Plume AQI: An Air Quality Index aligned with health recommendations

Abstract

Air pollution is a multifactorial and complex phenomenon spanning across multiple pollutants, each one with specific impacts on health and specific concentration and exposure thresholds. As a consequence, air pollution readings for the greater public are usually expressed with Air Quality Indices (AQIs) rather than concentrations. Though this should help boost understanding, we find that existing AQIs are not coherent with the latest World Health Organisation (WHO) health recommendations. We therefore propose a new AQI, the Plume Air Quality Index, covering 5 pollutants in line with WHO annual, daily and hourly exposure guidelines.

1. Introduction

In the past few years, concern has been growing on air pollution. Air pollution is now blamed for several phenomena, such as facial dark spots [1], premature births [2] and asthma [3]. Governments and local authorities have responded by setting up monitoring networks and making measurements available to the general public. Nowadays, most countries in Europe and North America and several Asian countries do publish pollution data but do not use the same scale when providing AQI readings. First, we detail why an Air Quality Index is needed and review the existing ones. Then, we present the structure of our proposed Air Quality Index, called the Plume Air Quality Index. We base the thresholds on recommendations of the World Health Organisation (WHO). Finally, we show how the Plume Index compares with other existing AQIs.

2. Air quality indices and how Plume uses them

2.1 Why an Air Quality Index (AQI) ?

All pollutants do not have the same impacts on human health at the same concentrations. As will be described below, some pollutants, such as benzene, are carcinogenic even at very low concentrations (less than 1 µg/m^3), while others, such as

ozone only have strong effects at concentrations around 100 µg/m^3. It would thus be deceptive to compare concentrations of two different pollutants: what matters is their effects on human health. That is why we need an Air Quality Index, based on health recommendations.

2.2 Why not use existing indices?

Several countries have developed and published their own air quality indices. Each country uses its own index, and each index has its own thresholds. That is why it is difficult, when changing country, to compare the pollution levels. Below are the main differences between some indices from the United States [4], Canada [5], China [6], India [7], the United Kingdom [8] and Europe [9] :

- The number of pollutants taken into account : 3 for the Canadian AQI (Ozone, Nitrogen and PM2.5) 5 for the British AQI (adding PM10 and sulfur dioxide), 6 for the European, Chinese and American AQIs (adding CO) and even 8 pollutants in India (with Ammonia and Lead);
- The number of categories : there are 6 categories for AQIs from India, China and the United States, 5 categories for the European common AQI, and 4 categories divided in 10 sublevels for the British and Canadian AQIs;
- The Averaging period : whereas monitoring stations provide continuous data, the AQIs are computed based on averages. For instance, for nitrogen dioxide, the Indian AQI averages value on 24 hours, the Canadian AQI on 3 hours, the British, American and Chinese AQIs on 1 hour, The European Index gives hourly, daily and annual values;
- The values of thresholds : as shown by Figure 1, for a given pollutant, even when data is averaged on the same period, each index has its own scale to assess the contribution of the pollutant to the index.

