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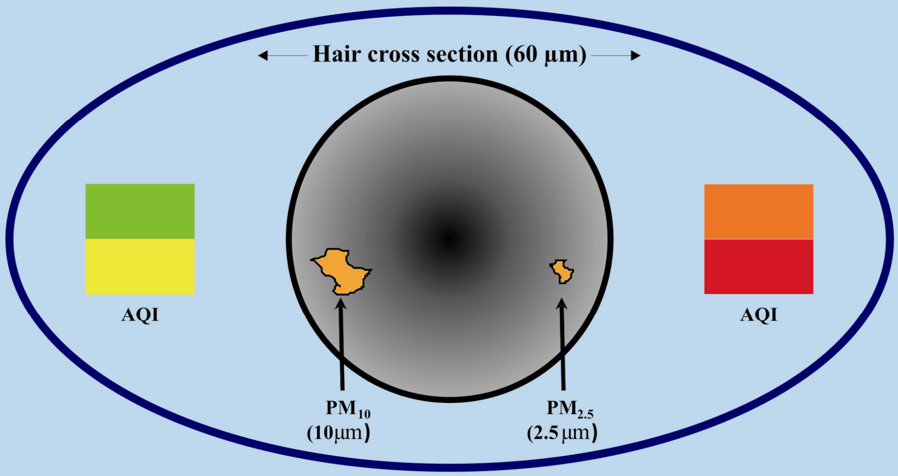

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Indian Institute of Tropical Meteorology
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Content

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FOREWORD

Clean air is considered to be a basic necessity of human health and well-being. India is also experiencing the deterioration of air quality. The Air Quality Index (AQI) is a new public information tool that helps protect public health on a daily basis from the negative effects of air pollution. The AQI is a scale designed to help public understand quality of air around them means to their health. The concept of AQI is all the more important in India where the common man is not much familiar with technical terminology and measuring units.

The World Health Organization (WHO) and U.S. Environmental Protection Agency (EPA) are widely recognized all over the globe as general guideline book for providing the general Air Quality Index and air quality standards baseline threshold limits of different air pollutants. But the standards and cut of limits required for AQI vary from country to country. The first step is to come up with country specific National Ambient Air Quality Standards (NAQS) which the Ministry of Environment and Forests has revised recently for India. However, AQI for classifying the air quality in India is still under developing stage. The concept of AQI becomes all the more significant when the air quality forecasting system is in place for a country.

Since the scientists of our ministry has taken up the SAFAR project to forecast the air quality of Delhi on the occasion of Commonwealth games for the first time in our country, the present report to define the AQI is very timely and prepared keeping NAQS as base line criteria. This report is an out come of the scientific knowledge based judgment and available scientific evidences. These guidelines are also based on expert evaluation of studies and current scientific evidence on the health effects of air pollution, and may be useful for policy-makers for reducing the health impacts of air pollution and air quality management.

I appreciate the efforts of our scientific team at the Indian Institute of Tropical Meteorology (IITM) for their untiring and timely efforts to publish this report.

(Shailesh Nayak)

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1. Introduction

Clean air is one of the basic requirement for good human health and well-being of the humanity. Air pollution continues to be a well-known environmental problem worldwide. It can pose a serious threat to human health if it exceeds the permissible limit (WHO, 2000; USEPA. 2008). The quality of the air is the result of complex interaction of many factors that involve the chemistry and the meteorology of the atmosphere, as well as the emissions of variety of pollutants both from natural and anthropogenic sources. According to a World Health Organization's (WHO) assessment of the burden of disease due to air pollution, more than two million premature deaths per year can be attributed to the effects of urban (outdoor /indoor) air pollution that is mainly caused by burning of solid fuels (WHO,2000, 2002, 2005). More than half of the air pollution driven disease burden is borne by the population of developing countries (WHO, 2005). The WHO air quality guidelines are intended for worldwide use but have been developed to support actions to achieve air quality that protects public health in different contexts. Globally, air quality guidelines are designed to offer guidance in reducing the adverse health impacts of the air pollution. These guidelines are based on expert evaluation of the studies on the health effects of air pollution and current scientific evidence. These guidelines are intended to suggest policy-makers about the gravity of the air pollution problem and to provide appropriate targets for a broad range of policy options for air quality management in different parts of the world (WHO, 2002, 2005; USEPA, 2008).

