 µg/m^3 in semi- urban, 111 µg/m^3 in rural, 108 µg/m^3 in Saint. Martin island and 55 µg/m^3 in Teknaf (Peri –rural) (Table 4.16).The Fig.4.8.9 shows that the highest NH_3 was found in Urban area followed by semi- urban, rural, teknaf , Island due to vegetations, vehicles emissions. The average value is significantly different as the 95% confidence between urban and semi-urban, semi-urban and rural, teknaf and urban, semi-urban and Island.

4.9 H_2S Concentrations (µg/m^3) measured for Dhaka City during 2009 -2011.

Hydrogen sulphide (H_2S) concentrations (µg/$m^{3)}$ measured for Dhaka city at different hot spots during 2009 to 2011 presented in tables 4.4.1, 4.4.2 and 4.4.3 show a significant level of spatial and temporal variations in H_2S. The concentrations varied from 78 µg/m^3 to 117 µg/m^3 in the spots. Among the hot spots the maximum concentrations were measured for Ashulia 117 µg/m^3 in 2011 followed by Mohakhali 116 µg/m^3 , Ramna park 114 µg/m^3 , Amin bazar 113 µg/m^3 , Mouchak 112 µg/m^3 , Farmgate 103 µg/m^3 , Science laboratory 97 µg/m^3 , Curzon hall 81 µg/m^3. The concentrations of H_2S measured in the present investigation is higher than the concentrations reported for Dhaka city *(Mehedi, 2010).*

Continuous assessment of exposure levels of H_2S in Dhaka city for three years from 2009 to 2011 (January – December) and a generalized analysis of the data depict that the concentration varied from 83 - 139 µg/m^3. The highest level 139 µg/m^3 was measured in the months of July (in rainy season) and the lowest level 83 µg/m^3 in the months of November (in winter season) with an average 102 µg/m^3 (Table: 4.17).

Both natural and anthropogenic sources contribute to the H_2S precursors, and the composition of emissions sources may show large variations across locations. H_2S is formed in the air by the photochemical reaction of sunlight and nitrogen oxides (NOx), facilitated by a variety of volatile organic compounds (VOCs), which are photo chemically reactive hydrocarbons. One of the major anthropogenic sources of H_2S precursors is motor vehicles. It is possible that the increasing number of motor vehicles (Table 2.16, 2.17) plying in the streets of Dhaka city at present is contributing in the H_2S precursors. A strong negative correlation (r = - 0.77) between H_2S and TVOC, positive correlation (r = 0.65) between H_2S and NH_3 and positive correlation (r = - 0.84) between H_2S and PH_3 obtained in the present investigation. That is H_2S concentration increased with a concomitant decrease in TVOC. Whereas, the concentrate in increased with increasing concentration of NO. The variation can be explained by the presence of sunshine, solar radiation and the photochemical reactions by which H_2S is converted to O_2 during day time period. The H_2S concentrations also varied with relative humidity. A significant positive correlation (r = 0.698) was obtained for H_2S and relative humidity. The diurnal and seasonal variations occur in response to changes in sunlight. In addition, ground-level H_2S accumulation occurs when temperature-induced air inversions trap the compounds that produce smog (*Chilton and Sholtz, 1989*). Peak ground-level H_2S concentrations are measured in the afternoon. Mean concentrations are generally highest in the summer. Peak concentrations of ground-level H_2S rarely last longer than two to three hours *(WHO, 1979).*The diurnal and seasonal variations occur in response to changes in sunlight. Hydrogen sulfide is most commonly obtained from sour gas, which is natural gas with high content of H_2S. It can also be produced by reacting hydrogen gas with molten elemental sulfur at about 450 °C. Hydrocarbons can replace hydrogen in this process. Sulfate-reducing (resp. sulfur-reducing) bacteria generate usable energy under low-oxygen conditions by using sulfates (resp. elemental sulfur) to oxidize organic compounds or hydrogen; this produces hydrogen sulfide as a waste product *(WHO, 2012).* Hydrogen sulfide is considered a broad-spectrum poison, meaning that it can poison different systems in the body, although the nervous system is most affected. The toxicity of H_2S is comparable with that of hydrogen cyanide. It forms a complex bond with iron in the

mitochondrialcytochromeenzymes, thus preventing cellular respiration *(Belley et. al., 2005).*

Since hydrogen sulfide occurs naturally in the body, the environment and the gut, enzymes exist in the body capable of detoxifying it by oxidation to (harmless) sulfate (*Ramasamy et. al., 2006).*

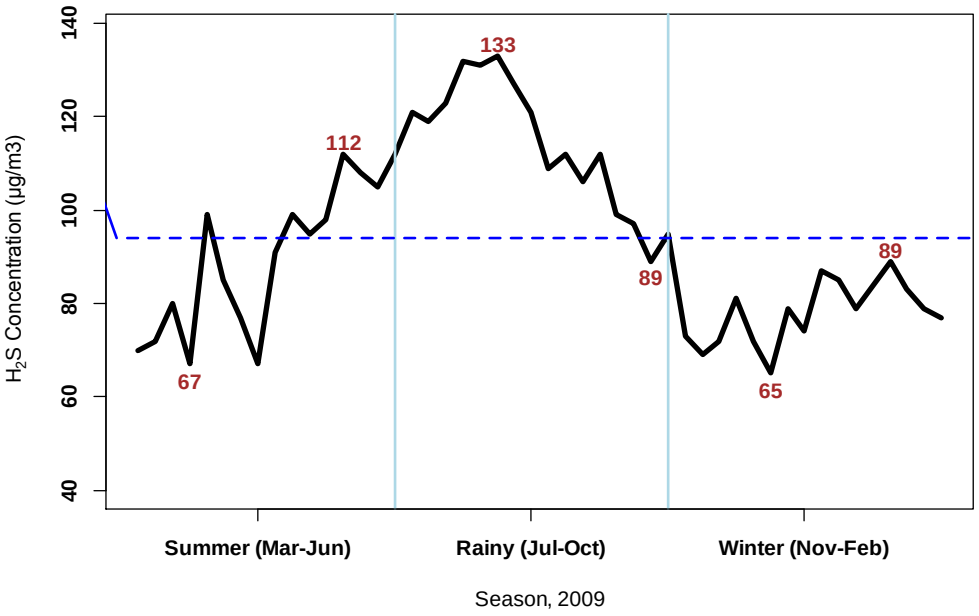


Fig. 4. 9.1: H_2S Concentrations (µg/m^3) in 2009 in Dhaka City.

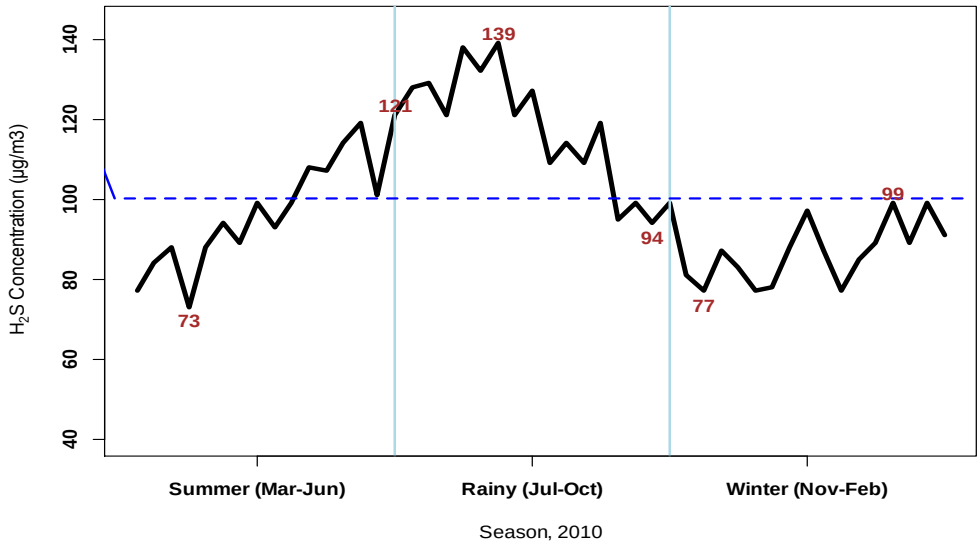


Fig. 4. 9.2: H_2S Concentrations (µg/m^3) in 2010 in Dhaka City.

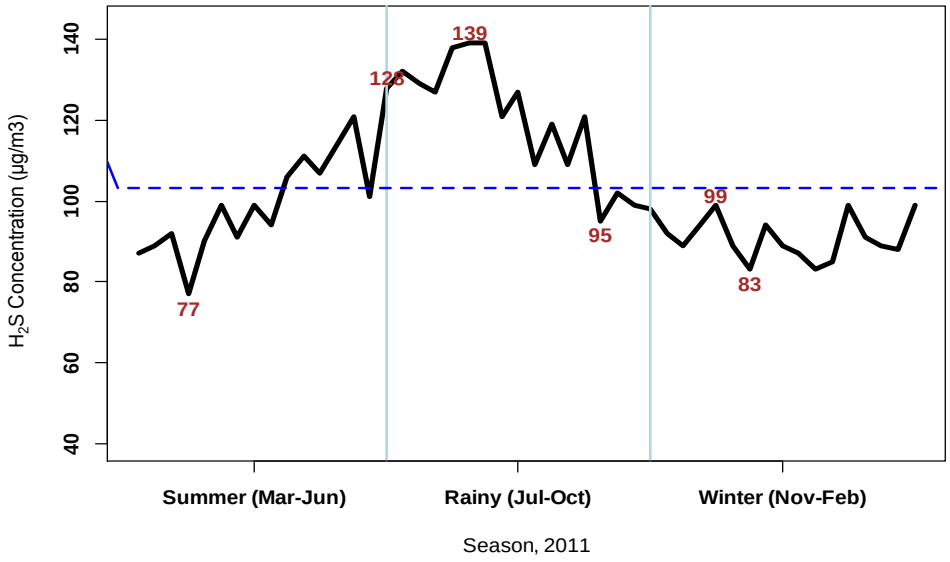


Fig. 4. 9.3: H_2S Concentrations (µg/m^3) in 2011 in Dhaka City.

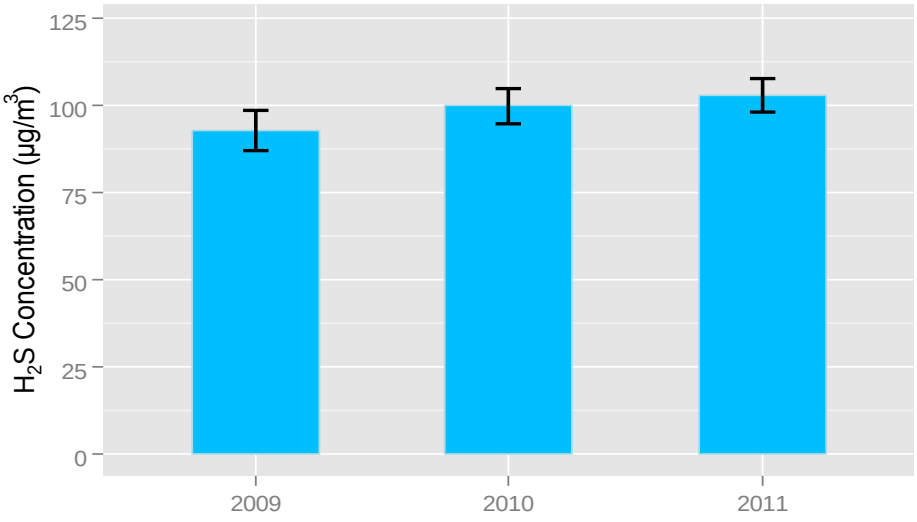


Fig.4.9.4: Yearly variations in H_2S Concentrations (µg/m^3) in 2009, 2010 and 2011 in Dhaka City.

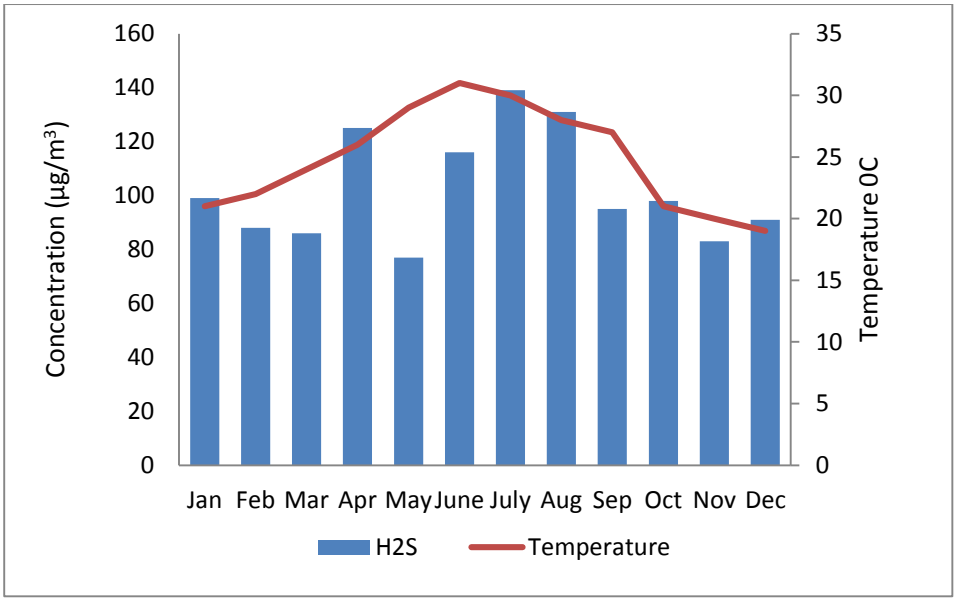


Fig. 4.9.5: H_2S variation along with temperature ^{O}C in Dhaka city (2009-2011).

In addition there was also seasonal trend where in winter, rainy and summer season. The Fig. 4.7.1, 4.7.2, 4.7.3 shows that the H_2S concentration was highest value in rainy season followed by and summer and winter season.

From Fig. 4.9.4 shows that there is an increasing trend in average concentration of H_2S from year 2009-2011. Although the difference between the average values for the years is not significantly different as the 95% confidence intervals are over lapped.

The reason also behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction H_2S convert to another gases during this day time period. The H_2S concentrations also varied with relative humidity. A significant negative correlation (r = 0.698 %) was obtained for H_2S and relative humidity. It is evident from the results that H_2S concentrations increased with increasing relative humidity.

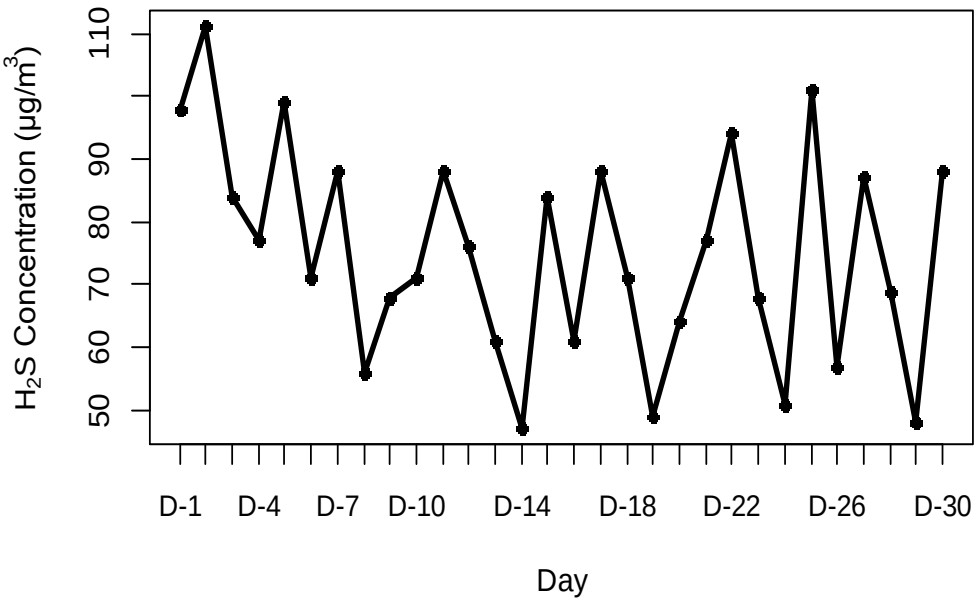


Fig. 4.9.6: Monthly variations in H_2S Concentrations (µg/m^3) in Dhaka city (June, 2011).

Hydrogen sulphide (H_2S) concentrations (µg/m^3) measured for 30 days on June, 2011 in Dhaka city (presented in Fig 4.9.6 shows that the concentrations varied significantly from 1st June to 30thJune. The Concentrations measured on 1st, 2th, 3th ,4th, 5th, 6th June were 98 µg/m^3, 111 µg/m^3, 84 µg/m^3, 77 µg/m^3, 99 µg/m^3, 71 µg/m^3 (Table 4.5) . The highest value was 111 µg/m^3 in 2th June and the lowest value 47 µg/m^3 in 14th June, 2011 .The reason behind the variation can be explained by the vehicular emissions of H_2S during the holyday, rainy day, cloudy day in this time period . The average value is significantly different as the 95% confidence between 2th, 14th June and 5th June. The lowest value was found in 14th and 26th June because these days were sunny day. The 3rd, 10th, 17th, 24th June were holidays. For these reason the concentrations of H_2S were low than the other days.