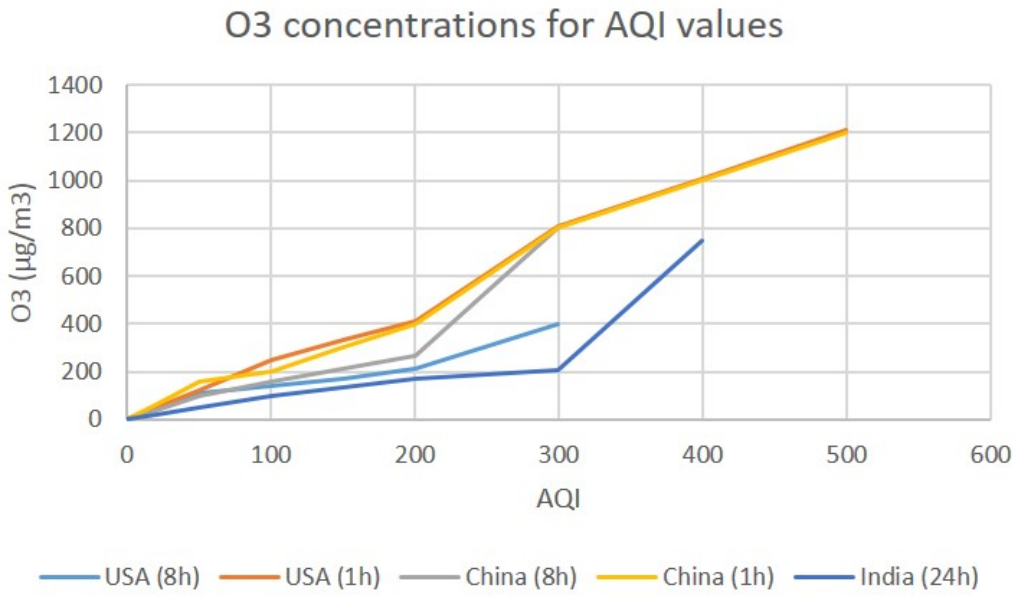

Figure 1: Concentration of O3 corresponding to the value of the index for various AQIs

There are two reasons why a new AQI is needed, on top of the existing ones. First, most existing AQIs are not based on generally-admitted health recommendations: it is not clear how their thresholds were chosen. Second, the levels (whatever their number may be) do not have any explicit meaning for the citizen.

3. The Plume Index

To create the Plume Index and its levels, we proceed in the following way. To make it easy for citizens to understand the levels, each of them corresponds to a time period for which exposure is safe: a year (PI<20), a day (PI<50), an hour (PI<100). Beyond these levels, there are some recommendations dealing with shorter periods: a few minutes (which would correspond to PI<150) and a minute (PI<200) (Table 1). The last threshold (PI=300) would correspond to a few seconds. To determine what concentrations correspond to each threshold, we rely on health recommendations.

Level	<20	<50	<100	<150	<200	<300
Longest harmless exposure	1 year	1 day	1 hour	A few minutes	1 minute	A few seconds

Table 1 : Levels and time periods

3.1 The principle

The Plume Index is a positive number ; a Plume Index equal to 0 would mean the absence of any pollutant, whereas a high Plume Index is synonymous of a high pollution. The Plume Index is based on 7 levels of pollution, for which recommendations are detailed in Table 2.

Range	Title	Headline	Description
0-20	Fresh air	No risk	The air is pure, ideal for outdoor activities !
20-50	Moderate pollution	Impact risk if chronic exposure	The air is moderately polluted. Greater than the maximum limit established for one year by WHO. A long-term exposure constitutes a health risk.
50-100	High pollution	Impact if chronic exposure	The air has reached a high level of pollution. Higher than the maximum limit for 24 hours established by WHO.
100-150	Very high pollution	Immediate impact on health	The air has reached a very high level of pollution. Effects can be immediately felt by individuals at risk. Everybody feels the effects of a prolonged exposure.
150-200	Excessive pollution	Immediate effects for individuals at risk	The pollution level has reached a critical level. Individuals at risk feel immediate effects. Even healthy people may show symptoms for short exposures.
200-300	Extreme pollution	Immediate effects for everybody	The pollution has reached extreme levels. Immediate effects on health.
>300	Airpocalypse	Major immediate effects	Airpocalyse ! Immediate and heavy effects on everybody.

Table 2 : The seven categories of the Plume Index

To compute the Plume Index, five pollutants are taken into account : O3, NO2, SO2 and particles under 10 µm diameter (PM10) and under 2.5 µm diameter (PM2.5). These are the five common outdoor pollutants which are harmful and frequently measured by monitoring stations.

The Plume Index does not include, among others :

- Carbon monoxide (CO), since its outdoor concentration is very unlikely to reach harmful levels ;

- Benzene (C_6H_6), for which most cities do not have any data ;
- Ammonia (NH3) and Lead (Pb) are also rarely measured by urban monitoring stations.

The calculus formula is the following :

- For each pollutant, a Plume Index is computed. To compute the pollutant-specific Plume Index : 6 concentration thresholds are determined as described below, to match the boundaries between our categories. Between these thresholds, the function is a piecewise linear function.
- The Plume Index value is the maximum of all pollutant-specific Plume Indices.

Thresholds are determined following health recommendations from the World Health Organisation (WHO). The WHO publishes guidelines for most pollutants [10]. There are four different guidelines :

- An annual average : this is the annual limit that should not be breached on average on a year. When this value is given by the WHO, the Plume Index takes it as the first threshold, between “fresh air” and “moderate pollution” (PI=20) ;
- A daily average : when it exists, the Plume Index takes it as the upper limit of “moderate pollution” (PI=50) ;
- An hourly average : when it exists, the Plume Index takes it as the upper limit of “high pollution” (PI=100) ;
- Recommendation for a shorter period (typically a few minutes) : the Plume Index takes it as the upper limit of “very high pollution” (PI=150).