Air quality standards are set by individual countries to protect the public health of their citizens and as such are an important component of national risk management and environmental policies. For purpose of setting Air Quality Standards, air pollutant concentrations should be measured at such monitoring sites that are representative of population exposures. Air pollution levels may be higher in the vicinity of specific sources of air pollution, such as roads, power plants and large stationary emission sources. So the protection of populations living in such situations may require special measures to bring the pollution levels to below the guideline values. National Air Quality standards will vary according to the approach adopted for balancing health risks, technological feasibility, economic considerations and various other political and social factors, which in turn will depend on, among other things, the level of development and national capability in air quality management.

The Air Quality Index (AQI) is a scale designed to help one understand what the air quality around one means to ones health. It is a health protection alarming tool that is designed to help one make decision to protect ones health by limiting short-term exposure to air pollution and adjusting ones activity levels during increased levels of air pollution. It also provides advice on how one can improve the quality of the air one inhales. This index pays particular attention to people who are sensitive to air pollution and provides them with advice on how to the protect their health during air quality levels associated with low, moderate, high and very high health risks. The AQI reports current air quality based on a specific level of an individual air pollutant. The AQI communicates primarily a number from 1 to 500 indicating the quality of the air. The higher the number, the greater the health risk associated with the air quality. When the level of air pollution is very high, the number will be reported above 300.

2. Health Versus Exposure to Pollution

Exposure to air pollutants can cause a range of symptoms (Avol, et al., 1998; Delfino, et al., 1998 ; Wong, et al., 2002; Katsouyanni, et al., 2001; Pope, 2002; Burenett, et al., 2004). People with lung or heart disease may experience increased frequency and/or severity of symptoms, and increased medication requirements. Of course, each individual will react differently to air pollution. Individual reactions to air pollutants depend on the type of pollutant a person is exposed to, the degree of exposure, the individual's health status (immunity) and genetics. Negative health effects increase as air pollution worsens. During high pollution episode, the healthy people may show more resistant than the individual suffering from the pre-existing heath problem does. Studies have shown that even modest increases in the air pollution for a short period can cause small but measurable increase in emergency room visit and hospital admissions among sensitive or at-risk people, while healthy individual may not show any effect. However, even healthy people, especially those who work or exercise outside, may have difficulty in breathing when air pollution levels are very high.

The most common categories of people at increased risk are the people who have acute respiratory illnesses such as asthma, chronic obstructive pulmonary disease (COPD), which includes chronic bronchitis and emphysema or lung cancer. The peoples with existing cardiovascular conditions such as angina, previous heart attack, congestive heart failure or heart rhythm problems (arrhythmia or irregular heartbeat) are sensitive to air pollution. People with diabetes are also more sensitive to air pollution because they are more likely to have cardiovascular disease. Air pollution makes it even harder for people to breathe, can make existing lung or heart-related symptoms worse. For example, it can trigger heart attack. Infants and children are especially susceptible to the health effects of air pollution as their bodies and lungs are still in the tender stage. Children, in particular, have greater exposure to air pollution because they breathe in more air per kilogram of body weight than adults do and they spend more time outside being active outdoors. Their elevated metabolic rate and young defence systems make them more susceptible to air pollution. Children with asthma or other respiratory diseases are more likely to be affected. Air pollution can trigger asthmatic attack and aggravate symptoms of respiratory ailments like coughing and throat irritation even in healthy children. The elderly people also are more likely to be affected by air pollution, due to generally weaker lungs, heart and defence systems, or undiagnosed respiratory or cardiovascular health conditions. People participating in sports or strenuous works outdoors breathe more deeply and rapidly allowing more air pollutants to enter the lungs. On days when air pollution levels are significantly elevated, even people not in the above groups may develop symptoms of respiratory problems. People who are otherwise healthy may have the symptoms like eye irritation, increased mucus production in the nose or throat, coughing, difficulty in breathing especially during exercise. People with asthma or COPD may notice an increase in cough, wheezing, shortness of breath or phlegm. People with heart failure may experience increased shortness of breath or swelling in the ankles and feet and those with heart rhythm problems may notice increased fluttering in the chest and feeling light-headed. People with angina or coronary artery disease may have an increase in the chest or the arm pain.

2.1. Particulate Matter

The evidence on airborne particulate matter (PM) and its public health impact is consistent in showing adverse health effects at exposures that are currently experienced by urban populations in both developed and developing countries. The range of health effects is broad, but these effects are predominantly related to the respiratory and the cardiovascular systems. All kinds of populations are affected, but the susceptibility to the pollution may vary with health, age, etc. The risk for various adverse outcome has been shown to increase with exposure, but the scale to suggest a threshold below which no adverse health effects would be anticipated is not available. In fact, the low end of the range of concentrations at which adverse health effects has been demonstrated is not greatly above the background concentration; which for particles smaller than 2.5 µm ($PM_{2.5}$) has been estimated to be 3-5 µg/m3 in both the United States and the western Europe. The epidemiological evidence shows adverse effects of PM following both short-term and long-term exposures.

