A Critical Review on Air Quality Index

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Abstract Air quality index (AQI) is used worldwide to inform the public about levels of air pollution (degradation or improvement) and associated to different biological effects. Different types of anthropogenic activity mainly transportation have an enormous impact on the ambient air quality in several ways. The transportation dependence continues to grow; it is adversely affecting the quality of human life. Due to pollution, the ambient air quality in major cities (Delhi, Agra, Kanpur, Lucknow, Varanasi, Faridabad, Ahmedabad, Chennai, Bangalore and Hyderabad) in India is very poor. According to WHO surveys, India is one of the most polluted countries in the world. Concentrations of air pollutants affect Air Quality Index. Air Quality scenario in most of the Indian cities presents a harsh picture, the majority of national monitoring stations have recorded particulate concentrations exceeding the WHO recommended guideline. The higher the AQI value, the greater the level of air pollution and greater the health concern. This review paper is helpful to understand the development of Air quality Index in India with the experience of the world.

Keywords Ambient air quality · Air quality index · Air pollution Transportation · Health effect

Introduction

Unpolluted air can be considered a basic requirement of human health and well-being. Today, air pollution is a well-known environmental problem associated with urban areas around the world (Beig 2010). Urban air pollution is the largest

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contributor to the regional burden of disease. There are a profound relation between human health and well-being from the one side and air pollution levels from another side. The high concentration of air pollutants can be life threatening causing breathing problems, headache, and dizziness; sometimes they even result in heart attacks (CPCB 2014).

Awareness of pollution levels is important not only to those who suffer from illnesses aggravated by air pollution but also to members of the general public, who, if conscious of daily variations in air pollution levels, may choose to alter their activities accordingly. In order to oppose air pollution problems and to plan abatement strategies, both the scientific community and the relevant authorities have focused on monitoring and analysing the atmospheric pollutants concentration. Various monitoring programmes have been undertaken to know the quality of air by generating the vast amount of data on the concentration of each air pollutant (e.g. SPM, CO, NO_x, SO_2, etc.) in different parts of the world (Pandey et al. 2014). The large data often do not convey the air quality status to the scientific community, government officials, policymakers and in particular to the general public in a simple and straightforward manner. So, in recent years air quality index (AQI) has become an adequate tool to understand pollution levels of an area and is of utmost importance for local and central governments (Ott and Thorn 1976). AQIs are synthetic indices summarizing multiple and multiscale measurements in a unique indicator, being air quality monitored with respect to many stations and different pollutants and inform the citizens about the levels of pollution in an adequate and understandable way and also to be used by the relevant authorities to take a series of predetermined measures to protect the health of the population (Air Quality Index 2003).

Objective

The main objective of the present study is to review for the daily Air Quality Index, which can provide the timely information to the public to take precautionary measures to protect their health (Kyrkilis et al. 2007)

Air Quality Index (AQI)

Air quality index (AQI) is an integral part of the environmental quality index (EQI), which was developed and used by National Wildlife Federation of U.S. in the late 1960s (Inhaber 1976). In 1971 the EQI, with a numerical index scale from 0 to 100 (0 for complete environmental degradation and 100 for perfect environmental conditions). In 1976, the USEPA established PSI which rated air quality from 0 to 500. The daily PSI is determined by the highest value of one of the five main air pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM10 and PM2.5) and sulphur dioxide (SO_2) (EPA 1999). Lohani (1984) applied factor analysis approach for finding the environmental index for Taiwan (Kumar and Goyal 2011).

Definition

An "air pollution index" may be defined as a scheme that transforms the (weighted) values of individual air pollution related parameters (for example, carbon monoxide concentration or visibility) into a single number, or set of numbers. In other words, an index is an equation which combines many pollutants in some mathematical expression to arrive at a single number for air quality (Bishoi et al. 2009). According to EPA Air Quality Index is defined as "the AQI is an index for reporting daily air quality. It tells how clean or polluted ambient air is, and what associated health effects might be a concern for you. The AQI focuses on health effects one may experience within a few hours or days after breathing polluted air" (Air Quality Index 2003) (Table 1).

Classification of Indices

There have been several Air Quality Indices proposed in the past. These indices are described in the following subsections.

