A Review on Air Quality Indexing System

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ABSTRACT

Air quality index (AQI) or air pollution index (API) is commonly used to report the level of severity of air pollution to public. A number of methods were developed in the past by various researchers/environmental agencies for determination of AQI or API but there is no universally accepted method exists, which is appropriate for all situations. Different method uses different aggregation function in calculating AQI or API and also considers different types and numbers of pollutants. The intended uses of AQI or API are to identify the poor air quality zones and public reporting for severity of exposure of poor air quality. Most of the AQI or API indices can be broadly classify as single pollutant index or multi-pollutant index with different aggregation method. Every indexing method has its own characteristic strengths and weaknesses that affect its suitability for particular applications. This paper attempt to present a review of all the major air quality indices developed worldwide.

Key words: Air pollution, Air quality index, Health, Environmental factors, Literature review

1. INTRODUCTION

Air pollution is global environmental problem that influences mostly health of urban population. Over the past few decades, epidemiological studies have demonstrated adverse health effects due to higher ambient levels of air pollution. Studies have indicated that repeated exposures to ambient air pollutants over a prolonged period of time increases the risk of being susceptible to air borne diseases such as cardiovascular disease, respiratory disease, and lung cancer (WHO, 2009). Air pollution has been consistently linked to substantial burdens of ill-health in developed and developing countries (Gorai *et al*., 2014; Bruce *et al*., 2000; Smith *et al*., 2000; WHO, 1999; Schwartz, 1994).

Globally, many cities continuously assess air quality using monitoring networks designed to measure and record air pollutant concentrations at several points deemed to represent exposure of the population to these pollutants. Current research indicates that guidelines of recommended pollution values cannot be regarded as threshold values below which a zero adverse response may be expected. Therefore, the simplistic comparison of observed values against guidelines may mislead unless suitably quantified. In recent years, air quality information are provided by governments to the public comes in a number of forms like annual reports, environment reviews, and site or subject specific analyses/report. These are generally having available or access to limited audiences and also require time, interest and necessary background to digest its contents. Presently, governments throughout the world have also started to use real-time access to sophisticated database management programs to provide their citizens with access to site-specific air quality index/air pollution index and its probable health consequences. Thus, a more sophisticated tool has been developed to communicate the health risk of ambient concentrations using air pollution index (API) or air quality index (AQI). The World Health Organization (WHO) estimates that 25% of all deaths in the developing world can be directly attributed to environmental factors (WHO, 2006). The problem of air pollution and its corresponding adverse health impacts have been aggravated due to increasing industrial and other developmental activities.

The monitoring concentrations of pre-determined air pollutants in the residential/commercial/industrial areas are used for the calculation of an air quality index (AQI) or air pollution index (API). The monitoring data are aggregated and converted into a single index with a variety of methods. This means that indexing systems and air pollution descriptors often differ from one country/region to another. The indicators of air quality give the public an opportunity to track the state of their local, regional and national air quality status without the need for an understanding of the details of the monitoring data upon which they are based. Since the sen-

sitivity of the people to expose of air pollution changes with changing in geographical location, quality of life etc., an universal technique to measure the air quality index is not very much helpful.

1. 1 Design Criteria for an Ideal Air Quality Index

The basic objective of any air quality index is to transform the measured concentrations of individual air pollutant into a single numerical index using suitable aggregation mechanism. Ideally, every index should reflect both the measured and publicly perceived quality of the ambient air for the time period it covers. As a result, air quality indices attempt to standardize and synthesize air pollution information and permit comparisons to be readily undertaken, and to satisfy public demands for accurate, easy to interpret data. In design of air quality indices, the following criteria should be used:

1. be readily understandable by the public;
2. include the major criteria pollutants and their synergisms;
3. be expandable for other pollutants and averaging times;
4. be related to National Ambient Air Quality standards used in individual provinces;
5. avoid "eclipsing" (eclipsing occurs when an air pollution index does not indicate poor air quality despite the fact that concentrations of one or more air pollutants may have reached unacceptably high values);
6. avoid "ambiguity" (ambiguity occurs when an air pollution index gives falls alarm despite the fact that concentrations of all the pollutants are within the permissible limit except one);
7. be usable as an alert system;
8. be based on valid air quality data obtained from monitoring stations that are situated so as to represent the general air quality in the community;

2. REVIEW OF AIR QUALITY INDICES (AQI)

The large databases often do not convey the air quality status to the scientific community, government officials, policy makers, and in particular to the general public in a simple and straightforward manner. This problem is addressed by determining the Air Quality Index (AQI) of a given area. AQI, which is also known as Air Pollution Index (API) (Murena, 2004; Ott and Thom, 1976; Thom and Ott, 1976; Shenfeld, 1970) or Pollutant Standards Index (PSI) (U.S. EPA, 1994; Ott and Hunt, 1976), was developed by various environ-

mental agencies/researchers for different country/regions. Though, there is a widespread use of air pollution (quality) index systems but currently no internationally accepted methodology for constructing such a system (Stieb et al., 2005; Maynard and Coster, 1999) are available. In this paper, an attempt has been done to demonstrate the critical review on different AQI systems.