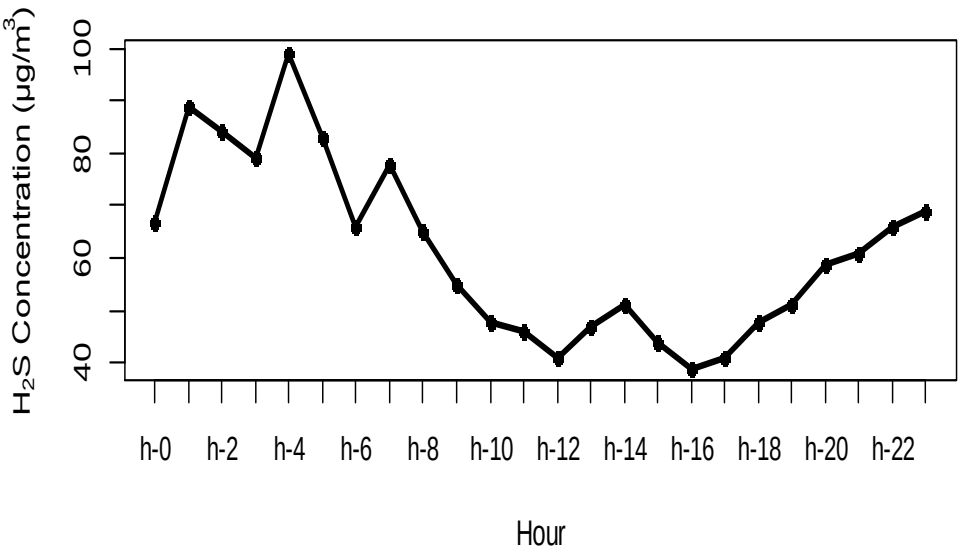


Fig. 4. 9.7: Diurnal variation in H_2S Concentrations (µg/m^3) in Dhaka city (3 June, 2011).

Hydrogen sulphide (H_2S) concentrations (µg/m^3) measured for 24 hours on 3 June, 2011 in Dhaka city (presented in Fig.4.9.7) shows that the concentrations varied significantly from 0 hour to 24 hours. The concentrations measured a peak between 0 hour to 9 hour were 67 µg/m^3, 89 µg/m^3, 84 µg/m^3, 79 µg/m^3, 99 µg/m^3, 83 µg/m^3, 66 µg/m^3, 78 µg/m^3, 65 µg/m^3 , 55 µg/m^3 (Table 4.6)and then declined 10h -17h .The highest value 99 µg/m^3 in 4 hour and the lowest value 41 µg/m^3 in 12 hour .The reason behind the variation can be explained by the presence of sunshine, sunlight and the photochemical reaction H_2S convert to another gases during this day time period. The H_2S concentrations also varied with relative humidity. A significant negative correlation (r = 0.698 %) was obtained for H_2S and relative humidity. H_2S concentrations increase with increasing hydrocarbons and decrease with increasing H_2S. Presented in Fig 4.9.7 shows that the concentrations varied significantly from hour to hour. The average value is significantly different as the 95% confidence between 0 hour to 9 hour and 10 hour to 23 hour. The average value is also significantly different as the 95% confidence between 0 hour to 10 hour and 10 hour to 23 hour.

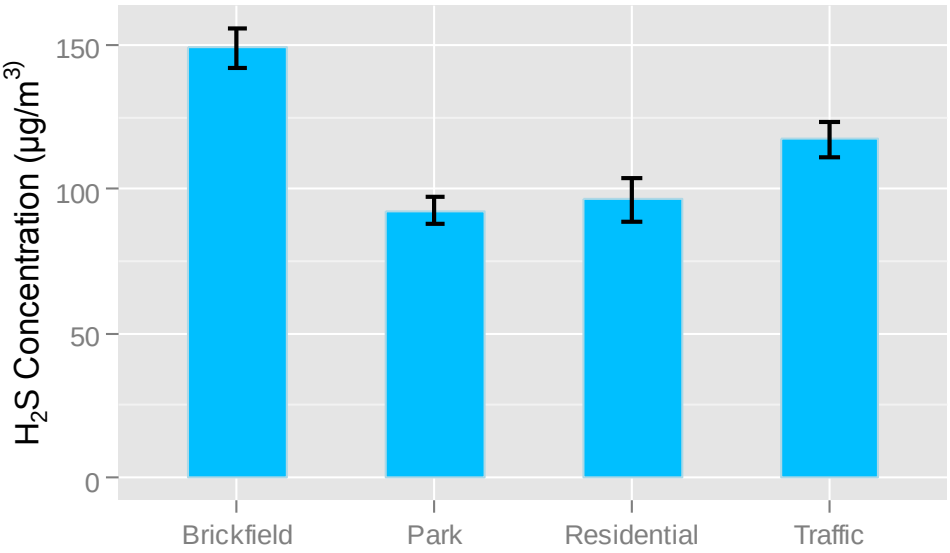


Fig. 4.9.8: Comparison of H_2S Concentrations (µg/m^3) measured for different locations in and around Dhaka city from 2009-2011.

Hydrogen sulphide (H_2S) concentrations determined at residential area, traffic area, park, brick-field etc to observe the locations variation. Presented in Fig 4.9.8 shows that the concentrations varied not significantly from place to place. The highest concentrations measured in brick-field 177 µg/m^3 followed by traffic 154 µg/m^3, residential area 137 µg/m^3, and park 110 µg/m^3 (Table 4.15). Although the difference between traffic and residential area, the average value is not significantly different. Due to Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of H_2S. Huge amount of running vehicles, long time traffic jam produced H_2S resulting in an air pollution. To use low quality coal, wood in brick-kilns to produced H_2S.

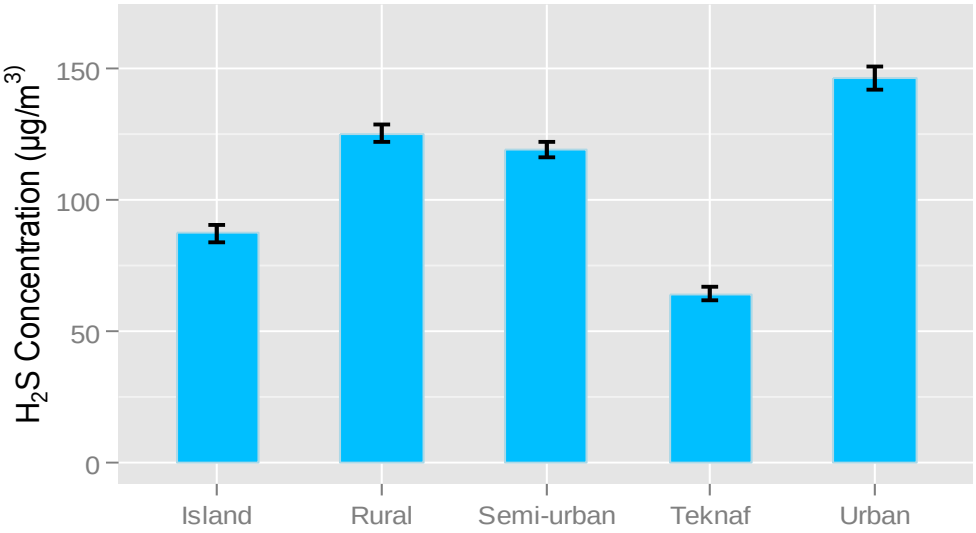


Fig.4.9.9: Comparison of H_2S Concentrations (µg/m^3) measured for different locations in Bangladesh (December, 2009-2011).

Hydrogen sulphide (H_2S) concentrations varied significantly from urban to semi-urban,semi-urban to rural, island and teknaf. In urban - Farm gat , Science laboratory, Mouchak, Curzon Hall, Mohakhali, Topkhana, saidabad bus stand,Park, D.U.R/A, (Dhaka city), rural- Jamalpur, Mymensing (Dhaka division), Chittagong BFRI, semi-urban- Amin-bazar , Asholia, Island-Saint Martin, Periy-rural- Teknaf in Bangladesh .The average concentrations of H_2S was 146 µg/m^{3}in urban sites, 119 µg/m^3 in semi- urban, 125 µg/m^3 in rural, 87 µg/m^3 in Saint. Martin island and 64 µg/m^3 in Teknaf (Peri –rural) (Table 4.16). The Fig.4.9.9 shows that the highest H_2S was found in Urban area followed by semi- urban, rural, teknaf , Island due to vegetations, vehicles emissions. The average value is significantly different as the 95% confidence between urban and semi-urban, semi-urban and rural, teknaf and urban, semi-urban and Island.

4.10: Correlation co-efficient (R^2) and mean ratios

Since the toxic gases such as - SO_2, CO, NO, NO_2, O_3, TVOC, NH_3, H_2S and PH_3 were measured in Dhaka city (Curzon Hall, Science Lab., Farmgate, Topkhana, Saidabad Bus Stand, Mouchak, Mohakhali, Ramna park, D.U. Res. Area, Amin bazar, Ashulia, Chittagong, Mymensingh , Jamalpur, Teknaf, St. Martin Island and the temperature and humidity were also recorded along with the above gases with the help of TG- 501 and TG-502 probes. Linear regression analyses between Temperature and Relative humidity was also carried out to determine any relationship.

The correlation between temperature ^{0}C and relative humidity% during sampling periods are shown in Fig.4.10.1.

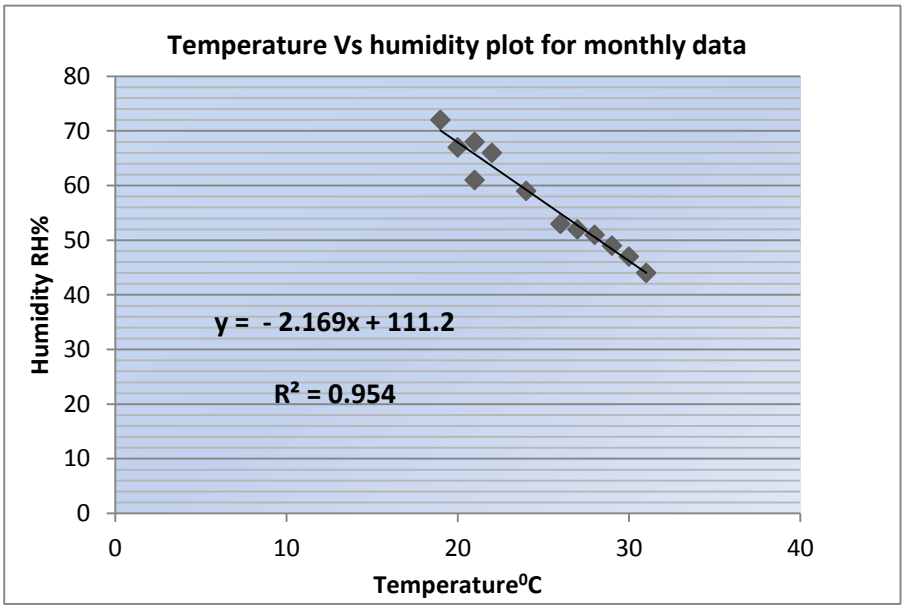


Fig.4.10.1: Relationship between temperature ^{0}C and relative humidity% during sampling periods.

4.11: Air mass trajectory analysis:

Industrial emissions, vehicular emissions, anthropogenic activities, brick-kilns, city wastes burning etc are produce a huge amount of toxic gases. Moreover a huge amount of toxic gases such as - SO_2, CO, NO, NO_2, O_3, TVOC, NH_3, H_2S and PH_3 are also entering into Bangladesh carried over by wind blowing from North, North-West, North-East, south-East coming from over landmass in India, China, Myanmar and other neighbouring countries causing air pollution in our country in Fig. 4.11.1and 4.11.2 (*HYSPLIT model NOAA, 2012).*

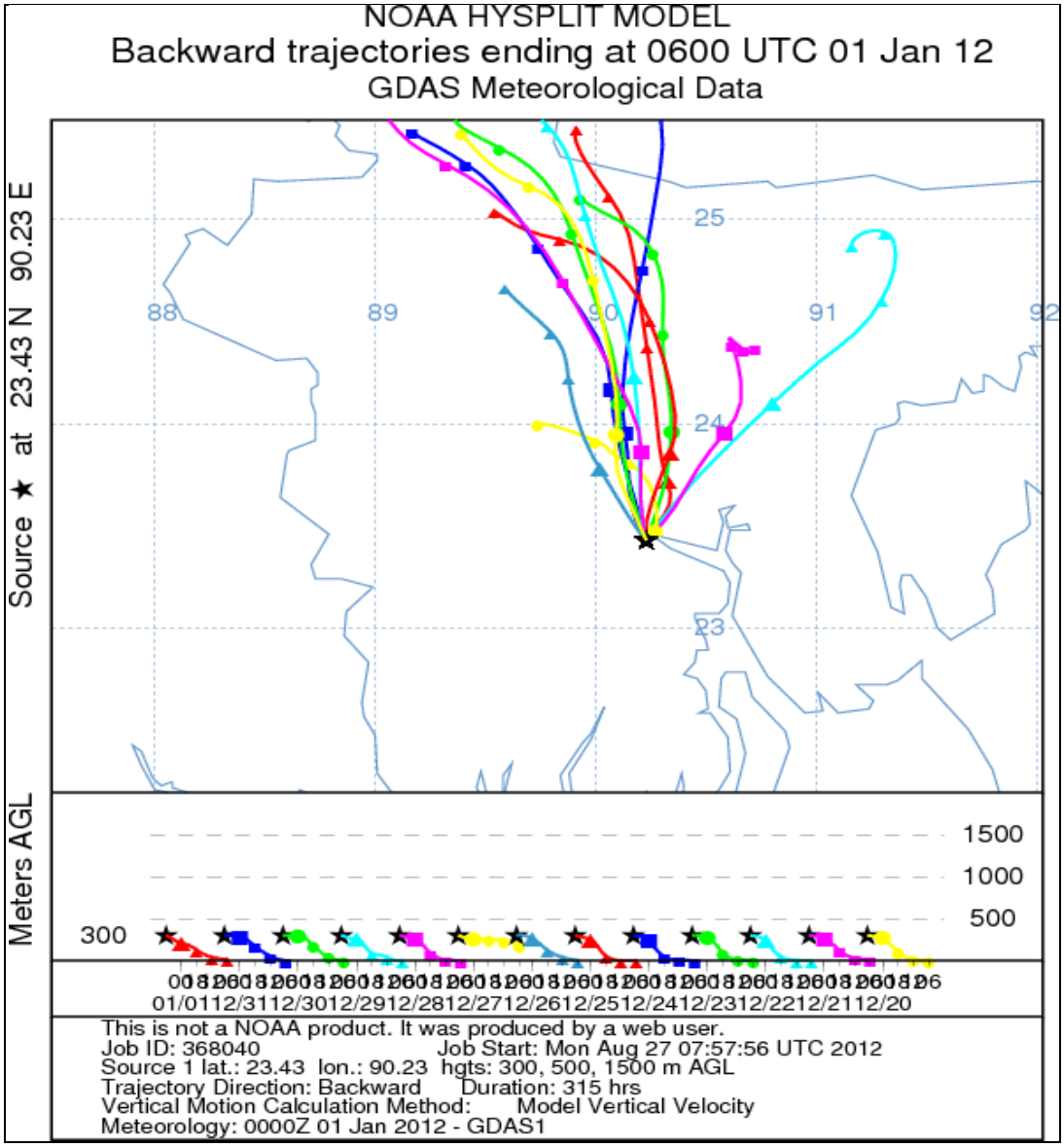


Fig. 4.11.1: Air mass trajectory analysis (01-01-2012).

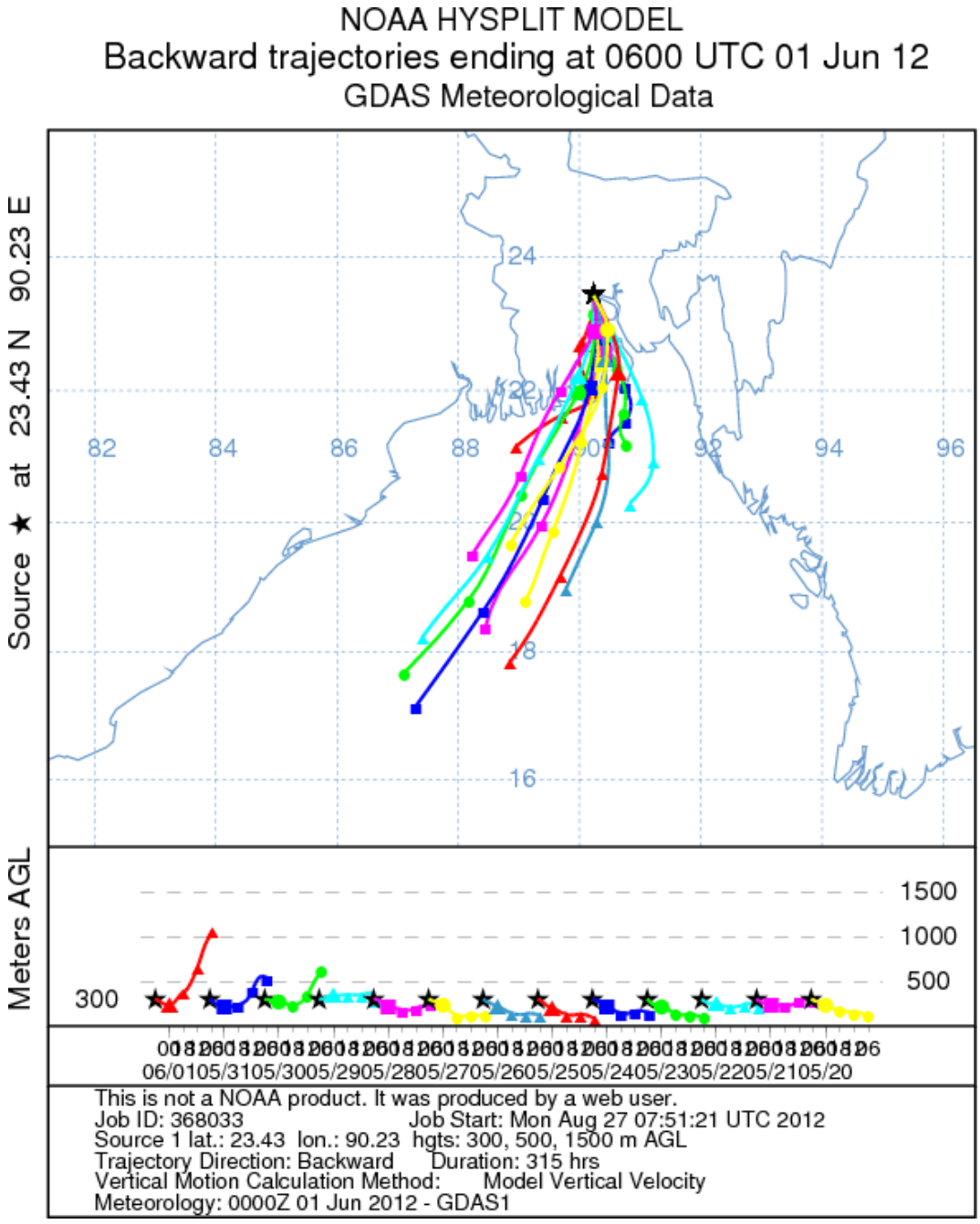


Fig. 4.11.2: Air mass trajectory analysis (01-06-2012).