Table 1 Pollutant concentration for each AQI category according to EPA

Category	Good	Moderate	Unhealthy for sensitive groups	Unhealthy	Very unhealthy	Hazardous	Severe
Index value	0–50	51–100	101–150	151–200	201–300	301–400	401–500
Pollutant	Conc. range	–	–	–	–	–	
CO 8 h (ppm)	0.0–4.5	4.5–9	9–12	12–15	15–30	30–40	40–50
NO_2	–	–	–	–	–	1.2–1.6	1.6–2.0
O_3 daily max (ppm)	–	–	–	–	0.20–0.40	0.40–0.50	0.50–0.60
O_3 8 h	0.00–0.06	0.06–0.08	0.08–0.10	0.10–0.12	0.12–0.37	–	–
PM 10 daily mean (ppm)	0–50	50–150	150–250	250–350	350–420	420–500	500–600
SO_2	0.0–0.03	0.03–0.14	0.14–0.22	0.22–0.3	0.3–0.6	0.6–0.8	0.8–1.0

US EPA Air Quality Index

Initially, the US EPA produced an Air Quality Index known as the Pollutant Standards Index (PSI) to measure pollutant concentrations for five criteria pollutants (particulate matter, sulphur dioxide, carbon monoxide, nitrogen dioxide and ground-level ozone). The measurements were converted to a scale of 0–500. An index value of 100 was ascribed to the numerical level of the short-term (i.e. averaging time of 24 h or less) primary NAAQS and a level of 500 to the significant harm levels (SHLs). An index value of 50, which is half the value of the short-term standard, was assigned to the annual standard or a concentration. Other index values were described as follows: 0–100, good; 101–200, unhealthy; greater than 200, very unhealthy. Use of the index was mandated in all metropolitan areas with a population in excess of 250,000. The EPA advocated calculation of the index value on a daily basis for each of the four criteria pollutants and the reporting of the highest value and identification of the pollutant responsible. Where two or more pollutants exceeded the level of 100, although the PSI value released was the one pertaining to the pollutant with the highest level, information on the other pollutants was also released. Levels above 100 could be associated with progressive preventive action by state or local officials involving issuance of health advisories for citizens or susceptible groups to limit their activities and for industries to cut back on emissions. At a PSI level of 400, the EPA deemed that "emergency" conditions would exist and that this would require cessation of most industrial and commercial activity. In July 1999, EPA issued its new "air quality index" (AQI) replacing the PSI. The principal differences between the two indices are that the new AQI does the following:

1. Incorporates revisions to the primary health-based national ambient air quality standards for ground-level ozone and particulate matter, issued by the EPA in 1977, incorporating separate values for particulate matter of 2.5 and 10.0 μg (PM2.5 and PM10), respectively.
2. Includes a new category in the index described as "unhealthy for sensitive groups" (index value of 101–150) and the addition of an optional cautionary statement, which can be used at the upper bounds of the "moderate" range of the 8-h ozone standard.
3. Incorporates colour symbols to represent different ranges of AQI values ("scaled" in the manner of colour topographical maps from green to maroon) that must be used if the index is reported in a colour format.
4. Includes mandatory requirements for the authorities to supply information to the public on the health effects that may be encountered at the various levels, including a requirement to report a pollutant-specific sensitive group statement when the index is above 100.
5. Mandates that the AQI shall be routinely collected and that state and local authorities shall be required to report it, for all metropolitan areas with more than 350,000 people (previously the threshold was urban areas with populations of more than 200,000).

6. Incorporates a new matrix of index values and cautionary statements for each pollutant.
7. Calculates the AQI using a method similar to that of the PSI—using concentration data obtained daily from “population-oriented State/Local Air Monitoring Stations (SLAMS)” for all pollutants except particulate matter (PM) (Ott and Thorn 1976).

The Mitre Air Quality Index (MAQI)

The Mitre air quality index (MAQI) was based on the 1970 Secondary Federal National Ambient Air Quality Standards. The index is the root sum square (RSS) value of individual pollutant indices, each based on one of the secondary air quality standard (Ott and Thorn 1976). This index is computed as follows:

$$\text{MAQI} = \left[I_S^2 + I_C^2 + I_P^2 + I_N^2 + I^2 o\right]^{0.5} \quad (1)$$

where I_S is an index of pollution for sulphur dioxide, I_c is an index of pollution for carbon monoxide, I_P is an index of pollution for total suspended particulates, In is an index of pollution for nitrogen dioxide and I_O is an index of pollution for photochemical oxidants.