In 1976, the U.S. EPA established a Pollutant Standards Index (PSI) which rated air quality. They suggested the formula for aggregating pollutants to determine PSI. The index ranged from 0-500, with 100 equal to the National Ambient Air Quality Standards (NAAQS). The PSI is calculated for every pollutant with a NAAQS, but the only level reported for a given time and location is for the pollutant most exceeding its standard. The daily PSI is determined by the highest value of one of the five main air pollutants: particulate material (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2). The PSI does not indicate exposure to many other pollutants, some of which may be dangerous for people with respiratory problems (Qian et al., 2004, Radojevic and Hassan, 1999). The PSI was revised, renamed to the Air Quality Index (AQI), and subsequently implemented in 1999 by the U.S. EPA.

2. 1 AQI System of U.S. EPA

U.S. EPA's AQI is defined with respect to the five main common pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$) and sulphur dioxide (SO_2). The individual pollutant index as in the eqn. (1) is calculated first by using the following linear interpolation equation, pollutant concentration data and reference concentration. The breakpoint concentrations have been defined by the EPA on the basis of National Ambient Air Quality Standards (NAAQS) as shown in Table 1, and on the results of epidemiological studies which refer to the effect of single pollutants on human health.

$$I_p = \frac{(I_{HI} - I_{LO})}{BP_{HI} - BP_{LO}} (C_P - BP_{LO}) + I_{LO} \qquad (1)$$

where

I_P = Index for pollutant P
C_P = Rounded concentration of pollutant P
BP_{HI} = Break point that is greater than or equal to C_P
BP_{LO} = Breakpoint that is less than or equal to C_P
I_{HI} = AQI value corresponding to BP_{HI}
I_{LO} = AQI value corresponding to BP_{LO}

The highest individual pollutant index, I_P, represents the Air Quality Index (AQI) of the location.

The above method does not have the flexibility to

Table 1. Breakpoint Concentration of air pollutants defined by U.S. EPA.

Breakpoints								
O_3 (ppm) 8-hour	O_3 (ppm) 8-hour[1]	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	AQI	Category
0-0.064	–	0-54	0-15.4	0-4.4	0-0.034	([2])	0-50	Good
0.065-0.084	–	55-154	15.5-40.4	4.5-9.4	0.035-0.144	([2])	51-100	Moderate
0.085-0.104	0.125-0.164	155-254	40.5-65.4	9.5-12.4	0.145-0.224	([2])	101-150	Unhealthy for sensitive groups
0.105-0.124	0.165-204	255-354	65.5-150.4	12.5-15.4	0.225-0.304	([2])	151-200	Unhealthy
0.125-0.374 (0.155-0.404)[4]	0.205-0.404	355-424	150.5-250.4	15.5-30.4	0.305-0.604	0.65-1.24	201-300	Very unhealthy
([3])	0.405-504	425-504	250.5-350.4	30.5-40.4	0.605-0.804	1.25-1.64	301-400	Hazardous
([3])	0.505-0.604	505-604	350.5-500.4	40.5-50.4	0.805-1.004	1.65-2.04	401-500	Hazardous

[1]Areas are required to report the AQI based on 8 hour ozone values. However, there are areas where an AQI based on 1-hour ozone values would be more protective. In these cases the index for both the 8-hour and the 1-hour ozone values may be calculated and the maximum AQI reported.
[2]NO_2 has no short term NAAQS and can generate an AQI only above a value of 200.
[3]8-hour O_3 values do not define higher AQI values (≥ 301). AQI values of 301 or higher are calculated with 1-hour O_3 concentration.
[4]The numbers in parentheses are associated 1 hour values to be used in this overlapping category only.

incorporate any number of air pollutants. The method also not considers the pollutant aggregation and spatial aggregation. It can be used for determining the short term and long term air quality indices.

Cheng *et al.* (2004) proposed a revised EPA air quality index (RAQI) by introducing an entropy function to include effect of the concentrations of the rest of pollutants other than the pollutant with maximum AQI. The revised Air Quality Index (RAQI) can be determined by eqn. (2) as given below:

$$RAQI = Max\ (I_1, I_2 \ldots I_n) \times \frac{Avg_{daily} \sum_{j=1}^{n} I_j}{Avg_{annual}\ [Avg_{daily} \sum_{j=1}^{n} I_j]}$$

$$\times \frac{Avg_{annual}\{Entropy_{daily} * Max[I_1, I_2, \ldots I_n]\}}{Entropy_{daily} * Max[I_1, I_2, \ldots I_n]} \quad (2)$$

The second term on RHS establishes the background arithmetic mean index in which the numerator is the sum of the daily arithmetic averages of all sub-indexes $(I_1 \ldots I_n)$, and the denominator is the yearly average of the sum of daily average for these pollutants.