The choice of indicator for particulate matter requires number of considerations. At present, most routine air quality monitoring systems generate data based on the measurement of PM_{10} and not on the size segregated. Consequently, the majority of epidemiological studies use PM_{10} as the exposure indicator. PM_{10} represents the particle mass that enters the respiratory tract and, moreover, it includes both the coarse (particle size between 2.5 and 5 µm) and the fine particles (measuring less than 2.5 µm, $PM_{2.5}$) that are considered to contribute to the detrimental health effects observed in the urban environments. The former particles are primarily produced by mechanical processes such as construction activities, road dust re-suspension and wind; whereas the latter originate primarily from combustion sources. In most urban environments, both coarse and fine mode particles are present, but the proportion of particles in these two size ranges is likely to vary substantially from one city to another around the world, depending on local geography, meteorology and specific PM sources. In some areas, the combustion of wood and other biomass fuels can be an important source of particulate air pollution, the resulting combustion particles being largely in the fine ($PM_{2.5}$) mode. Although few epidemiological studies have compared the relative toxicity of the products of fossil fuel and biomass combustion, comparable effect estimates are found for a wide range of cities in both developed and developing countries. It is, therefore, reasonable to assume that the health effects of $PM_{2.5}$ from both the sources are broadly the same.

2.2. Ozone

Ozone is formed in the atmosphere by photochemical reactions in the presence of sunlight and precursor pollutants, such as the oxides of nitrogen (NO_X) and volatile organic compounds (VOCs). It is destroyed by reactions with NO_2 and is deposited to the ground. Several studies have shown that ozone concentrations correlate with various other toxic photochemical oxidants arising from similar sources, including the peroxyacetyl nitrate, nitric acid and hydrogen peroxide. Measures to control tropospheric ozone levels focus its precursor gas emissions, but are likely to also control the levels and impacts of a number of other pollutants. Significant additions to the health effects evidence base have come from epidemiological time-series studies. Collectively these studies have revealed positive, small, though convincing, associations between daily mortality and ozone levels, which are independent of the effects of particulate matter. Similar associations have been observed in both North America and Europe.

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

2.3. Nitrogen Dioxide

Most atmospheric NO_2 is emitted as NO, which is rapidly oxidized by ozone to NO_2. Nitrogen dioxide, in the presence of hydrocarbons and ultraviolet light, is the main source of tropospheric ozone and of nitrate aerosols, which form an important fraction of the ambient air $PM_{2.5}$ mass. As an air pollutant, nitrogen dioxide (NO_2) has multiple roles, which are often difficult or sometimes impossible to separate from one another. The primary sources of nitrogen oxides are motor vehicles, power plants, and waste disposal systems. There is still no robust basis for setting an annual average guideline value for NO_2 through any direct toxic effect. Evidence has emerged, however, that increases the concern over health effects associated with outdoor air pollution mixtures that include NO_2. For instance, epidemiological studies have shown that bronchitic symptoms of asthmatic children increase in association with annual NO_2 concentration, and that reduced lung function growth in children is linked to elevated NO_2 concentrations within communities already at current North American and European urban ambient air levels. A number of recently published studies have demonstrated that NO_2 can have a higher spatial variation than other traffic-related air pollutants, for example, particle mass. These studies also found adverse effects on the health of children living in metropolitan areas characterized by higher levels of NO_2 even in cases where the overall city-wide NO_2 level was fairly low.

2.4. Sulfur Dioxide

Controlled studies involving exercising asthmatics indicate that a proportion of population experiences changes in pulmonary function and respiratory symptoms after periods of exposure to SO_2 as short as 10 minutes. Early estimates of day-to-day changes in mortality, morbidity or lung function in relation to 24 -hour average concentrations of SO_2 were necessarily based on epidemiological studies in which people were typically exposed to a mixture of pollutants. There is still considerable uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects or whether it is a surrogate for ultrafine particles or some other correlated substance.