Sulphur Dioxide Index (***I_S***): The sulphur dioxide index is the RSS value of individual terms corresponding to each of the secondary standards. The RSS value is used to ensure that the index value will be greater than 1 if one of the standard values is exceeded. The index is defined as

$$I_s = \left[(C_{\text{sa}}/S_{\text{sa}})^2 + K_1(C_{s24}/S_{s24}) + K^2(C_{s3}/S_{s3})^2\right] \quad (2)$$

where C_{sa} is the annual arithmetic mean observed concentration of sulphur dioxide, S_{sa} is the annual secondary standard value (i.e., 0.02 ppm or 60 μg/m^3) consistent with the unit of measure of C_{sa}, C_{s24} is the maximum observed 24-h concentration of sulphur dioxide, S_{s24} is the 24-h secondary standard value (i.e., 0.1 ppm or 260 μg/m^3) consistent with the unit of measure of C_{s24}, C_{s3} is the maximum observed 3-h concentration of sulphur dioxide, S_{s3} is the 3-h secondary standard value (i.e., 0.5 ppm or 1300 μg/m^3) consistent with the unit of measure of C_{s3}, K_1 is 1 if $C_{s24} \geq S_{s24}$ and is 0 otherwise and K_2 is 1 if $C_{s3} \geq S_{s3}$ and is 0 otherwise.

Carbon Monoxide Index (***I_c***): The carbon monoxide index component of the MAQI is computed in a fashion similar to the sulphur dioxide index:

$$I_c = \left[(C_{c8}/S_{c8})^2 + K(C_{c1}/S_{c1})^2\right]^{0.5} \quad (3)$$

where C_{c8} is the maximum observed 8-h concentration of carbon monoxide, S_{c8} is the 8-h secondary standard value (i.e. 9 ppm or 10,000 μg/m^3) consistent with the unit of measure of C_{c8}, C_{c1} is the maximum observed 1-h concentration of carbon monoxide, S_{c1} is the 1-h secondary standard value (i.e. 35 ppm or 40,000 μg/m^3) consistent with the unit of measure of C_{c1}, and K is 1 if $C_{c1} \geq S_{c1}$ and is 0 otherwise.

Total Suspended Particulates Index (***I_P***): Total suspended particulate concentrations are always measured in micrograms per cubic metre. The index of total suspended particulates is computed as

$$I_p = \left[\left(C_{\text{pa}}/S_{\text{pa}} \right)^2 + K \left(C_{p24}/S_{p24} \right)^2 \right]^{0.5} \tag{4}$$

where C_{pa} is the annual geometric mean observed concentration of total suspended particulate matter. The geometric mean is defined as

$$g = \left[\prod_{i=1}^{n} X_i \right]^{1/n} \tag{4a}$$

Because of the nature of a geometric mean, a single 24-h reading of 0 would result in an annual geometric mean of 0. The EPA recommends that one-half of the measurement method's minimum detectable value be substituted (in this case, 0.5 μg/m^3) when a "zero" value occurs. The S_{pa} is the annual secondary standard value (i.e., 60 μg/m^3), C_{p24} is the maximum observed 24-h concentration of total suspended particulate matter, S_{p24} is the 24-h secondary standard value (i.e., 150 μg/m^3) and K is 1 if $C_{p24} \geq S_{p24}$ and is 0 otherwise. Nitrogen Dioxide Index (In): The index of nitrogen dioxide does not require the RSS technique because only a single annual federal standard has been promulgated. The index is

$$I_n = C_{na}/S_{na} \tag{5}$$

where C_{na} is the annual arithmetic mean observed in the concentration of nitrogen dioxide and S_{na} is the annual secondary standard value (i.e., 0.05 ppm or 100 μg/m^3) consistent with the unit of measure of C_{na}.

Photochemical Oxidants Index (***I_o***): The index is computed in a manner similar to the nitrogen dioxide index. A single standard value is used as the basis of the index, which is

$$I_o = [C_{01}/S_{01}] \tag{6}$$

where C_{01} is the maximum observed the 1-h concentration of photochemical oxidants and S_{01} is the 1-h secondary standard value (i.e., 0.08 ppm or 160 μg/m^3) consistent with the unit of measure of C_{01}.

Application of the MAQI

An MAQI value of less than 1 indicates that all standards are being met for those pollutants in the MAQI computations. Because nine standards for five pollutants are involved in computing MAQI, any MAQI value greater than 3 guarantees that at least one standard value has been exceeded. If the MAQI values to be estimated by Eq. (1) are based on only five standards for three pollutants, then, for these figures, any MAQI value greater than 2.24 guarantees that at least one standard has been exceeded (Wang et al. 2005).