The third term in RHS represents the background arithmetic mean entropy index in which the numerator is the yearly average of the average daily entropy, and the denominator is the entropy function of the sub-index pollutants.

The RAQI method facilitates for aggregation of pollutants sub-indices and also health based study but failed to measure uncertainty and spatial aggregation.

2. 2 Common Air Quality Index (CAQI)

The CAQI was developed by the Citeair project in 2008, which was co-funded by the INTERREG IIIC and INTERREG IVC programs in Europe. To present the air quality situation in European cities in a comparable and understandable way, all detailed measurements are transformed into a single relative figure called the Common Air Quality Index (CAQI). An important feature of this index system is that it differentiates between traffic and city background conditions. The Common Air Quality Index (CAQI) is designed to present and compare air quality in near-real time on an hourly or daily basis. It has 5 levels, using a scale from 0 (very low) to > 100 (very high) and the matching colours range from light green to dark red. The CAQI is computed according to the grid system (shown in Table 2) by linear interpolation between the class borders. The final index is the highest value of the sub-indices for each component (pollutant); nevertheless, the choice of the classes for the CAQI is inspired by the EC legislation. The CAQI do not take into account the adverse effects due to the coexistence of all the pollutants. The existing air quality indices were used by van den Elshout *et al.* in 2008 for air quality assessment in European cities. They compared all the existing method for identification of suitable alternative.

The above method can be applied to make comparative study of urban air quality in real time without facilitating or considering the spatial aggregation, pollutant aggregation, uncertainty measures and health

Table 2. Pollutants and calculation grid for the CAQI.

Index class	Grid	Traffic					City background						
		Mandatory pollutant			Auxiliary pollutant		Mandatory pollutant			Auxiliary pollutant			
		NO$_2$	PM$_{10}$		CO		NO$_2$	PM$_{10}$		O$_3$	CO	SO$_2$	
			1-hr	24-hrs				1-hr	24-hrs				
Very low	0 25	0 50	0 25	0 12	0 5000		0 50	0 25	0 12	0 60	0 5000	0 50	
Low	26 50	51 100	26 50	13 25	5001 7500		51 100	26 50	13 25	61 120	5001 7500	51 100	
Medium	51 75	101 200	51 90	26 50	7501 10000		101 200	51 90	26 50	121 180	7501 10000	101 300	
High	76 100	201 400	91 180	51 100	10001 20000		201 400	91 180	51 100	181 240	10001 20000	301 500	
Very high	>100	>400	>180	>100	>20000		>400	>180	>100	>240	>20000	>500	

NO$_2$, O$_3$, SO$_2$: hourly value/maximum hourly value in µg/m^3
CO: 8 hours moving average maximum 8 hours moving average in µg/m^3
PM$_{10}$: hourly value/daily value in µg/m^3

effects.

2. 3 Oak Ridge Air Quality Index (ORAQI)

The Oak Ridge Air Quality Index (ORAQI) method was developed by Oak Ridge National Laboratory. The Oak Ridge Air Quality Index is defined for any number of pollutants. Thom and Ott (1975) suggested the use of Oak Ridge Air Quality Index (ORAQI). The ORAQI is given by eqn. (3)

$$ORAQI = \left(a \sum \frac{C_i}{C_s} \right)^b \tag{3}$$

where,

C_i = Monitored/Predicted concentration of pollutant 'i'

C_s = National ambient air quality standard (NAAQS) for pollutant 'i'

a & b = constant for specific number of pollutants

The above method can be applied to assess the air quality in urban area without facilitating or considering the spatial aggregation, and uncertainty measures but considers pollutant aggregation and health effects.

2. 4 New Air Quality Index (NAQI)

New Air Quality Index is based on Factor Analysis of the major pollutants. The index is proposed by Bishoi et al. in 2009. The method is based on principal component factors which causes the variation of AQI. The concentration of each pollutant or there deviation from the mean or their standardized values are expressed as a linear combination of these factors. The fac-

tors contribute to about 60% of the variation of AQI are considered and the rest can be neglected (Dunteman, 1994; Johnston, 1978; Harman, 1968). Also, the first factor will cause the highest variance of AQI. The second will contribute less variance than first but more than the third factor and so on. These factors are also called the principal components or eigen vector pairs.

The New Air Quality Index (NAQI) is given by the equation as below in the eqn. (4)

$$NAQI = \{ \sum_{i=1}^{n} (P_i E_i) / \sum_{i=1}^{n} E_i \} \tag{4}$$

where n = 3, P_1, P_2, P_3 are the three Principal Components for which the cumulative variance is more than 60%. E_1, E_2 and E_3 are the initial eigen values (≥ 1) with respect to the percentage variance.

The principal components were given by Lohani (1984) in the eqn. (5)

$$P_i = \sum_{j=1}^{n} \frac{a_{ji} X_j}{\lambda_i} \tag{5}$$

where λ_i is the Eigen value associated with P_i

x_j is the concentration of ith pollutant and can be determined as:

$$X_j = \sum_{1}^{n} a_{ji} P_i$$

The method can be applied to assess the relative air quality without facilitating or considering the spatial aggregation, health effects and uncertainty measures but considers pollutant aggregation.