2.5. Carbon Monoxide

Carbon monoxide is an odorless, colorless and toxic gas. Because it is impossible to see, taste or smell the toxic fumes, CO can kill you before you are aware it is in your home. At lower levels of exposure, CO causes mild effects that are often mistaken for the flu. These symptoms include headaches, dizziness, disorientation, nausea and fatigue. The effects of CO exposure can vary greatly from person to person depending on age, overall health and the concentration and length of exposure. Sources of Carbon Monoxide are unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline powered equipment; automobile exhaust from attached garages; and tobacco smoke. Incomplete oxidation during combustion in gas ranges and unvented gas or kerosene heaters may cause high concentrations of CO in indoor air. Worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces) can be significant sources, or if the flow is improperly sized, blocked, disconnected, or is leaking. Auto, truck, or bus exhaust from attached garages, nearby roads, or parking areas can also be a source. At low concentrations, fatigue is seen in healthy people and chest pain in people with heart disease. At higher concentrations, impaired vision and coordination; headaches; dizziness; confusion; nausea can cause flu-like symptoms that clear up after leaving home. It may be fatal at very high concentrations. Acute effects are due to the formation of carboxyhemoglobin in the blood, which inhibits oxygen intake. At moderate concentrations, angina, impaired vision, and reduced brain function may result.

3. Science of Linkages of Air Quality and Health -MoES Perspective

In the Indian urban areas, the dominant sources of air pollution are often transport sector and in the rural areas, the domestic /residential wood combustion /cooking is also one of the major factors (Dalvi, et al., 006; Ghude, et al., 2008; Sahu and Beig, 2008). The most significant individual pollution episodes are caused by wild fires, fire management burns and dust storms. The frequency of air pollution episodes are likely to peak in India during El Nino years when the Indian monsoonal rainfall is most likely to be poor causing dry environment, afrequent of hot days, wild fires and dust storms. However, a wide range of gap exists between the atmospheric chemistry communities who are capable of providing accurate data and understand the physical and the chemical characteristics of air pollutants and medical practitioners who diagnose its impact on Human health. This is one of the major reasons that scientific evaluation of air quality index could not be properly done in many countries including India until now which need to be attempted by scientists.

The public health impacts of air pollution can be classified in two categories namely (a) acute and (b) chronic health outcomes, due to exposures to particulate and gaseous air pollutants, which can be assessed with mortality, hospital admissions, and other clinically significant health indicators. The three-legged stool in the discipline of Environmental Health to study health effects caused by chemicals is epidemiology, toxicology, and exposure science. Epidemiologists assess the association of chemical exposures and health outcomes with statistics, considering other factors such as demographic, dietary, etc. The findings are evaluated /confirmed by toxicologists who search for plausible biological mechanisms of compounds in humans in the laboratories. After the toxicity of certain chemicals are confirmed, Exposure Scientists investigate the processes of human in contact with chemicals. Exposure science is the bridge between environment and health. It is also the field that atmospheric chemists can make significant contributions!

Figure 1 shows the complex progression involving various physical, chemical, and biological processes from emission sources to health effects manifested; none of the current methodology is able to consider all factors from sources to health effects in detail. Due to the complex nature of the human body, it is difficult to conclude properly whether the health effects might occur and the extent of the effects caused by pollutants in the inner environments of the humans are significantly different among individuals, depending on individual factors such as genetic predisposition, nutritional status, pre-existing diseases, stress, etc. In order to protect public health, it is important to examine influential factors on population levels. Thus, it is important to focus on the outer environments of humans (Figure 1) where pollutants move through multiple environmental media after release and reach human population receptors via multiple pathways.

Air pollution epidemiology over the past 50 years has been continuously challenged by the limitations of coarsely resolved exposure measures. Time series studies of daily mortality, asthma symptoms or hospital admissions have had to rely upon particle and gas measurements made at a relatively few locations in a city (Pope and Dockery, 2006; Schwartz, 1994). Recent studies have shown that better characterization and better spatially resolved exposure estimates leads to improved quantification of exposure-health relationships. For example, where populations lived relatively close to the monitors, the adjusted regression coefficient for mortality and particles was larger than in the other kind of study that relied on the more dispersed EPA ambient monitoring network.

Exposure occurs at the environment-human interface, where pollutants are contacted in the course of human activities. It is difficult to assess exposure accurately. Therefore, accurately assessing exposure remains a big challenge in the environmental health sciences. Atmospheric chemists can advance the exposure science by instrumentation and model development to better quantify exposure. As a result, the exposure-health relationships can be accurately evaluated by epidemiologists.

