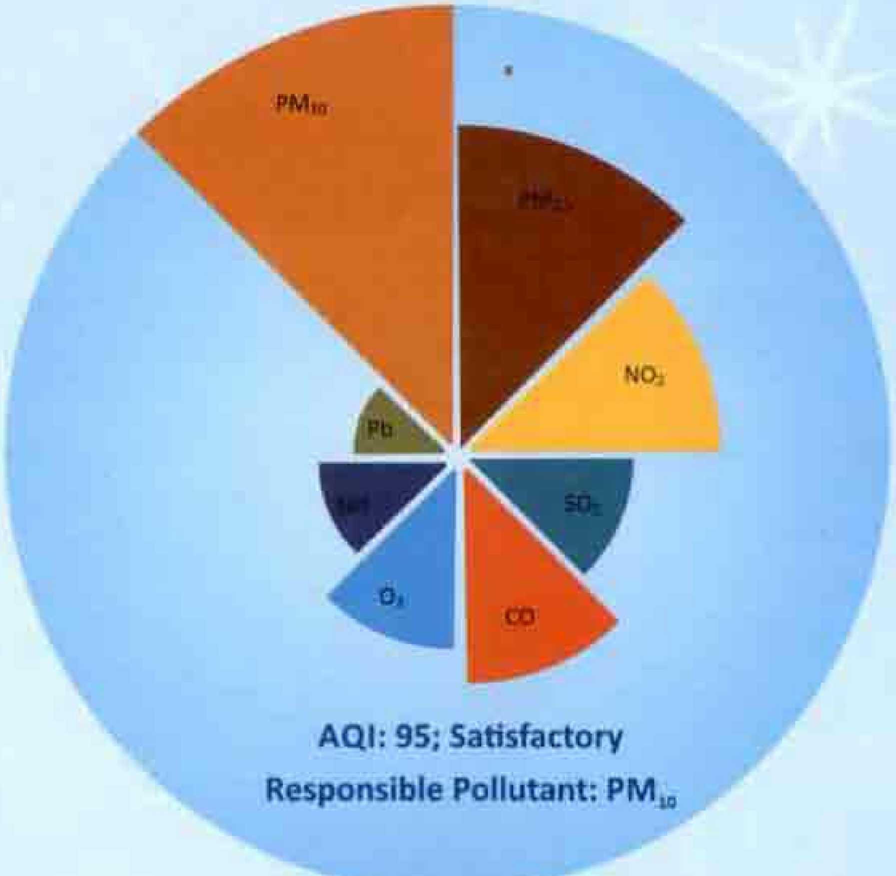
Control of Urban Pollution Series
CUPS/ 82 /2014-15

NATIONAL AIR QUALITY INDEX



CENTRAL POLLUTION CONTROL BOARD
Ministry of Environment, Forests & Climate Change

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Foreword

Air pollution levels in most of the urban areas have been a matter of serious concern. It is the right of the people to know the quality of air they breathe. However, the data generated through National Ambient Air Monitoring Network are reported in the form that may not be easily understood by a common person, and therefore, present system of air quality information does not facilitate people's participation in air quality improvement efforts.

In view of this, CPCB took initiative for developing a national Air Quality Index (AQI) for Indian cities. AQI is a tool to disseminate information on air quality in qualitative terms (e.g. good, satisfactory, poor) as well as its associated likely health impacts. An Expert Group comprising medical professionals, air quality experts, academia, NGOs, and SPCBs developed National AQI. Necessary technical information was provided by IIT Kanpur. The draft AQI was launched in October 2014 for seeking public comments. It was also circulated to States Governments, Pollution Control Boards, concerned Central Government Ministries and premier research institutes for inputs. Comments received were examined by the Expert Group and a National AQI scheme was finalized, which is presented in this report. There are six AQI categories, namely Good, Satisfactory, Moderately polluted, Poor, Very Poor, and Severe. The AQI considers eight pollutants for which short-term (up to 24-hourly averaging period) standards are prescribed, however, AQI can be calculated if monitoring data are available for minimum three pollutants of which one should necessarily be $PM_{2.5}$ or PM_{10}. Based on the measured ambient concentrations, corresponding standards and likely health impact, a sub-index is calculated for each of these pollutants. The worst sub-index reflects overall AQI.

I gratefully acknowledge the contributions made by the members of the Expert Group and Professors Mukesh Sharma and Arnab Bhattacharya of IIT Kanpur in finalizing the AQI scheme and preparation of this report. The efforts made by my colleagues Dr. Prashant Gargava, Additional Director, who conceptualized and coordinated the project and Ms. Garima Sharma, Environmental Engineer, CPCB are appreciated. Efforts put in by Shri A. Sudhakar, Additional Director; Shri Aditya Sharma, Environmental Engineer, and Ms. Kavitha B., Environmental engineer for operating web dissemination AQI system is also acknowledged.

It is hoped that the AQI will provide more meaningful air quality information to the people, ensure everyone's participation to strengthen efforts being made for improving air quality in urban areas.

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Chapter 1
Introduction

1.1 Origin and Concepts of Air Quality Index

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

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

To address the above concerns, the concept of an Air Quality Index (AQI) has been developed and used effectively in many developed countries for over last three decades (USEPA 1976, 2014; Ontario, 2013; Shenfeld, 1970). An AQI is defined as an overall scheme that transforms weighted values of individual air pollution related parameters (SO_2, CO, visibility, etc.) into a single number or set of numbers. There have not been significant efforts to develop and use AQI in India, primarily due to the fact that a modest air quality monitoring programme was started only in 1984 and public awareness about air pollution was almost non-existent. The challenge of communicating with the people in a comprehensible manner has two dimensions: (i) translate the complex scientific and medical information into simple and precise knowledge and (ii) communicate with the citizens in the historical, current and futuristic sense. Addressing these challenges and thus developing an efficient and comprehensible AQI scale is required for citizens and policy makers to make decisions to prevent and minimize air pollution exposure and ailments induced from the exposure.

1.2 Applications of Air Quality Index

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

1. Resource Allocation: To assist administrators in allocating funds and determining priorities. Enable evaluation of trade-offs involved in alternative air pollution control strategies.
2. Ranking of Locations: To assist in comparing air quality conditions at different locations/cities. Thus, pointing out areas and frequencies of potential hazards.

3. Enforcement of Standards: To determine extent to which the legislative standards and existing criteria are being adhered. Also helps in identifying faulty standards and inadequate monitoring programs.

4. Trend Analysis: To determine change in air quality (degradation or improvement) which have occurred over a specified period. This enables forecasting of air quality (i.e., tracking the behaviour of pollutants in air) and plan pollution control measures.

5. Public Information: To inform the public about environmental conditions (state of environment). It's useful for people who suffer from illness aggravated or caused by air pollution. Thus it enables them to modify their daily activities at times when they are informed of high pollution levels.

6. Scientific Research: As a means for reducing a large set of data to a comprehendible form that gives better insight to the researcher while conducting a study of some environmental phenomena. This enables more objective determination of the contribution of individual pollutants and sources to overall air quality. Such tools become more useful when used in conjunction with other sources such as local emission surveys.

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

1.3 Project Conceptualization

In the past, AQI has been based on maximum sub-index approach using five parameters i.e. suspended particulate matter (SPM), SO_2, CO, PM_{10}, and NO_2 (Sharma 2001). However, the calculated AQI was always dominated by sub-index of SPM due to lack of data availability for other pollutants. Recently, Indian Institute of Tropical Meteorology (IITM), Pune has evolved an AQI, which provides sub-index for PM_{10}, $PM_{2.5}$, O_3, NO_2, and CO (Beig et al, 2010), and has applied to continuous air quality monitoring network. The IITM-AQI describes air quality in terms of very unhealthy, very poor, poor (unhealthy for sensitive groups), moderate and good.

The revised CPCB air quality standards necessitate that the concept of AQI in India is examined afresh. The revised National Ambient Air Quality Standards (CPCB 2009) are notified for 12 parameters – PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, Pb, Ni, As, Benzo(a)pyrene, and Benzene. Although AQI is usually based on criteria pollutants (i.e. PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and O_3), a new approach to AQI which considers as many pollutants from the list of notified pollutants as possible is desirable. However, the selection of parameters primarily depends on AQI objective(s), data availability, averaging period, monitoring frequency, and measurement methods. While PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, and Pb have 24-hourly as well annual average standards, Ni, As, benzo(a)pyrene, and benzene have only annual standards and CO and O_3 have short-term standards (01 and 08 hourly average). PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, and $O_3$are measured on a continuous basis at many air quality stations (including NH_3 at some stations), Pb, Ni, As, Benzo(a)pyrene,and$NH_{3,}$ if monitored, use manual systems. To get an updated AQI at short time intervals, ideally eight parameters (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) for which, short-term standards are prescribed should, be measured on a continuous basis.

It is seen that multiple agencies propose AQI schemes which may provide varying air quality assessments, e.g. air quality may be termed as ‘good’ by one scheme and ‘poor’ by the other; this may be very confusing to general public. There is a need to devise a uniform and efficient AQI scheme which provides information about every pollutant and generates an overall index and be unique for the entire country.

In view of the above background, Central Pollution Control Board (CPCB) and the Ministry of Environment and Forests (MoEF) have initiated this project on National Air Quality Index to strengthen air quality information dissemination system for larger public awareness and their participation on air quality management. An expert committee was constituted with members drawn from academia, medical fraternity, research institutes, MoEF, advocacy groups, SPCBs and CPCB. The committee was mandated to deliberate, discuss and devise consensus on the AQI system that is appropriate for Indian conditions. The technical study was assigned to IIT Kanpur on grant-in-aid basis.

1.4 Project Objectives

The project aims to achieve the following:

(i) Inform public regarding overall status of air quality through a summation parameter that is easy to understand;

(ii) Inform citizens about associated health impacts of air pollution exposure; and

(iii) Rank cities/towns for prioritizing actions based on measure of AQI.

The overall objective of the project can be stated as under:

"To adopt/develop an Air Quality Index (AQI) based on national air quality standards, health impacts and monitoring programme which represent perceivable air quality for general public in easy to understand terms and assist in data interpretation and decision making processes related to pollution mitigation measures."

1.5 Scope of Work

The scope of the work is summarized below:

(i) Review of available AQIs including international practices;

(ii) Suggest health impact threshold limits for eight parameters for which short-term air quality standards are prescribed;

(iii) Develop a uniform AQI considering objectives, health impacts, air quality standards, existing and future monitoring scenario including parameters, method and frequency of measurements, and other relevant aspects;

(iv) Suggest qualitative description of air quality and associated likely health impacts for different AQI values;

(v) Evaluate AQI with data from a few major cities and towns;

(vi) Develop web-based system for dissemination of AQI to public using current and historical air quality database; and

(vii) Finalize AQI and dissemination system in consultation with leading air quality experts, medical professionals working in the field of air pollution health impacts, State Pollution Control Boards and other stakeholders

For this project, CPCB constituted an expert committee comprising members from renowned academicians, medical fraternity, research institutes, MoEF, advocacy groups, SPCBs and CPCB. The committee deliberated, discussed and devised consensus on the AQI system. The committee oversaw the progress of the project on a continual basis and had four meetings in the last three months and has documented this report. The AQI developed in this study is based on human exposure and health effects and may not be strictly applicable to ecologically sensitive areas.