Table 3. Values, Index and Health Risks for PI.

Numeric value	Quality indicator	Numeric index	Health risks
0-50	Optimum	1	No risks for people
51-75	Good	2	No risks for people
76-100	Moderate	3	No risks for people
101-125	Mediocre	4	Generally there aren't risks for people. People with asthma, chronic bronchitis, croniche o cardiopathy may feel light respiratory symptoms only during an intense physical activity
126-150	Not Much Healthy	5	There risks for people with heart diseases, olds and children
151-175	Unhealthy	6	Many people may feel light adverse symptoms, however reversible. Weak people may feel gravest symptoms.
>175	Very Unhealthy	7	People may feel light adverse effects for health. There are more risks for olds, children and people with respiratory diseases.

2. 5 Pollution Index (PI)

Pollution index (PI) was developed and applied by Cannistraro, *et al*. in 2009 for reporting air quality status in the city of Naples, Italy. The pollution index method is based on a simple indicator of the air quality in an urban context that is useful for communicating to citizens' information about the state of air quality of a waste urban area. The calculation of the PI is based on the weighted mean value of the sub-indexes of the most critical pollutants. Additive effects of air pollutants have also been considered and the PI re-evaluated. It is expressed by a numerical index ranging from 1 to 7. A highest value of the index represents a highest value of environmental pollution, and, of course a highest health risk. This index of air quality has been developed by means of a series of critical pollutants in the Italian urban contexts and correlated with pollution level and health risk and level of satisfaction of the people. PI can be calculated with the arithmetic averages of sub-indices of two most critical pollutants. This is given by eqn. (6) as given below:

$$I = \frac{(I_1 + I_2)}{2} \tag{6}$$

The two sub-indices (I_1 and I_2) are calculated for the two most critical pollutants having the highest concentrations. The sub-indices of each pollutant can be determined by eqn. (7) as given below:

$$I_x = \frac{V_{max\,hx}}{V_{rif}} * 100 \tag{7}$$

where, I_x is the sub-index of xth pollutant

$V_{max\,hx}$ is the maximum 1 hour mean value of the xth pollutant in a day in all the monitoring stations of the area.

V_{rif} is maximum 1 hour limit value of the xth pollutant for protection of human health

The Pollution index classification, quality indicator, and its health risks are represented in Table 3.

The method considers the pollutant aggregation and health effects to determine the air quality index but not considers spatial aggregation and uncertainty issues.

2. 6 Air Quality Depreciation Index (AQDI)

AQDI was used by Singh in 2006 to measure the depreciation in air quality using the value function curves for individual pollutants. The method considers the pollutant aggregation to determine the depreciation in air quality with respect to standard air quality. The air quality depreciation is measured in a scale between 0 to -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. The shifting of Index value from 0 towards -10 represents successive depreciation in air quality from the most desirable. The AQDI is given as follows in the eqn. (8)

$$AQ_{dep} = \left\{ \sum_{i=1}^{n} (AQ_i * CW_i) \right\} - \left\{ \sum_{i=1}^{n} CW_i \right\} \tag{8}$$

where,

AQ_i = Air Quality Index for the ith parameter and obtained from value function curve defined by Jain *et al*. in 1977. In the value function curve 0 represent the worst quality and 1 represent the best quality of air due to pollutant under consideration.

CW_i is composite weight for i^{th} parameter.

n is the total no of pollutants considered.

Composite weight (CW_i) in eqn. (8) can be calculated using the following eqn. (9).

$$CW_i = \left\{ \frac{TW_i}{\sum_{i=1}^{n} TW_i} \right\} * 10 \qquad (9)$$

where,

TW_i = total weight of the ith parameter = AW_i + $BPIW_i$ + HW_i

AW_i = aesthetic weight of ith parameter

$BPIW_i$ = bio-physical impact weight of ith parameter

HW_i = health weight of ith parameter

TW_i is computed by assigning weights between 1 to 5 to AW_i, $BPIW_i$, and HW_i by a team of assessors or experts. 1 is the least and 5 is the highest weight.

2. 7 Integral Air Pollution Index (IAPI)

Bezuglaya *et al.* (1993) suggested integral air pollution index (IAPI) for Russian cities that is simply a sum of the pre-selected number of the highest individual pollutant indices calculated by normalising the pollution concentrations to maximum permissible concentration (MPC). Russian health experts had established maximum permissible concentrations (MPC) for more than 400 pollutants. To understand the degree of air pollution, the measured value of concentration pollutants are compared with either short-term MPC or mean value of long-term MPCs.