4.12 : Time-series model of O_3, CO , SO_2, TVOC , NO, NO_2, PH_3, NH_3, H_2S in different locations in Dhaka city.

In time series analysis, an autoregressive integrated moving average (ARIMA) model is a generalization of an autoregressive moving average (ARMA) model (*Hyndman, A., 2015).* These models are fitted to time series data either to better understand the data or to predict future points in the series (forecasting).

- An ARIMA (0, 1, 0) model is given by $X_t = X_{t-1} + \varepsilon_t$— which is simply a random walk.

- An ARIMA (0, 1, 0) with a constant, given by $X_t = c + X_{t-1} + \varepsilon_t$— which is a random walk with drift.

- An ARIMA (0, 2, 2) model is given by $X_t = X_{t-1} + X_{t-2} + (\alpha + \beta - 2)\varepsilon_{t-1} + (1 - \alpha)\varepsilon_{t-2} + \varepsilon_t$— which is equivalent to Holt's linear method with additive errors.

The toxic gas values obtained during the consecutive months started from Jan, 2009 - Dec, 2011 were put in the time – series model and the prediction of gas concentrations for the next 48 consecutive months were made as mentioned by *Asteriou et. al., 2011.*

The prediction plots (based on the ARIMA model) made for each of the gases at 4 different places residential area, traffic area, vicinity of brickfields, park area etc are presented in figures 4.12.1, 4.12.2,4.12.3, 4.12.4, 4.12.5, 4.12.6, 4.12.7, 4.12.8, 4.12.9. The figures show the future trends of the atmospheric toxic gases such as - O3, CO, SO_2, TVOC, NO, NO_2, PH_3, NH_3, H_2S. The plot tells us the present and future trend of the gas concentrations. The black line show the present trend 2009-2011 and the blue one is the trend prediction for 2012-2016.The light grey band in the prediction part is the 95% confidence internal for the predicted concentration varies over 2012-2016. Deep grey band in the prediction part is the 80% confidence internal for the predicted concentration varies over 2012-2016.

It is evident from the prediction analyses that if no actions to curb the level of some of the toxic gases are taken right now, the concentrations may go high enough within next few years to cause significant level of damaging effects on human health and crop plants / tree species in and around Dhaka city.

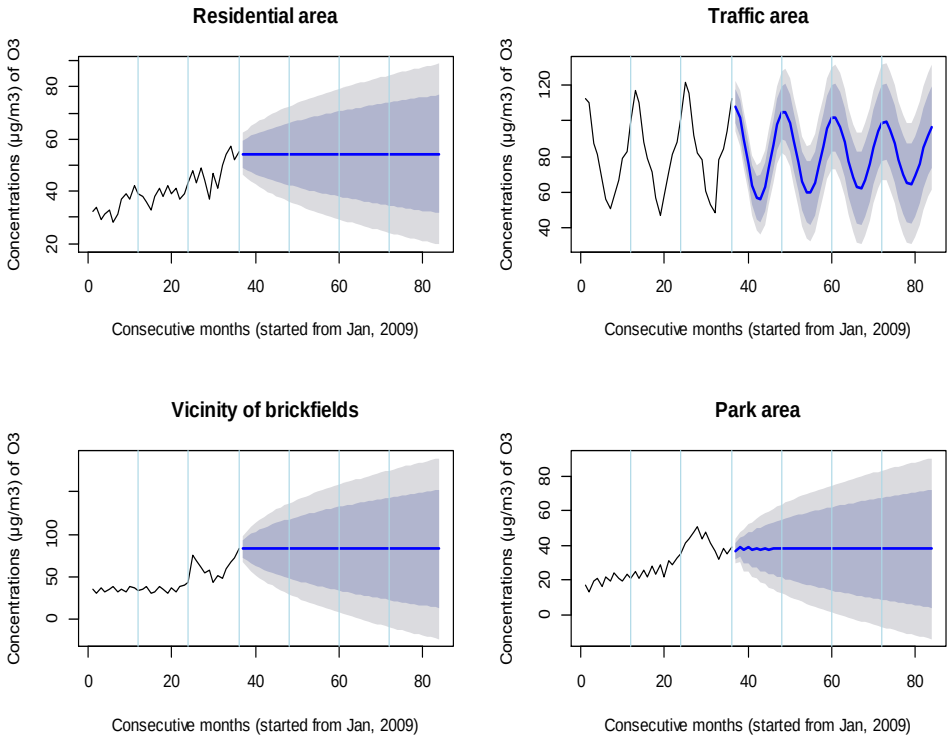


Fig. 4.12.1: Time-series model of O_3 in different locations in Dhaka city.

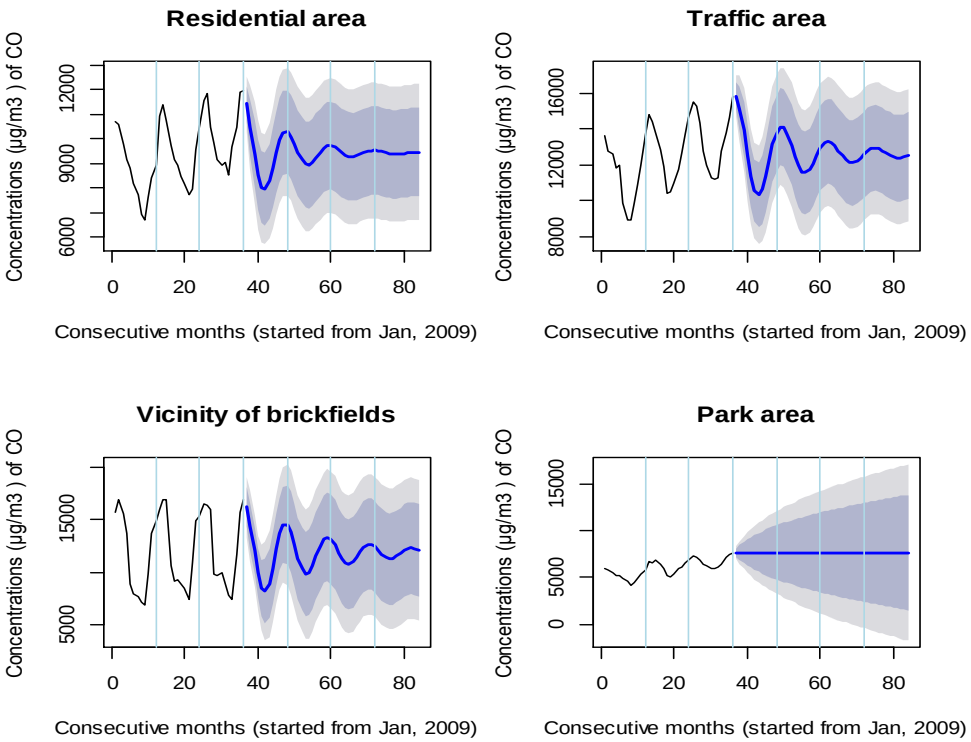


Fig. 4.12.2: Time-series model of CO in different locations in Dhaka city.

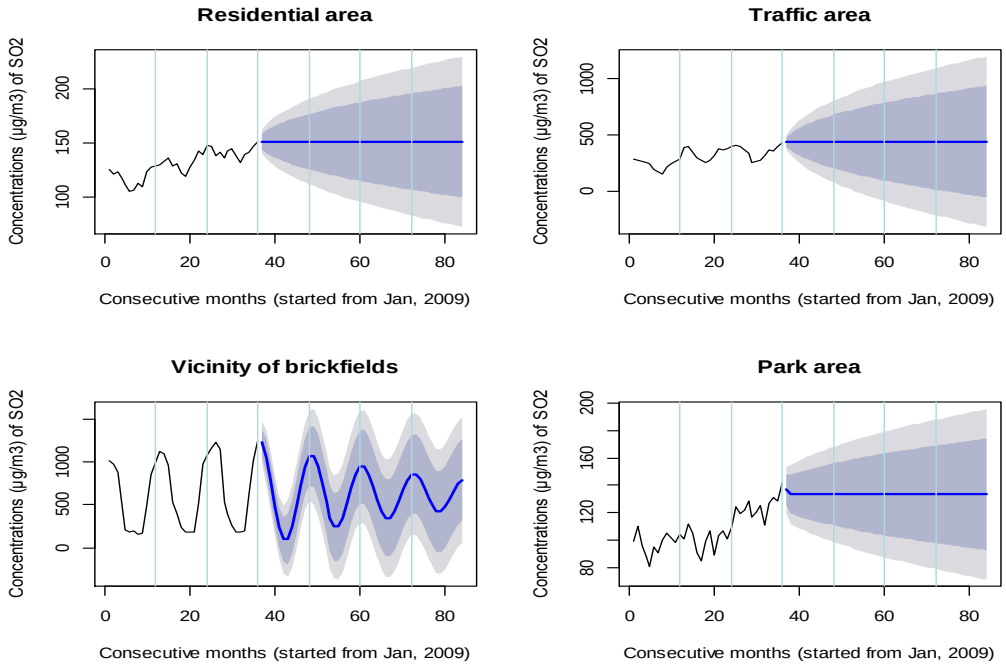


Fig. 4.12.3: Time-series model of SO_2 in different locations in Dhaka city.

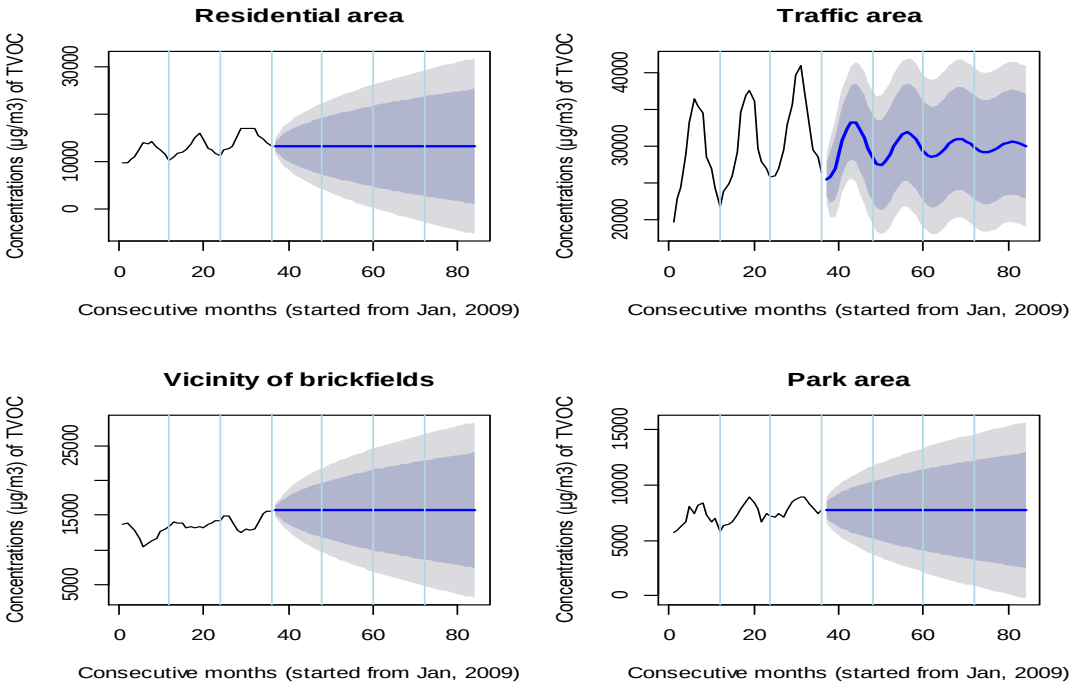


Fig. 4.12.4: Time-series model of TVOC in different locations in Dhaka city.

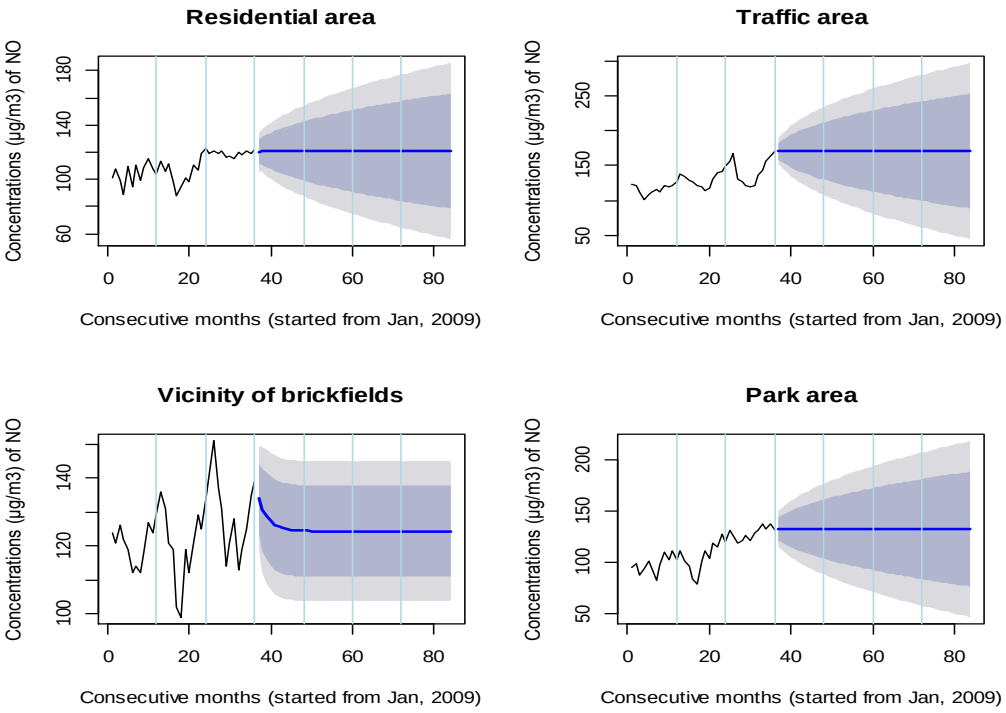


Fig. 4.12.5: Time-series model of NO in different locations in Dhaka city.

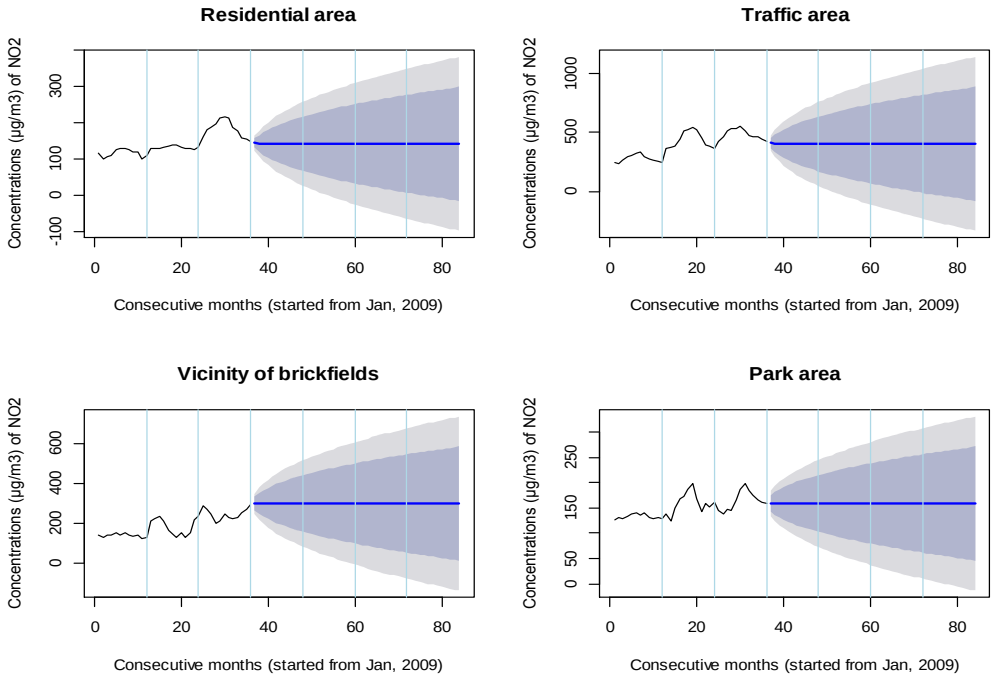


Fig. 4.12.6: Time-series model of NO_2 in different locations in Dhaka city.