Chapter 2

Air Quality Index: A Review

2.1 Definition of Air Quality Index

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

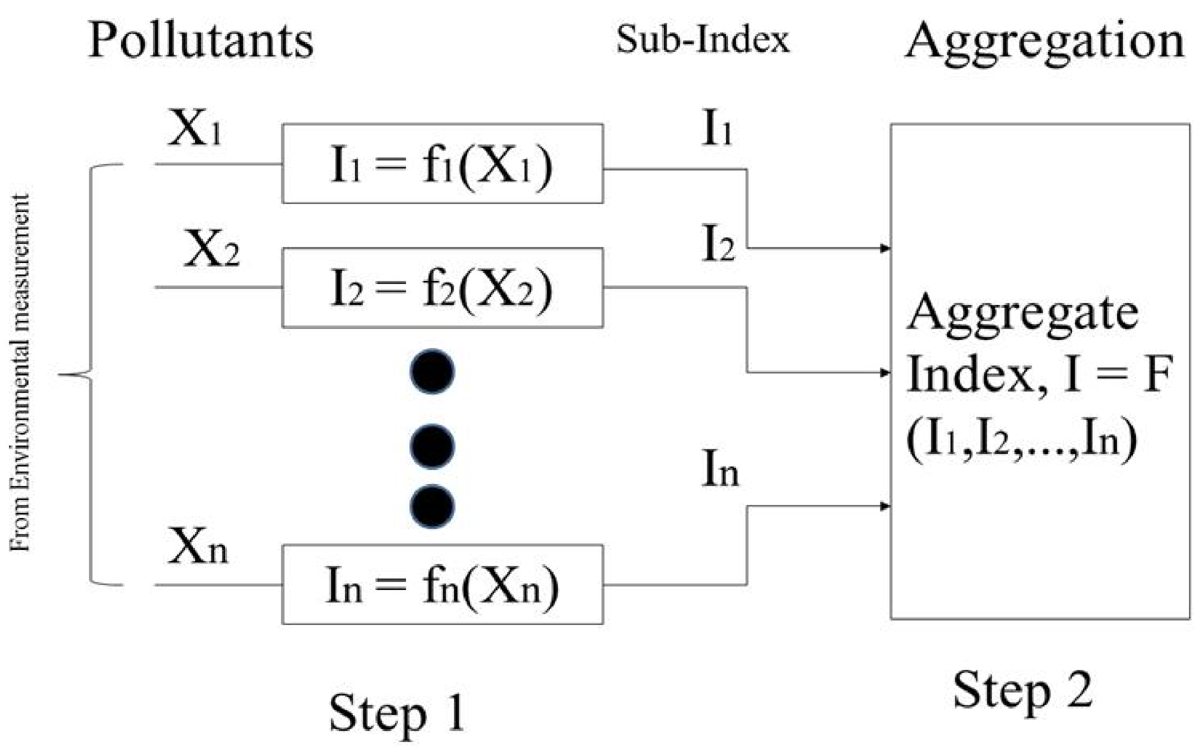


Figure 2.1 Formation of an Aggregated AQI

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

2.2 Structure of an Index

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

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

[1] $I_i = f(X_i), i=1, 2,...,n$

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

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

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

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

2.2.1 Sub-indices (Step 1)

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

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

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

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

[4] $I_i = [\{(I_{HI} - I_{LO})/(B_{HI} - B_{LO})\} * (C_p - B_{LO})] + I_{LO}$

where,

B_{HI}= Breakpoint concentration greater or equal to given concentration.

B_{LO}= Breakpoint concentration smaller or equal to given concentration.

I_{HI} =AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

Cp = Pollutant concentration

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

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

= 85

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

2.2.2 Aggregation of Sub-indices (Step 2)

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

Weighted Additive Form

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

where,

$\sum w_i = 1$

I_i= sub-index for pollutant i

n = number of pollutant variables

w_i= weightage of the pollutant

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

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

where, p is the positive real number >1.

Root-Mean-Square Form

[7] $I = \text{Aggregated Index} = \{1/k\ (I_1^2 + I_2^2 + \ldots\ldots + I_k^2\}^{0.5}$

Min or Max Operator (Ott 1978)

[8] $I = \text{Min or Max}(I_1, I_2, I_3, ..., I_n)$

2.3 Indices in the Literature

2.3.1 Green Index (GI)

One of the earliest air pollution indices to appear in literature was proposed by Green (1966). It included just two-pollutant variables - SO_2 and COH (Coefficient of Haze). The equations to calculate the sub-indices were:

$$I_{SO2} = 84 * X^{0.431}$$

$$I_{COH} = 26.6 * X^{0.576}$$

Where,

I_{SO2} = Sulphur dioxide sub-index

I_{COH}= Coefficient of Haze Sub-index

X = Observed pollutant concentration

The Green Index is computed as the arithmetic mean of the two sub-indices:

$$GI = 0.5 * (I_{SO2} + I_{COH})$$

The above equations are obtained from the break point concentration shown in Table 2.1

Table 2.1 Break Point Concentration of Green Index

Index	**SO_2(ppm)**	**COH**	**Descriptors**	**Remarks**
0-25	0.06	0.9	Desired	Clean, safe Air
25-50	0.3	3.0	Alert	Potentially Hazardous
50-100	1.5	10.0	Extreme	Curtail Air pollution sources

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

2.3.2 Fenstock Air Quality Index (AQI)

Fenstock (1969) proposed an index to assess the relative severity of air pollution and applied it to assess AQI of 29 US cities. This was the first index to estimate air pollutant concentrations from the data on source emissions and meteorological conditions in each city:

$$AQI = W_i \, I_i$$

where, W_i =weightages for CO, TSP and SO_2

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

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

2.3.3 Ontario Air Pollution Index

Shenfeld (1970) developed Ontario Air Pollution Index (API) in Canada. This index was intended to provide the public with daily information about air quality levels and to trigger control actions during air pollution episodes. It includes two pollutants variables:

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

Both COH and SO_2 (in ppm) are 24 hour running averages; Descriptor scale is given in Table 2.2

Table 2.2 Descriptor categories for Ontario API

Index	Description
0-31	Acceptable
32-49	Advisory
50-74	First Alert
75-99	Second Alert
100	Episode Threshold Level

2.3.4 Oak Ridge Air Quality Index (ORAQI)

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

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

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

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

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

X= Observed pollutant concentration

Xs= Pollutant Standard

I = Pollutant

The standards for the pollutants used in developing ORAQI are given in Table2.3

Table 2.3 Break Point Concentrations of ORAQI

Pollutant	Standard Value (24-hr Average)
Photochemical Oxidants	0.03 ppm
Sulphur Oxides	0.10 ppm
Nitrogen dioxide	0.20 ppm
Carbon monoxide	7.0 ppm
Particulate Matter	150 $\mu g/m^3$

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

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

2.3.5 Greater Vancouver Air Quality Index (GVAQI)

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

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

GVAQI values are divided into ranges. The federal Desirable, Acceptable and Tolerable air quality objectives levels are assigned GVAQI values of 25, 50 and 100 respectively. Intermediate values can be obtained by extrapolation. Each range is associated with descriptor categories. The break point concentrations used to find GVAQI are shown in Table 2.4 below.

Table 2.4: Break point concentrations for GVAQI

Index	SO_2 24-hr (ppm)	CO 8-hr (ppm)	NO_2 1-hr (ppm)	O_3 1-hr (ppm)	TSP 24-hr ($\mu g/m^3$)	COH 1-hr (units)	PM_{10} 24-hr ($\mu g/m^3$)	Descriptors
25	0.06	5	0.105*	0.051	60	1.7	25*	Good
50	0.11	13	0.21	0.082	120	4	50	Fair
100	0.31	18	0.53	0.153	400	6	100	Poor

Notes:

1) GVAQI breakpoints are based on federal Government air quality objectives with the exceptions of COH that is based on criteria developed by Province of Ontario.
2) * indicates extrapolation from other break point concentrations of the series.

The overall GVAQI value is determined by calculating a sub-index for each pollutant measurement and averaging time. Each sub-index is calculated by straight-line extrapolation of the break point concentrations corresponding to GVAQI values of 25, 50 and 100 respectively, which are shown in Table 2.4. The maximum sub-index is reported as the GVAQI, based on the assumption that the combined effect of a number of air pollutants is related to the highest concentrations relative to air quality objectives. The particular pollutant responsible for the maximum Sub-Index is called the "Index pollutant". It is reported with the GVAQI when the index value is greater than 25. Each GVAQI range is associated with descriptor categories, general health effects and cautionary statements.

2.3.6 Most Undesirable Respirable Contaminants Index (MURC)

MURC was published in 1968 (taken from Ott, 1978). This was routinely used in the city of Detroit to report air quality data to the public and was broadcast between 8:30 A.M. and 9.00 A.M. each day on local radio stations. MURC is based on just one pollutant variable, coefficient of Haze (COH)

$$MURC = 70X^{0.7} \text{ where, } X = \text{COH units}$$

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

Table 2.5 Break Point Concentrations of MURC Index

Index	COH (units)	Descriptors
0-30	0.3	Extremely Light contamination
31-60	0.92	Light Contamination
61-90	1.53	Medium contamination
91-120	2.15	Heavy Contamination
121	>2.15	Extremely Heavy contaminants

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

2.4 Current Status of AQI Application in India

There have not been significant efforts to develop and use AQI in India, primarily due to the fact that the National Air Quality Monitoring Programme has started only in 1984. Although NEERI, Nagpur started monitoring programme in 10 cities in 1978 and Bombay Municipal Corporation even before 1978, attempts were not made to use AQI for data interpretation and public broadcasting. Agharkar (1982) reviewed available AQIs and compared Air Quality status of the city of Bombay with its suburbs. The AQI proposed by Swami and Tyagi (1999) is similar to ORAQI. Their index does not suggest any correlation with health effects, although it is free from eclipsing. In view of the revised air quality standards and monitoring of many more air quality parameters, the AQI proposed by Swami and Tyagi (1999) cannot be used. Gurjar et al. (2008) have proposed a multi-pollutant index (MPI)considering the combined level of the three criteria pollutants (i.e.,TSP, SO_2, and NO_2). Currently, eight parameters are considered for AQI calculations and TSP is not included, therefore, the proposed MPI is of limited application. A recent study to define AQI in India has been taken up by Beig et al (2010a and 2010b) which includes air quality forecasting and is named as SAFAR (System of Air Quality-Weather Forecasting and Research). This study considered correlation analysis of long term air quality data of different pollutants and health data for two cities, Chennai and Delhi. The shortcoming of this study was that it accounted health data of only two cities whereas for an ideal AQI, representative of the country, one needs to account for health data of as many cities and towns as possible.

2.5 Eclipsing and Ambiguity

Two important characteristics, eclipsing and ambiguity are common to many indices and are significant to interpret any index in the right perspective. This could be best illustrated by a simple aggregation of two indices as in situation presented below:

Example: Let $I= I_1 + I_2$ and if $I_1> 100, I_2> 100$ indicate that the concentration of each pollutant is greater than the 'standard'. Question arises whether 'I' combined in this manner reflect properly the meaning implied in each index? It is possible to have combinations of I_1 and I_2such that I = 100, yet $I_1<100$ and $I_2<100$. Figure 2.2 shows each pollutant being within the prescribed standards but for e.g. if $I_1 = 70$, $I_2 = 70$; I =140. This gives an impression that combined Index, I > 100, i.e. pollution standards are violated, when they are actually not. Such a situation shown in Figure 2.2 is called as 'ambiguous region'. In this region, Index I exaggerates pollution status i.e. Over-estimation of pollution level. In case of more than 2 sub-indices I will be greater than 100, if each sub-index is slightly more than 100/n without violating standards.

Now, let $I = 0.5(I_1 + I_2)$. Effect of this on I=100, is to move the line parallel to itself without changing its slope as shown in Figure 2.2. If $I_2 = 60$ and $I_1 = 120$; I = 90. Hence, though the standards are violated for I_2 the combined index underestimates the pollution. This is known as "Eclipsing" (Figure 2.3). These two characteristics of index (Ambiguity and Eclipsing) are serious problems of additive and multiplicative indices. There is a significant difference between air quality perceived by index and actual air quality. Therefore, new indices which have been proposed are not of additive or multiplicative type; but based on Maximum operator approach as it removes Ambiguity and Eclipsing.