The sub-indices of IAPI can be determined using eqn. (10) as shown below:

$$I_{1i} = \frac{X_i}{MPC_i} \qquad (10)$$

where, x_i is the concentration of ith pollutant,

I_i is the sub-index of ith pollutant,

c_i is the degree of exponent, and

MPC_i is the maximum permissible concentration of ith pollutant

The degree of air pollution with any pollutant can be expressed through comparison with the degree of air pollution with sulphur dioxide using the degree exponent c_i as shown in eqn. (11):

$$I_{2i} = \left(\frac{x_i}{MPC_i} \right)^{C_i} \qquad (11)$$

The reason behind sulphur dioxide was used as a basis is that this pollutant is monitor in all cities. IAPI can be determined by the arithmetic sum of all the sub-indices corresponding to each air pollutants considered for air quality assessment.

Swamee and Tyagi (1999) had criticised the addition of sub-indices suggested by Bezuglaya *et al.* (1993), concluding that the function is ambiguous in nature and can lead to an index in the hazardous category, which may be a false alarm. Hence, they suggested a nonlinear aggregation of sub-indices. They proposed an air pollution index which is a quantitative tool through which air pollution data can be reported uniformly. An ambiguity and eclipcity-free function was presented for aggregating the air pollutants sub-indices.

The sub-indices are aggregated to yield air quality index using eqn. (12) as given below:

$$I = \left(\sum_{i=1}^{N} s_i^{\frac{1}{p}} \right)^{p} \qquad (12)$$

where, I = aggregate index;

N = the number of sub-indices;

s_i = sub-index of ith pollutant, and

p = an exponent.

After an extensive study, authors suggested that the value of p = 0.4 in the aggregation function minimize the effect of ambiguity.

2. 8 Aggregate Air Quality Index (AQI)

An aggregate AQI was proposed by Kyrkilis *et al.* in 2007. The index is based on the combined effects of five criteria pollutants (CO, SO_2, NO_2, O_3, and PM_{10}) taking into account the European standards. This method was used for air quality evaluation for each monitoring station situated in whole area of Athens, Greece. The indexing system is based on the AQI system developed by Swamee and Tyagi in 1999. An aggregate AQI can be determined by eqn. (13) shown below:

$$I = [\sum_{i=1}^{n} (AQI_i)^p]^{\frac{1}{p}} \qquad (13)$$

where, I is the aggregate AQI,

AQI_i = the sub-index for i[th] pollutant, and

p = a constant.

According to eqn. (13), when p = ∞ the index I is equal to the max AQI of a single pollutant, regardless of the rest of the pollutants' AQI value. This kind of calculation corresponds to the way that EPA calculates the overall AQI; however, it underestimates the air pollution levels. When p is equal to 1, at the other extreme, the overall index (I) is equal to the sum of all AQI indices. The selection of the most proper value for p is still an open support this statement.

The sub-indices are expressed as functions of the ratio of pollutant concentration q to standard concentration q_s, shown in eqn. (14):

$$AQI_i = AQIs \left(\frac{q}{q_s} \right) \qquad (14)$$

where, AQI_i = Sub-index of ith pollutant, and

AQIs = a scaling coefficient equal to 500 (Swamee and Tyagi, 1999).

2. 9 The Aggregate Risk Index (ARI)

Sciard *et al*. (2011) designed the aggregate risk index for assessing the health impact due to air pollution in the South East of France. The ARI is a measure of the mortality risk associated with simultaneous exposure to the common air pollutants and provides a ready method of comparing the relative contribution of each pollutant to total risk. An arbitrary index scale (1-10), with a colour coding system, was used to facilitate risk communication. The ARI is based on the exposure-response relationship and Relative Risk (RR) of the well-established increased daily mortality, en-abling an assessment of additive effects of short-term exposure to the major air pollutants. This study presents the modified formula of AQI based on Cairncross's concept (Cairncross *et al*., 2007).

The total attributable risk for simultaneous short-term exposure to several air pollutants is given by the eqn. (15):

$$ARI = \sum_i (RR_i - 1) = \sum Index_i = \sum a_i * c_i \qquad (15)$$

To account for the reality of the multiple exposures impacts of chemical agents, the final index is the sum of the normalised values of the individual RRi values (Pyta, 2008; Cairncross *et al*., 2007). It thus provides a ready method of comparing the relative contribution of each pollutant to total risk. The index is defined to reflect the contribution of individual pollutants to total risk. C_i is the corresponding time-averaged concentrations (in mg/m^3) and the coefficient "ai" is proportional to the incremental risk values ($RR_i - 1$). This index uses exposure-response relative risk functions and a particular set of RRi values for a given health endpoint associated with increasing major air pollutants. These functions and values were published by the WHO (2008, 2004, 2001), APHEA (Air Pollution and Health- a European Approach)-2, (2006) and InVS (PSAS-9 project, French air pollution and health surveillance program, 2008, 2006, 2002) under a procedure for health impact assessment.

From the published RR_i values for i^{th} pollutant, the coefficients for the terms a_i can be determined using eqn. (16) in order to derive a numerical scale specific to each of the pollutants.

$$a_i = \frac{a_{PM10} * (RR_i - 1)}{(RR_{PM10} - 1)} \qquad (16)$$

The breakpoint values between different levels considered correspond to the air quality standards defined by the WHO (2005). The air quality classes and the relevant RR values are determined in terms of the PM_{10} concentration (significant RR_i values). The breakpoint concentrations for the remaining pollutants are calculated proportionally to the individual levels of the relative risk.