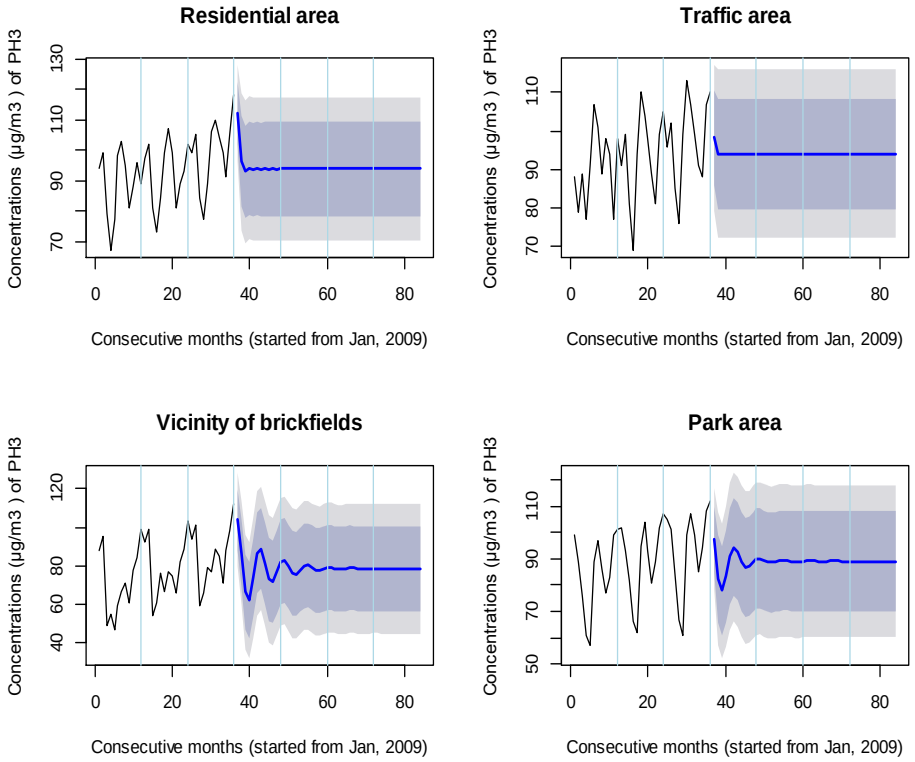


Fig. 4.12.7: Time-series model of PH_3 in different locations in Dhaka city.

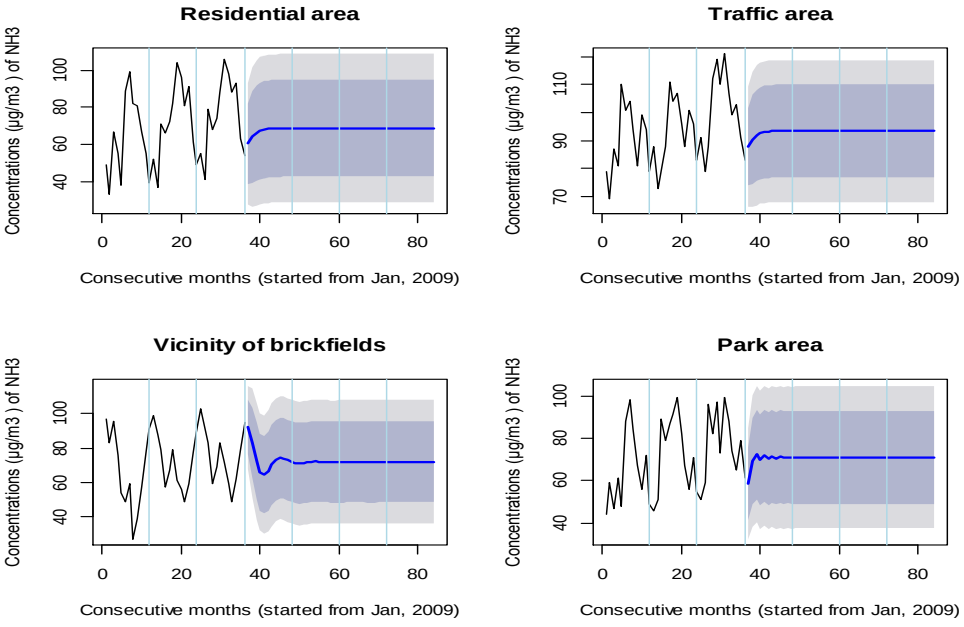


Fig. 4.12.8: Time-series model of NH_3 in different locations in Dhaka city.

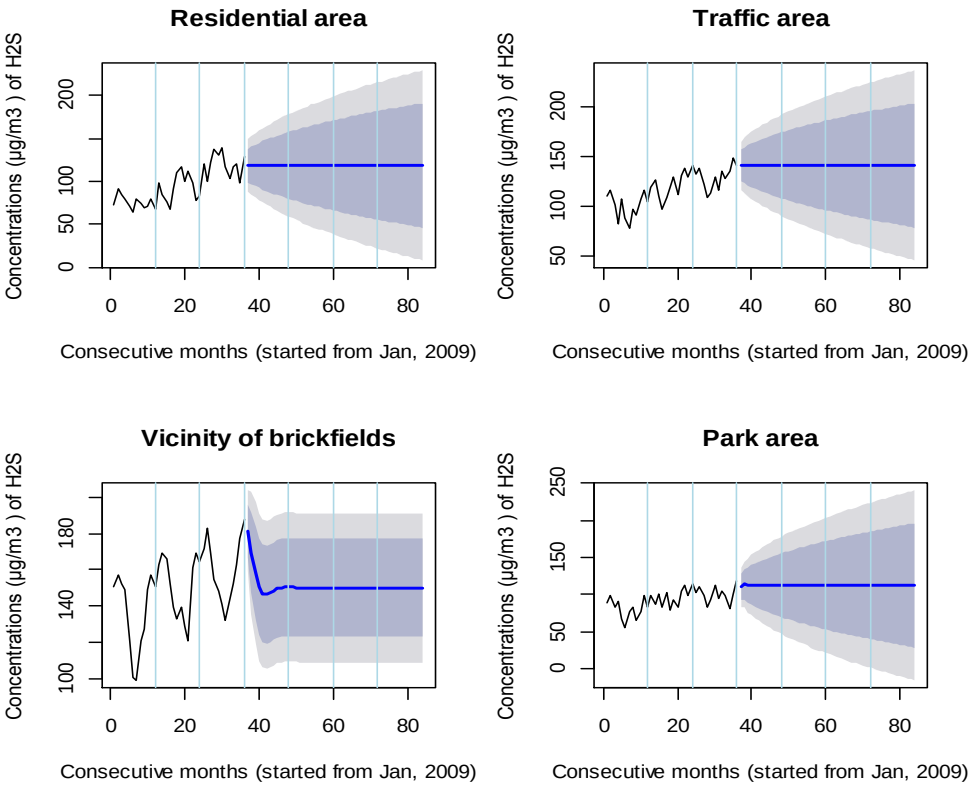


Fig. 4.12.9: Time-series model of H_2S in different locations in Dhaka city.

4.13 Effects on Crops and Plants

A structured questionnaire (See Appendix 4.26) survey was carried out on 305 randomly selected persons including senior citizens, farmers, working on agricultural lands within the immediate vicinity of brick-kilns, highways with heavy traffic and industrial activities and scientists at different organizations.

The respondents from their experience mentioned that there are reductions in crop yield specially cereal crops and they are having damaging symptoms on vegetables and road side tress and reduction in locally grown fruit yield and production. They are suspecting a probable relationship between gases released from brick-kilns and industries around and effects on crops.

The response of the persons interviewed and the yield reductions are presented in Tab. 4.1 and Figs. 4.13.1; 4.13.2; 4.13.3; 4.13.4; 4.13.5; 4.13.6; 4.13.7; 4.13.8.

The questionnaire survey results are presented in Table 4.1.

Table 4.1: The response of the persons interviewed.

Location	Farmer's, and scientists interviewed	Comments	Concentrations µg/m^{3}of toxic gases (2009-2011)
Narshinghopur, Savar.	30 (Farmers)	Reduction in production of cereal crops. (Rice, wheat, maize, pulses). Spotted leaves (pumpkin). Spotted fruits. (Guava, coconut etc.) . Smaller fruit size. Top dying (Coconut trees).	O_3 - 35 µg/m^3 CO - 9523 µg/m^3 SO_2 - 126 µg/m^3 TVOC - 11043 µg/m^3 NO - 113 µg/m^3 NO_2 - 126 µg/m^3 PH_3 - 105 µg/m^3 NH_3 - 87 µg/m^3 H_2S - 113 µg/m^3
Diakhali, Savar.	35 (Farmers)	Spotted leaves ((pumpkin). Spotted fruits. (Guava, coconut etc.) . Smaller fruit size. Top dying of tree species (Coconut trees).	O_3 - 35 µg/m^3 CO - 9623 µg/m^3 SO_2 - 129 µg/m^3 TVOC - 10043 µg/m^3 NO - 113 µg/m^3 NO_2 - 127 µg/m^3 PH_3 - 105 µg/m^3 NH_3 - 88 µg/m^3 H_2S - 113 µg/m^3
BARI,Bagbari ,Gagipur.	44 (Net house workers, Scientists)	Plant cell membrane damage. Dying of tree species on the high-way road-side. Spotted	O_3 - 37 µg/m^3 CO - 9623 µg/m^3 SO_2 - 124 µg/m^3 TVOC - 12043 µg/m^3

		leaves (pumpkin). Spotted fruits (Guava, coconut etc). Fruits are small in size. Top dying the tree (Coconut tree).	NO - 110 µg/m^3 NO_2 - 126 µg/m^3 PH_3 - 101 µg/m^3 NH_3 - 87 µg/m^3 H_2S - 119 µg/m^3
BADC, Kashimpur.	37 (Mostly Scientists)	The symptoms appear as a yellowing or chlorosis of the leaf. Spotted leaves (pumpkin). Spotted fruits (guava). Fruits are small in size etc. Top dying (Coconut tree). Ozone, ammonia injury to vegetations.	O_3 - 37 µg/m^3 CO - 9323 µg/m^3 SO_2 - 129 µg/m^3 TVOC - 13043 µg/m^3 NO - 113 µg/m^3 NO_2 - 122 µg/m^3 PH_3 - 105 µg/m^3 NH_3 - 85 µg/m^3 H_2S - 117 µg/m^3
BINA,Borarchar, Mymensing.	30 (Mostly Scientists and Govt. officers).	Ozone symptoms characteristically occur on the upper surface of affected leaves and appear as a flecking, bronzing or bleaching of the leaf tissues (Soybean). The symptoms appear as a yellowing or chlorosis of the leaf. Spotted leaves (pumping). Spotted fruits (guava). Ozone injury to vegetations. Woody tree had died.	O_3 - 42 µg/m^3 CO - 9123 µg/m^3 SO_2 - 131 µg/m^3 TVOC - 12043 µg/m^3 NO - 114 µg/m^3 NO_2 - 126 µg/m^3 PH_3 - 105 µg/m^3 NH_3 - 88 µg/m^3 H_2S - 119 µg/m^3
Bandra ,Tangail.	40 (Farmers and Senior citizens).	Crop damages, reduction in yield of crops and fruits and top dying of tree species. Spotted leaves (pumpkin). Spotted fruits (guava). Fruits are small in size etc.	O_3 – 40 µg/m^3 CO - 8823 µg/m^3 SO_2 - 121 µg/m^3 TVOC - 11053 µg/m^3 NO - 123 µg/m^3 NO_2 - 115 µg/m^3 PH_3 - 99 µg/m^3 NH_3 - 79 µg/m^3 H_2S - 121 µg/m^3
Amin bazar, Dhaka.	45 (Farmers, workers and Senior citizens).	Plant cell membrane damage. Dying of tree species on the high-way road-side. Spotted leaves (pumpkin). Spotted fruits (Guava, coconut etc). Fruits are small in size. Top dying the tree (Coconut tree	O_3 - 33 µg/m^3 CO - 9953 µg/m^3 SO_2 - 139 µg/m^3 TVOC - 13043 µg/m^3 NO - 124 µg/m^3 NO_2 - 121 µg/m^3 PH_3 - 108 µg/m^3 NH_3 - 88 µg/m^3 H_2S - 126 µg/m^3

Ashulia, Dhaka.	44 (Farmers, workers and Senior citizens).	Reduction in production of cereal crops. (Rice, wheat, maize, pulses). Spotted leaves (pumpkin). Spotted fruits. (Guava, coconut etc.) . Smaller fruit size. Top dying (Coconut trees).	O_3 - 33 µg/m^3 CO - 10223 µg/m^3 SO_2 - 133 µg/m^3 TVOC - 13043 µg/m^3 NO - 121 µg/m^3 NO_2 - 129 µg/m^3 PH_3 - 101 µg/m^3 NH_3 - 94 µg/m^3 H_2S - 118 µg/m^3

Source: Survey report, 2011.

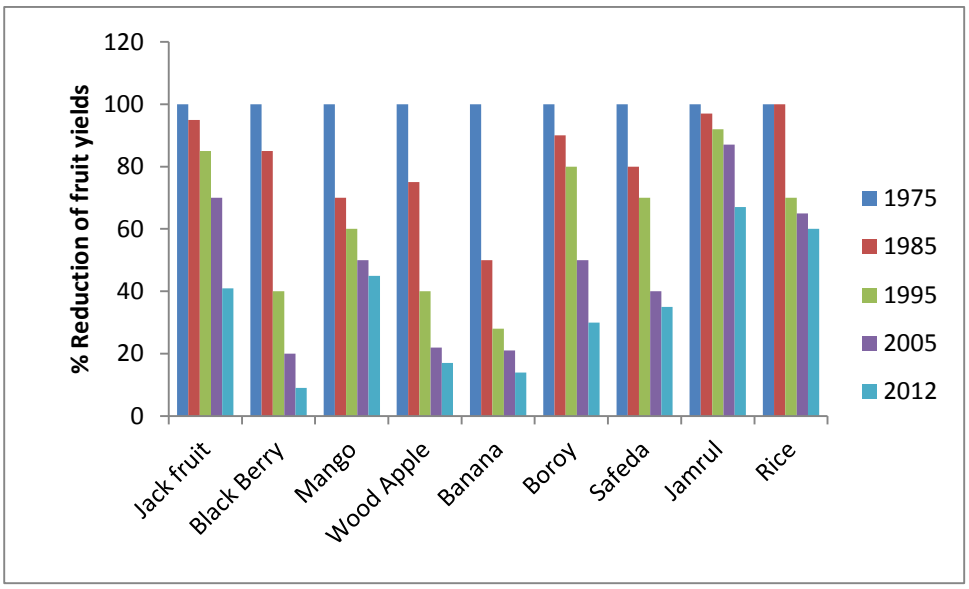


Fig. 4.13.1: Reduction of fruit reported at Narshinghopur, Savar.

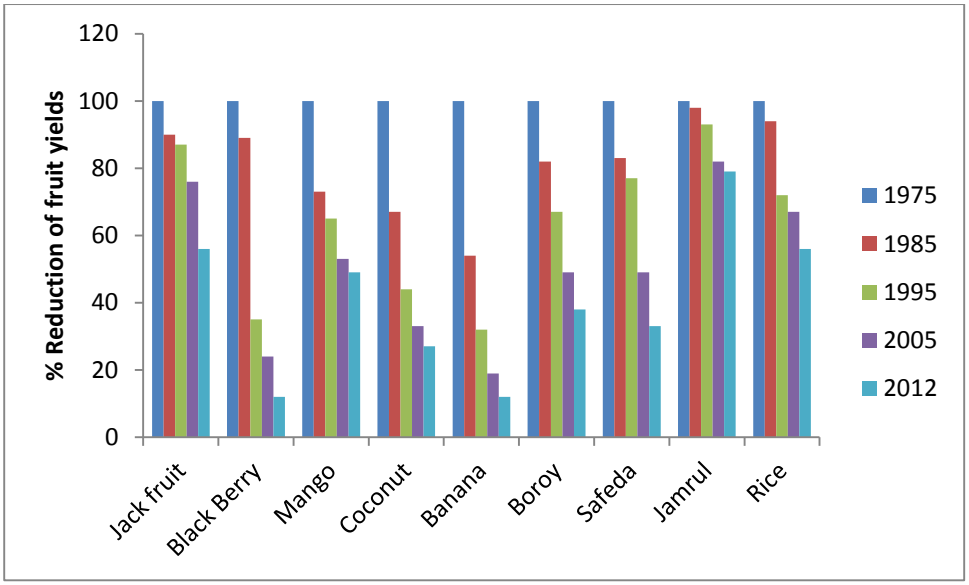


Fig. 4.13.2: Reduction of fruit reported at Diakhali, Savar.

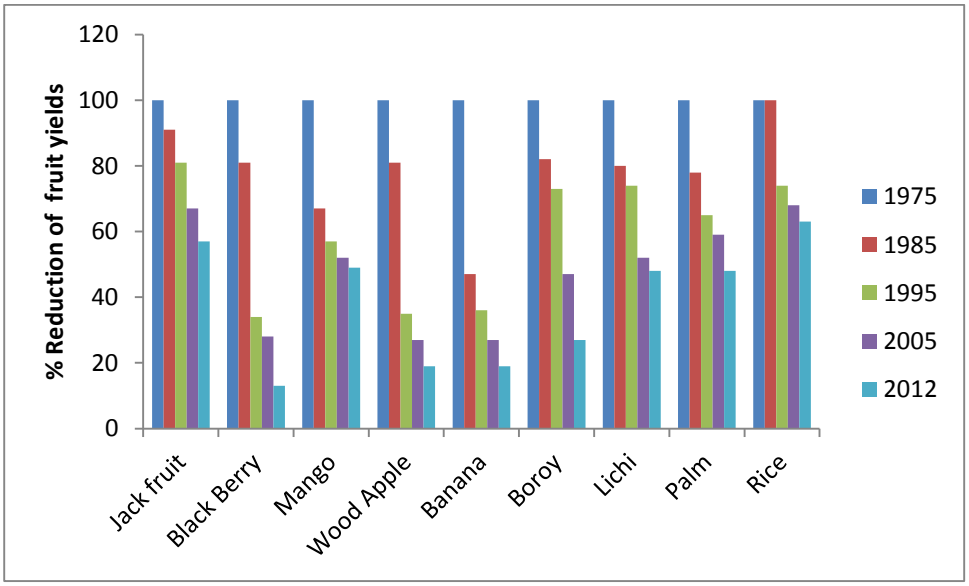


Fig. 4.13.3: Reduction of fruit reported at Bagbari ,Gagipur.