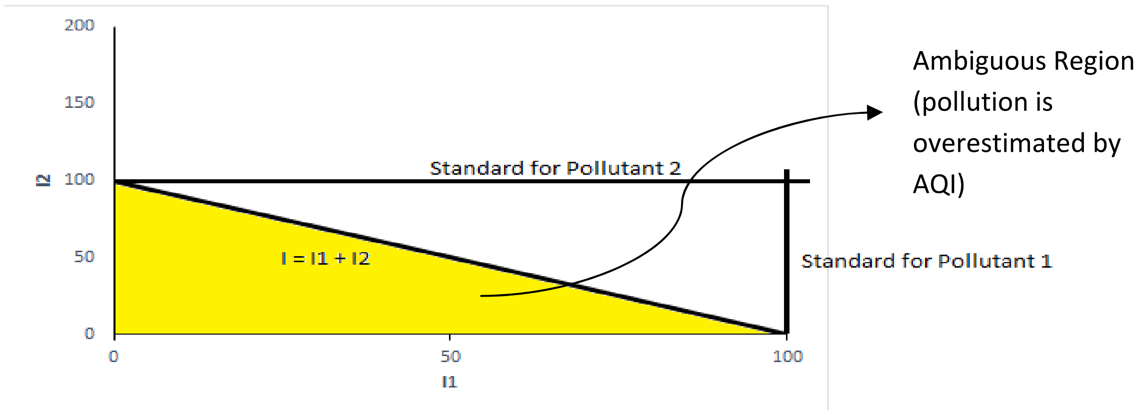


Figure 2.2 Ambiguity Characteristic of Indices

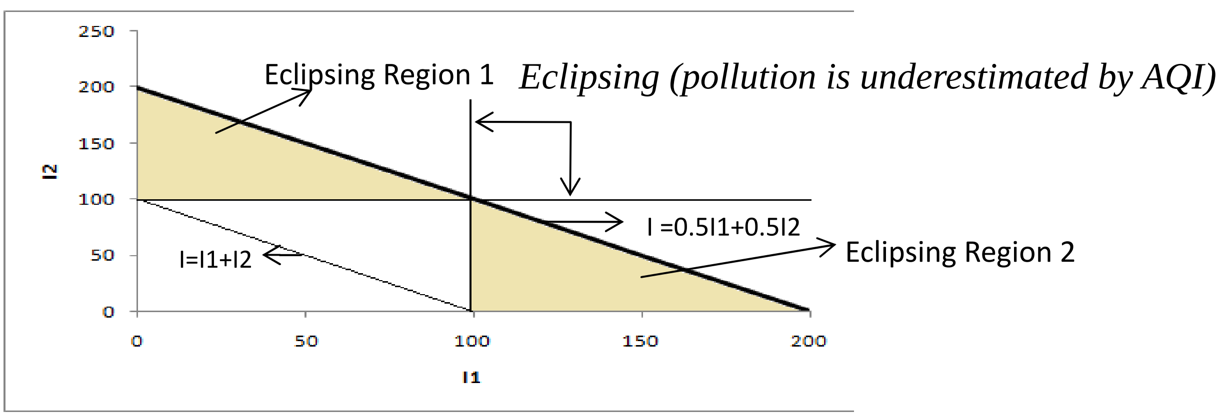


Figure 2.3 Eclipsing Characteristic of Indices

For the AQI, a maximum operator system is selected:

$$AQI = Max(I_1, I_2, I_3, ..., I_n)$$

There are two reasons for adopting a maximum operator function:

- Free from eclipsing and ambiguity (Ott 1978)
- Health effects of combination of pollutants (synergistic effects) are not known and thus a health-based index cannot be combined or weighted

Maximum operator approach has been adopted by Sharma et al. (2001, 2002 and 2003) for development of an AQI scale for IIT-Kanpur and for entire India respectively.

Chapter 3

Development, Implementation and Dissemination of AQI

3.1 Indian Air Quality Index (IND-AQI)

Air quality standards are the basic foundation that provides a legal framework for air pollution control. An air quality standard is a description of a level of air quality that is adopted by a regulatory authority as enforceable. The basis of development of standards is to provide a rational for protecting public health from adverse effects of air pollutants, to eliminate or reduce exposure to hazardous air pollutants, and to guide national/local authorities for pollution control decisions. With these objectives, CPCB notified (http://www.cpcb.nic.in) a new set of Indian National Air Quality Standards (INAQS) for 12 parameters [carbon monoxide (CO) nitrogen dioxide (NO_2), sulphur dioxide (SO_2), particulate matter (PM) of less than 2.5 microns size ($PM_{2.5}$), PM of less than 10 microns size (PM_{10}), Ozone (O_3), Lead (Pb), Ammonia (NH_3), Benzo(a)Pyrene (BaP), Benzene (C_6H_6), Arsenic (As), and Nickel (Ni)] . The first eight parameters (Table 3.1) have short-term (1/8/24 hrs) and annual standards (except for CO and O_3) and rest four parameters have only annual standards.

Table 3.1: Indian National Air Quality Standards (units: µg/m^3 unless mentioned otherwise)

Pollutant	**SO_2**	**NO_2**	**$PM_{2.5}$**	**PM_{10}**	**O_3**		**CO (mg/m^3)**		**Pb**	**NH_3**
Averaging time (hr)	24	24	24	24	1	8	1	8	24	24
Standard	80	80	60	100	180	100	4	2	1	400

BaP, C_6H_6, As, and Ni have annual standards

As stated in Chapter 1, an AQI scheme transforms weighted values of individual air pollutant concentrations into a single number or set of numbers. It is important that an AQI system should initially build on the sacrosanct AQS and then embark on pollutant dose-response relationships to describe air quality in simple terms which clearly relate to health impacts. While complexity in building the AQI is inevitable, simplicity in AQI description is essential for general public to understand the air pollution, possibly take actions to protect themselves and for policy makers to take quick and broad decisions to improve air quality.

The objective of an AQI is to quickly disseminate air quality information (almost in real-time) that entails the system to account for pollutants which have short-term impacts. It is equally important that most of these pollutants are measured continuously through an online monitoring network. Consequently, in the AQI system, the following pollutants are considered CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3, NH_3 and Pb. It is recognized that air concentrations of Pb are not known in real-time and cannot contribute to real-time AQI but its consideration in AQI calculation of past days will help in scrutinizing the status of this important toxic.

It is described in Chapter 2 that the aggregation function, F of combining sub-indices of individual pollutants is delicate as most indices suffer from ambiguity and eclipsing. For the AQI, a maximum operator system has been adopted which is free from ambiguity and eclipsing, as shown below:

$$AQI=Max(I_1,I_2,...,I_n)$$

Figure 3.1 shows the operational scheme of AQI system based of maximum operator function (i.e. maximum sub-index being the overall index). To present status of the air quality and its effects on human health, the following description categories have been adopted for IND-AQI (Table 3.2):

Table 3.2: IND-AQI Category and Range

AQI Category	AQI Range
Good	0 – 50
Satisfactory	51 – 100
Moderate	101 – 200
Poor	201 – 300
Very Poor	301 – 400
Severe	401 - 500

These categories/AQI ranges should map to key references (breakpoints) of concentration of each pollutants through a segmented linear or a nonlinear function.

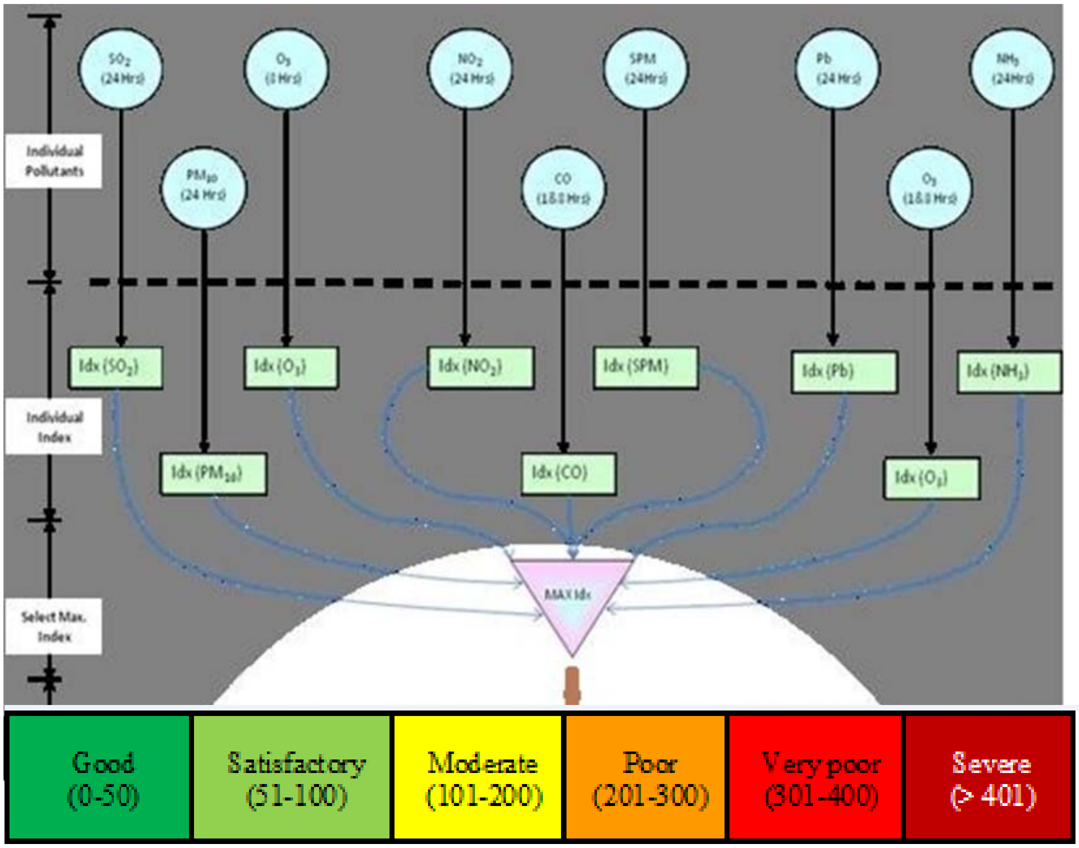


Figure 3.1 Overall AQI System

3.2 Air Quality Monitoring and AQI Considerations

The air quality monitoring network in India can be classified as (i) online and (ii) manual. The pollutant parameters, frequency of measurement and monitoring methodologies for two networks are very different. The AQI system for these networks could be at variance, especially for reporting and completeness in terms of parameters.

(i) ***Online Monitoring Network*****:** These are automated air quality monitoring stations which record continuous hourly, monthly or annually averaged data. In India, ~ 40 automatic monitoring stations are operated (e.g. Figure 3.2: online stations in Delhi), where parameters like PM_{10}, $PM_{2.5,}$ NO_2, SO_2, CO, O_3, etc. are monitored continuously. Data from these stations are available almost in real-time. Thus such networks are most suitable for computation of AQI sub-indices, as information on AQI can be generated in real time. For AQI to be more useful and effective, there is a need to set up more online monitoring stations for continuous and easy availability of air quality data for computation of AQI for more Indian cities.