2. 10 AQI Based on PCA-Neural Network Model

Kumar and Goyal (2013) designed forecasting system for daily AQI using a coupled artificial neural network (ANN) - Principal component analysis (PCA) model. The architecture of the system is shown in Fig. 1. It was designed for forecasting AQI in one day advance using the previous day's AQI and meteorological variables.

There are two steps involved in determining the AQI. The first step is the formation of sub-indices for each pollutant and the second one is the aggregation of sub indices. The sub-indices were calculated using the same formula as that of U.S. EPA but the breakpoint concentration of each pollutant is based on the Indian NAAQS and epidemiological studies, which are indicating the risk of adverse health effects of specific pollutants.

The AQI value was calculated for each individual pollutant (SO_2, NO_2, RSPM, and SPM) and highest among them was declared as the AQI of the day. The previous day's AQI value was used as one of the input parameters in the PCA-ANN model for forecasting the AQI value of subsequent day.
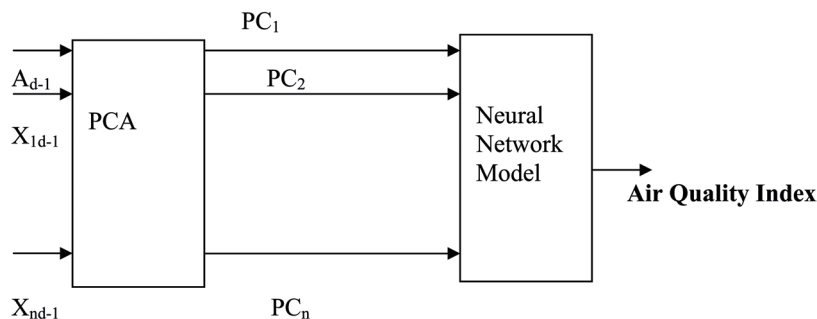

Fig. 1. Architecture of PCA-neural network model for the forecasting of AQI.

2. 11 Fuzzy Air Quality Index

Mandal *et al.* (2012) developed a method for prediction of AQI on the basis of fuzzy aggregation. The output AQI value using fuzzy aggregation method was compared to that of the output from conventional method. It was demonstrated that computing with linguistic terms using fuzzy inference system improves tolerance for impression data.

The relationship between air pollutants and output parameter (FAQI) is mathematically expressed as given in the eqn. (17)

$$FAQI = f(SPM, RPM, SO_2, NO_X) \qquad (17)$$

Gorai *et al.* (2014) developed a fuzzy pattern recognition model for AQI determination. The method was used for air quality assessment of Agra city. This method considered five air pollutants (PM_{10}, CO, SO_2, NO_2, and O_3) for AQI determination. The method also considers weights of the individual pollutants on the basis of its degree of health impacts during aggregation. Analytical hierarchical process (AHP) was used for determination of weights of various pollutants. The air quality index is ranged from 1 to 6. The higher is the value of AQI, higher is the health risk and vice versa. Authors suggested that depending upon the risk level, air quality mangers can take preventive measures for reducing the level of index. Though, the formula or method used for determination AQI is relatively complex in comparison to that of the arithmetic aggregation method but this can be easily programmed for determination of AQI.

2. 12 Air Quality Health Index

A new Air Quality health index (AQHI) was developed in Canada to understand the state of local air quality with respect of public health. AQHI is available for about ten communities in Canada, including Vancouver and Victoria.

The AQHI is constructed as the sum of excess mortality risk associated with NO_2, ground-level O_3, and $PM_{2.5}$ at certain concentrations. It is calculated hourly based on 3-hour rolling average pollutant concentrations, and is then adjusted to a scale of 1 to 10. The value of 10 corresponds to the highest observed weighted average in an initial data set covering a reference period from 1998 to 2000 (Stieb *et al.*, 2008; Taylor, 2008).

The scientific basis for the formulation of AQHI is based on the epidemiological research undertaken at Health Canada. Relative risk (RR) values are estimated, based on the local time series analyses of air pollution and mortality (Stieb *et al.*, 2008; Taylor, 2008). Air Quality Health Index is determined by the eqn.

(18) as shown below:

$$AQHI = \frac{10}{c} \sum_{i=1\cdots,p} 100(e^{\beta_i x_i} - 1) \qquad (18)$$

where, β_i is the regression coefficient from same Poisson model linking the ith air pollutant with mortality, x_i is the concentration of the ith pollutant, and c is the scaling factor.