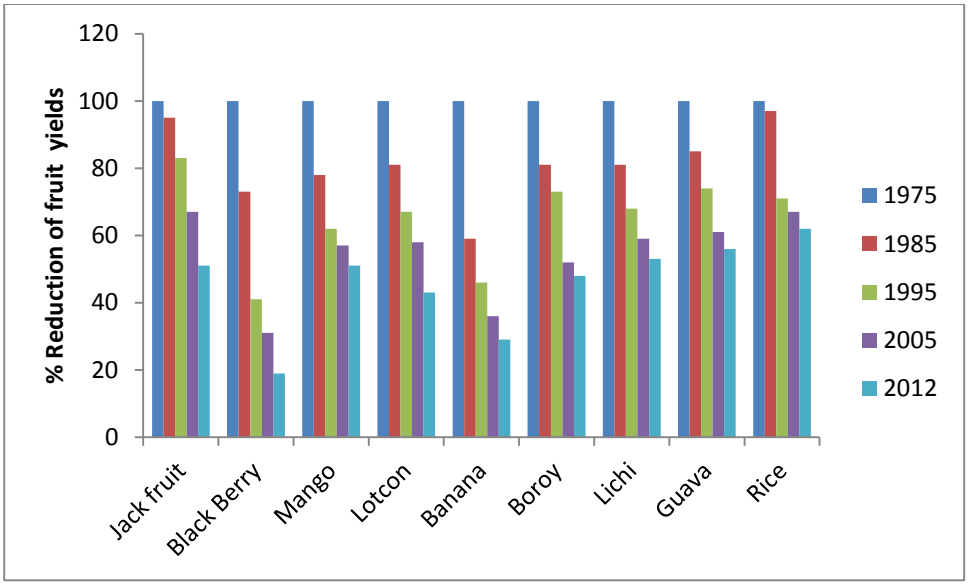


Fig. 4.13.4: Reduction of fruit reported at BARI, BADC, Kashimpur.

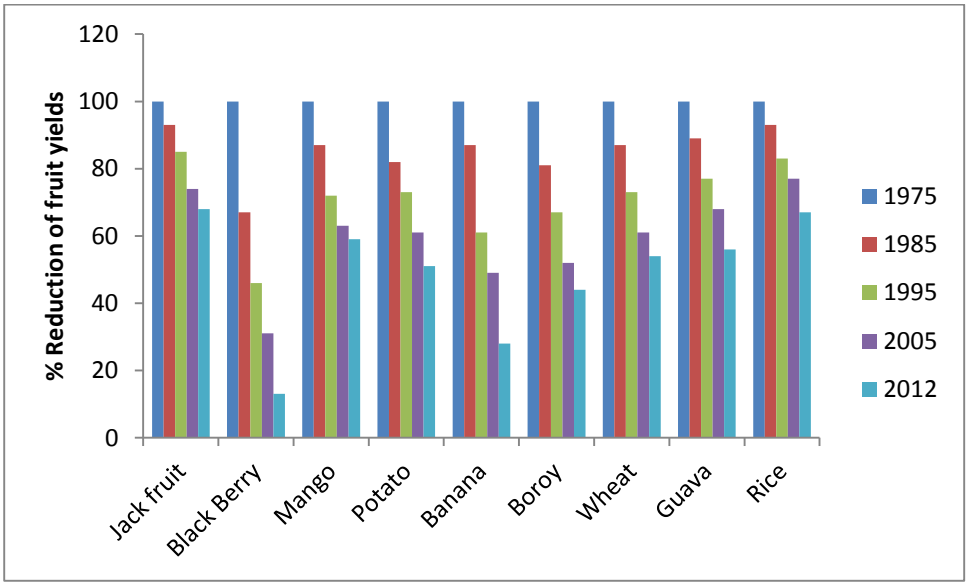


Fig. 4.13.5: Reduction of fruit at BINA, Borarchar, Mymensing.

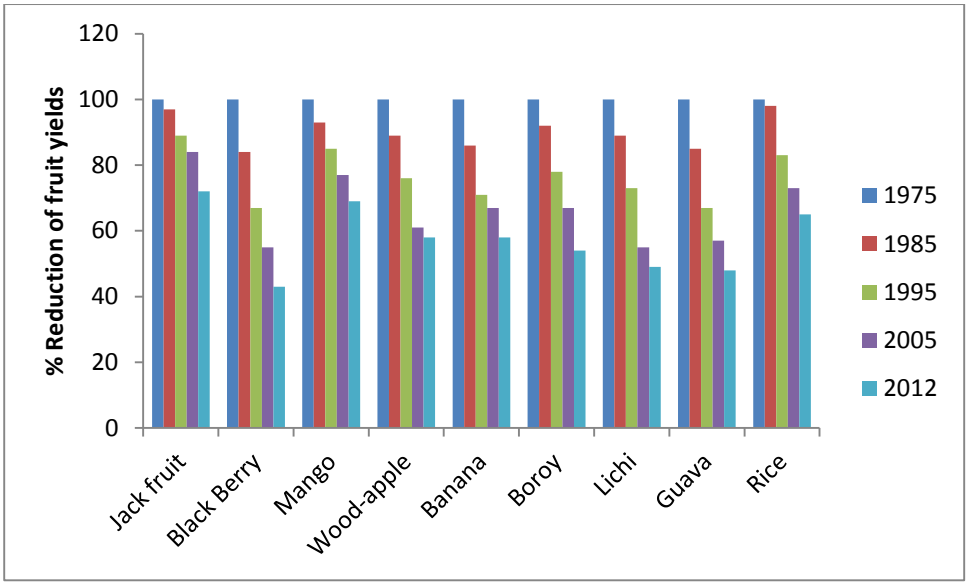


Fig. 4.13.6: Reduction of fruit reported at Bandra ,Tangail.

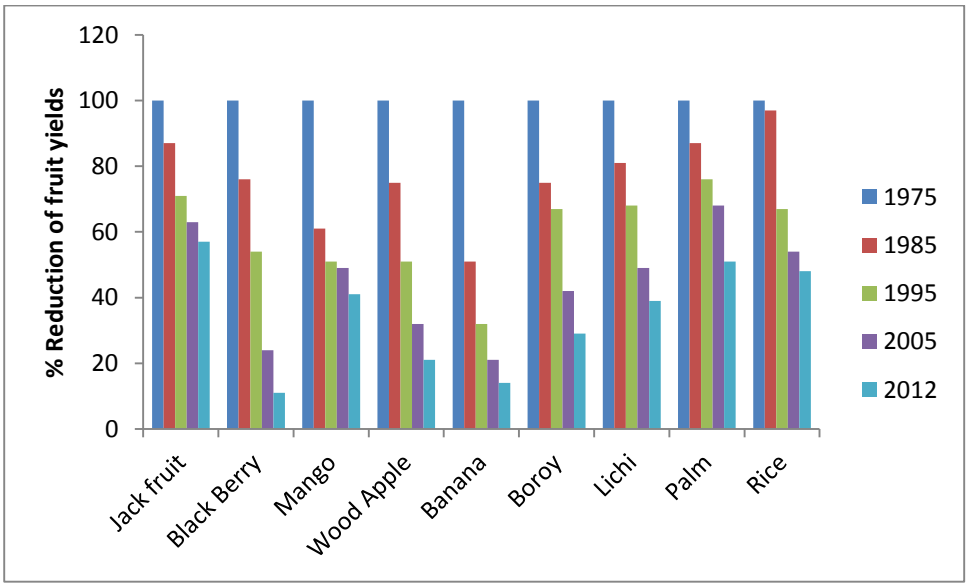


Fig. 4.13.7: Reduction of fruit reported at Amin bazar, Dhaka.

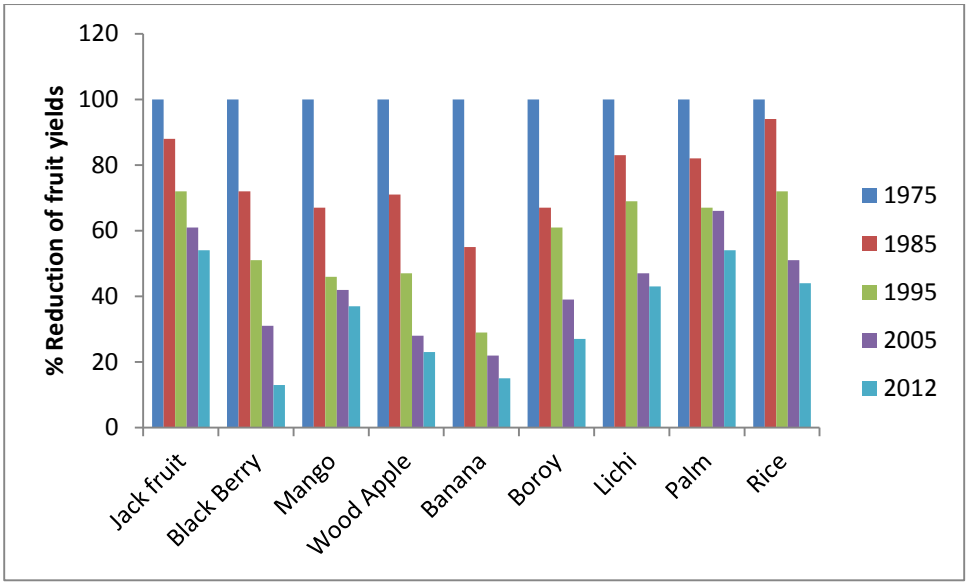


Fig. 4.13.8: Reduction of fruit reported at Ashulia, Dhaka.

Table 4.1.1: Concentrations (µg/m^3) of toxic gases measured in Tongi and Mymensing road from 2009-2011.

Parameter	2009	2010	2011
SO_2	129	136	149
CO	8996	9520	10170
TVOC	11730	12188	13949
O_3	47	51	54
NO	140	149	157
NO_2	133	143	152
NH_3	71	84	99
H_2S	96	110	119
PH_3	99	103	121

Fig. 4.13.9: Probable effect of toxic gases on road-side trees seen in Tongi and Mymensing road.

Effects of atmospheric toxic gases were investigated on Cereal crops (rice, wheat, maize, and pulses), fruits, vegetables, trees along the road-sides. Many sensitive trees had died due to the vehicle and industrial emissions of toxic gases. Investigations were conducted at Hazaribagh, where SO_2, H_2S and NOx emissions are the common phenomena. For comparison with the cities and industrial areas, unpolluted rural areas were investigated. The graph 4.13.1; 4.13.2; 4.13.3; 4.13.4; 4.13.5; 4.13.6; 4.13.7; 4.13.8 Shows that the production of jack-fruit, Black-berry, palm, mango, boroy, wood-apple, litchis are decreasing day by day by the effect of toxic gases (Table 4.18; 4.19; 4.20; 4.21; 4.22; 4.23; 4.24; 4.25). Vegetables are growing well with fertilizer, pesticides and organic fertilizer applications .In the past in these places a huge amount of fruits grownup, but impacts on atmospheric toxic gases the productions are decreasing day by day. Spatially the effect of O_3 and SO_2 are very much sensitive on the crops and fruits (*Hewitt et. al., 2006).*

Recently expanded leaves usually are the most sensitive to acute sulfur dioxide injury, the very youngest and oldest being somewhat more resistant. Chronic injury is caused by long-term absorption of sulphur dioxide at sub-lethal concentrations. The symptoms appear as a yellowing or chlorosis of the leaf, and occasionally as a bronzing on the under surface of the leaves *(Fam et. al., 1974).*

Different plant species and varieties and even individuals of the same species may vary considerably in their sensitivity to sulphur dioxide. These variations occur because of the

differences in geographical location, climate, stage of growth and maturation. The following crop plants are generally considered susceptible to sulphur dioxide: alfalfa, barley, buckwheat, clover, oats, pumpkin, radish, rhubarb, spinach, squash, Swiss chard and tobacco. Resistant crop plants include asparagus, cabbage, celery, corn, onion and potato. Physiological and developmental processes of plants are affected by UVB radiation, even by the amount of UVB in present-day sunlight. Despite mechanisms to reduce or repair these effects and a limited ability to adapt to increased levels of UVB, plant growth can be directly affected by UVB radiation (*Islam et. al., 2008).* Indirect changes caused by UVB (such as changes in plant form, how nutrients are distributed within the plant, timing of developmental phases and secondary metabolism) may be equally, or sometimes more, important than damaging effects of UVB. These changes can have important implications for plant competitive balance, plant diseases, and biogeochemical cycles. Injury in a pumpkin leaf, guava leaf by O_3. Resistant crop plants include asparagus, cabbage, celery, corn, onion and potato. Plants damaged by sulfur dioxide can be as far as 30 miles from its source, but the most severe damage, defoliation and discoloring is typically found within five miles. For some plants, it can take exposure of only four hours to suffer damage. A wide variety of plants are vulnerable, from alfalfa and carrots to crab apple and fir trees (*Mannan, 2006).*

4.14 Effects on Human health

A structured questionnaire (See Appendix 4.27) survey was carried out on 656 randomly selected persons - females, children, traffic polices, drivers, city dwellers at different locations in Dhaka city. Data were also collected from the hospitals like Dhaka Medical College hospital, Community hospital, Holy family hospital, Apollo hospital etc.

About 90% of the females interviewed complained about breathing problems, irritations of eyes, skin problem, cough etc and that the magnitude of the effect increases in dry season (winter). Similar results were obtained for Children's, drivers, traffic police, city dwellers etc.

Table 4.2: Response of females interviewed on health effect in Dhaka city during 2012.

Age-group	Number of Female	Reported Problem	Probable Causes
25-30	65	Breathing Problem, Eye-irritation	Air pollution, Dust, Black smoke etc.
30-35	54	Breathing Problem, Eye-irritation	Air pollution, Dust, Black smoke etc.
35-40	44	Breathing Problem, Eye-irritation, Skin diseases.	Air pollution, Dust, Black smoke etc.
40-45	22	Breathing Problem, Eye-irritation, Caught, and Asthma.	Air pollution, Dust, Black smoke etc.
45-50	14	Breathing Problem, Eye-irritation, Caught, Asthma, vomiting, headache.	Air pollution, Dust, Black smoke etc.

Table 4.3: Response of Children's interviewed on health effect in Dhaka city during 2012.

Age-group	Number of Children	Reported Problem	Probable Causes
3-6	67	Breathing Problem, Eye-irritation.	Air pollution, Dust, Black smoke etc.
6-9	59	Breathing Problem, Eye-irritation.	Air pollution, Dust, Black smoke etc.
9-12	61	Breathing Problem, Eye-irritation, vomiting, headache.	Air pollution, Dust, Black smoke etc.
12-15	33	Breathing Problem, Eye-irritation, Cough, Asthma, bronchitis.	Air pollution, Dust, Black smoke etc.

Table 4.4: Response of Traffic polices interviewed on health effect in Dhaka city during 2012.

Age-group	Number of traffic polices	Reported Problem	Probable Causes
25-30	22	Breathing Problem, Eye-irritation, Skin diseases	Air pollution, Dust, Black smoke etc.
30-35	46	Breathing Problem, Eye-irritation ,Skin diseases	Air pollution, Dust, Black smoke etc.
35-40	39	Breathing Problem, Eye-irritation, Skin diseases	Air pollution, Dust, Black smoke etc.
40-45	55	Breathing Problem, Eye-irritation, Cough, Skin diseases	Air pollution, Dust, Black smoke etc.
45-50	37	Breathing Problem, Eye-irritation, Skin diseases, Cough.	Air pollution, Dust, Black smoke etc.
50-55	18	Breathing Problem, Eye-irritation, Skin diseases, Cough.	Air pollution, Dust, Black smoke etc.

Table 4.5: Response of Drivers interviewed on health effect in Dhaka city during 2012.

Age-group	Number of drivers	Reported Problem	Probable Causes
25-30	29	Breathing Problem, Eye-irritation, Skin diseases.	Air pollution, Dust, Black smoke etc.
30-35	34	Breathing Problem, Eye-irritation, Skin diseases.	Air pollution, Dust, Black smoke etc.
35-40	27	Breathing Problem, Eye-irritation Skin diseases.	Air pollution, Dust, Black smoke etc.
40-45	25	Breathing Problem, Eye-irritation, Cough, Skin diseases.	Air pollution, Dust, Black smoke etc.
45-50	17	Breathing Problem, Eye-irritation, Cough, Skin diseases.	Air pollution, Dust, Black smoke etc.

Physicians interviewed at different hospitals reported that they attend increasing number of patients during winter and that relates well with the statements made by the city dwellers at all levels in the present investigation. Although it was not possible to indentify or relate a single trigger factor inducing such health effects, the level of toxic gases in particular, O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 measured in the present investigation alone or in combination with other gases and suspended particulate matter (SPM) might have contributed to the effects.

Sulfur dioxide (SO_2) and nitrogen oxides (NOx) are two primary examples of particle-forming air pollutants (particulate matter) from coal power plants. Particulate matter is known to contribute to serious health problems, including lung cancer and other cardiopulmonary mortality. SO_2 and NOx are both highly toxic to human health, and contribute directly to thousands of hospitalizations, heart attacks, and deaths annually. SO_2 is particularly dangerous for children. Studies correlate SO_2 emissions from petroleum refineries — even in lower exposure levels over time — to higher rates of childhood asthma in children who live or attend school in proximity to those refineries. Similarly, small particles of NOx can penetrate deeply into sensitive lung tissue and damage it, causing .premature death in extreme cases. Inhalation of such particles is associated with emphysema and bronchitis (*Ahmad et. al., 2008*). Current scientific evidence links

short-term NO_2 exposures, ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma. Also, studies show a connection between breathing elevated short-term NO_2 concentrations, and increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma.