On the other hand, exposure science can provide preventive measures and prioritize control strategies in advance while epidemiology assesses health outcomes after certain biological changes have already occurred. Exposure science is a scientific process of estimating or measuring the magnitude, frequency, and duration of exposure to chemicals, along with the number and characteristics of the population exposed (Zartarian et al., 2005). Sophisticated technologies and innovative study design are used to identify exposure sources, pathways, routes, and factors and characterize the exposure that occurs in various environmental settings. These findings have significant public health implications. For instance, government agencies can prioritize control strategies focusing on major exposure sources accordingly. Furthermore, the general public can be educated to avoid exposures by knowing the critical exposure pathways, routes, and factors of human activities. Consequently, public health can be protected in advance and health risks can be reduced based on scientific findings of exposure science. Atmospheric chemists engage in such works would have significant impacts on our society. In a long run, the advancement in our understanding in this area will require shared insights and partnerships between air chemistry community and epidemiologists/medical investigator which is hitherto practiced. From our scientific understanding and expert opinion, we may conclude the following: (1) Ambient particles remain poorly characterized, and the specific characteristics of particles responsible for the observed health effects are poorly understood which need to be explored; (2) we need to identify sub-groups of the population particularly susceptible to the effects of fine particles, mapping the distribution of particles within the community, and identifying the sources and characteristics responsible for the observed associations; (3) We need the epidemiological assessment of the health effects of the spatial distribution of fine particulates (provided by air pollution community) which could be attributed to chemical and physical characteristics of these particles and the ability to measure exposures in the community; (4) The assessment of major sources and controlling factors of human exposure to toxic constituents in different areas (different climate, culture, city vs. rural, etc.), especially for the most susceptible sub-populations, are essential to provide preventive measures and prioritize control strategies in advance; (5) pollution sources are concentrated in cities where population densities are also high; fresh emissions cause direct human exposure as well as resulting in high spatial variability of pollutant distribution. It is important to better estimate the spatial distribution of toxic constituents within cities on street levels, considering the street canyon effects, heat island effects, etc.

4. Indian Scenario on Standards

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

Despite the fact that pollutant concentrations near major industries, intersections and roadways in the cities are exceeding the Indian national ambient air quality standards (NAAQS), Air Quality Index for classifying the air quality in India is still under developing stage. National Ambient Air Quality Monitoring Programme in India has not yet scaled out any AQI levels over the region of India. Few studies have recently proposed AQI for some of the selected cities in India. Through CPCB, MOEF sponsored project, a study carried out at Indian Institute of Technology (IIT) Kanpur have recently come up with the preliminary Indian Air Quality Index (IND-AQI) where they have proposed the break-point concentrations and air quality standard are reported for criteria pollutant (http://home.iitk.ac.in/). The break-point concentration for the safe limit (good AQI) proposed in their study is analogous with recent notification of the NAAQS for most of the criteria pollutant, whereas it differs for Ozone and for $PM_{2.5}$, the break-point concentration for AQI is not provided.

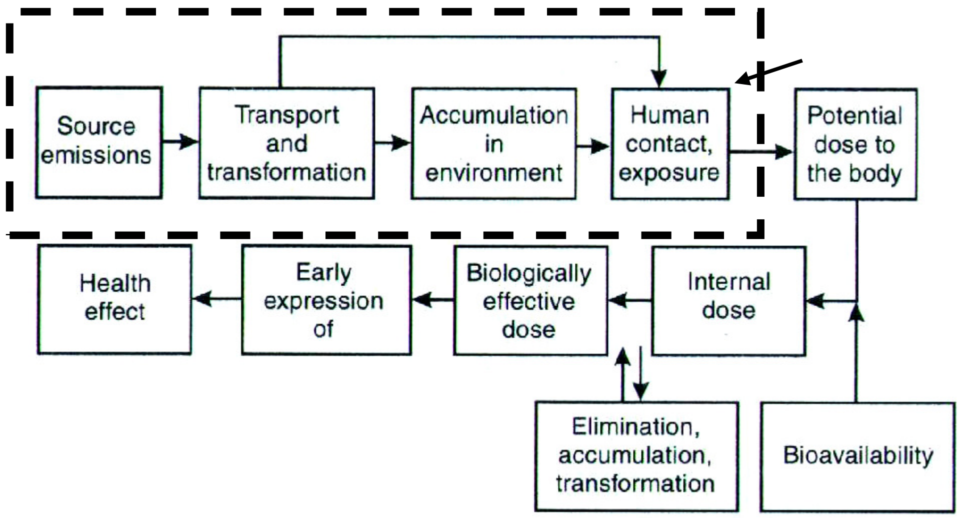

***Figure 1**. Progression of factors that influence the behavior of a contaminant within the environment, its uptake by humans, and the resulting health effects.*

