

Urban air quality monitoring technology for megacities in the developing countries

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Abstract:

As the vehicle fleet continues to grow, motor vehicle emissions are becoming major air pollution problem. In "megacities" in the developing countries due to rise in motor vehicle air quality has deteriorated and have severe effects on human health and mortality. 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. 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.

We plan to develop smart devices for environmental monitoring which should have high selectivity properties, good detection limits, at-site measurement and of low cost so that they can be attractive for use in the developing countries. Such devices are essential to improve environmental policing and regulatory testing in addition to improving the cost effectiveness of environmental monitoring. The prime objective of this project is to determine the appropriate technology for urban air quality monitoring in the developing countries and propose action that can improve air quality

1 Background

The air pollution problem is widespread throughout the world and the elimination of the risks to human health is of paramount importance. Urban areas are one of the major sources of air pollution and have characteristic patterns of pollutant emissions, with adverse consequences to the health of their inhabitants. 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 effect people with respiratory diseases and also the people with cardiovascular disease (Moroz 1989, Pfafflin & Ziegler 1992, Power & Baldasono 1998, Miller 1997).

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.

1.1 Serious Air Pollutants

The following eight pollutants have been identified as most widespread and serious

(Power 1994, 1996, Pfafflin & Ziegler 1992, Reid 1997).

- 1) Suspended particulate matter. This is a complex mixture of solid particles and aerosols suspended in the air. We see these particles as dust, smoke, and haze. PM 10 (particles less than 10 microns in size) has the greatest effect on health because of its capacity to be inhaled.
- 2) Volatile organic compound (VOCs). These include materials such as gasoline, paint solvents, and organic cleaning solutions, which evaporate and enter the air in a vapour state. VOCs are prime agents of ozone formation.
- 3) Carbon monoxide (CO). This is an invisible, odourless gas that is highly poisonous to air-breathing animals because of its ability to block delivery of oxygen to the organs and tissues.
- 4) Nitrogen oxides (NO_x). Nitrogen dioxide is a lung irritant that can lead to acute respiratory disease in children.
- 5) Sulphur oxides (SO_x), mainly Sulphur dioxide (SO₂). Sulphur dioxide is gas that is poisonous to both plants and animals. Children and elderly are especially sensitive to SO₂.
- 6) Lead and other heavy metals. Lead is very dangerous at low concentrations and can lead to brain damage and death. It accumulated in the body and impairs many tissue and organs.
- 7) Ozone and the photochemical oxidants. Ground ozone is highly toxic to both plants and animals; damages lung tissue and is implicated in many lung disorders.
- 8) Air toxics and radon; Toxic chemicals in the air include carcinogenic chemicals, radioactive materials and other chemicals such as asbestos, vinyl chloride, and benzene that are emitted as pollutants.

1.2 Effects of Pollutants on Human Health

Human beings breathe 14 kg of air into their lungs each day. Although some of the symptoms of pollution that people suffer involve the moist surfaces of the eyes, nose, and throat, the major site of impact is the lungs. Three categories of impact can be distinguished:

- a) Chronic: Pollution cause the gradual deterioration of a variety of physiological functions over a period of years.
- b) Acute: Pollutants bring on life-threatening reactions within a period of hours or days.

c) Carcinogenic: Pollutants initiate changes within cells that lead to uncontrolled growth and division (cancer).

Long term exposure to sulphur dioxide, SO₂ can lead to bronchitis. Chronic inhalation of ozone, O₃ and particulates can cause inflammation and ultimately, fibrosis of the lungs, a scarring that permanently impairs function. Carbon monoxide, CO reduces the capacity of the blood to carry oxygen, and extended low levels of carbon monoxide can contribute to heart disease. Chronic exposure to nitrogen oxides, NO is known to impair the immune system, leaving the lungs open to attack by bacteria and viruses (Pfafflin & Ziegler 1992, Miller 1997). A 10 microgram per cubic metre increment in PM₁₀, particles less than 10 micrometers, was associated with approximately a 5% increment in emergency hospital admissions for cardiovascular disease such as heart attacks.

Estimates made using models indicate that some 225 cases of cancer are caused by hydrocarbons (volatile organic compounds and polyaromatic compounds) in Sweden each year (REF). According to a results of a study in Switzerland the largest contribution to health cost relates to 2100 premature deaths in Switzerland due to exposure to fine particles (Wiederkehr 1998).