Extreme Value Index (EVI)

The extreme value index (EVI) was developed by Mitre Corporation for use in conjunction with the MAQI values. It is an accumulation of the ratio of the extreme values for each pollutant. The EVIs for individual pollutants are combined using the RSS method. Only those pollutants are included for which secondary "maximum values not to be exceeded more than once per year" are defined. The EVI is given by

$$EVI = [E_c^2 + E_s^2 + E_p^2 + E_o^2]^{0.5} \tag{7}$$

where E_c is an extreme value index for carbon monoxide, E_s is an extreme value index for sulphur dioxide, E_p is an extreme value index for total suspended particulates and E_o is an extreme value index for photochemical oxidants.

Carbon Monoxide Extreme Value Index (***E_c***): The carbon monoxide extreme value is the RSS of the accumulated extreme values divided by the secondary standard values. The index is defined as

$$E_c = [(A_{c8}/S_{c8})^2 + (A_{c1}/S_{c1})^2]^{0.5} \tag{8}$$

where A_{c8} is the accumulation of values of those observed 8-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{c8} = \sum_i K_i (C_{c8})_i \tag{8a}$$

where K_i is 1 if $(C_{c8})\ i \geq S_{c8}$ and is 0 otherwise, S_{c8} is the 8-h secondary standard value (i.e., 9 ppm or 10,000 μg/m^3) consistent with the unit of measure of the $(C_{c8})_i$ values, A_{c1} is the accumulation of values of those observed 1-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{c1} = \sum_i K_i (C_{c1})_i \quad (8b)$$

where K_i is 1 if $(C_{c1})_i \geq S_{c1}$ and is 0 otherwise, and S_{c1} is 1-h secondary standard value (i.e. 35 ppm or 40,000 μg/m^3) consistent with the unit of measure of the $(C_{c1})_{\mathrm{i}}$ values.

Sulphur Dioxide Extreme Value Index **(E_s)**: The sulphur dioxide extreme value is computed in the same manner as the carbon monoxide EVI. This index also includes two terms, one for each of the secondary standards, which are maximum values, and to be expected more than once per year. It should be noted that no term is included for the annual standard. The index is computed as

$$\mathrm{E_s} = \left[(\mathrm{A_{s24}} / \mathrm{S_{s24}})^2 + \mathrm{A_{s3}} / \mathrm{S_{s3}})^2 \right]^{0.5} \quad (9)$$

where A_{s24} is the accumulation of those observed 24-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{s24} = \sum_i K_i (C_{s24})_i \quad (9a)$$

where K_i is 1 if $(C_{s24})_i \geq S_{s24}$ and is 0 otherwise, S_{s24} is the 24-h secondary standard value (i.e., 0.1 ppm or 260 mg/m^3) consistent with the unit of measure of the $(C_{s24})_i$ values, A_{s3} is the accumulation of values of those observed 3-h concentration that exceed the secondary standard and is expressed mathematically as

$$A_{s3} = \sum\nolimits_i K_i (C_s)_i \quad (9b)$$

where K_i is 1 if $(C_{s3})_i \geq S_{s3}$ and is 0 otherwise, and S_{s3} is the 3-h secondary standard value (i.e., 0.1 ppm or 260 μg/m^3) consistent with the unit of measure of the $(C_{s3})I$ values.

Total Suspended Particulates Extreme Value Index **(E_p)**: A secondary standard single maximum value not to be exceeded more than once per year is defined for total suspended particulates. The total suspended particulates EVI has only one term; no annual term is included. This index is computed as

$$E_p = A_{p24} / S_{p24} \quad (10)$$

where A_{p24} is the accumulation of those observed 24-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{p24} = \sum_i K_i (C_{p24})_i \quad (10b)$$

where K_i is 1 if $(C_{p24}) \geq S_{p24}$ and is 0 otherwise, and S_{p24} is the 24-h secondary standard value (i.e., 150 μg/m^3).