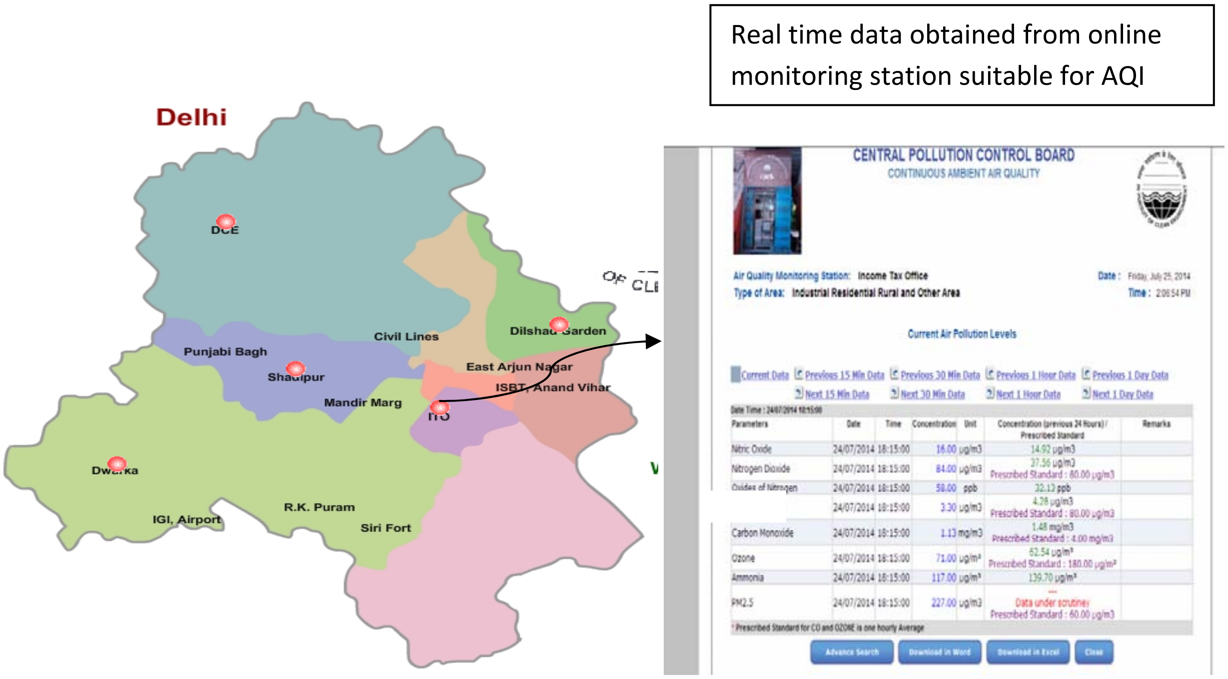


Figure 3.2 Online monitoring station (ITO, New Delhi) (www.cpcb.nic.in)

(ii) ***Manual Monitoring Network:*** The manual stations involve mostly intermittent air quality data collection, thus such stations are not suitable for AQI calculation particularly for its quick dissemination. In India, air quality is being monitored manually at 573 locations under National Air Monitoring Programme (NAMP). In most of these manually operated stations, only three criteria pollutants viz. PM_{10}, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) are measured, at some stations $PM_{2.5}$ and Pb are also measured. The monitoring frequency is twice a week. Such manual networks are not suitable for computing AQI, as availability of monitored data could have a lag of 1-3 days and sometimes not available at all. However, some efforts are required to use the information in some productive manner. Historical AQIs on weekly basis can be calculated and used for data interpretation and ranking of cities or towns for further prioritization of actions on air pollution control.

3.3 Computation and Basis of Sub-index Breakpoints

Segmented linear functions are used for relating actual air pollution concentration (X_i) (of each pollutant) to a normalized number referred to as sub-index (I_i). While AQI system is not complex in understanding, to arrive at breakpoints which will relate to AQI description is of paramount significance. Consequences of inappropriate adoption of breakpoints could be far reaching; it may lead to incorrect information to general public (on health effects) and decisions taken for pollution control may be incorrect.

The basis for linear functions (for this study) to relate air quality levels to AQI requires careful consideration. Services of practicing doctors and experts in this field (see Appendix I) have proved very useful. In this study, in addition to dose response relationship, the breakpoints adopted by other countries/agencies (USEPA 2014; UK 2013; Malaysia 2013; GVAQI 2013; Ontario 2013) have been examined for using these in IND-AQI.

It is important that an AQI system should build on AQS and pollutant dose-response relationships to describe air quality in simple terms which clearly relates to health impacts. The first step for arriving at breakpoints for each pollutant is to consider attainment of INAQS (Table 3.1). The index category is classified as 'good' for concentration range up to half of INAQS (for example, for SO_2 AQI=0-50 for concentration range of 0-40 $\mu g/m^3$) and as 'satisfactory' up to attainment of INAQS (i.e. SO_2 range 41-80$\mu g/m^3$ linearly maps to AQI=51-100). To arrive at breakpoints for other categories (for each pollutant), we require a thorough research/review of dose response relationships, which is described here.

3.3.1 Carbon Mono-oxide (CO)

Carbon monoxide (CO) is an important criteria pollutant which is ubiquitous in urban environment. CO production mostly occurs from sources having incomplete combustion. Due to its toxicity and appreciable mass in atmosphere, it should be considered as an important pollutant in AQI scheme.

CO rapidly diffuses across alveolar, capillary and placental membranes. Approximately 80-90% of absorbed CO binds with Hb to from Carboxyhaemoglobin (COHb), which is a specific biomarker of exposure in blood. The affinity of Hb for CO is 200-250 times than that of oxygen. In patients with hemolyticanemia, the CO production rate was 2–8 times higher and blood COHb concentration was

2–3 times higher than in normal person (WHO 2000). The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered and may lead to Coma or death if high exposures continue. A US study estimated that 6 per cent of the congestive heart failures and hospitalizations in the cities were related to an increase in CO concentration in ambient atmosphere (WHO 2000). Reduction in the ability of blood to transport oxygen leads to tissue hypoxia. The body compensates for this stress by increasing cardiac output and the blood flow to specific areas, such as the heart and brain. As the level of COHb in the blood increases, the person suffers from effects which become progressively more serious. CO has both 1 hr and 8 hr standard. Figure 3.3 shows CO level and percent of COHb in blood. The symptoms associated with various percent blood saturation levels of COHb are shown in Figure 3.4

After giving due consideration to INAQS for CO, two categories - Good (sub-index: 0-50 at half level of standard) and Satisfactory (51-100 at air quality standard) for attainment of INAQS are considered. For concentration of 10 mg/m^3, percentage COHb level could be about 2%. This may be just a beginning to slightly effect the people having lung or heart diseases, therefore, this AQI category can be taken as *moderate*. The next stage of categories has been taken as per the USEPA criteria. The details of breakpoints and that of USEPA, China and EU are given in Table 3.3.

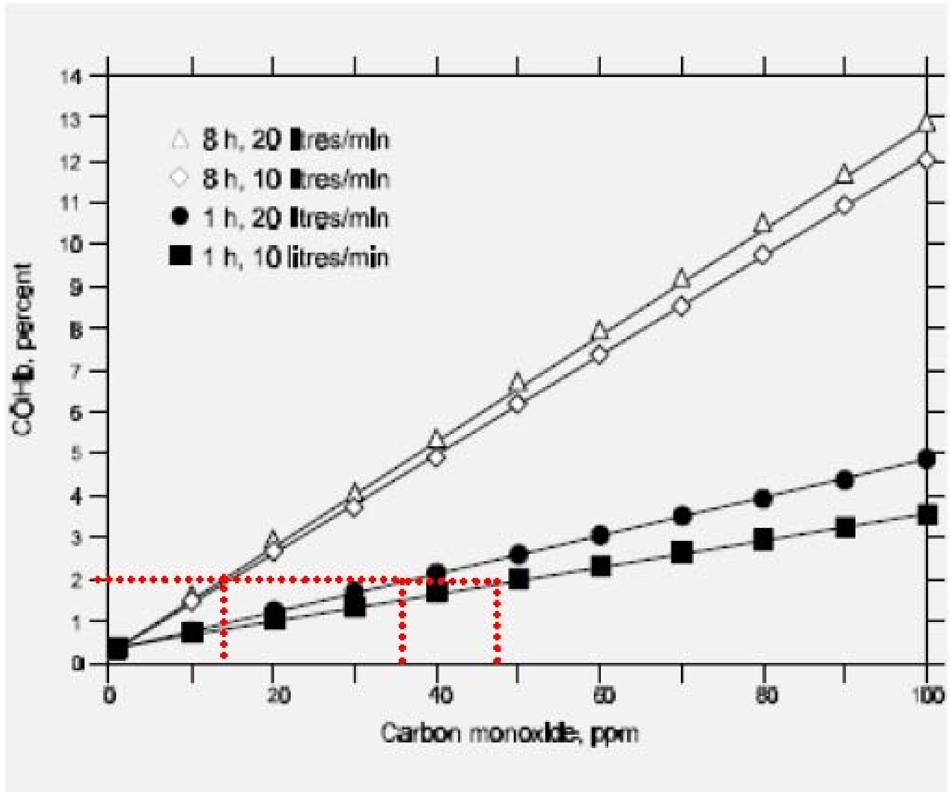


Figure 3.3 CO Concentration and COHb level in Blood (Coburn et al., 1965)

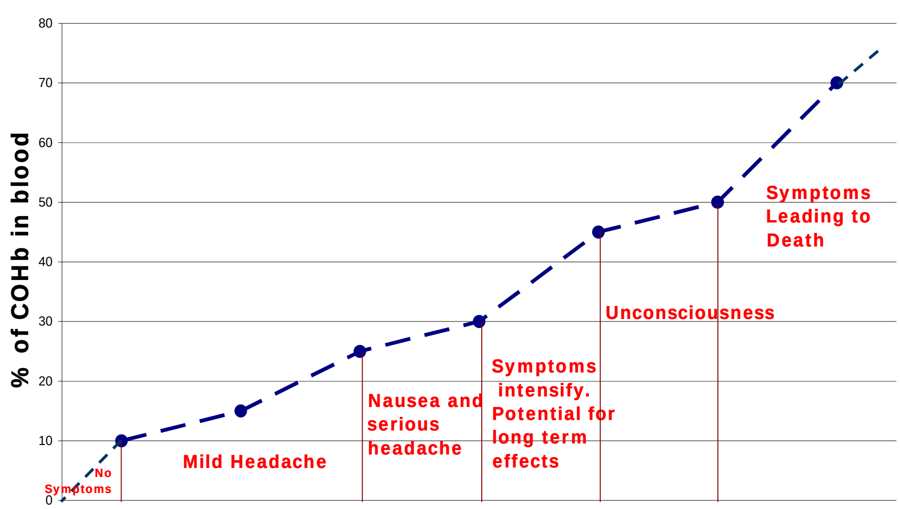


Figure 3.4: Symptoms Based on COHb Level in blood (CPCB 2000)

Table 3.3 Breakpoints for CO (mg/m^3)

India (8-hr)		US (8-hr)[(a)*]		China[(b)] (24-hr)		EU[(c)] (8-hr)	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	1	Good	5	Excellent	2	Very low	5
Satisfactory	2	Moderate	11	Good	4	Low	7.5
Moderate	10	Unhealthy for sensitive groups	14	Lightly Polluted	14	Medium	10
Poor	17	Unhealthy	18	Moderately Polluted	24	High	20
Very Poor	34	Very Unhealthy	35	Heavily Polluted	36	Very high	20+
Severe	34+	Hazardous	35+	Severely Polluted	36+		

[(a)]USEPA(2013)[(b)]Gao (2013) [(c)] CAQI (2012)*converted from ppm to mg/m^3 and rounded off

3.3.2 Nitrogen Dioxide (NO_2)

The major source of NO_2 is combustion processes. An appreciable quantity of NO_2 is present in rural and urban environments. Further, NO_2 is showing alarmingly high increasing trend in Indian cities due to increase in number of vehicles. On inhalation, 70–90% of NO_2 can be absorbed in the respiratory tract of humans, and physical exercise increases the total percentage absorbed (Miller et al., 1982). NO_2 exposure can cause decrement in lung function (i.e. increased airway resistance), increased airway responsiveness to broncho-constrictions in healthy subjects at concentration exceeding 1 ppm (WHO 2000). Below 1 ppm level, there are evidences of change in lung volume, flow volume, characteristics of lung or airway resistance in healthy persons. It has been established that continuous exposure with as little as 0.1 ppm NO_2 over a period of one to three years, increases incidence of bronchitis, emphysema and have adverse effect on lung performance (WHO 2000). Exposure to excessive NO_2, affects the defence mechanism leaving the host susceptible to respiratory illness.