Although this information base has gaps and uncertainties, it offers a strong foundation for the guidelines recommendation. Several key findings that have emerged in recent years merit special mention. In this report, based on our scientific judgment and available scientific evidences, an attempt has been made to fulfill the existing gaps by keeping the National Ambient Air Quality Standards as base line criteria, so that the revised Air Quality Index for criteria pollutant O_3, CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ can be calculated in different ranges as practiced worldwide where air quality forecasting system is placed and operational on routine basis. This will ensure that we do not remain left behind and always remain in the frontier in science at international level. The scientific basis for fulfilling the missing information is also briefly discussed. This concept of AQI is all the more important in India where the common man is not much familiar with technical terminology and measuring units (like ppm /ppb /ppt or $\mu g/mg^3$). Hence the AQI (which is represented in unit-less number) and its categorization in different colors which is based on the quality of air with respect to Human health will pave the way for a common man to understand its impact in most simplistic manner. It is also felt that at this juncture when the country is heading towards the development of first air quality forecasting system which is associated with an international sport event viz. Commonwealth games-2010, it is the most appropriate time to define the AQI for India which is attempted in this work.

5. Role of Guidelines in Protecting Public Health

An increasing range of adverse health effects has been linked to air pollution, and at even-lower concentrations. New studies use more refined methods and more subtle but sensitive indicators of effects, such as physiological measures (e.g. changes in lung function, inflammation markers). Various monitoring programmes have been undertaken to know the quality of air by generating vast amount of data on concentration of each air pollutant (e.g., O_3, NO_X, CO, Particulate Matter, etc.) in different parts of the world. The U.S. Environmental Protection Agency (EPA) is widely accepted and recognized all over the globe as general guideline book for providing the baseline threshold limits of different air pollutants. The US-EPA designed a term called as the AQI (Air Quality Index) for five major air pollutants regulated by the Clean Air Act: viz. ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. The Air Quality Index (AQI) is a new public information tool that helps protect public health on a daily basis from the negative effects of air pollution. For each of these pollutants, the EPA has established national air quality standards to protect public health.

6. Defining Air Quality Index for India

Several air quality standards and guidelines have been introduced by the Central Pollution Control Board (CPCB) of the Indian Ministry of Environment and Forests to reference and regulate urban air quality. Of particular importance are the Air (prevention and control of pollution) Act (1981), the Environmental Protection Act (1986), the Motor Vehicles Act (1988) and the Central Motor Vehicles Rules (1989). Recently the Ministry of Environment and Forests revised NAAQS and announced the notification of the new National Ambient Air Quality Standards 2009 in the official Gazette. The revised Indian NAAQS for criteria pollutants are summarized in Table 1. These standards and guidelines address individual pollutants and are developed based on highest percentile values over various averaging periods (Rao et al., 2002; CPCB, 2000, 2003; Beig and Gunthe, 2004). As per the norms, the residential & industrial areas have the same standards. As such, it is difficult to incorporate these standards into a reference scale. Further, the awareness of high air pollution concentrations and/or even the frequency of the NAAQS exceedence is not sufficient for the citizens to assess urban air quality. The general public needs information on the levels and potential health risks of air pollution presented in a simple, understandable format. In recent years, air quality indices (AQIs) as suggested by the US Environmental Protection Agency (EPA) are used in many cities to highlight the severity of air pollution and risks of adverse health effects (USEPA, 2003, 2008). The AQIs are related to the overall status of air pollution via a pre-defined set of clearly identified criteria. These criteria should be universal and irrespective of the level of pollution. It should be sufficiently flexible to account for different levels of population exposure, variable meteorological and climatic conditions occurring in an area as well as the sensitivity of flora and fauna

(USEPA, 1998). The main objective of the AQI is to inform and caution the public about the risk of exposure to daily pollution levels. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects. The computation of the AQI requires an air pollutant concentration from a monitor or model. The function used to convert from air pollutant concentration to AQI varies by pollutant, and is different in different countries (see equation 1). Air quality index values are divided into ranges, and each range is assigned a descriptor and a color code. Standardized public health advisories are associated with each AQI range. There are primarily two steps involved in formulating an AQI: first the formation of sub-indices for each pollutant, and second the aggregation (breakpoints) of sub-indices. The segmented linear function (Equation 1) is used for relating the actual air pollution concentrations (of each pollutant) to a normalized number (i.e. sub-index). An index for any given pollutant is its concentration expressed as a percentage of the relevant standard (USEPA, 1998).