Photochemical Oxidants Extreme Value Index (E_o): The index, like the total suspended particulates index, consists of a single term. The index is calculated as

$$E_o = A_{o1}/S_{o1} \tag{11}$$

where A_{o1} is the accumulation of those observed 1-h concentrations that exceed the secondary standard and is expressed mathematically as

$$A_{o1} = \sum_i K_i (C_{o1})_i \tag{11a}$$

where K_i is 1 if $(C_{o1})_i \geq S_{o1}$ and is 0 otherwise, and So 1 is the 1-h secondary standard value (i.e., 0.08 ppm or 160 μg/m^3) consistent with the unit of measure of the $(C_{o1})_i$ values.

Application of the EVI

The number or percentage of extreme values provides a meaningful measure of the ambient air quality because extreme high air pollution values are mostly related to personal comfort and well-being and affect plants, animals and property. The EVI and its component indices always indicate that all standards are not being attained if the index values are greater than 0. The index value will always be at least 1 if any standards based on a "maximum value not to be exceeded more than once per year" is surpassed. It should be noted that the index truly depicts the ambient air quality only if observations are made for all periods of interest (i.e. 1-h, 3-h, 8-h, and 24-h) during the year for which secondary standards are defined. Trend analyses using EVI values based on differing numbers of observations may be inadequate and even misleading.

Oak Ridge Air Quality Index (ORAQI)

The Oak Ridge Air Quality Index (ORAQI), which was designed for use with all major pollutants recognized by the EPA, was based on the following formula:

$$ORAQI = \left[COEF \sum_{i=1}^{3} ((Concentration\ of\ Pollutanti)/(EPA\ Standard\ for\ pollutanti))\right]^{0.967} \tag{12}$$

COEF equals 39.02 when $n = 3$, and equals 23.4 when $n = 5$. The concentration of the pollutants was based on the annual mean as measured by the EPA National Air Sampling Network (NASN). These are the same data on which the MAQI was based. The EPA standards used in the calculation were the EPA secondary standards normalized to a 24-h average basis. For SO_2, the standard used was 0.10 ppm; for NO_2, it was 0.20 ppm; and for particulates, it was 150–160 μg/m^3.

Application of the ORAQI

The coefficient and exponent values in the ORAQI formula mathematically adjust the ORAQI value so that a value of 10 describes the condition of naturally occurring unpolluted air. A value of 100 is the equivalent of all pollutant concentrations reaching the federally established standards.

Air Quality Depreciation Index

The air quality depreciation index, as proposed here, attempts to measure deterioration in air quality on an arbitrary scale that ranges between 0 and −10. An index value of '0' represents most desirable air quality having no depreciation from the best possible air quality with respect to the pollutants under consideration, while an index value of −10 represents maximum depreciation or worst air quality. Index value differing from 0 towards 10 represents successive depreciation in air quality from the most desirable.

The air quality depreciation index is defined as:

$$AQ_{dep} = \sum_{i=1}^{n} (AQ_i \times CW_{\mathrm{i}}) - \sum_{i=1}^{n} CW_i \tag{13}$$

where AQ_i = Air Quality Index value for ith parameter, CW_i = Composite weight for ith parameter, n = Total no. of pollutants considered.

The values of the AQ_i were obtained from the value function curves. In the value function curves, the value of 0 signifies worst air quality and value of 1 represents the best air quality for corresponding pollutant concentration.

Value of CW_i in Eq. (13) is computed using the following expression:

$$CW_i = \frac{TW_i}{\sum_{i=1}^{n} TW_i} \times 10 \tag{14}$$

where

TW_i Total weight of ith parameter	AWi + $BPIW_i$ + HW_i
AW_i	Aesthetic weight for ith parameter
$BPIW_i$	Bio-physical impact weight for ith parameter
HW_i	Health weight for ith parameter

Air Quality Index Worldwide

Air Quality Index China

China has been monitoring the ambient atmosphere since the 1980s. Beginning in 1998, the Chinese government began to report the weekly air pollution index (API) by considering the total suspended particle (TSP), nitrogen oxide and sulphur dioxide concentration. Beginning in June 2000, major cities in China began to report daily API with daily measurements of PM10, nitrogen dioxide, and sulphur dioxide under the request of former State Environmental Protection Agency of China (now the Ministry of Environmental Protection of China) (Wang et al. 2013). A national ambient air quality standard of China was released in 1996 (NAAQS-1996) to define API calculation. The API (Air Pollution Index) is an index that indicates the pollution level of the atmosphere, ranging from 0 to 500. The higher the API value, the heavier the atmospheric pollution. According to NAAQS-1996, PM10, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) were included in the calculation of the API. The first step in calculating the API is to calculate the IAPI (Individual Air Pollution Index) for each pollutant. The IAPI of each pollutant mentioned above is calculated as follows:

$$\mathrm{IAPI}_p = \frac{\mathrm{IAPI_{Hi}} - \mathrm{IAPI_{Lo}}}{\mathrm{BP_{Hi}} - \mathrm{BP_{Lo}}}(C_P - \mathrm{B}P_{Lo}) + \mathrm{IAPI}_{Lo} \tag{15}$$

where IAPI_P is the individual air pollution index for pollutant *P* (PM10, sulphur dioxide, and nitrogen dioxide) and C_P is daily mean concentration of pollutant *P*. $\mathrm{BP_{Hi}}$ and $\mathrm{BP_{Lo}}$ are the nearby high and low values of CP. $\mathrm{IAPI_{Hi}}$ and $\mathrm{IAPI_{Lo}}$ are the individual air pollution indexes in terms of $\mathrm{BP_{Hi}}$ and $\mathrm{BP_{Lo}}$. After the calculation of each IAPI_P, the API is then calculated by choosing the max IAPI_P as follows:

$$\mathrm{API} = \max(\mathrm{IAPI}_1; \ldots; \mathrm{IAPI}_n) \tag{16}$$

This equation suggests that the API is not the sum contribution of all of the air pollutants but rather the maximum value of the IAPI. The air pollutant with a maximum IAPI when the API is larger than 50 is designated as the primary pollutant. according to NAAQS-2012, 6 pollutants (PM2.5, PM10, Ozone, SO_2, NO_2 and CO) with 7 indexes (daily average PM2.5 concentration, daily average PM10 concentration, daily maximum 1-h Ozone concentration, maximum 8-h Ozone concentration, daily average SO_2 concentration, daily average NO_2 concentration and daily average CO concentration) are included in the new standard. The calculation of AQI replacing API is similar to that of API except that there are 7 individual AQI for each pollutant as follows:

$$IAQI = \frac{IAQI_{Hi} - IAQI_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{Lo}) + IAQI_{Lo} \quad (17)$$

where $IAQI_{Hi}$ and IAQ I_{Lo} are the individual air pollution indices in terms of BP_{Hi} and BP_{Lo}, respectively.

The daily API or AQI not exceeding 100 is considered to represent an attainment day. The number of attainment days in a year or the attainment rate is a key index to evaluate the air quality of a city. The attainment rate is the rate during the monitoring days when the API or AQI does not exceed 100 as follows (Tables 2, 3, 4 and 5).

Table 2 Concentration limits for AQI calculation

IAQI	PM 10 (μg/m^3)	SO_2 (μg/m^3)	PM 2.5 (μg/m^3)	NO_2 (μg/m^3)	1 h peak O_3 (μg/m^3)	8 h peak O_3 (μg/m^3)	CO (mg/m^3)
50	50	50	35	40	160	100	2
100	150	150	75	80	200	160	4
150	250	475	115	180	300	215	14
200	350	800	150	280	400	265	24
300	420	1600	250	565	800	800	36
400	500	2100	350	750	1000	–	48
500	600	620	500	940	1200	–	60

Source Chen et al. (2016)
*When 1 h average concentration of O_3 is higher than 800 μg/m^3, the 1 h average concentration of O_3 is used to calculate individual AQI or O_3 here
Attainment Rate = Sum of Attainment Days/Sum of Total Monitoring Day

Table 3 Each pollutants rate as the primary pollutant for all 190 cities with AQI data

Area	PM 2.5	PM 10	O_3	SO_2	NO_2	CO
National average	59.16	38.86	0.49	0	1.48	0.01
North China	60.36	37.27	0.20	0	0.28	0.01
South China	63.81	35.15	0.74	0	0.28	0.01
North-east China	52.64	41.26	0.03	0	6.04	0.03
North-west China	36.64	60.36	0.23	0	2.77	0

Source Chen et al. (2016); On the basis of above data

Table 4 10 cities with worst air quality

S. No.	City	Average AQI	Part of China
1	Xingtai	245	Hebei Province, North China
2	Shijiazhuang	229	Hebei Province, North China
3	Baoding	206	Hebei Province, North China
4	Korla	191	Xingjiang Province, North-west China
5	Handan	189	Hebei Province, North China
6	Hengshui	181	Hebei Province, North China
7	Yichang	172	Hubei Province, South China
8	Heze	167	Shandong Province, North China
9	Dezhou	165	Shandong Province, North China
10	Langfang	163	Hebei Province, North China