Chronic exposure of NO_2 may lead to chronic lung disease and variety of structural/morphological changes in lung epithelium conducting airways and air -gas exchange region. Exposure to high levels

(>1.0 ppm) of NO_2 causes Eustachian of bronchiolar and alveolar epithelium, inflammation of epithelium and definite emphysema (WHO 2000).

Normal healthy people exposed at rest or with light exercise for less than 2 hours to concentrations of more than 4700µg/m^3 (2.5ppm) experience pronounced decrements in pulmonary function; generally, such people are not affected at less than 1880µg/m^3 (1ppm). One study showed that the lung function of people with chronic obstructive pulmonary disease is slightly affected by a 3.75-hour exposure to 560µg/m^3 (0.3ppm). A wide range of findings in asthmatics has been reported; one study observed no effects from a 75-minute exposure to 7520µg/m^3 (4ppm), whereas others showed decreases in FEV1 (forced expiration volume in one second) after 10 minutes of exercise during exposure to 560µg/m^3 (0.3ppm). The lowest concentration causing effects on pulmonary function was reported from two laboratories that exposed mild asthmatics for 30–110 minutes to 560µg/m^3 (0.3ppm) during intermittent exercise (WHO 2000).

WHO (2003) has reported some but not all studies show increased responsiveness to bronchoconstrictors at nitrogen dioxide levels as low as 376–560 µg/m^3 (0.2–0.3 ppm); in other studies, higher levels had no such effect. Studies of asthmatics exposed to 380–560 µg/m^3 indicate a change of about 5% in pulmonary function and an increase in airway responsiveness to bronchoconstrictors. Asthmatics are more susceptible to the acute effects of nitrogen dioxide as they have higher baseline airway responsiveness.

For acute exposures, only very high concentrations (1990 µg/m^3; > 1000 ppb) affect healthy people. Asthmatics and patients with chronic obstructive pulmonary disease are clearly more susceptible to acute changes in lung function, airway responsiveness and respiratory symptoms. Given the small changes in lung function (< 5% drop in FEV1 between air and nitrogen dioxide exposure) and changes in airway responsiveness reported in several studies, 375–565 µg/m^3 (0.20 to 0.30 ppm) is a clear lowest-observed-effect level. A 50% margin of safety is proposed because of the reported statistically significant increase in response to a bronchoconstrictor (increased airway responsiveness) with exposure to 190 µg/m^3 and a meta-analysis suggesting changes in airway responsiveness below 365 µg/m^3 (WHO 2000)

After giving due consideration to INAQS for NO_2, two categories good (Sub-Index: 0-50) and satisfactory (51-100), the breakpoint concentration are fixed as 40µg/m^3 and 80µg/m^3. Various studies reported that the small change in lung function (< 5% drop in FEV1 between air and nitrogen dioxide exposure) and changes in airway responsiveness gives 375–565μg/m^3 (0.20 to 0.30 ppm), as the lowest-observed-effect level. Therefore, breakpoints of 280μg/m^3 for poor, 400 μg/m^{3}for very poor and 400+ μg/m^3 for severe category are adopted. For moderately-polluted category an intermediate value of 180 μg/m^3 (between 80 and 280 μg/m^3) has been adopted. It may be noted that minor tweaking has been done with breakpoints so that these also corroborate with international breakpoints adopted by other countries. The details of break points for IND-AQI and breakpoints of USEPA, China and EU for $NO_2$are given in Table 3.4.

Table 3.4 Breakpoints for NO_2 (μg/m^3)

INDIA (24-hr)		US (1-hr)[(a)*]		China[(b)] (24-hr)		EU[(c)] (8-hr)	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	40	Good	100	Excellent	40	Very low	50
Satisfactory	80	Moderate	190	Good	80	Low	100
Moderate	180	Unhealthy for sensitive groups	680	Lightly Polluted	180	Medium	200
Poor	280	Unhealthy	1220	Moderately Polluted	280	High	400
Very Poor	400	Very Unhealthy	2350	Heavily Polluted	565	Very high	400+
Severe	400+	Hazardous	2350+	Severely Polluted	565+		

[(a)]USEPA (2013) [(b)]Gao (2013) [(c)] CAQI (2012)*converted from ppb to μg/m^3 and rounded off

3.3.3 Particulate Matter (PM):PM_{10} and $PM_{2.5}$

PM levels in Indian cities are about 4-5 times higher than in the US cities (WRI, 1996). These high PM levels may have severe impact on public health. The sixteen-year long survey by Dockery *et al.* (1994) has revealed that there is a strong correlation between ambient PM concentrations and increase in mortality and hospitalizations due to respiratory diseases. Several epidemiological studies (Pope, 1989; Schwartz, 1996) have linked PM_{10}(aerodynamic diameter ≤ 10 μm) and $PM_{2.5}$(aerodynamic diameter ≤2.5μm) with significant health problems, including: premature mortality, chronic respiratory disease, emergency visits and hospital admissions, aggravated asthma, acute respiratory symptoms, and decrease in lung function. $PM_{2.5}$ is of specific concern because it contains a high proportion of various toxic metals and acids, and aerodynamically it can penetrate deeper into the respiratory tract.

A HEI study, (Wichmannet al., 2000) reported that the concentration of both ultrafine ($PM_{<0.1}$) and fine particles ($PM_{0.1-2.5}$) was associated with increased daily mortality. Lippmann et al. (2000) reported that four of five size fractions (PM_{40} PM_{10-40} PM_{10} $PM_{2.5-10}$ $PM_{2.5}$) were associated with increased in morbidity and mortality. The largest particle size fraction (10 µm – 40 µm) was not associated with increased morbidity and mortality. However, Castillejos *et al.* (2000) in Mexico City and Ostro *et al.* (2000) in western United States have found health effects being associated with the coarse fraction as well but studies (Schwartz *et al.*, 1996) conducted in other parts of the United States and in Canada have reported that effects of fine particles are predominant.

Major concerns for human health from exposure to PM_{10} include effects on breathing, respiratory symptoms, decrease in pulmonary function and damage to lung tissue, cancer, and premature death. An association between elevated PM_{10} levels and hospital admissions for pneumonia, bronchitis, and asthma was observed by Pope (1989). Long-term particulate exposure was associated with an increase in risk of respiratory illness in children (Dockery *et al.*, 1989). Statistically significant relationships were observed between TSP levels and forced vital capacity (FVC) and FEV_1 (Chestnut *et al.*, 1991). Ostro (1993) has reported a series of studies that observed associations between daily changes in particulate pollution and daily mortality. Prospective cohort studies by Pope *et al.* (1995) observed 30 to 50% increase in lung cancer rates associated with exposure to respiratory particles. Associations between mortality risk and air pollution were strongest for respiratory particles and sulfates (Pope *et al.*, 1995). PEFR (peak expiratory flowrate) and respiratory symptoms were strongly associated with PM_{10} levels and marginally with ozone levels (Romieu*et al.*, 1996). Increase in PM concentration correlated with increase in mortality and morbidity rates. An increase of 10µg/m^{3}of PM_{10} levels resulted in a 3-6 % increase in visits for asthma people and a 1-3 % increase in visits for upper respiratory diseases not with asthma to hospitals. The findings are consistent with the result of previous studies of particulate pollution in other urban areas and provide evidence that the coarse fraction of PM_{10} may affect the health of working people (Gordian *et al.*, 1996). A study in six US cities has shown that there is an association between fine particulate matter ($PM_{2.5}$) primarily from combustion sources and daily mortality (Schwartz *et al.*, 1996). Combustion particles in the fine fraction from mobile and coal combustion sources, both not fine crustal particles, are associated with increase in mortality (Laden *et al.*, 2000).

Sharma et al. (2004) through a study in Kanpur reported that mean PEF (L/min) values of a cohort (of over 100 subjects) decrease with the increase in PM_{10} and/or $PM_{2.5}$. The findings of the study can be summarized as under:

(i) The correlation (negative) between mean ΔPEF (i.e. deviation in PEF) of a day (no. of days of sampling = 39) and four indicators of PM levels (PM_{10}, $PM_{2.5}$, PM_{10} (one-day lag) and $PM_{2.5}$ (one-day lag)) was found to be statistically significant ($p < 0.05$). It showed that as the pollution level increases the lung function in terms of PEFR reduces/deteriorates. The negative correlation with PM_{10} (one day lag) and $PM_{2.5}$ (one-day lag) also suggested that PM pollution may have sustained effect on PEFR value due to pollution level of previous day.

(ii) PM_{10} and $PM_{2.5}$ correlate with ΔPEF, PM_{10} and their concentration levels are better indicator to reflect changes in PEFR values. This suggests that the deposition of larger particles (PM_{10}) takes place in upper part of respiratory system that activates mucus secretion resulting is constriction of airways and thus lowering PEFR value. The fine particles impact the pulmonary region (lower respiratory system), which are known to cause long-term chronic effects.

(iii) FEV_1, PEFR and FVC are the key lung function parameters that reflect health impact of air pollution (Bates, 2002). The deviations found in FEV_1 and FVC are: (a) FEV_1 -0.30 L (at Vikas Nagar (VN): PM_{10}: 300μg/m^3), -0.31 (at Juhi Colony (JC): PM_{10}: 300 μg/m^3) and -0.18 L (IIT Kanpur (IITK): PM_{10}: 185 μg/m^{3}IITK) and (b) FVC -0.42 L (VN), -0.40 (JC) and -0.27 L (IITK).

It is evident from the above discussion that both PM_{10} and $PM_{2.5}$ have specific health impacts and both of these pollutants should be considered for AQI.

PM_{10}

WHO (2005) suggests that there is no threshold for particulate concentration below which there is no harmful effect. At the same time, high PM_{10} background concentration in India cannot be disregarded which is reflected in relatively high level of INAQS for PM_{10}; Sharma (2009) has estimated background concentration of PM_{10} as 35 μg/m^3. For PM_{10}, in view of no specific studies in India, it is proposed that the breakpoints proposed by USEPA may be adopted after accounting for INAQS (Table 3.5).

Table 3.5 Breakpoints for PM_{10} ($\mu g/m^3$)

INDIA (24-hr)		**US (24-hr)[(a)]**		**China[(b)] (24-hr)**		**EU[(c)] (8-hr)**	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	50	Good	55	Excellent	50	Very low	15
Satisfactory	100	Moderate	155	Good	150	Low	30
Moderate	250	Unhealthy for sensitive groups	255	Lightly Polluted	250	Medium	50
Poor	350	Unhealthy	355	Moderately Polluted	350	High	100
Very Poor	430	Very Unhealthy	425	Heavily Polluted	420	Very high	100+
Severe	430+	Hazardous	425+	Severely Polluted	420+		

[(a)]USEPA (2013) [(b)]Gao (2013) [(c)] CAQI (2012)

$PM_{2.5}$

Sharma (2009) has estimated background concentration of $PM_{2.5}$ as 17-28 $\mu g/m^3$. The background concentration in Europe and the US is very low (< 5 $\mu g/m^3$). Therefore, for lower concentration range, it is not reasonable to follow the breakpoints as proposed by US or EU. With due regard to INAQS (which accounts for background pollution), the first two categories, Good and Satisfactory, the breakpoints are kept as 30 and 60 $\mu g/m^3$. As per HEI Global Burden of disease report (2013), till 90$\mu g/m^3$ the relative risk of Ischemic Heart Disease increase and then more or less it plateaus off, therefore the next break point for category *moderate* is kept as 90$\mu g/m^3$.