The most sensitive to air pollution are small children, asthmatics, people with chronic pulmonary and heart disease, and the elderly. Asthma, an immune system disorder characterised by impaired breathing caused by constriction of air passageways, is usually brought on by contact with allergens. Many air pollutants increase the severity of asthma; the 58% increase in the incidence of asthma in the United States since 1970 is thought to be largely due to synergistic effects of air pollutants. Studies have shown that asthmatics are extremely sensitive to levels of sulphur dioxide, SO₂ that are well below concentrations found in polluted cities (Miller 1997, Power & Baldasono 1998).

1.3 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-motorised vehicles on roads, lack of application of adequate and proper traffic management schemes are producing severe transport problems in the developing countries. In "megacities" 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 were 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 eliminated leaded gasoline and the concentration of lead in the environment has dramatically reduced.

Emissions of pollutants in Mexico city, hourly ozone, levels of $600 \mu\text{gm}^{-3}$, SO_2 levels $80\text{-}200 \mu\text{gm}^{-3}$, suspended particulate matter $100\text{-}500 \mu\text{gm}^{-3}$ all exceed the World Health Organization, WHO recommended level (WHO 1994).

1.4 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 occurs 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 generalisations. **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.**

1.5 Air Pollution in Dhaka

Dhaka, the capital city of Bangladesh, has rapidly grown into a busy city of more than 10 million people with an area of 815 km^2 . 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 recognised, 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 NO_x , HC, CO, PM, and SO_x , respectively (Karim, et. al., 1997). High share of SO_x 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, (<http://www.bangla.net/>). BAEC scientists detected 463 nanogram 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 & 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 NO_x , 5133 t of PM, and 1680 t of SO_2 emitted from automobiles in Dhaka City (Karim, 1999).

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.

1.5 Air quality monitoring methods

The Differential Optical Absorption Spectroscopy (DOAS), as developed by PLATT and PERNER (1980), used for air quality monitoring is extremely expensive, demands skilled technicians and only rich cities can afford that. Detailed study concerning traffic congestion and pollution problems for urban areas of Bangladesh has not yet been done. Research to develop new methods of sampling and analysing gaseous contaminants in the urban air is essential in monitoring air quality in the developing countries.

1.6 Research area of the Department in Västerås:

The recently started Biomedical Engineering Research group at the Department of Electrical and Electronic Engineering, University of Mälardalen focuses on research activities to integrate the following areas:

- a) Preventive Health Care Technology
- b) Biosensors for Environmental monitoring
- c) Health care technology for the masses

In order to reach the goal we have started collaborations with other groups, Environment and Biotechnology at our university, and with the following Universities:

- i) Department of Physics and Measurement Technology, Linköping University,
- ii) Cranfield Biotechnology Centre, Cranfield University, UK and
- iii) Gono Bishwabidyalay (People's University) in Dhaka, Bangladesh.

2 The aim of this planning project:

We plan to develop biosensors for environmental monitoring which should have high selectivity properties, good detection limits, at-site measurement and of low cost so that they can be attractive for use in the developing countries. Devices capable of monitoring the urban air quality have the potential to significantly improve environmental policing and regulatory testing in addition to improving the cost effectiveness of environmental monitoring.

The prime objective of this project is to:

- determine the appropriate technology for urban air quality monitoring in the developing countries
- propose action that can improve air quality

Initially we plan to conduct a preliminary study to:

- a) identify air pollutants, determine their sources and level of pollution in Dhaka city by measuring NO_x, HC, CO, PM and SO_x
- b) compare current methods of sampling and analysing gaseous pollutants and to evaluate the measurement methods by comparing their sensitivity, reliability, design, cost, environmental compatibility.
- c) study the severity of the possible consequences of excessive exposure by conducting epidemiological study on the most exposed groups and demonstrate which pollutants are responsible for particular adverse health and /or environmental effects.
- d) to hold a seminar to focus on the key areas of concern such as better environmental quality fuel, environmentally cleaner transportation, environmental education, encourage local research on environmental issues with international collaborators.
- e) prepare grant application to develop appropriate methods for monitoring, recording and transmitting air quality data, essential for implementing suitable controls and standards.