2. 13 Air Pollution Indexing System in South Africa

An air pollution index was developed in a dynamic air pollution prediction system (DAPPS) project, which was led by a consortium of four South African partners, including the Cape Peninsula University of Technology (Cairncross *et al.*, 2007). The API system is based on the relative risk of the well-established excess daily mortality associated with short-term exposure to common air pollutants, including PM_{10}, $PM_{2.5}$, SO_2, O_3, NO_2, and CO. A scale of 0 to 10 was used for the assessment of air quality. Incremental risk values for each pollutant are assumed to be constant, and a continuous exposure metrics, the exposures that correspond to the same relative risk are assigned the same sub-index value. The final API is the sum of the normalized values of the individual indices for all pollutants is given by the eqn. (19)

$$API = \sum PSI_i = \sum a \cdot C \qquad (19)$$

where, C is the time averaged concentration of pollutant, and a is a coefficient directly proportional to the incremental risk value associated with the pollutant.

The proposed API was applied to ambient concentration data collected at monitoring stations in the City of Cape Town for testing.

2. 14 Air Pollution Indexing System in China

China's state pollution control board is responsible for measuring the air pollution in the cities. The air pollution index (API) in China is based on the five atmospheric pollutants sulfur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulates (PM_{10}), carbon monoxide (CO), and ozone (O_3) measured in the monitoring stations. Chinese API system follow the same method for calculating the air quality index but the health definition corresponding to each AQI classes are different.

Hämekoski *et al.* (1998) developed a simple air quality index (AQI) for the Helsinki Metropolitan Area in order to inform the public about the air quality status for better understanding. The pollutants consider in the AQI system are CO (1 hr. and 8 hrs.), NO_2 (1 hr. and 24 hrs.), SO_2 (1 hr. and 24 hrs.), O_3 (1 hr.) and PM_{10}

Table 4. AQI methods with their merits, demerits and application.

Author/Organization/Method	Name	Index and aggregation function	Pollutant aggregation	Health based	Purpose/Application
Thomas and Ott (1975)	ORAQI	$ORAQI = \left(a\sum \dfrac{C_i}{C_s}\right)^b$	Yes	Yes	To assess air quality status in metropolitan cities
U.S. EPA, AQI (1976, 1999)	AQI	$AQI = Max\,(I_1, I_2, \ldots I_n)$	No	Yes	Use for continuous reporting of air quality status to public
Hämekoski et al. (1998)	A simple AQI	Based on U.S. EPA formula	Yes	Yes	The AQI is based on acute health effects, but long term effects on nature and materials are also taken into consideration.
Cheng et al. (2004)	RAQI	$RAQI = Max\,(I_1, I_2 \ldots I_n)$ $\times \dfrac{Avg_{daily}\sum_{j=1}^n I_j}{Avg_{annual}[Avg_{daily}\sum_{j=1}^n I_j]}$ $\times \dfrac{Avg_{annual}\{Entropy_{daily} * Max[I_1, I_2,\ldots,I_n]\}}{Entropy_{daily} * Max[I_1, I_2,\ldots,I_n]}$	Yes	Yes	To produce an objective result in the long-term effect of air pollution
Murena et al. (2004)	PI	$PI_S = PIb_C \sum_{p=1}^n \dfrac{C_P}{BP_{p,c}}$	No	Yes	The index aims at measuring the status of air pollution with respect to its effect on human health.
Singh G. (2006)	AQDI	$AQ_{dep} = \left\{\sum_{i=1}^n (AQ_i * CW_i)\right\} - \left\{\sum_{i=1}^n CW_i\right\}$	Yes	No	To define the depreciation in air quality with respect to standard
Kyrkilis et al. (2007)	Aggregate AQI	$I = [\sum_{i=1}^n (AQI_i)^p]^{\frac{1}{p}}$	Yes	No	Based on the combined effects of five criteria pollutants (CO, SO_2, NO_2, O_3, and PM_{10}) taking into account European standards. Useful towards the informing of the citizens and protection of human health in an urban agglomeration.
Cairncross et al., 2007	API	$API = \sum PSI_i = \sum a \cdot C$	Yes	Yes	The system is based on the relative risk of the well-established excess daily mortality associated with short-term exposure to common air pollutants (PM_{10}, $PM_{2.5}$, SO_2, O_3, NO_2 and CO)
CITEAIR II Project, Europe (2008)	CAQI	Based on U.S. EPA method but with different criteria	No	No	Comparing urban air quality in real time.
Steib et al., 2008, Taylor et al., 2008	AQHI	$AQHI = (10/c)$ $\sum_{i=1\ldots p}100\,(e^{\beta_i X_i} - 1)$	Yes	Yes	Described the application of concentration of - response functions from epidemiological studies of air pollution to an AQI.
Bishoi et al. (2009)	NAQI	$NAQI = \{\sum_{i=1}^n (P_i E_i)/\sum_{i=1}^n E_i\}$	Yes	No	To define the state of air in relative terms

Table 4. Continued.