For $PM_{2.5}$, in view of no specific studies in India, it is proposed that the breakpoints proposed by USEPA may be adopted. Beyond first three categories, the breakpoints proposed by USEPA and China are adopted (Table3.6).

Table 3.6 Breakpoints for PM $_{2.5}$ (μg/m^3)

INDIA (24-hr)		US (24-hr)[(a)]		China[(b)] (24-hr)		EU[(c)] (8-hr)	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	30	Good	12	Excellent	35	Very low	10
Satisfactory	60	Moderate	35	Good	75	Low	20
Moderate	90	Unhealthy for sensitive groups	55	Lightly Polluted	115	Medium	30
Poor	120	Unhealthy	150	Moderately Polluted	150	High	60
Very Poor	250	Very Unhealthy	250	Heavily Polluted	250	Very high	60+
Severe	250+	Hazardous	250+	Severely Polluted	250+		

[(a)]USEPA (2013) [(b)]Gao (2013) [(c)] CAQI (2012)

3.3.4 Ozone

Ozone, a secondary pollutant formed in the atmosphere, has serious health impacts. Ozone is a strong oxidant, and it can react with a wide range of cellular components and biological materials. Ozone can aggravate bronchitis, heart disease, emphysema, asthma and reduce lung capacity. Irritation can occur in respiratory system, causing coughing, and uncomfortable sensation in chest (WHO, 2000). It can reduce lung function and can make breathing difficult. Ozone makes people more sensitive to allergens, which are the most common triggers for asthma attacks, thus it can aggravate asthma, when ambient ozone levels are high. Also, asthmatics are more severely affected by the reduced lung function and irritation in the respiratory system. Ozone can inflame and damage lung cells. Within few days of ozone exposure the damaged cells are replaced and the old cells shed (WHO 2000). Ozone may aggravate chronic lung diseases such as emphysema and bronchitis and reduce the immune system's ability to fight off bacterial infections in the respiratory system. For 1–3 hours of ozone exposure in healthy subjects during moderate-to-heavy exercise (ventilation > 45 litres/minute), changes in pulmonary function have been reported for the following tests (lowest-observed-effect levels under conditions of strenuous exercise) (McDonnell et al., 1983 and Gong et al., 1986):

- Forced expiratory volume in 1 second (FEV1) (240 μg/m^3)
- Airway resistance (360 μg/m^3)
- Forced vital capacity (FVC) (240 μg/m^3)
- Increased respiratory frequency (400 μg/m^3).

For 4–8 hours of ozone exposure in healthy adults doing moderate exercise, the following changes in pulmonary function tests have been reported (Horstman et al., 1990) with given concentrations.

- FEV1,160 μg/m^3
- Airway resistance, 160 μg/m^3
- FVC, 200 μg/m^3
- Increased airway responsiveness, 160 μg/m^3.

Table 3.7 summarizes health impacts at different levels of ozone exposure.

Table 3.7: Health Outcomes Associated with Controlled Ozone Exposures [WHO 2000]

Health outcome	**Ozone concentration (μg/m^3) at which the health effect(s) is/are expected**	
Increase in inflammatory changes (neutrophil influx) (healthy young adults at >40 litres/minute breathing rate at outdoors)	**Averaging time 1 hour**	**Averaging time 8 hours**
2-fold	400	180
4-fold	600	250
8-fold	800	320

After giving due consideration to INAQS for ozone, for two categories - Good (sub-index 0-50) and Satisfactory (51-100), the breakpoint concentrations are fixed as 50 μg/m^{3}and 100 μg/m^3. It can be seen that 180, 250 and 320 μg/m^3 (8-hour concentration) cause important health endpoints leading to 2, 4 and 8 fold inflammatory changes in population (Table 3.7). With these endpoints, the breakpoints are: *moderate* at 200 μg/m^3 poor at 250 μg/m^{3}and 1-hr concentration break points for very poor is taken as 750 and for severe it is taken as 750+ μg/m^3 (this concentration will nearly match to 350 μg/m^{3}of 8-hr average concentration). Table 3.8 presents, AQI breakpoints for various categories for ozone along with breakpoints of other countries.

Table 3.8 Breakpoints for Ozone (μg/m^3)

INDIA (8-hr)		US (8-hr)[a]		China[b] (8-hr)		EU[c] (8-hr)	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	50	Good	120	Excellent	100	Very low	60
Satisfactory	100	Moderate	150	Good	160	Low	120
Moderate	168	Unhealthy for sensitive groups	190	Lightly Polluted	215	Medium	180
Poor	208	Unhealthy	230	Moderately Polluted	265	High	240
Very Poor	748**	Very unhealthy	750	Heavily Polluted	800	Very high	240+
Severe	748+**	Hazardous	750+**	Severely Polluted	-		

[a] USEPA (2013) [b]Gao (2013) [c] CAQI (2012)*converted from ppm to μg/m^3 and rounded off***1-hr monitoring values*

3.3.5 Sulphur Dioxide (SO_2)

SO_2 is soluble in aqueous media and affects mucous membranes of the nose and upper respiratory tract. Reduction in mean lung function values among groups of healthy individual have been observed for 10-minute exposures at 4000 ppb (11 440 μg/m^3) *(*Linn *et al.* 1984*)* and at 5000 ppb (14 300 μg/m^3) (Lawther et al., 1975). No significant changes in group mean lung function value have been seen below 1000 ppb (2860 μg/m^3) even during exercise.

Asthmatic people appear to respond in a similar way to normal subjects, with development of bronchoconstriction, but at lower concentrations. Several studies (Linn et al., 1984) have shown fairly large changes in mean values of lung function indices with 600 ppb (1716 μg/m^3) and heavy exercise. Linn et al. (1984) examined the dose–response relationship of change in mean FEV1 with increasing concentrations of SO_2 with exercise in patients with moderate or severe asthma. Overall, the mean response at 400 ppb (1144 μg/m^3) has been definite though small, at around 300-ml fall in mean values and at 200 ppb (572 μg/m^3) changes were negligible. Hence, from the information published hitherto, it can be concluded that the minimum concentration evoking changes in lung function in exercising asthmatics is of the order of 400 ppb (1144 μg/m^3).

The first step is the attainment of INAQS (Table 3.1). The index category for SO_2 is classified as 'good' for concentration range 0-40μg/m^3 (half of INAQS for SO_2) for AQI range 0-50 and as 'satisfactory' from 41-80μg/m^3 for AQI range 51-100. For the third sub-index range 101–200, violations of USEPA standards are examined. The INAQS for SO_2 (80μg/m^3) is more stringent than the USEPA standard (377μg/m^3, USEPA 2014). In other words, the built-in safety factor is higher for the Indian standard. The USEPA standard (and discussions above) suggests that for SO_2 levels up to 365μg/m^3, the air quality is acceptable from a public health point of view. Thus, for SO_2 levels between 81 and 365μg/m^3, the corresponding sub-index value has been taken to vary linearly between 101 and 200, and the AQI category for SO_2 is classified as 'moderate'. In absence of any other pollutant health criteria in India the rest of the categorization of AQI is based on the USEPA federal episode criteria and significant harm level (USEPA 1998) and studies of Lawther et al., 1975*)* and Linn et al. (1983 and 1984). Table 3.9 shows SO_2 breakpoints.

Table 3.9 Breakpoints for SO_2 *(μg/m^3)*

INDIA (24-hr)		**US (1-hr)[(a)]**		**China[(b)] (24-hr)**		**EU[(c)] (8-hr)**	
AQI Category	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**	**AQI Category**	**Break point concentration**
Good	40	Good	95	Excellent	50	Very low	50
Satisfactory	80	Moderate	200	Good	150	Low	100
Moderate	380	Unhealthy for sensitive groups	485	Lightly Polluted	475	Medium	350
Poor	800	Unhealthy	795	Moderately Polluted	800	High	500
Very Poor	1600	Very Unhealthy	1580	Heavily Polluted	1600	Very high	500+
Severe	1600+	Hazardous	1580+	Severely Polluted	2620		

[(a)] USEPA (2013) [(b)]Gao (2013) [(c)] CAQI (2012)*converted from ppb to μg/m^3 and rounded off

3.3.6 Pb and NH_3

It is to be noted that most of the countries have taken only six pollutants (described above) for formulation of AQI. An attempt has been made to propose breakpoints for NH_3 and Pb as these two pollutants also have short-term standards of 24-hr. While NH_3 can be measured on continuous basis and can be included in the list of real time parameters for AQI, such measurements are not possible for Pb. However, Pb levels can be utilized in calculation of AQI of past days to assess impact of lead pollution.

Inhalation of high levels of NH_3 causes irritation to the nose, throat and respiratory tract. Increased inhalation may result in cough and an increased respiratory rate as well as respiratory distress. An association has been reported between exposure to ammonia and cough, phlegm, wheezing, and asthma at high concentration. A study (http://www.hpa.org.uk/webc/hpawebfile/hpaweb_c/1194947398510) has reported that for NH_3 levels at 18 mg/m^3, reduction in FEV1 and FVC% were significant in symptomatic than asymptomatic individuals. For a factor of safety as 10, concentration of 1800 µg/m^3 should be considered to be severe in ambient air. The other breakpoints for ammonia have been evolved on a linear scale from the level of 1800 µg/m^3 to the standard concentration of 400 µg/m^3.

Pb is a toxic metal and its exposure through all routes results in increased blood lead level. At lower concentrations, the blood lead level is proportional to air concentration (after accounting for all resulting exposure routes). For example, 1µg/m^3 of annual lead level will result in 5µg/dL (on an average) of blood lead level (WHO 2000). The effect of blood level above 10µg/dL is seen in hematological changes in sensitive population, therefore, at moderate pollution level the break point is at 2µg/m^3. At 20µg/dL blood lead level the effects become more prominent and this corresponds to break point of 4 µg/m^{3}but to account for factor of safety, next break point is kept at 3.0 µg/m^3 (and not at 4 µg/m^3) and if the lead concentration in air is more than 3.5 µg/m^{3}the AQI category will be severe.

In view of the above discussions, Table 3.10 presents the breakpoints for NH_3 and Pb; due consideration has been given to INAQS in deciding breakpoints for categories, Good and Satisfactory.

Table 3.10 AQI Breakpoints for NH_3 and Pb (24-hr)

(Pb from gasoline phased out in 2000)

AQI Category	NH_3 µg/m^3	Pb µg/m^3
Good (0-50)	200	0.5
Satisfactory (51-100)	400	1.0
Moderate(101-200)	800	2.0
Poor (201-300)	1200	3.0
Very poor (301-400)	1800	3.5
Severe (401-500)	1800+	3.5+

Sections 3.3.1 to 3.3.6 have presented basis of AQI breakpoints for eight pollutant parameters considered for AQI and these are summarized below in Table 3.11 with colour scheme to represent the AQI bands. Table 3.12 shows health statements for every AQI category for people to understand health effects and protect themselves from these effects.

Table 3.11 Breakpoints for AQI Scale 0-500 (units: µg/m^3 unless mentioned otherwise)

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.6 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17.1-34	801-1600	1201-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

**One hourly monitoring (for mathematical calculation only)*

CPCB may consider reviewing the AQI breakpoints every three years after accounting the new research findings on air pollution exposure and health effects.

Table 3.12 Health Statements for AQI Categories

AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people
Moderate (101–200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401-500)	May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity

3.4 Broad Guidelines for Actions during Very Poor and Severe Categories of AQI

Regulating Agencies

The regulating agencies should establish source-receptor relationships in terms of impact of emissions on air quality. In case AQI category is severe or very poor, necessary steps need to be taken by further regulating the emissions which are causing maximum impact to ambient air quality. Specific actions, for example, may include: (i) strict vigilance and no-tolerance to visible polluting vehicles, industries, open burning, construction activities, etc.; (ii) regulating traffic; and (iii) identifying sources contributing significantly to rising air quality levels and actions for reducing emissions from such sources.