Nitrogen di Oxide (NO_2) exposure concentrations near roadways are of particular concern for susceptible individuals, including people with asthma asthmatics, children, and the elderly. NOx react with ammonia, moisture, and other compounds to form small particles. These small particles penetrate deeply into sensitive parts of the lungs and can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death. Ozone is formed when NOx and volatile organic compounds react in the presence of heat and sunlight. Children, the elderly, people with lung diseases such as asthma, and people who work or exercise outside are at risk for adverse effects from ozone. These include reduction in lung function and increased respiratory symptoms as well as respiratory-related emergency department visits, hospital admissions, and possibly premature deaths. Emissions that lead to the formation of NO_2 generally also lead to the formation of other NOx. Emissions control measures leading to reductions in NO_2 can generally be expected to reduce population exposures to all gaseous NOx. This may have the important co-benefit of reducing the formation of ozone and fine particles both of which pose significant public health threats.

Carbon monoxide (CO) can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death. Exposure to CO can reduce the oxygen-carrying capacity of the blood. People with several types of heart disease already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by chest pain (angina), when exercising or under increased stress. For these people, short-term CO exposure further affects their body’s already compromised ability to respond to the increased oxygen demands of exercise or exertion. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death. Exposure to CO can reduce the oxygen-carrying capacity of the blood. People with several types of heart disease already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by chest pain (angina), when exercising or under increased stress. For these people, short-term CO exposure further affects their body’s already compromised ability to respond to the increased oxygen demands of exercise or exertion (*WHO, 2015).*

These effects may lead to increased school absences, medication use, visits to doctors and emergency rooms, and hospital admissions. Research also indicates that ozone exposure may increase the risk of premature death from heart or lung disease. Ozone is particularly likely to reach unhealthy levels on hot sunny days in urban environments. It is a major part of urban smog. Ozone can also be transported long distances by wind. For this reason, even rural areas can experience high ozone levels. Short-term exposure to high levels of

some VOCs can cause headaches, dizziness, light-headedness, drowsiness, nausea, and eye and respiratory irritation. These effects usually go away after the exposure stops. In laboratory animals, long-term exposure to high levels of some VOCs has caused cancer and affected the liver, kidney and nervous system. In general, we recommend minimizing exposure to chemicals, if possible (*EPA, 2010*). Hence, H_2S has been referred to as the "knock down gas" because inhalation of high concentrations can cause immediate loss of consciousness and death. However, prolonged exposure to lower concentrations, such as 10-500 ppm, can cause various respiratory symptoms that range from rhinitis to acute respiratory failure. Injury due to H_2S exposure occurs primarily by inhalation. Once absorbed, the compound is distributed in the blood and taken up by the brain, liver, kidney, pancreas, and small intestines. Sulphur compounds are severely irritating to the respiratory tract, leading to rhino rhea, sneezing, sore throat, wheezing, shortness of breath, chest tightness and a feeling of suffocation. Immediate full recovery. This phenomenon usually occurs after short-term exposure to very high concentrations of H_2S (*EPA, 2015).*

Ammonia (NH_3) is a highly hydrophilic base that has irritant properties when inhaled which, when combined with water, can injure and burn the respiratory tract (42). The base form of ammonia, ammonium hydroxide, dissolves in the water of mucus membranes, hydrolyzes, and rapidly irritates tissues due to the high pH that results (43). Ammonia can also alter the uptake of oxygen by hemoglobin due to the increase of pH within the blood (42), which leads to decreased oxygenation of tissues, and decreased metabolic function *(EPA,2014).*

Ozone (O_3) in the air we breathe can harm our health—typically on hot, sunny days when ozone can reach unhealthy levels. Even relatively low levels of ozone can cause health effects. Children, people with lung disease, older adults, and people who are active outdoors, including outdoor workers, may be particularly sensitive to ozone. Children are at greatest risk from exposure to O_3 (Ozone) because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma. Breathing O_3 (Ozone) can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma. Ground level ozone also can reduce lung function and inflame the linings of the lungs. Repeated exposure may permanently scar lung tissue *(EPA, 2015*).

4.15 **Summary of the results**

- Elevated Concentrations of O_3 (47 μg/m^3), CO (14818 μg/m^3), SO_2 (239 μg/m^3), TVOC (15881 μg/m^3), NO (178 μg/m^3), NO_2 (264 μg/m^3), PH_3 (118 μg/m^3), NH_3 (121 μg/m^3) and H_2S (117 μg/m^3) in 2011 were measured at different hot spots in Dhaka city and these results were comparable with the concentrations measured at selected rural, semi-urban and St. Martin's Island at the Bay of Bengal.

- The concentrations measured for O_3, 47 μg/m^3 was within the safe limits as prescribed by the WHO guideline 100 μg/m^3 (Eight hours), 2005; Bangladesh standards 157 μg/m^3 (*DoE, 2005*), EU 80 μg/m^3, 2008; EPA 120 μg/m^3, 2010 and ECR 120 μg/m^3, 1995 amended in 2005. The concentrations reported here for O_3 is higher than the concentrations reported by *Mehedi* in 2010.

- The concentrations measured for SO_2, 239 μg/m^3 exceeded the limit values as mentioned in the WHO guideline 120 μg/m^3, 2005 and EPA 120 μg/m^3, 2009.

- The concentration of CO, 14818 μg/m^3 exceeded the limit values as mentioned in the WHO guideline 5000 μg/m^3, 2005; EPA 5000 μg/m^3, 2009 and EU 5000 μg/m^3, 2008.

- The concentration of NO, 178 μg/m^3 and NO_2, 264 μg/m^3 exceeded the limit values as mentioned in the WHO guideline 80 μg/m^3, 2005; EPA 120 μg/m^3, 2009 and EU 120 μg/m^3, 2008.

- Significant level of diurnal and seasonal variations were observed for O_3 (12 hr), CO (14 hr), SO_2 (10 hr), NO (13 hr) and NO_2 (15 hr).The concentration of O_3 and SO_2 observed to be decreased to zero between 9 and 17 hours during day time probably because of photo dissociation.

- The highest level of O_3 (40 μg/m^3), CO (12314 μg/m^3), SO_2 (139 μg/m^3), TVOC (10756 μg/m^3), NO (139 μg/m^3), NO_2 (147 μg/m^3), PH_3 (121 μg/m^3), NH_3 (62 μg/m^3), H_2S (92 μg/m^3) were measured in winter in 2011.

- Significant level of variations in O_3, CO, SO_2, TVOC, NO, NO_2, H_2S, NH_3, PH_3 concentrations were noted between 2009 and 2011. Concentrations of some of the gases appeared to be increasing.

The most likely contributors or the sources of toxic gases in Dhaka city appeared to be the automobiles, various types of industries, brick kilns and solid waste land-fill sites/grounds.

However, an air mass trajectory analysis using HYSPLIT model (*NOAA, 2012*) showed that there are cross country or trans boundary contributions as well.

The effect of toxic gases on human health and crop plants evaluated based on the interview of farmers, workers, scientists and researchers at different organizations, physicians at govt. hospitals, traffic polices and road goers using structured questionnaire reveal that the people in Dhaka city are reported to have been suffering from breathing problems, eye-irritation, cough, skin diseases, chest and lung diseases. However, it was not possible to ascertain whether the effects were occurring through the elevated concentrations of measured gases in the present investigation. It is assumed that a combined effect along with Suspended Particulate Matter (SPM) and other gases not taken into account could possibly inducing the effects.

5. Conclusion

The present research was able to generate significant level of information regarding concentrations of some of the toxic gases in the ambient air of Dhaka city and the probable sources. It was however, not possible to link any of the particular toxic gases measured affecting human health and/or crop production individually. Significantly high levels of some of the toxic gases measured compared to rural areas are indicative of deteriorating air quality in Dhaka city and deserves continuous monitoring and policy framing for curbing production and emission of the gases. Some recommendations are put forward.

Recommendations -

- Emission control measures to be taken.
- Improve traffic management system in Dhaka city. Measures to reduce fuel demand and improve traffic conditions are also critical to ensuring a net emission reduction and should be used as a complement to technical measures.
- Use of alternative fuel source like bio-fuel and low emission automobiles to be introduced.
- Use of catalytic converter in all kind of motor vehicles to be enforced.
- Brick making and brick- kilns establishment (control) Act to be enacted.
- Introduction of 3R concept (Reduce, Reuse, Recycle) to be enforced in case of solid waste management in Dhaka city. Modern closed waste management system needs to be adopted for municipal waste. The toxic waste from industries can be controlled through installation of scrubbers. Effluent treatment plant (ETP) should be installed.
- Regulation for controlling construction dust should be enforced.
- Steps to be taken for creating public awareness regarding health effects of air pollution through seminars and talk shows.
- Government should strengthen vehicle emission standards, regulations, monitoring and enforcement.

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Appendix

Table 4.1: Concentrations (µg/m^3) of atmospheric toxic gases measured in Dhaka City in 2009.

Month	Week	O_3	CO	SO_2	TVOC	NO	NO_2	PH_3	NH_3	H_2S
January	1	35	10354	119	9686	109	112	114	49	73
	2	34	10425	117	9785	103	101	106	41	69
	3	29	10143	123	9823	111	106	109	44	72
	4	31	10365	121	9634	102	110	102	55	81
February	1	33	10534	122	10534	104	127	99	38	72
	2	28	10376	105	10498	103	131	103	51	65
	3	31	10723	108	10745	110	129	107	55	79
	4	37	10634	113	10476	102	126	111	57	74
March	1	39	9756	109	11867	112	119	88	57	70
	2	37	9376	101	12387	114	121	89	67	72
	3	42	9287	118	12745	108	101	96	55	80
	4	39	9453	99	11945	104	111	99	49	67
April	1	38	9186	112	12856	109	129	97	52	99
	2	36	8745	127	12945	106	131	99	58	85
	3	33	8712	119	11967	111	129	81	59	77
	4	38	8574	128	12487	93	133	73	49	67
May	1	29	8934	109	12534	88	137	84	61	91
	2	38	6854	122	12856	91	133	99	58	99
	3	42	7345	117	12756	101	139	94	62	95
	4	39	8125	127	12745	98	127	98	69	98
June	1	35	6734	131	12756	102	121	81	53	112
	2	37	6154	111	12436	107	126	89	66	108
	3	39	6834	122	11678	119	122	93	69	105
	4	41	6743	122	11265	123	121	89	59	112
July	1	35	6823	117	12376	116	135	83	66	121
	2	31	6265	126	12634	121	118	95	69	119
	3	29	6912	123	12734	117	122	87	77	123
	4	33	6312	133	11634	121	126	99	89	132
August	1	31	7834	125	11945	114	129	89	97	131
	2	37	7598	122	12745	117	131	93	88	133
	3	32	7934	121	12856	115	122	99	91	127
	4	36	7143	131	11845	113	136	87	93	121
September	1	32	8354	128	11834	118	131	93	88	109
	2	38	8164	124	12734	116	137	82	93	112
	3	33	8894	123	11867	115	133	89	63	106
	4	29	8376	129	11734	121	137	94	66	112
October	1	33	9243	127	12945	117	133	99	57	99
	2	35	9167	131	12645	122	129	103	61	97

	3	28	9745	133	12165	121	122	101	53	89
	4	31	9823	128	11734	120	127	112	59	95
November	1	26	10276	133	11315	112	122	113	66	87
	2	34	10934	136	11623	106	118	109	57	85
	3	31	10423	133	11376	112	112	112	55	79
	4	37	11324	131	10231	114	109	115	49	84
December	1	32	10834	132	10834	121	111	104	48	89
	2	38	10365	134	10524	119	109	117	55	83
	3	34	11867	132	10934	112	116	113	51	79
	4	31	10934	131	10387	117	110	116	46	77

Table 4.2: Concentrations (µg/m^3) of atmospheric toxic gases measured in Dhaka City in 2010.

Month	Week	O_3	CO	SO_2	TVOC	NO	NO_2	PH_3	NH_3	H_2S
January	1	37	11967	125	10324	114	117	117	55	81
	2	32	11276	121	10623	112	103	112	49	77
	3	31	11745	123	10156	109	106	118	52	87
	4	33	12412	117	10241	102	111	109	58	83
February	1	37	11745	121	10845	110	127	111	41	77
	2	29	11867	105	10498	103	131	121	55	78
	3	33	11281	106	10426	111	121	113	67	88
	4	36	11222	113	10476	106	126	118	59	97
March	1	39	9823	109	12967	112	117	99	77	77
	2	37	9376	104	12276	115	121	94	61	84
	3	44	10231	118	12845	108	104	99	52	88
	4	39	9453	121	12956	104	111	91	62	73
April	1	35	10634	116	12856	113	126	104	55	88
	2	36	8834	127	12945	106	131	105	58	94
	3	33	9534	121	12543	112	133	88	59	89
	4	39	8376	128	12634	101	136	89	68	99
May	1	29	8734	112	13165	111	138	94	77	93
	2	34	7856	122	13978	104	139	96	88	99
	3	42	7834	119	13276	101	141	99	99	108
	4	41	8454	127	13287	104	144	98	89	107
June	1	33	6934	134	12956	111	129	88	94	114
	2	37	6382	111	12598	107	125	89	99	119
	3	40	6834	126	12745	119	122	93	107	101
	4	41	6923	122	12856	123	122	93	88	121
July	1	36	6823	119	12765	119	137	99	105	128
	2	29	6412	126	12867	112	121	89	112	129

	3	31	6912	129	12967	109	122	93	105	121
	4	33	6623	133	11745	118	127	102	111	138
August	1	36	7923	127	11845	116	129	94	104	132
	2	37	7745	122	11845	117	128	96	99	139
	3	38	7523	128	12945	111	125	99	84	121
	4	36	7645	131	12734	120	136	99	99	127
September	1	34	8354	132	11945	118	138	89	94	109
	2	38	8423	128	12945	121	137	87	89	114
	3	37	8894	123	12856	115	139	94	77	109
	4	29	8623	127	11734	137	125	99	84	119
October	1	31	10241	129	12945	117	114	102	68	95
	2	35	10165	132	12967	133	125	109	66	99
	3	32	10287	136	12165	129	127	112	61	94
	4	33	10523	131	12756	132	129	117	65	99
November	1	26	11423	133	12845	126	121	121	71	87
	2	37	11546	138	12597	121	111	118	77	77
	3	31	11523	135	11376	113	109	113	59	85
	4	39	11176	131	11534	116	110	119	55	89
December	1	32	12198	133	11276	122	112	121	59	99
	2	36	11879	136	11534	123	114	124	61	89
	3	39	12856	138	11756	124	111	128	59	99
	4	37	11563	134	11645	119	108	122	62	91

Table 4.3: Concentrations (µg/m^3) of atmospheric toxic gases measured in Dhaka City in 2011.

Month	Week	O_3	CO	SO_2	TVOC	NO	NO_2	PH_3	NH_3	H_2S
January	1	40	12314	139	10756	139	147	121	62	92
	2	34	12176	112	10945	137	140	125	55	89
	3	39	12187	115	11756	134	145	118	59	94
	4	36	12534	106	11534	132	144	120	61	99
February	1	31	11423	102	11856	119	116	117	44	89
	2	33	12534	114	11834	132	115	121	59	83
	3	28	11756	99	11487	131	126	118	71	94
	4	35	12167	109	11956	135	127	121	66	89
March	1	44	10321	111	13765	128	117	104	79	87
	2	39	10423	105	13867	131	121	99	67	89
	3	40	10143	118	13267	135	104	102	54	92
	4	45	10523	122	13856	137	119	99	66	77
April	1	39	10324	116	13967	122	132	112	59	90
	2	36	9352	127	13276	109	139	109	64	99
	3	34	9574	126	14276	122	140	98	71	91
	4	39	9276	128	14232	106	144	99	77	99

May	1	29	8556	112	14286	122	138	97	83	94
	2	38	8365	121	14734	111	141	103	97	106
	3	42	8846	119	14856	112	144	106	112	111
	4	33	9435	127	14287	121	149	99	118	107
June	1	31	7387	137	13986	111	98	94	109	114
	2	26	7785	111	13287	106	104	99	111	121
	3	35	8312	121	13298	119	110	93	119	101
	4	24	8164	122	13295	123	105	93	105	128
July	1	33	7784	129	11967	119	137	103	113	132
	2	31	7834	139	11745	121	129	112	115	129
	3	32	8165	142	12176	119	133	107	121	127
	4	33	7795	138	12534	122	127	102	106	138
August	1	31	8176	123	12176	116	131	99	111	139
	2	32	8376	122	12867	118	128	101	109	139
	3	34	7934	131	12165	114	137	106	95	121
	4	29	8846	133	12956	120	141	109	108	127
September	1	38	8354	137	11856	119	138	112	99	109
	2	41	8831	125	13287	121	144	98	94	119
	3	37	8964	123	12856	119	137	99	86	109
	4	33	8953	129	13287	125	141	106	84	121
October	1	40	9974	101	13287	133	138	102	66	95
	2	44	10845	113	13287	126	128	112	66	102
	3	38	10387	107	13867	131	127	121	69	99
	4	42	10925	103	13287	129	133	125	65	98
November	1	31	10734	136	13856	129	122	128	77	87
	2	37	11934	138	13276	132	127	129	77	83
	3	33	11723	135	12967	126	117	132	64	85
	4	39	11912	133	12745	129	118	137	55	99
December	1	44	11856	138	12978	111	121	139	64	91
	2	41	12154	136	12314	113	118	131	66	89
	3	43	12423	132	12989	116	124	136	61	88
	4	45	12523	139	12214	110	122	129	68	99

Table 4.4: Yearly changes the Concentrations (μg/m^3) of atmospheric toxic gases measured in Dhaka City from 2009-2011.

Parameter	2009		2010		2011	
	average	St.d	average	St.d	average	St.d
SO_2	122	9.087	124	8.8	125	9.16
CO	8956	1556.44	9520	1926.77	9870	2110.65
TVOC	11730	1005.82	12188	973	12949	984.6
O_3	34	3.93	35	3.868	36	3.927
NO	110	8.453	114	8.492	120	8.219
NO_2	123	10.014	123	10.786	128	11.19
NH_3	61	14.52	74	19.51	81	22.07
H_2S	93	19.75	100	17.79	103	16.79
PH_3	98	10.811	103	11.92	111	13.02

Table 4.4.1: Changes in concentrations (μg/m^3) of toxic gases among the locations in Dhaka city in 2009.