Author/Organization/Method	Name	Index and aggregation function	Pollutant aggregation	Health based	Purpose/Application
Cannistraro et al. (2009)	PI	$I = \dfrac{(I_1+I_2)}{2}$, Where I_1 and I_2 are the sub-indices of the two most critical pollutants having highest concentration	Yes	Yes	Useful for communicating to citizens' information about the state of air quality of a waste urban area.
Sciard et al. (2011)	ARI (Aggregate Risk Index)	$ARI = \sum_i (RR_i - 1) = \sum Index_i = \sum a_i * c_i$	Yes	Yes	The index measure of the mortality/morbidity risk associated with simultaneous exposure to the common air pollutants and provides a ready method of comparing the relative contribution of each pollutant to total risk. An arbitrary index scale facilitates risk communication. The index values may extend beyond 0 for highly polluted areas.
Kumar et al. (2013)	AQI	Based on U.S. EPA formula	No	Yes	The AQI of each pollutant has been calculated individually and highest among them is declared as the AQI of the day.
Mandal et al. (2012)	FAQI	$FAQI = f(SPM, RPM, SO_2, NO_2)$	Yes	No	A new aggregation approach suggested for air quality assessment
Gorai et al. (2014)	FAQI	$H_i = \sum_{h=1}^{6} u_{i,h} * h$	Yes	No	A new fuzzy pattern recognition model suggested for air quality assessment. This can cover the uncertainty factors.
Bezuglaya et al. (1993)	IAPI	$IAPI = \sum_{i=1}^{n}(I_{2i}) = \sum_{i=1}^{n}\left(\dfrac{X_i}{MPC_i}\right)^{c_i}$	Yes	No	The use of API allowed obtaining a complex degree of urban air pollution.
Swamee and Tyagi (1999)	I	$I = \left(\sum_{i=1}^{N} s_i^{\frac{1}{p}}\right)^p$	Yes	No	An ambiguity and eclipsity free function was developed.
Air Pollution Indexing System in China	API	Based on U.S.EPA formula	Yes	No	The final API value is calculated per hour. Based on six atmospheric pollutant (PM_{10}, $PM_{2.5}$, SO_2, O_3, NO_2 and CO)

(24 hrs.). The AQI is based on acute health effects, but long term effects on nature and materials are also taken into consideration. Sub-indices are calculated hourly for all pollutants and for a given hour the highest sub-index becomes the AQI. The development is partly based on the work conducted in United States and Canada, for example by Ott and Hunt (1976) and Mignacca and others (1991).

3. SUMMARY AND CONCLUSIONS

This brief review on air quality indices shows the wide interest or concern for poor air quality problem. But at the same time it shows lack of a common strategy, which allow to compare the state of the air for cities that follow different directives. The major differences among the indices in the literature are found in the aggregation function, type and number of pollutants, number of index classes (and their associated colors) and related descriptive terms. It was observed that the guidelines are sometimes consistently different from place to place, not only in indicating the pollutants to be monitored, but also in setting the threshold values. It is also true that WHO recommended (WHO, 2006) that during formulating policy targets, governments should consider their own local circumstances carefully, that is the specificities of places must be taken into account. The complexity of air pollution and its science has created problems to both the public and policy makers. There are many pollutants to consider with some being secondary products of atmospheric transformations. The science is often so sophisticated that it becomes hard for politicians and the public to interpret. Thus, it is desirable that air pollution information will continue to be represented in simple forms such as indices. In an attempt to meet the public's needs for information on air quality a variety of indexes have been developed and they continue to evolve. In terms of their ongoing development, an AQI also needs to be useful for forecasting, and the method of calculation needs to be sufficiently flexible to allow for pollutants to be added or subtracted as changes to their health impact are revealed. The Air Quality Index (AQI) is a widely used concept to communicate with the public on air quality. A growing number of national and local environment agencies use the AQI for (near) real-time dissemination of air quality information. Although the basic concepts are similar, the AQIs show large differences in practical implementation. It is also observed that when applying the AQIs on a common set of air quality data, large differences in index value and the determining pollutant are found (de Leeuw and Mol 2005).Current AQIs potentially contribute to public understanding by providing information that is easily accessible and allows them the opportunity to modify their behaviour appropriately in response to changes in air quality. However, much progress is still to be made,

mainly through more careful consideration of the combined impact of multiple pollutants, consideration of low level exposure, and with more timely transfer of usable information to the public. The summary of various AQI systems and its aggregation methods are listed in Table 4. These are mainly demonstrated in this review work. Table 4 represents the chronological evolution of various air quality indices that are described in this paper including to other important statistical issues like aggregation function, the availability of uncertainty measures for the index, availability of health descriptors, and their purpose or applicability. The review of various methods reveals that most of the methods do not have the flexibility to accommodate a new pollutant. This is because, either the methods is designed for specific number of pollutants or the aggregation function does not have the suitability to accommodate this. Table 4 also clearly indicates that many of the indexing method do not consider the synergistic effects of the pollutants, that is, pollutants are not aggregated in index calculation. Furthermore, many indexing method are not based on health criterion. Thus, further work is required on the statistical structure and effects of the aggregation function on index, the nature of the scale (1-10, 1-100, 1-500) and the multi-pollutant problem to make it uniform.

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