Public

People should maintain vehicles properly (e.g. get PUC checks, replace car air filter, maintain right tires pressure), follow lane discipline and speed limits, avoid prolong idling and turn off engines at red traffic signals. In addition, during severe or very poor AQI categories, people should minimize travel; avoid using private vehicles and instead use public transport, bikes or walk, and carpool; use smaller vehicles (e.g. avoid SUVs). The uses of diesel generators should be minimized. People, especially those suffering from heart diseases and asthma, may consider avoiding undue exposures.

3.5 Interpretation of Air quality using IND-AQI: an example

An exampele of AQI calculation and description for Delhi (online air quality monitoring network) and Kanpur (manual network) is presented here for two seasons, monsoon and winter. The sub-index (I_p) for a given pollutant concentration (C_p), as based on 'linear segmented principle' is calculated as:

$$I_{p}= [\{(I_{HI} - I_{LO})/ (B_{HI} - B_{LO})\} * (C_p - B_{LO})] + I_{LO}$$

B_{HI}= Breakpoint concentration greater or equal to given concentration

B_{LO}= Breakpoint concentration smaller or equal to given concentration

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}; subtract one from I_{LO}, if I_{LO} is greater than 50

Finally;

$$AQI = Max (I_p) \text{ (where; p= 1,2,...,n; denotes n pollutants)}$$

AQI of Delhi (online stations)

AQI has been calculated for July (clean period) and November (highly polluted period) for monitoring stations Anand Vihar, RKPuram, Punjabi Bagh, and Mandir Marg.
(Source of data: http://www.dpcc.delhigovt.nic.in/Air40.html)

Legend for AQI

AQI Description	Good (0-50)	Satisfactory (51-100)	Moderate (101-200)	Poor (201-300)	Very poor (301-400)	Severe (> 401)

July AQI

Anand Vihar:

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
26-Jul-13	57	72	12	36	101	16	48	80	112	112
27-Jul-13	48	115	15	42	84	13	29	83	124	124
28-Jul-13	56	115	17	37	97	15	33	188	205	205
29-Jul-13	62	105	14	38	82	15	28	91	162	162
30-Jul-13	54	105	10	29	80	13	26	98	167	167

Responsible Parameter PM_{10}

The AQI for CO and O_3 has been calculated for running 8-hr averages. This will give 23 AQI values, here maximum and minimum AQI of CO and O_3 are presented. It can be seen that for most pollutants air quality is good/satisfactory. It is PM_{10} which is in *moderate* category.

RK Puram

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
15-Jul-13	38	50	8	20	57	7	17	93	75	93
16-Jul-13	42	74	6	18	66	8	20	105	78	105
17-Jul-13	38	61	11	20	61	8	19	117	87	117
18-Jul-13	35	85	10	19	69	8	17	156	104	156
19-Jul-13	41	84	9	17	59	9	18	98	75	98

Responsible Parameter $PM_{2.5}$

Panjabi Bagh

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
30-Jul-13	66	83	36	57	61	13	16	72	101	101
31-Jul-13	48	77	36	49	53	13	14	696	56	696
1-Aug-13	41	77	30	62	84	13	17	97	128	128
2-Aug-13	41	76	30	41	72	14	19	76	126	126
3-Aug-13	27	56	27	49	74	14	20	71	115	115

Responsible Parameter PM_{10}

MandirMarg

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
28-Jul-13	22	106	16	18	47	9	14	221	126	221
29-Jul-13	30	79	10	18	37	9	14	90	77	90
30-Jul-13	30	96	12	18	51	9	17	130	105	130
31-Jul-13	33	76	12	18	49	9	12	70	62	76
1-Aug-13	26	67	8	13	46	10	16	102	92	102

Responsible Parameter $PM_{2.5}$

November AQI

The AQI for CO and O_3 has been calculated for running 8-hr averages. This will give 23 AQI values; here maximum and min AQI of CO and O_3 are presented. It can be seen that for most pollutants air quality is good/satisfactory. It is PM_{10} and $PM_{2.5}$ which suggest AQI to be in severe category.

Anand Vihar

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
10-Nov-13	88	113	13	32	69	5	23	438	992	992
11-Nov-13	92	121	13	41	67	4	17	444	1158	1158
12-Nov-13	92	151	14	60	62	4	23	578	1559	1559
13-Nov-13	97	160	18	50	55	3	20	540	1442	1442
14-Nov-13	101	143	12	47	45	2	30	530	1765	1765

Responsible Parameter PM_{10}

RK Puram

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
10-Nov-13	47	80	0	55	100	6	20	377	300	377
11-Nov-13	52	85	0	69	129	6	22	314	310	314
12-Nov-13	51	107	1	92	111	9	25	388	462	462
13-Nov-13	47	110	9	103	111	7	25	388	424	424
14-Nov-13	52	114	9	98	110	9	66	370	443	443

Responsible Parameter PM_{10}

Panjabi Bagh

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
10-Nov-13	41	96	13	64	67	12	12	371	294	371
11-Nov-13	52	105	22	68	76	9	15	320	272	320
12-Nov-13	44	114	15	76	93	11	12	384	390	390
13-Nov-13	43	114	9	79	91	13	15	407	406	407
14-Nov-13	37	110	11	68	90	10	13	335	306	335

Responsible Parameter $PM_{2.5}$

MandirMarg

Day	Sub-index									AQI
	CO (min)	CO (max)	O_3 (min)	O_3 (max)	NO_2	NH_3	SO_2	$PM_{2.5}$	PM_{10}	
10-Nov-13	83	112	5	136	95	14	20	397	307	397
11-Nov-13	88	114	6	128	109	13	23	352	269	352
12-Nov-13	97	122	7	167	140	13	20	389	361	389
13-Nov-13	101	131	8	171	139	13	28	438	340	438
14-Nov-13	98	122	7	148	124	11	22	326	294	326

Responsible Parameter $PM_{2.5}$

From the above interpretaion of air Quality index for Delhi responsible parameter for pollution is PM_{10} and $PM_{2.5}$. In Monsoon the responsible parameter for pollution in Anand Vihar and Panjabi Baag is PM_{10} with moderate pollution, R K Puram and Mandir Marg with $PM_{2.5}$ responsible parameter is satisfactory or moderate polluted. In winters Anand Vihar and R K Puram has very severe PM_{10} index, whereas Panjabi Baag and Mandir Marg hasvery severe $PM_{2.5}$ index.

AQI of Kanpur (manual stations)

It has been observed from AQI results of Delhi that responsible pollutant is PM_{10}/$PM_{2.5}$. Since manual stations measure PM_{10}, it is suggested that for manual station AQI for past days can be calculated as long as PM_{10} or $PM_{2.5}$ is measured. It is proposed that for manual station, AQI is reported for at least three parameters and one of them should be PM_{10} or $PM_{2.5}$ possibly on a week basis.

July AQI

RamaDevi

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
10-Jul-13	35	3	75	75
11-Jul-13	10	3	58	58
19-Jul-13	7	4	60	60
20-Jul-13	7	3	194	194
22-Jul-13	18	4	163	163

Responsible Parameter PM_{10}

DadaNagar

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
12-Jul-13	18	3	87	87
13-Jul-13	17	7	98	98
15-Jul-13	23	5	79	79
16-Jul-13	37	3	105	105
24-Jul-13	15	4	80	80

Responsible Parameter PM_{10}

IIT Kanpur

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
8-Jul-13	8	3	60	60
9-Jul-13	14	3	42	42
17-Jul-13	14	3	45	45
18-Jul-13	11	6	72	72
26-Jul-13	6	3	82	82

Responsible Parameter PM_{10}

November AQI

RamaDevi

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
3-Nov-13	53	3	607	607
4-Nov-13	64	3	411	411
5-Nov-13	45	3	339	339
13-Nov-13	84	3	487	487
14-Nov-13	96	3	417	417

Responsible Parameter PM_{10}

DadaNagar

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
16-Nov-13	72	3	412	412
18-Nov-13	79	8	439	439
19-Nov-13	94	5	446	446
27-Nov-13	66	3	296	296
28-Nov-13	67	3	530	530

Responsible Parameter PM_{10}

IIT Kanpur

Day	Sub-index			AQI
	NO_2	SO_2	PM_{10}	
11-Nov-13	6	3	296	296
12-Nov-13	17	3	184	184
20-Nov-13	21	3	226	226
21-Nov-13	30	3	245	245
29-Nov-13	17	3	216	216

Responsible Parameter PM_{10}

From the above interpretaion of AQI for Kanpur,the responsible parameter for pollution is PM_{10}. In monsoon, Rama Devi and Dada Nagar are *moderate* while IIT Kanpur has satisfactory PM_{10} index. In winters, Rama Devi has very severe PM_{10} index, Dada Nagar has very poor and severe PM_{10} index and IIT Kanpur is poor and moderate.

3.6 Web-based AQI Dissemination

The AQI system should have web-based AQI dissemination which should be designed for online calculation and display of nation-wide AQI. The website should render a quick, simple and an elegant looking response to an AQI query. The other features of the website should include reporting of pollutant responsible for index, pollutants exceeding the standards and health effects.

The AQI query is answered by navigating on map and clicking on the air quality station which renders AQI at that station with sub-indices (Figure 3.5). In addition, website can also render menu-based AQI by searching through states and cities (Figure 3.6) from dropdown menu.

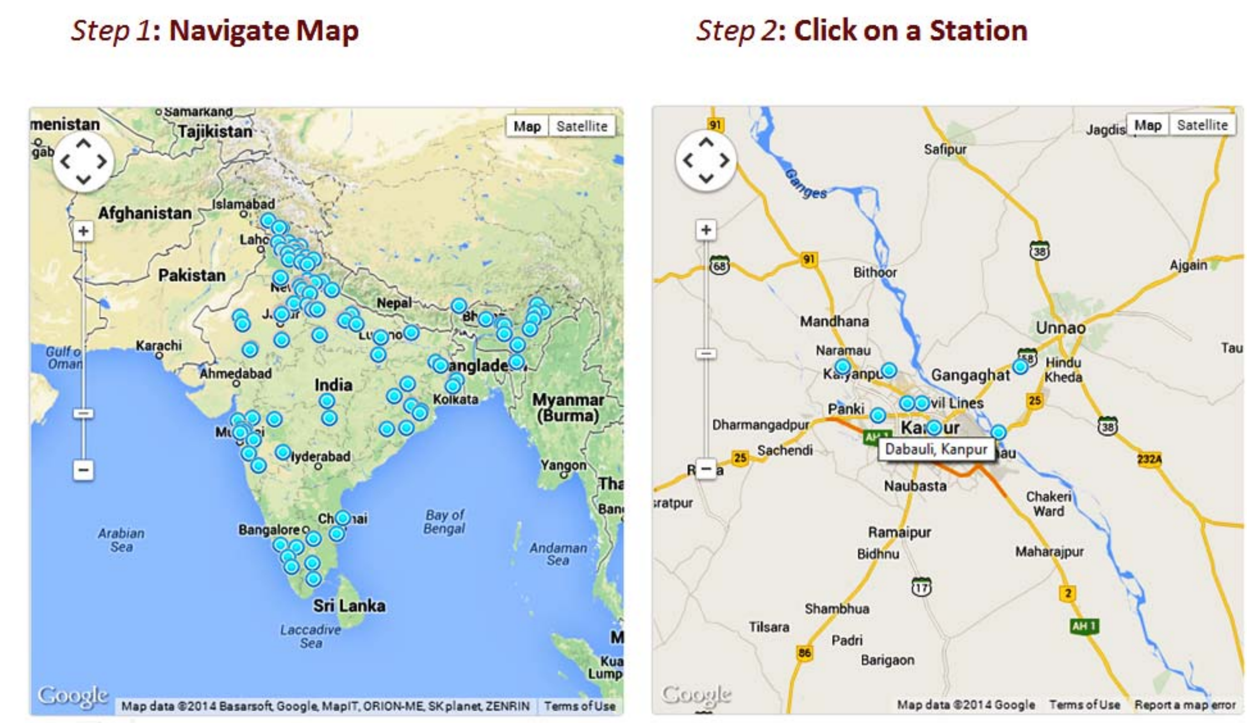


Figure 3.5 Web-based AQI Query: Reporting and Display

As a second part of the functionality, the website can also render menu-based AQI query by searching through states and cities (Figure 3.6)