Parameters	Giasuddin R/S	Curzon hall	Topkhana	Saidabad	Mouchak	Ramna park	Mohakhali	Science laboratory	Farmgate	Amin bazar	Ashulia
SO_2	**98**	**110**	**124**	**127**	**138**	**94**	**142**	**152**	**149**	**228**	**213**
CO	**6478**	**7894**	**9576**	**9946**	**10476**	**6845**	**11645**	**12457**	**13518**	**12784**	**11245**
TVOC	**10548**	**11257**	**12548**	**11457**	**13512**	**11578**	**12145**	**13645**	**14981**	**11645**	**10745**
O_3	**27**	**33**	**32**	**27**	**26**	**25**	**29**	**22**	**39**	**33**	**31**
NO	**124**	**132**	**137**	**142**	**145**	**151**	**139**	**137**	**164**	**144**	**147**
NO_2	**157**	**149**	**219**	**234**	**237**	**241**	**247**	**244**	**249**	**251**	**252**
NH_3	**89**	**97**	**95**	**96**	**101**	**105**	**99**	**88**	**89**	**112**	**108**
H_2S	**78**	**85**	**91**	**99**	**94**	**102**	**97**	**82**	**91**	**102**	**107**
PH_3	**68**	**74**	**72**	**69**	**68**	**73**	**77**	**81**	**74**	**99**	**97**

Table 4.4.2: Changes in concentrations (μg/m^3) of toxic gases among the locations in Dhaka city in 2010.

Parameters	Giasuddin R/S	Curzon hall	Topkhana	Saidabad	Mouchak	Ramna park	Mohakhali	Science lab	Farmgate	Amin bazar	Ashulia
SO_2	103	115	129	131	137	90	149	144	157	232	227
CO	6978	7994	10763	11466	12476	6945	12645	12857	13818	12984	11845
TVOC	10748	10257	13548	12457	13712	11978	13145	13945	14881	12645	11745
O_3	33	35	38	28	31	29	33	39	44	43	41
NO	128	138	141	144	155	158	142	148	171	159	156
NO_2	158	151	223	239	241	244	255	249	258	257	254
NH_3	95	99	96	101	108	109	95	89	98	119	115
H_2S	79	88	99	101	105	109	104	88	98	109	111
PH_3	72	79	84	73	78	81	79	85	89	105	102

Table 4.4.3: Changes in concentrations (μg/m^3) of toxic gases among the locations in Dhaka city in 2011.

Parameters	Giasuddin R/S	Curzon hall	Topkhana	Saidabad	Mouchak	Ramna park	Mohakhali	Science lab	Farmgate	Amin bazar	Ashulia
SO_2	110	121	133	137	141	99	151	149	161	239	237
CO	7978	8994	11762	12464	13476	7945	13645	13857	14818	13984	12845
TVOC	11748	11257	14548	13457	14712	12978	14145	14945	15881	13645	12745
O_3	38	39	41	34	40	31	40	41	47	46	45
NO	132	141	144	149	159	161	149	155	178	166	167
NO_2	161	155	229	241	244	249	259	256	264	261	257
NH_3	99	102	103	109	111	114	99	95	104	121	119
H_2S	86	99	105	109	112	114	116	98	103	113	117
PH_3	77	81	89	78	83	88	94	97	99	118	115

Table 4.5: Monthly variations in the Concentrations (µg/m^3) of atmospheric toxic gases in Dhaka city (June, 2011).

Days	SO2	CO	O_3	NO	NO2	TVOC	NH3	H2S	PH3
D-1	128	12845	28	274	315	27845	122	98	104
D-2	121	11745	19	315	214	21548	133	111	87
D-3	131	12547	24	214	345	17458	121	84	99
D-4	112	10245	18	264	384	22548	133	77	89
D-5	105	13451	29	258	167	29458	138	99	65
D-6	129	12845	11	236	341	27451	121	71	84
D-7	121	11547	19	249	249	22451	138	88	59
D-8	114	14651	17	221	354	18456	124	56	99
D-9	101	13587	27	246	189	29547	139	68	79
D-10	113	12741	13	315	247	25641	147	71	87
D-11	121	11689	25	384	219	22485	134	88	64
D-12	111	12485	29	268	341	17642	129	76	87
D-13	125	9456	34	315	248	24851	128	61	54
D-14	127	10541	28	247	298	29548	111	47	89
D-15	101	12784	39	316	249	22648	137	84	64
D-16	124	13475	21	319	274	17541	114	61	79
D-17	119	12598	19	289	346	13458	131	88	57
D-18	99	10452	28	215	312	23548	117	71	49
D-19	127	9458	21	324	214	27851	132	49	67
D-20	111	11945	15	269	398	21845	128	64	54
D-21	129	13458	11	247	328	24956	134	77	67
D-22	113	12485	34	216	461	31845	111	94	61
D-23	121	11974	28	289	317	29458	116	68	51

D-24	129	9452	26	315	429	37945	137	51	88
D-25	125	10254	27	374	248	29845	121	101	67
D-26	118	13845	38	164	428	33485	134	57	78
D-27	128	13942	29	249	289	24856	139	87	59
D-28	111	12845	22	341	247	18456	127	69	48
D-29	129	11945	19	301	248	33458	139	48	99
D-30	139	12894	37	247	461	37945	117	88	64
St.d	10.0434	1417.03	7.637	49.8594	79.5744	6097.094	9.51442	17.1945	16.758
LSD	3.512	2.645	3.634	4.561	2.745	3.856	4.845	3.934	3.734

Table 4. 6: Diurnal variations in the Concentrations (µg/m^3) of atmospheric toxic gases in Dhaka city (3June, 2011).

Hour	SO_2	CO	O_3	TVOC	NO	NO_2	NH_3	H_2S	PH_3	Temp0c	RH %
h-0	352	7957	86	8463	378	0	123	67	111	24.5	59
h-1	356	8274	79	8385	368	0	133	89	114	24.6	61
h-2	365	8845	81	9175	352	0	137	84	119	24.4	58
h-3	376	9167	77	9834	368	0	134	79	115	23	56
h-4	379	8734	79	8956	389	0	145	99	117	24.1	61
h-5	386	9845	83	7933	391	0	131	83	121	24	58
h-6	337	10573	77	8945	373	33	129	66	113	24.6	57
h-7	214	11956	61	9945	289	67	126	78	103	24.9	54
h-8	187	12856	47	10576	219	88	121	65	99	25	55
h-9	0	16856	0	11056	0	112	112	55	89	25.6	51
h-10	0	17945	0	13856	0	213	101	48	93	26	50
h-11	0	21856	0	14978	0	254	99	46	85	27	52
h-12	0	26845	0	15945	0	265	89	41	79	27.3	47

h-13	0	27845	0	16956	0	272	81	47	88	28	45
h-14	0	27935	0	18454	0	286	79	51	79	28.5	47
h-15	0	28547	0	15845	0	296	67	44	77	28.3	49
h-16	0	29467	0	14834	0	289	79	39	81	28.7	53
h-17	0	27353	0	13956	0	283	83	41	84	28.3	55
h-18	96	26823	21	13978	121	278	89	48	74	28.7	56
h-19	143	23845	27	12967	129	254	99	51	99	27.9	53
h-20	217	21856	38	12956	178	198	121	59	103	24.3	55
h-21	225	21186	45	11867	198	167	145	61	112	24.1	58
h-22	264	19254	51	10467	213	67	167	66	117	24.8	59
h-23	289	17964	59	11956	245	64	171	69	113	24.2	61

Table 4.7: Comparison of O_3 (µg/m^3) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	32	112	35	17	42.73172	3.645
2009	Feb	34	110	31	13	43.01163	4.756
2009	March	29	87	37	19	30.24346	3.967
2009	April	31	81	33	21	26.85144	4.056
2009	May	33	67	36	16	21.24461	4.067
2009	June	28	56	39	22	14.93039	1.945
2009	July	31	51	32	19	13.22561	4.067
2009	Aug	37	58	36	24	14.1274	4.067
2009	Sep	39	67	33	21	19.49359	3.956
2009	Oct	37	79	39	19	25.31798	2.967
2009	Nov	42	83	37	23	25.78598	2.923

2009	Dec	39	99	34	21	34.67348	5.045
2010	Jan	38	117	35	25	42.53136	5.045
2010	Feb	36	110	38	21	39.89465	6.045
2010	March	33	88	31	26	29.14904	6.034
2010	April	38	79	33	22	24.91318	4.856
2010	May	41	71	39	28	18.40969	4.845
2010	June	38	57	36	23	14.0119	4.934
2010	July	42	47	31	29	8.655441	3.945
2010	Aug	39	58	37	22	14.76482	3.945
2010	Sep	41	71	32	31	18.71497	4.923
2010	Oct	37	81	38	29	23.51418	5.046
2010	Nov	39	88	41	33	25.39521	5.046
2010	Dec	43	101	44	35	30.43436	6..84
2011	Jan	48	121	75	41	36.26178	3.046
2011	Feb	43	115	69	44	33.71819	3.034
2011	March	49	92	61	48	20.53452	4.056
2011	April	44	82	55	51	16.6333	2.945
2011	May	37	78	58	44	18.08084	6.045
2011	June	47	61	43	48	7.804913	1.845
2011	July	41	53	51	41	6.403124	3.956
2011	Aug	50	49	49	37	6.184658	1.967
2011	Sep	54	78	59	32	18.90987	4.935
2011	Oct	57	84	67	38	19.22672	5.945
2011	Nov	52	94	73	35	25.59297	2.845
2011	Dec	55	112	83	39	32.13902	4.923

Table 4.8: Comparisons of CO (µg/m^3) Concentrations measured for different locations in and around Dhaka city from2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	10675	13654	15746	5945	4250.756	4.078
2009	Feb	10567	12763	16856	5857	4582.408	5.967
2009	March	9785	12584	15584	5465	4303.095	6.045
2009	April	9186	11845	13756	5198	3707.349	3.967
2009	May	8796	11945	8956	5287	2723.043	2.078
2009	June	8185	9834	7945	4922	2046.513	5.876
2009	July	7704	8945	7694	4627	1839.944	4.078
2009	Aug	6934	8945	7153	4198	1959.062	4.067
2009	Sep	6694	9845	6935	4478	2202.407	3.645
2009	Oct	7594	10845	9845	4967	2612.197	2.967
2009	Nov	8394	11978	13756	5378	3737.251	3.312
2009	Dec	8923	13756	14856	5896	4193.172	3.746
2010	Jan	10945	14786	15934	6784	4143.567	4.967
2010	Feb	11376	14387	16845	6645	4391.078	5.967
2010	March	10756	13745	16923	6923	4265.142	4.834
2010	April	9734	12845	10645	6498	2634.735	4.856
2010	May	9174	11856	9165	5934	2422.838	5.945
2010	June	8945	10435	9285	5195	2271.314	6.956
2010	July	8493	10453	8923	5034	2288.048	4.056
2010	Aug	8195	10945	8425	5297	2310.276	2.967
2010	Sep	7756	11745	7386	5934	2487.395	4.923
2010	Oct	7934	12645	10956	6187	2910.897	3.745

2010	Nov	9568	13674	14934	6593	3827.578	4.845
2010	Dec	10387	14634	15276	6923	3911.339	3.834
2011	Jan	11534	15534	16473	7327	4183.086	4.756
2011	Feb	11834	15276	16398	7156	4155.007	5.867
2011	March	10476	14325	15945	6934	4038.563	5.934
2011	April	9845	12756	9845	6378	2608.75	4.956
2011	May	9167	11956	9685	6287	2330.641	3.906
2011	June	8934	11243	9945	6021	2220.943	4.056
2011	July	9034	11176	8956	5946	2150.027	4.623
2011	Aug	8523	11254	7786	6187	2115.749	5.934
2011	Sep	9685	12765	7356	6425	2826.333	4.935
2011	Oct	10456	13756	11645	7245	2720.657	4.845
2011	Nov	11897	14634	15746	7523	3661.266	3.834
2011	Dec	11976	15834	16845	7612	4198.288	4.923

Table 4.9: Comparison of SO_2 ($\mu g/m^3$) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	125	289	1025	99	435.2053	5.089
2009	Feb	121	278	985	110	414.8257	4.756
2009	March	123	262	879	96	366.6197	4.078
2009	April	117	251	476	87	177.1485	4.056
2009	May	111	239	213	81	76.78542	3.956
2009	June	105	198	178	95	51.62041	1.945

2009	July	106	173	199	91	51.98317	4.078
2009	Aug	113	157	156	100	29.35416	4.067
2009	Sep	109	213	172	105	52.14962	4.067
2009	Oct	123	245	489	102	177.7252	2.967
2009	Nov	127	267	856	98	353.7805	3.312
2009	Dec	129	289	998	104	420.0722	5.045
2010	Jan	130	387	1123	101	476.1753	6.423
2010	Feb	133	399	1098	112	460.5783	6.045
2010	March	136	346	967	105	400.2487	4.834
2010	April	129	295	534	91	201.6621	4.856
2010	May	131	279	399	85	143.3167	5.945
2010	June	122	256	243	99	80.97325	4.934
2010	July	119	273	185	107	76.15773	4.056
2010	Aug	127	313	177	89	97.87577	3.945
2010	Sep	134	376	189	103	122.2852	4.923
2010	Oct	142	365	523	107	195.9377	3.745
2010	Nov	139	374	978	101	405.0786	5.046
2010	Dec	148	399	1087	109	452.785	3.834
2011	Jan	147	411	1173	124	490.4348	3.046
2011	Feb	138	395	1231	119	522.2288	5.867
2011	March	141	367	1152	122	483.9687	4.056
2011	April	136	333	539	129	194.3834	4.956
2011	May	142	251	400	117	128.8785	6.045
2011	June	144	264	257	120	74.88825	5.043
2011	July	138	271	188	125	66.16394	3.956

2011	Aug	132	317	181	111	92.60085	5.934
2011	Sep	139	361	195	127	107.8193	4.935
2011	Oct	141	352	624	131	231.6218	3.856
2011	Nov	146	399	1023	129	417.8256	2.845
2011	Dec	151	423	1243	141	519.0437	4.923

Table 4.10: Comparison of TVOC (µg/m^3) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	9686	19567	13657	5748	5897.429	4.078
2009	Feb	9785	22867	13786	5934	7261.898	4.756
2009	March	10534	24257	13287	6278	7674.225	4.078
2009	April	10945	28845	12867	6734	9676.617	3.967
2009	May	12765	25845	11634	8123	11379.61	2.078
2009	June	11867	12745	10498	7435	13178.95	1.876
2009	July	10745	11967	10967	8145	12517.58	4.078
2009	Aug	14276	22756	11387	8375	11803.98	4.067
2009	Sep	12967	25945	11657	7321	9282.882	3.645
2009	Oct	12387	19574	12745	6734	8571.665	2.967
2009	Nov	9756	20446	12978	6967	7374.175	3.312
2009	Dec	10143	21765	13276	5845	6722.171	3.746
2010	Jan	10956	23756	13967	6382	7354.365	4.967
2010	Feb	11685	24867	13897	6478	7742.247	5.967
2010	March	11967	25856	13796	6734	8085.997	4.834
2010	April	12487	21978	13178	7356	9483.038	4.856

2010	May	13653	27845	13276	7845	11832.7	5.945
2010	June	13978	21756	13155	8465	12683.41	6.956
2010	July	12756	20756	13427	8934	12743.39	4.056
2010	Aug	14756	21745	13128	8376	12331.39	2.967
2010	Sep	12756	29678	13645	7856	9477.709	4.923
2010	Oct	12436	22645	13856	6734	8968.312	3.745
2010	Nov	11678	23745	14165	7423	8402.693	4.845
2010	Dec	11265	24723	14278	7267	7987.237	3.834
2011	Jan	12376	25867	14978	7143	7888.322	4.756
2011	Feb	12634	26956	14945	7387	8278.107	5.867
2011	March	13276	22867	13978	7153	9554.081	5.934
2011	April	15347	26845	12898	7786	10897.99	4.956
2011	May	16857	23856	12537	8467	12025.11	3.906
2011	June	15734	21756	12978	8734	13841.15	4.056
2011	July	16845	22756	12856	8943	14403.26	4.623
2011	Aug	16835	24856	12978	8974	12762.63	5.934
2011	Sep	15326	27423	13867	8312	10582.77	4.935
2011	Oct	14734	29576	15176	7956	9098.234	4.845
2011	Nov	13856	22856	15498	7487	8804.106	3.834
2011	Dec	13187	25867	15634	7756	7823.723	4.923

Table 4.11: Comparison of NO (µg/m^3) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	101	123	124	95	14.93039	5.845
2009	Feb	108	121	121	99	10.75097	4.756
2009	March	99	112	126	88	16.41899	4.078
2009	April	89	101	122	94	14.52584	6.945
2009	May	110	109	119	101	7.36546	2.078
2009	June	95	112	112	94	10.11187	4.935
2009	July	111	115	114	83	15.26161	4.078
2009	Aug	99	112	112	98	7.804913	5.923
2009	Sep	109	122	118	110	6.291529	3.645
2009	Oct	115	119	127	103	10	2.967
2009	Nov	108	121	124	112	7.5	3.946
2009	Dec	104	126	129	103	13.91642	3.746
2010	Jan	113	138	136	112	14.17451	4.967
2010	Feb	106	135	131	101	17.23127	5.967
2010	March	112	129	121	97	13.72042	1.846
2010	April	98	127	119	84	19.61292	4.856
2010	May	88	121	102	79	18.30301	3.845
2010	June	95	119	99	101	10.63015	6.956
2010	July	101	114	119	112	7.593857	4.056
2010	Aug	98	118	112	104	8.793937	2.967
2010	Sep	111	131	121	119	8.225975	4.95