3 Collaborators in the project

- a) Measurement of pollutants part of the project will be performed in collaboration with Dr. M. Mridha and Mr R. Falk, Biomedical engineering group and Dr. L. Wester and Mr. G. Bird, Environmental technology group at the university of Mälardalen in Västerås, Sweden.
- b) Assessment of adverse effects of air pollution on humans part of the project will be performed in collaboration with Dr. M. Mridha, Biomedical engineering group at the university of Mälardalen in Västerås and the Prof S. Talukder and Dr N. Islam, epidemiologists at the People's University, Dhaka, Bangladesh (Enclosed letter)..
- c) Development of sensors part of the project will be performed in collaboration with Dr. M. Mridha and Dr R. Falk Biomedical engineering group, at the university of Mälardalen in Västerås and Prof. Bertil Hök from the Hök Instrument AB., in Västerås. Biotechnology group from the Department of Biology and Chemistry has shown keen interest for collaboration.

4 Methods

Field study will be conducted in Dhaka, Bangladesh in collaboration with the Gono University where the author has earlier worked as guest professor and had research collaborations.

4.1 Measurement of emissions:

There are two basic types of source emission monitoring instrumentation

Emissions will be measured at several places in Dhaka city using the following laboratory equipment available at the Department of Environmental Technology:

Multi-gas Monitor Type 1302 (Bruel & Kjaer), a highly accurate, reliable and stable quantitative gas analyser can be used for analysis of gases . Its measurement principle is based on the photoacoustic infra-red detection method. In effect this means that the 1302 can be used to measure almost any gas which absorbs infrared light. The equipment is easily portable and will be suitable for field study for quantitative analysis of gases such as CO, CO₂, TOC, Benzeneto 5 components and water vapour in any air sample.

Nitrogen Oxide Analyzer, Model 200A, NO_x Analyzer, is also available in our laboratory to measure the concentration of nitric oxide, NO, total oxide of nitrogen NO_x and by calculation nitrogen dioxide, NO₂.

UV Absorption Ozone Analyzer (Model 400 series) will be available to detect ozone molecules. The detection is based on absorption of 254 nm UV light due to an internal electronic resonance of the O₃ molecule. The Beer-Lambert equation, calculates the concentration of the ozone from the ratio of the light intensities (API Model 400 O₃ Analyzer Operation Manual).

$$C_{O_3} = -\frac{10^9}{\alpha \cdot l} \cdot \frac{T}{273(^{\circ}K)} \cdot \frac{29,92 \text{ (in Hg)}}{P} \cdot \ln \frac{I}{I_o}$$

where

- I = Intensity of light passing through the sample
- I_o = Intensity of light through sample free of ozone
- α = absorption coefficient
- l = Path length
- C_{O₃} = Concentration of ozone in ppb
- T = sample temperature in degrees Kelvin
- P = pressure in inches of mercury

Passive samples: The passive samples should be collected for later analysis of the weekly average emission of SO₂ and NO₂, in the laboratory using the standard methods (REF). This sampling method is not influenced by wind because it uses molecular diffusion theory, therefore easy to use at any site. Traffic flow census data, average vehicle speed, number of trips by various modes, and average trip length will be taken into consideration to predict concentration of NO₂.

The results from the measurement should be compared with the:

- estimated data for fuel consumption obtained from the relevant departments.
- rate of emissions/km, total number of trip and triplength should be considered to calculate emissions.
- passive samples analysis results from the laboratory.

4.2 Epidemiological study on the adverse effects of air pollution:

Study of the adverse effects of air pollution (increased risk of developing asthma (on some most exposed group of people for example, Rikshawa pullers, street side shop keepers or traffic police) will be conducted in collaboration with the group of Prof. S. Talukder and Dr. N

Islam, consisting of Microbiologist, Chemist and Epidemiologist at the People's University, Dhaka, Bangladesh (Enclosed letter from Prof. S. Talukder).

a) Blood samples will be checked for a controlled group of Rikshapuller exposed in the Dhaka city compared with a similar group (as to age, sex, period of exposure, nutrition, other health factors and habits) from outside the Dhaka city, for fibrinogen (important in blood clotting) and other substances (such as cytokines). The study will see whether there is a relationship between particulate air pollution and the capacity of the blood to clot, and may therefore shed some light on the mechanisms underlying the association between particulate air pollution and an increased risk of cardiovascular ill-health. It will be interesting to determine whether specific metal content can explain the adverse health.

b) Chronic Obstructive Pulmonary Disease (COPD) is responsible for most of the respiratory mortality was found to be linked to particulate air pollution in the elderly. It is therefore very pertinent to explore whether increased levels of pollution are associated with an increased likelihood of exacerbations of COPD.

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