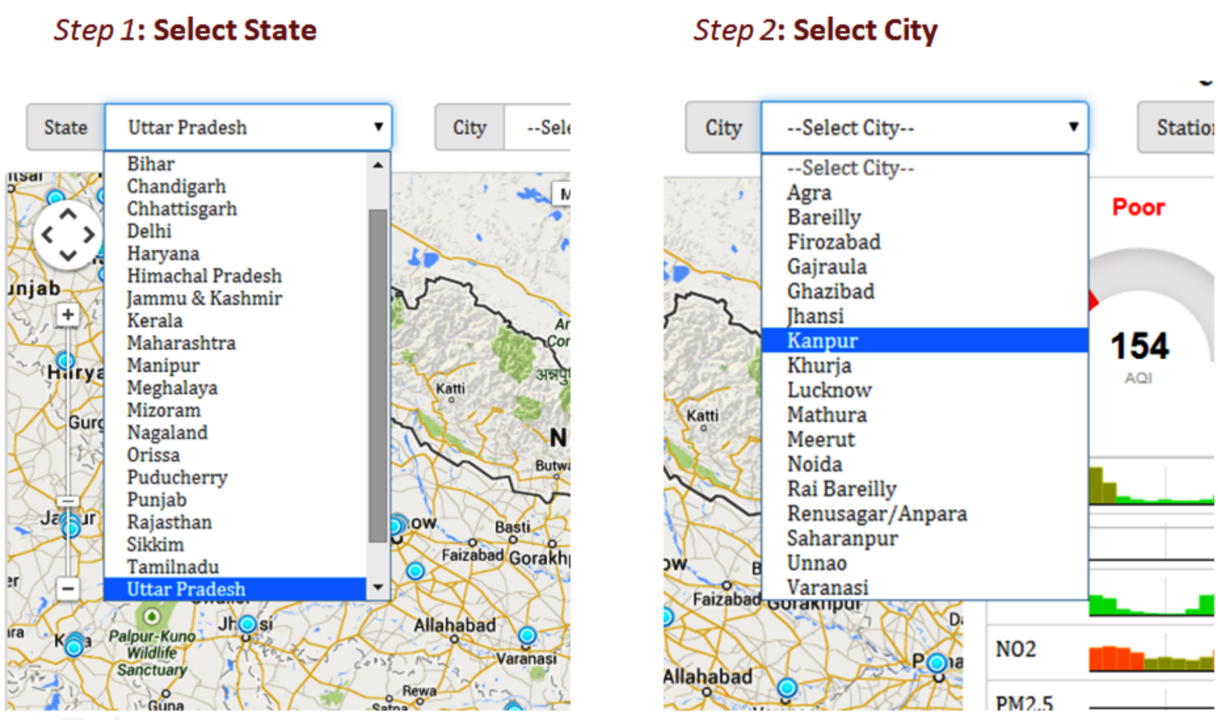


Figure 3.6 Menu-based AQI Query and display

It is expected and desired that informed citizens demand for better air quality. Under such a situation, city administration (municipal and local authority) should be asked to prepare a time-bound air pollution control plan and enforce it.

3.7 AQI Calculation Using Spreadsheet XL

AQI for a particular day and at a desired location can be calculated using the MS Excel (Figure 3.7), wherein a user friendly evaluation of AQI has been developed. The user needs to input at least three values of pollutant concentration (including at least one of PM_{10} or $PM_{2.5}$) in the blue cells and the sub-indices are calculated thus displaying the final AQI along with the colour signifying the AQI category. The health impacts corresponding to the AQI category are detailed in the legend at the bottom of the sheet. This XL program can be obtained from CPCB.

Overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either PM2.5 or PM10. Else, data are considered insufficient for calculating AQI. Similarly, a minimum of 16 hours' data is considered necessary for calculating subindex.

Calculation of AQI

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

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

Air Quality Index

AQI = **97**

* Concentrations of minimum three pollutants are required; one of them should be PM10 or PM2.5

* The check displays "1" when a non-zero value is entered

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

Figure 3.7 Spreadsheet for AQI calculation

3.8 AQI-Based Ranking of Cities

The following is an outline of the procedures that can be used for ranking the cities:

(i) Collect air quality data for all eight or minimum three pollutants for averaging time period as specified in INAQS.

(ii) AQI-based Ranking should be carried out for cities with population 1 million or larger.

(iii) Ranking should be done every six month on July 1st and January 1st.

(iv) Determine the area and corresponding population of the domain (2km x 2km) in which monitoring is being carried out in the city.

(v) For ranking purpose, both online monitoring and manual monitoring sites should be accounted.

(vi) AQ data from minimum of three stations should be available in the city.

(vii) Calculate the sub-index value for each pollutant and instead of reporting the AQI value at a given time-period in terms of the highest (as done in basic AQI computation), average the AQI's of all available pollutants (minimum of three) for a particular site $(\sum AQI_i/n)_m$ where i equals number of pollutants (i.e. n should be minimum 3) and m is the number of sites (should be minimum 3) in the city.

(viii) Now, the average AQI's of each site in the city are weighed with their designated population (of the grid 2km x 2km surrounding the site, p_m is fractional population of the grid of the site) to get Ranked AQI.

$AQI_R = [p1*(\sum AQI_i/n)_1 + p2*(\sum AQI_i/n)_2 + \ldots\ldots + pm*(\sum AQI_i/n)_m]/m$

The expert committee was of the view that population data may not be easily available and to maintain simplicity in calculation, the AQI_R can be calculated as:

$AQI_R = [(\sum AQI_i/n)_1 + (\sum AQI_i/n)_2 + \ldots\ldots + (\sum AQI_i/n)_m]/m$

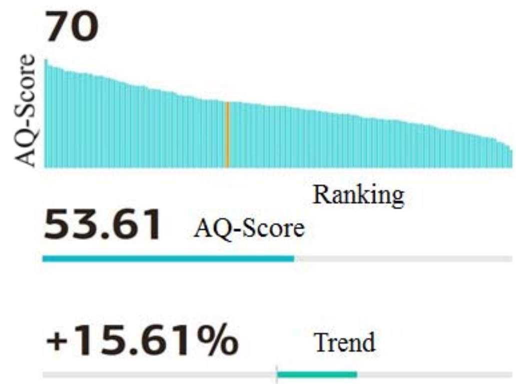
(ix) Recall that AQI is negative number (higher AQI higher pollution. Generate an AQ (or called Healthy) score for each city by the formulation:

AQ (or called Healthy) Score= 500- AQI_R (if < 0 then Score = 0)

(x) This score also varies between 0-500. IF Score is 0 it is the worst air quality and if score is 500 it is the best air quality. So, the city with Maximum 'AQ (Healthy) Score' will be ranked highest (Rank 1) and so on.

The AQI-based ranking can be presentation in an elegant manner as shown below in figures.

Sub-index



AQI-based Score, Ranking and Trend

It is proposed that to maintain uniformity in the ranking procedure, cities having minimum of five air quality monitoring stations and measuring all eight parameters are considered for ranking.

3.9 Conclusions and Protocols

The revised air quality standards (CPCB, 2009) necessitate that the concept of AQI in India is examined afresh. An AQI system based on maximum operator function (selecting the maximum of sub-indices of various pollutants as overall AQI) is adopted. Ideally, eight parameters (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) having short-term standards should be considered for near real-time dissemination of AQI. It is recognized that air concentrations of Pb are not known in real-time and cannot contribute to AQI. However, its consideration in AQI calculation of past days will help in scrutinizing the status of this important toxic.

The index has six categories and the colour schemes shown below.

Good (0-50)	Satisfactory (51-100)	Moderate(101-200)	Poor (201-300)	Very poor (301-400)	Severe (> 401)

A scientific basis in terms of attainment of air quality standards and dose-response relationships of various parameters have been derived and used in arriving at breakpoint concentrations for each AQI category (Table 3.11).

It is proposed that for continuous air quality stations, AQI is reported in near real-time for as many parameters as possible. For manual stations, the daily AQI is reported with a lag of one week to ensure manual data are scrutinized and available for AQI.

A web-based AQI dissemination system is developed for quick, simple and an elegant looking response to an AQI query. The other features of the website include reporting of pollutants responsible for index, pollutants exceeding the standards and health effects

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Appendix-I

केन्द्रीय प्रदूषण नियंत्रण बोर्ड
CENTRAL POLLUTION CONTROL BOARD
(पर्यावरण एवं वन मंत्रालय, भारत सरकार)
(MINISTRY OF ENVIRONMENT & FORESTS, GOVT. OF INDIA)

OFFICE ORDER

B-33014/30/PCI-II/2013 11815 March 12, 2014

Subject: Constitution of an Expert Group on Development of Uniform Air Quality Index for Indian cities

Central Pollution Control Board has decided to develop a uniform National Air Quality Index (AQI) for Indian cities and towns. AQI is intended for disseminating information in public domain about overall quality of ambient air and associated health risks, and for ranking of cities based on air quality status. For the purpose, a study has been commissioned and awarded to Indian Institute of Technology, Kanpur (IITK). Inputs of air quality professionals, health experts and other stakeholders are important for evolving an appropriate AQI. In view of this, an Expert Group comprising following is constituted:

1. Dr. A. K. Agarwal, Dean, Maulana Azad Medical College (MAMC) – Chairman
2. Dr. G. C. Khilnani, Professor, Pulmonary Medicine, AIIMS, New Delhi
3. Dr. T. K. Joshi, Member Secretary, Indraprastha Vyasayik Prayavaran Swasthya Samiti, MAMC
4. Dr. Kalpana Balakrishnan, Sri Ramachandra Medical College & Research Institute, Chennai
5. Dr. Rashid Hasan, Adviser, MoEF, New Delhi
6. Dr. B. Sengupta, Ex. Member Secretary, CPCB, Delhi
7. Prof Mukesh Khare, Department of Civil Engineering, IIT Delhi
8. Prof. A. L. Aggarwal, Ex. Deputy Director & Head Air Pollution Control Division, NEERI, New Delhi
9. Dr. S. D. Atri, Deputy Director General, IMD, New Delhi
10. Ms. Anumita Roy Choudhary, Executive Director, Center for Science and Environment, New Delhi
11. Dr. Sarath S. Gutikunda, Founder Director, UrbAirInfo, Goa
12. Member Secretary or representative, GPCB, Gujarat
13. Member Secretary or representative, APPCB, Hyderabad
14. Member Secretary or representative, WBPCB
15. Member Secretary or representative, DPCC, New Delhi
16. Member Secretary, CPCB
17. Dr. Prashant Gargava, Senior Environmental Engineer, CPCB, Member Convener

The Group will review the inputs from IITK study, and recommend a suitable AQI scheme that could be applied uniformly for Indian cities and towns. The Group will meet at least once in two months. The expenses towards organizing meetings including TA/DA and suitable honoraria to ex-officio members shall be met by IITK through the study grants provided by CPCB.

(A. B. Akolkar)
Member Secretary

To,

As per list

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