Table 1: Indian national ambient air quality standards (MoEF Gazette, 2009)

Pollutants	Time - weighted Average	Concentration of Pollutants in Ambient Air	
		Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area
Ozone (O_3), µg/m^3	8 h *	100	100
Carbon Monoxide (CO), mg/m^3	8 h *	02	02
Nitrogen Dioxide (NO_2), µg/m^3	24 h *	80	80
Particulate Matter (size less than 10 µm) (PM_{10}), µg/m^3	24 h *	100	100
Particulate Matter (size less than 2.5 µm) ($PM_{2.5}$), µg/m^3	24 h *	60	60

** 24 hourly or 08 hourly monitored values, as applicable, shall be compiled with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.*

To convert from concentration to AQI following function is used worldwide

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, I is the (Air Quality) index, C is the pollutant concentration, C_{low} is the concentration breakpoint that is $\leq C$, C_{high} is the concentration breakpoint that is $\geq C$, I_{low} is the index breakpoint corresponding to C_{low} and I_{high} is the index breakpoint corresponding to C_{high}.

Few studies have used the AQI concept to classify pollution levels in India. Through a sponsored project from the Central Pollution Control Board, New Delhi, Ministry of Environment and Forest, recently Sharma et al., (2003) have proposed the Indian Air Quality Index (IND-AQI) for a criteria pollutant SO_2 (24-h avg), NO_2 (1-h avg), SPM (24-h avg), CO(24-h avg and 1-h avg), O_3 (24-h avg and 1-h avg) and PM_{10} (24-h avg). In their proposed study, a maximum operator concept was used to determine the overall AQI. The maximum value of sub indices of each pollutant was taken to represent overall AQI of the location. Breakpoint concentrations depend on the NAAQS and results of epidemiological studies indicating the risk of adverse health effects of specific pollutants. Therefore, different breakpoint concentrations and air quality standards are reported in the literature (USEPA, 1998). In their study, the mathematical equations for calculating sub-indices were developed by considering heath criteria as adopted by the US Environmental Protection Agency (1998) and Indian NAAQS (CPCB, 2000). To reflect the attainment of NAAQS, the AQI is referred to as Good between the range 0 - 100. For the second breakpoint (at the standard of USEPA), the AQI takes the value of 200 and referred to as Moderate. In absence of any other pollutant health criteria in India, rest of categorization of

Index is based on the USEPA Federal Episode criteria and Significant Harm Level. IND-AQI is primarily a health related index with the following descriptor words: "Good (0 - 100)", "Moderate (101 - 200)", "Poor (201 - 300)", "Very poor (301 - 400)", "Severe (401 - 500)". Table 2 shows the linear segmented relationship for sub-index values and the corresponding pollutant concentrations that are calibrated to Indian conditions (Sharma et al., 2003a). It has been observed that the break-point for good air quality index proposed in above the study for criteria pollutant SO_2 (24-hr avg), CO (1-hr avg), NO_2 (24-hr avg) and PM_{10} (24-hr avg) is same as that of the recent notification of the new National Ambient Air Quality Standards 2009 in the official Gazette (see Table 1).

Table 2: Air Quality Index for different Pollutants as proposed earlier for India (Sharma et al., 2003b)

Index	Category	SO_2 (24 hr avg) (µg/m3)	NO_2 (24-hr avg) (µg/m3)	SPM (24-hr avg) (µg/m3)	CO (8-hr avg) (mg/m3)	O_3 (8-hr avg.) (µg/m3)	PM_{10} (24-hr avg) (µg/m3)
00-100	Good	0-80	0-80	0-200	0-2	0-157	0-100
101-200	Moderate	81-367	81-180	201-260	2.1-12	158-196	101-150
201-300	Poor	368-786	181-564	261-400	12.1-17	197-235	151-350
301-400	Very poor	787-1572	565-1272	401-800	17.1-35	236-784 (1-hr avg)	351-420
401-500	Severe	>1572	>1272	>800	>35	>784 (1-hr avg)	>420