Source Chen et al. (2016)

Table 5 10 cities with best air quality

S. No.	City	Average AQI	Location
1	Sanya	41	Hainan Province, South China
2	Zhanjiang	50	Guangdong Province, South China
3	Zhoushan	52	Zhejing Province, South China
4	Shenzhen	59	Guangdong Province, South China
5	Lasa	60	Tibet, North-west China
6	Xiamen	61	Fujian Province, South China
7	Zhuhai	61	Guangdong Province, South China
8	Shanwei	63	Guangdong Province, South China
9	Yunfu	63	Guangdong Province, South China
10	Fuzhou	64	Fujian Province, South China

Source Chen et al. (2016)

Air Quality Index United States

Air quality index (AQI) is built adapting the Pollutants Standard Index developed by the United States Environmental Protection Agency, 1994. AQI is calculated for each pollutant as:

$$I_i = \frac{C_i}{S_i} \times 100 \qquad (18)$$

where i, is the pollutant; C_i is the hourly concentration for nitrogen dioxide, carbon monoxide and ozone, while it is the 24-h carried mobile average for sulphur dioxide and particulate matter; S_i is the value for the attention state. The index 'I' is equal to 100 when the concentration measured or the mobile mean over 24 h is equal to the attention state; an index lower than 100 means that the pollutant has a value lower than the attention state. After the different indexes, I_i have been calculated for every pollutant, we select the maximum index I between different indexes:

$$I\ max_i\ I_i$$

In this way, a characterization of the pollution level apart from the pollutant taken into account is obtained (Wang et al. 2005).

Air Quality Index India

NAAQS Dependent Air Quality Index

In this method, equal importance was given to all the pollutants. Using observed and standards value, the quality rating for each pollutant was calculated. The geometric mean of these quality ratings gives the Air Quality Index. Based on this assumption, the Air Quality Index was derived in the manner outlined as under. The existing concentrations of pollutants were compared with ambient air quality standards (with the standard being assumed as reference baseline for each pollutant) and accordingly the quality rating for a particular pollutant was derived as shown below:

$$Q_i = 10(C_i/S_i) \tag{19}$$

where

Q_i Quality rating for a ith pollutant
C_i Concentration of ith pollutant
S_i Air quality standard for ith pollutant

$$\text{Air Quality Index (AQI)} = (Q_1 \times Q_2 \times \cdots \times Q_n)^{1/n} \tag{20}$$

where

n Number of pollutants considered.

Following the above criteria, air quality index (AQI) is calculated for all the monitoring stations. Given below (Table 6) is the Air Quality Index of some Indian cities as recorded by World Health Organization.

Table 6 Indian cities and their AQI

S. No.	City	PM 10 (annual mean, μg/m^3)	PM 2.5 (annual mean, μg/m^3)	AQI
1	Agra	196	105	Extremely high
2	Ahmedabad	83	100	High
3	Allahabad	317	170	Extremely high
4	Amritsar	202	108	Extremely high
5	Bangalore	118	63	Very high
6	Bhopal	173	93	Extremely high
7	Bhubaneswar	81	43	High
8	Chennai	57	44	High
9	Dehradun	188	100	Extremely high
10	Delhi	29	122	Extremely high
11	Dhanbad	178	95	Extremely high
12	Guwahati	92	49	High
13	Gwalior	329	176	Extremely high
14	Hyderabad	79	59	High
15	Indore	143	76	Very high
16	Jaipur	187	100	Extremely high
17	Jalandhar	140	75	Very high
18	Jammu	119	64	Very high
19	Jodhpur	189	101	Extremely high
20	Kanpur	215	115	Extremely high
21	Kolkata	135	61	Extremely high
22	Lucknow	211	113	Extremely high
23	Mumbai	117	63	Very high
24	Nagpur	103	55	Very high
25	Noida	136	73	Very High
26	Patna	167	149	Extremely high
27	Pune	92	49	High

Source WHO

Conclusion

The concept of AQI in India is examined and found easy to understand. 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 (PM10, PM2.5, NO_x, 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 examining the status of this important toxic. The proposed index has six categories and the colour schemes as shown below.

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

A scientific basis, for severe >401, 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. It is proposed that for continuous air quality stations, AQI is reported in near real time for as many parameters as possible.

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