2010	Oct	107	139	129	115	14.27118	3.745
2010	Nov	119	141	125	128	9.287088	4.845
2010	Dec	123	149	134	120	13.12758	5.967
2011	Jan	119	157	141	132	15.96611	6.945
2011	Feb	121	167	151	126	21.60825	5.867
2011	March	119	131	137	119	9	3.956
2011	April	121	126	131	122	4.546061	4.956
2011	May	116	121	114	127	5.802298	3.906
2011	June	117	119	121	121	1.914854	2.856
2011	July	115	122	128	129	6.454972	4.623
2011	Aug	120	136	113	131	10.42433	6.957
2011	Sep	118	144	119	138	13.22561	4.935
2011	Oct	121	156	125	133	15.64981	5.056
2011	Nov	119	164	135	138	18.63688	3.834
2011	Dec	122	171	139	131	21.32878	4.923

Table 4. 12 : Comparison of NO_2 ($\mu g/m^3$) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	117	248	139	126	61.00546	2.078
2009	Feb	101	237	131	131	59.69925	5.078
2009	March	106	267	139	129	72.4954	5.045
2009	April	110	298	141	133	86.00969	3.967
2009	May	127	312	151	139	87.05314	2.078

2009	June	131	324	139	141	93.59977	1.876
2009	July	129	336	151	137	98.91874	4.078
2009	Aug	126	298	142	140	81.31216	3.856
2009	Sep	119	278	133	132	75.27062	3.645
2009	Oct	121	265	139	128	68.23672	2.967
2009	Nov	101	259	122	131	71.6118	6.934
2009	Dec	111	247	132	129	62.19526	3.746
2010	Jan	129	369	210	139	110.8614	5.067
2010	Feb	131	372	222	124	115.4769	5.967
2010	March	129	389	234	149	118.2776	4.834
2010	April	133	445	213	169	140.5276	4.856
2010	May	137	512	167	173	177.2012	5.945
2010	June	141	523	145	188	183.736	4.067
2010	July	139	542	132	198	195.0921	4.056
2010	Aug	133	524	152	169	186.9126	2.967
2010	Sep	129	456	131	143	160.9521	4.078
2010	Oct	131	401	155	159	126.937	3.745
2010	Nov	127	389	217	152	118.0914	6.057
2010	Dec	133	367	234	161	104.5606	3.834
2011	Jan	162	423	287	145	129.0927	4.036
2011	Feb	181	461	272	139	143.044	5.867
2011	March	188	513	245	147	164.8077	5.934
2011	April	198	531	202	144	176.8227	6.023
2011	May	213	537	212	167	171.1829	3.906
2011	June	217	549	245	187	168.0109	4.056

2011	July	213	511	231	199	148.9105	4.623
2011	Aug	187	478	224	184	141.0115	5.934
2011	Sep	177	467	231	175	138.7792	4.935
2011	Oct	159	461	254	167	140.5783	5.946
2011	Nov	155	447	271	162	136.2752	3.834
2011	Dec	148	421	295	159	128.8652	5.967

Table 4.13: Comparison of PH_3 ($\mu g/m^3$) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	114	88	88	99	5.315073	3.067
2009	Feb	106	79	95	89	8.698659	5.065
2009	March	84	89	49	76	17.09532	4.078
2009	April	87	77	55	61	9.380832	6.934
2009	May	77	91	47	57	19.76529	2.078
2009	June	98	107	59	89	20.83867	1.876
2009	July	103	101	67	97	16.8523	5.723
2009	Aug	95	89	71	86	10.21029	4.067
2009	Sep	88	98	61	77	15.19594	3.645
2009	Oct	107	94	78	83	6.849574	2.967
2009	Nov	96	77	84	99	10.29563	3.312
2009	Dec	99	98	99	101	5.315073	5.078
2010	Jan	97	91	92	102	5.066228	4.967
2010	Feb	109	99	99	93	3.774917	3.745
2010	March	81	81	54	82	13.67479	4.834

2010	April	73	69	61	66	5.057997	4.856
2010	May	84	94	76	62	13.51542	5.734
2010	June	99	110	67	95	18.30073	6.956
2010	July	107	104	77	104	14.07125	4.056
2010	Aug	99	98	75	93	11.14675	2.967
2010	Sep	81	89	66	81	9.604686	7.132
2010	Oct	89	81	82	89	4.349329	3.745
2010	Nov	93	99	89	102	5.85235	4.845
2010	Dec	109	105	103	107	2.217356	5.473
2011	Jan	111	96	94	105	4.795832	4.756
2011	Feb	105	102	101	101	1.892969	5.328
2011	March	96	85	59	84	12.67544	5.934
2011	April	82	76	66	67	5.802298	4.956
2011	May	89	99	79	61	16.20699	3.906
2011	June	106	113	77	99	15.58578	4.056
2011	July	110	107	89	107	9.604686	4.623
2011	Aug	104	99	85	99	8.180261	5.934
2011	Sep	99	91	71	85	11.81807	4.935
2011	Oct	103	88	88	94	2.872281	6.046
2011	Nov	105	107	98	108	4.50925	3.834
2011	Dec	122	110	112	112	3.464102	5.934

Table 4.14: Comparison of NH_3 (µg/m^3) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	49	79	97	44	25.14458	3.067
2009	Feb	33	69	83	59	21.10292	4.756
2009	March	67	87	96	47	21.83842	6.046
2009	April	55	81	76	61	12.25765	3.967
2009	May	38	110	72	48	32.34708	2.078
2009	June	89	101	49	88	22.61821	6.045
2009	July	99	104	59	98	20.83267	4.078
2009	Aug	82	94	67	84	30.29164	4.067
2009	Sep	81	81	55	67	19.79899	5.036
2009	Oct	67	99	57	56	20.12254	2.967
2009	Nov	55	94	78	72	16.11159	3.312
2009	Dec	39	79	98	49	24.5153	3.746
2010	Jan	52	88	99	46	26.19637	5.045
2010	Feb	37	73	88	51	22.67708	5.967
2010	March	71	79	79	89	7.371115	4.057
2010	Jan	66	88	57	79	13.72346	4.856
2010	Feb	72	111	67	87	19.75475	3.946
2010	March	82	104	79	91	11.22497	6.956
2010	April	104	107	61	99	21.42234	4.056
2010	May	96	96	56	82	18.85913	5.027
2010	June	81	88	102	67	17.21191	4.923
2010	July	91	101	59	56	22.63294	3.745

2010	Aug	61	96	78	71	14.75353	5.734
2010	Sep	49	83	89	55	19.93322	3.834
2011	Oct	55	91	103	51	25.92296	4.756
2011	Nov	41	79	91	59	22.05297	6.045
2011	Dec	79	88	83	96	7.325754	5.934
2011	Jan	68	112	77	82	23.18584	4.982
2011	Feb	74	119	69	97	22.99819	3.906
2011	March	88	110	83	73	15.63117	4.056
2011	April	106	121	79	99	20.50203	4.623
2011	May	98	107	59	88	20.83267	5.934
2011	June	88	99	49	74	21.57931	2.045
2011	July	93	103	112	65	20.3695	4.845
2011	Aug	63	91	99	79	11.48913	3.045
2011	Sep	54	83	104	61	19.05037	4.923
2011	Oct	93	103	112	65	20.3695	4.845
2011	Nov	63	91	99	79	11.48913	3.045
2011	Dec	54	83	104	61	19.05037	4.923

Table 4.15: Comparison of H_2S (µg/m^3) Concentrations measured for different locations in and around Dhaka city from 2009-2011.

Year	Month	Residential	Traffic	Brickfield	Park	St.d	LSD
2009	Jan	73	110	151	89	33.75772	6.023
2009	Feb	92	116	157	99	29.13188	3.045
2009	March	85	101	152	84	31.96352	4.078
2009	April	79	82	149	91	32.89757	3.967

2009	May	72	107	121	67	26.39918	2.078
2009	June	65	89	101	55	21.18962	1.876
2009	July	79	78	99	77	10.5317	4.078
2009	Aug	74	98	121	83	20.54264	4.067
2009	Sep	70	92	127	66	27.94489	3.645
2009	Oct	72	107	149	77	35.38714	2.967
2009	Nov	80	117	157	99	32.84687	3.312
2009	Dec	67	104	151	83	36.46345	7.9845
2010	Jan	99	119	163	99	30.17725	4.967
2010	Feb	85	127	169	88	39.44933	5.945
2010	March	77	111	166	101	37.64195	5.945
2010	April	67	97	152	83	36.92673	4.834
2010	May	91	109	139	102	20.54872	5.945
2010	June	111	120	133	79	23.01268	6.956
2010	July	118	129	139	94	19.33908	3.845
2010	Aug	101	112	129	83	19.31105	2.967
2010	Sep	112	131	121	104	11.63329	4.923
2010	Oct	98	139	161	112	28.07727	2.845
2010	Nov	78	129	169	99	39.5	4.845
2010	Dec	84	141	164	114	34.52897	5.823
2011	Jan	121	132	172	102	29.55644	4.756
2011	Feb	101	139	183	111	36.71058	5.867
2011	March	123	122	169	98	29.67603	6.523
2011	April	137	109	155	83	31.62278	4.956
2011	May	131	114	148	93	23.53012	6.934

2011	June	139	129	141	112	13.25079	4.056
2011	July	117	117	132	95	15.23975	4.623
2011	Aug	104	136	144	105	20.75853	5.934
2011	Sep	118	128	152	99	22.06619	4.935
2011	Oct	121	136	163	81	34.23814	4.845
2011	Nov	98	149	177	101	38.422	3.834
2011	Dec	112	154	173	112	30.72865	4.734

Table 4.16: Comparison the Concentrations (µg/m^3) of atmospheric toxic gases measured for different locations in Bangladesh (December, 2009-2011).

Parameter	Urban area		Semi-urban		Rural		Saint martin Island		Teknaf	
	average	St.d	average	St.d	average	St.d	average	St.d	average	St.d
SO_2	243	13.523	212	7.616	98	10.42	56	8.395	38	5.33
CO	15324	938.685	13756	1162.11	9645	952.9	4756	604.229	2745	97.61
TVOC	9480	733.835	12645	755.347	18290	865.38	25768	908.192	1574	108.4
O_3	45	6.832	23	2.907	99	7.688	64	5.933	89	6.51
NO	332	7.13	145	4.221	219	6.505	167	7.484	112	5.043
NO_2	143	6.1	104	7.218	90	4.779	65	5.478	76	5.601
NH_3	137	4.448	96	7.714	111	4.115	108	6.624	55	6.471
H_2S	146	7.336	119	4.351	125	5.581	87	4.909	64	4.402
PH_3	132	6.239	101	7.454	112	5.287	54	4.589	75	5.108

Table 4.17: Variation toxic gases along with temperature ^{0}C and humidity % in Dhaka city (2009-2011).

Month	O_3	CO	SO_2	TVOC	NO	NO_2	PH_3	NH_3	H_2S	Temp.(0C)	RH %
January	37	12534	118	11247	135	104	117	44	99	19.4	49
February	31	11970	111	10756	129	121	119	60	88	19.9	51
March	42	10523	113	13688	132	115	101	54	86	30.5	59
April	38	9631	124	13937	114	138	112	67	125	30.1	53
May	35	8800	119	14856	116	149	101	102	77	31.1	55
June	29	7387	122	13265	101	104	93	121	116	30.3	67
July	32	7784	131	12105	120	131	117	113	139	30.1	72
August	31	8333	127	11745	117	127	125	105	131	29.8	69
September	37	8775	128	12821	121	144	98	90	95	29.2	70
October	41	10925	106	13867	129	131	115	65	98	27.1	52
November	45	10734	135	13856	128	121	131	77	83	20.7	55
December	41	12239	136	12623	112	127	139	64	91	20.2	53

Table 4.18: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Narsinglopur, Savar.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	95	85	70	41
Black Berry	100	85	40	20	9
Mango	100	70	60	50	45
Wood Apple	100	75	40	22	17
Banana	100	50	28	21	14
Boroy	100	90	80	50	30
Safeda	100	80	70	40	35
Jamrul	100	97	92	87	67
Rice	100	100	70	65	60

Table 4.19: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Diakhali, Savar.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	90	87	76	56
Black Berry	100	89	35	24	12
Mango	100	73	65	53	49
Coconut	100	67	44	33	27
Banana	100	54	32	19	12
Boroy	100	82	67	49	38
Safeda	100	83	77	49	33
Jamrul	100	98	93	82	79
Rice	100	94	72	67	56

Table 4.20: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Bagbari, Gagipur.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	91	81	67	57
Black Berry	100	81	34	28	13
Mango	100	67	57	52	49
Wood Apple	100	81	35	27	19
Banana	100	47	36	27	19
Boroy	100	82	73	47	27
Lichi	100	80	74	52	48
Palm	100	78	65	59	48
Rice	100	100	74	68	63

Table 4.21: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutant BADC, Kashimpur.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	95	83	67	51
Black Berry	100	73	41	31	19
Mango	100	78	62	57	51
Lotcon	100	81	67	58	43
Banana	100	59	46	36	29
Boroy	100	81	73	52	48
Lichi	100	81	68	59	53
Guava	100	85	74	61	56
Rice	100	97	71	67	62

Table 4.22: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutant Borarchar, Mymensing.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	93	85	74	68
Black Berry	100	67	46	31	13
Mango	100	87	72	63	59
Potato	100	82	73	61	51
Banana	100	87	61	49	28
Boroy	100	81	67	52	44
Wheat	100	87	73	61	54
Guava	100	89	77	68	56
Rice	100	93	83	77	67

Table 4.23: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Bandra, Tangail.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	97	89	84	72
Black Berry	100	84	67	55	43
Mango	100	93	85	77	69
Wood-apple	100	89	76	61	58
Banana	100	86	71	67	58
Boroy	100	92	78	67	54
Lichi	100	89	73	55	49
Guava	100	85	67	57	48
Rice	100	98	83	73	65

Table 4.24: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Amin bazaar, Dhaka.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	87	71	63	57
Black Berry	100	76	54	24	11
Mango	100	61	51	49	41
Wood Apple	100	75	51	32	21
Banana	100	51	32	21	14
Boroy	100	75	67	42	29
Lichi	100	81	68	49	39
Palm	100	87	76	68	51
Rice	100	97	67	54	48

Table 4.25: Reduction of food yields due to atmospheric toxic gasses and other environmental pollutants at Ashulia, Dhaka.

Fruits	1975	1985	1995	2005	2012
Jack fruit	100	88	72	61	54
Black Berry	100	72	51	31	13
Mango	100	67	46	42	37
Wood Apple	100	71	47	28	23
Banana	100	55	29	22	15
Boroy	100	67	61	39	27
Lichi	100	83	69	47	43
Palm	100	82	67	66	54
Rice	100	94	72	51	44

4.26 Questionnaire Survey

(Effect of toxic gases on crop production and tree species)

Interview Date: …….
Location: …….
Name of the farmer/worker/senior citizen/researcher interviewed: ……
Sex: ……..
Age: ……..

1. Do you see any difference in crop production i.e., reduction in production of cereal crops (rice, wheat, maize, pulses), vegetables etc. In the land where you have been working since long? If yes, do you think heavy traffic (vehicles) on road, brick kilns and industries around your land could probably having an effect on your crop production…….?

2. Which crop do you think is affected mostly…….?

3. What are the symptoms or damages you notice with your crop……?

4. Can you compare these differences with a land away from that you are working on……?

5. Do you hear any complain or notice any damages or affect (for the same reason) on seasonal fruits in this area? If yes, mention the extent of damages and/or indications……?

6. Do you notice top dying of any tree species on the road-side? Which tree species you think is affected mostly…….?

7. As you are a senior citizen, when you are young, there were lass industry/ brick-kilns/ vehicles, so now do you notice any subtle difference of environmental pollution such as air pollution than before ……..?

Questions for the scientists/researchers interviewed at different institutes

8. The farmers, workers and senior citizens interviewed at different locations on road-sides having heavy traffic, within the proximity of brick kilns and industries are saying that they are experiencing crop damages, reduction in yield of crops and fruits and top dying of tree species. Can you share your observation, views and experience in this context…….?

9. Do you notice Ozone symptoms characteristically occur on the upper surface of affected leaves and appear as a flecking, bronzing or bleaching of the leaf tissues Ex. Soybean. ……..?

10. Do you notice the symptoms appear as a yellowing or chlorosis of the leaf…….?

11. Do you notice spotted leaves Ex. pumping. Spotted fruits. Ex. Guava……?

12. Do you notice ozone injury to vegetations……..?

13. Do you notice damage cell membranes of plants……..?

14. Thank you so much for your cordial corporation.

4.27 Questionnaire Survey

(Effect of toxic gases on human health)

Interview Date: …….
Location: …….
Name of the female/ children/ traffic police/ driver/ city dweller interviewed: ……
Sex: ……..
Age: ……..

1. Do you see any difference in human health such as breathing Problem, Eye-irritation, Skin diseases, Cough, Asthma, bronchitis, Lung cancer……..?

2. Which diseases do you think is affected mostly…….?

3. What are the symptoms you notice on your body……?

4. Can you compare these differences between urban and rural female, child, traffic police, driver and dwellers……?

5. Do you hear any complain or notice any affect (for the same reason) on human body? If yes, mention the extent of damages and/or indications……?

Questions for the doctors interviewed at different hospitals

6. The females, children, traffic polices, drivers and city dwellers interviewed at different locations are saying that they are experiencing breathing Problem, Eye-irritation, Skin diseases, Cough, Asthma, bronchitis, Lung cancer. Can you share your observation, views and experience in this context…….?

7. Do you notice Ozone symptoms characteristically occur the eye-irritation, breathing problem most of the urban school going Childs…….?

8. Do you notice CO symptoms characteristically occur Asthma, bronchitis, Lung cancer most of the urban female, driver, traffic police……..?

9. Do you notice the PH_3 symptoms occurs faintness, vomiting, headache, tightness in the chest may appear rapidly after exposure ……?

10. Do you notice the TVOC symptoms occur Eye, nose and throat irritation……..?

11. Thank you so much for your cordial corporation.