However, for ozone, it has been observed that the break-point proposed in the above study for good air quality index is higher than that of the recent notification of the new National Ambient Air Quality Standards 2009 in the Official Gazette for 8-hr average ozone concentration. Linear segmented relationship for sub-index values and the corresponding concentration for $PM_{2.5}$ are not proposed in the IND-AQI (Sharma et al., 2003a), however recent notification of the new National Ambient Air Quality Standards 2009 set the limit of 60 $\mu g/m^3$ (24-hr avg) for $PM_{2.5}$. In this report, based on our scientific judgment, we combined all the available recent Indian AQI studies and notification of the new National Ambient Air Quality Standards and proposed Air Quality Index for criteria pollutants viz, O_3, CO, NO_2, PM_{10}, and $PM_{2.5}$. In our proposed AQI the breakpoints for the criteria pollutants ozone and $PM_{2.5}$ are revised by taking into consideration the revised NAAQS and based on the USEPA Federal Episode criteria and Significant Harm Level. Table 3 shows the proposed AQI sub-index and breakpoint pollutants concentration for India. The key reference point in the calculated AQI value is 100 indicating a safe limit is based on the attainment of NAAQS for India (Sharma et al., 2003). Since the AQI for safe limit for CO, NO_2 and PM_{10} reported by Sharma et al. (2003, 2003a) reflects the attainment of new NAAQS, the breakpoints proposed here for CO, NO_2 and PM_{10} are similar to those reported by Sharma et al. (2003, 2003a). To reflect the attainment of NAAQS for ozone, instead of 157 $\mu g/m^3$ (~79 ppb), we propose 100 $\mu g/m^3$ (50 ppb) break-point for the 'Good' AQI (0-100). In absence of any ozone health criteria in India, rest of categorization of Index is scaled to the breakpoints criteria proposed by Sharma et al. (2003, 2003a). For the second break point (at the standard of USEPA) we propose 196 $\mu g/m^3$ (98 ppb) break-points for the 'Moderate' AQI (101-200), 235 $\mu g/m^3$ (118 ppb) break-points for the 'Poor' AQI (201-300). Similarly, to reflect the attainment of NAAQS for $PM_{2.5}$, we proposed 60 $\mu g/m^3$ breakpoint for the 'Good' AQI (0-100).

Table 3: AQI Sub-index and breakpoint pollution concentration for India as proposed in this work of IITM

Description	**AQI Index**	**Ozone (8h avg) (ppb)**	**CO (8h avg) (ppm)**	**NO_2 (24h avg) (ppb)**	**PM_{10} (24h avg.) (μg/m^3)**	**$PM_{2.5}$ (24h avg) (μg/m^3)**
Good[a]	0 -100	0 -50	0 - 1.7	0 - 42	0 - 100	0 - 60
Moderate[b]	101 -200	51- 98	1.8 - 10.3	43 - 94	101 - 150	61 - 90
Poor[c]	201-300	99-118	10.4 - 14.7	95 - 295	151 - 350	91 - 210
Very poor[d]	301-400	119 & above	14.8 & above	296 & above	351 & above	211 & above

[a]***Good:*** *Air quality good (represented by green color)*

[b]***Moderate:*** *Air quality acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people (represented by yellow color)*

[c]***Poor:*** *Members of sensitive groups may experience health effects (represented by orange color)*

[d]***Very poor:*** *Triggers health alert, everyone may experience health effects (represented by red color)*

Description	**AQI**	**Colour Coding**
Good	0-100	
Moderate	101-200	
Poor	201-300	
Very poor	301-400	

WMO, in their approach, converted PM_{10} guideline values to the corresponding $PM_{2.5}$ guideline values by application of a $PM_{2.5}/PM_{10}$ ratio of 0.5. A $PM_{2.5}/PM_{10}$ ratio of 0.5 is a typical value for developing countries urban areas and is at the bottom of the range found in the developed countries urban areas (0.5–0.8). As per WMO report, when setting local standards, based on the availability, a different value for this ratio; i.e. one that better reflects local conditions; may be employed. It is generally observed that the percentage difference between annually averaged PM_{10} and $PM_{2.5}$ concentration is approximately 40% for most of the cities in India. Also, the percentage difference between PM_{10} and $PM_{2.5}$ in the new NAAQS is 40%. In absence of any $PM_{2.5}$ health criteria in India, rest of categorization of Air Quality Index for $PM_{2.5}$ is scaled to 40% lower than the PM_{10} Index for 'Moderate' and 'Poor' Index category. For the second $PM_{2.5}$ breakpoint we propose 90 $\mu g/m^3$ break-points for the 'Moderate' AQI (101-200), 210 $\mu g/m^3$ (118 ppb) break-points for the 'Poor' AQI (201-300).

7. Conclusion

It should be noted that the scientific studies and scientific judgment play an important role in establishing guidelines that can be used to indicate the acceptable levels of population exposure which can be helpful and determinable factors for policy makers and implementing agencies. Keeping the above scientific spirit in mind and the fact that it is high time that we make a novel beginning in Air quality forecasting in India through Commonwealth Games (which will be held in New Delhi, India in October 2010), this ambitious scientific report has been proposed and released. Hence, it should be noted that the AQI breakpoints for the Indian environment (and subsequent categorization) is generated as preliminary, based on our scientific understanding and atmospheric chemistry knowledge of the subject. However, we strongly feel that, at present, the AQI and the breakpoints classification proposed in this work is the best estimate under the given constraints and available official information for India.

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