To deal with cases where the WHO does not give one or several of these values for a given pollutant, we also take into account subsidiary sources :

- The European Commission [11] ;
- The American Environmental Protection Agency (EPA) [12] ;
- The Chinese Air Quality Standards [13] ;
- The French legislation regarding Air Quality [14].

The aim is, when no health recommendation is available from the WHO, to stick (by default) to national regulations and existing AQIs.

3.2 The thresholds

Threshold #1 : PI=20

This threshold corresponds to the limit between “fresh air” and “moderate pollution”. Sanitarily speaking, if the annual average is beyond this threshold, this pollutant becomes dangerous.

- Ozone : no threshold is proposed neither by the WHO nor by the subsidiary sources. Thus, the threshold is proposed to be 20 µg/m^3 , which is half the next threshold ;
- Nitrogen dioxide : 40 µg/m^3 , annual threshold from the WHO ;
- Sulfur dioxide : 20 µg/m^3 , annual threshold from the WHO ;
- PM10 : 20 µg/m^3 , annual threshold from the WHO ;
- PM2.5 : 10 µg/m^3 , annual threshold from the WHO.

Threshold #2 : PI=50

This threshold corresponds to the limit between “moderate pollution” and “high pollution”. Sanitarily speaking, if the daily average is beyond this threshold, this pollutant becomes dangerous.

- Ozone : 40 µg/m^3 corresponds to the threshold proposed by the WHO for the average over 8 hours. Recommendations are always made for 8-hour, since ozone is produced by sunrays and, consequently, disappears during the night ;
- Nitrogen dioxide : only the Chinese source provides a threshold : 80 µg/m^3 ;
- Sulfur dioxide : no recommendation from the WHO. We follow the European Commission : 125 µg/m^3 ;
- PM10 : no recommendation either from the WHO. We follow the guidelines issued by the European Commission and Chinese standards : 50 µg/m^3 ;
- PM2.5 : 25 µg/m^3 , as recommended by the WHO.

Threshold #3 : PI=100

This threshold corresponds to the limit between “high pollution” and “very high pollution”. Sanitarily speaking, if the hourly average is beyond this threshold, this pollutant becomes dangerous.

- Ozone : only the Chinese source gives a threshold : 160 µg/m^3 ;
- Nitrogen dioxide : we follow the hourly recommendation from the WHO : 200 µg/m^3 ;
- Sulfur dioxide : no recommendation from the WHO. We follow the European Commission : 350 µg/m^3 ;
- PM10 : no recommendation from any source, except the French legislation which triggers an alert at 80 µg/m^3 ;
- PM2.5 : we double the previous threshold to 50 µg/m^3 following the results of a study which highlights the linear health response to PM2.5 exposure increase [15].

Threshold #4 : PI=150

This threshold corresponds to the limit between “very high pollution” and “excessive pollution”. Sanitarily speaking, it corresponds to a concentration so high that it can prove

harmful even at very short exposures. Recommendations for these thresholds are more difficult to find.

- Ozone : we use the alert threshold from the French legislation : 240 µg/m^3 ;
- Nitrogen dioxide : we also use the alert threshold : 400 µg/m^3 ;
- Sulfur dioxide : we follow the recommendation for a 10-minute-long exposure from the WHO : 500 µg/m^3 ;
- PM10 and PM2.5 : no recommendation is available for short exposures. We thus only double the previous thresholds, at 160 µg/m^3 (PM10) and 100 µg/m^3 (PM2.5), to take into account the above-mentioned linearity [15].

Threshold #5 (PI=200) and #6 (PI=300)

To deal with superior levels of pollution, it appeared that the former Plume Index upper category was too coarse : city-dwellers from highly polluted areas needed to be able to discriminate between different degrees of extreme pollution. The new Plume Index thus adds two new categories, for which the scale is simply linearly prolonged. This is consistent with the above mentioned study [15], as well as with the other AQI's construction.

4. Results : how the Plume Index compares with other AQIs

To synthesize the previously defined thresholds and computation method, the following charts show how the Plume Index situates with respect to other similar existing AQIs, that is to say those from China, India and United States. The British and Canadian AQIs are not shown since they use a different scale, from 1 to 10 ; the European AQI is not displayed either : its scale varies from 1 to 100, which would make it deceptive to plot it against scales varying from 1 to more than 300.

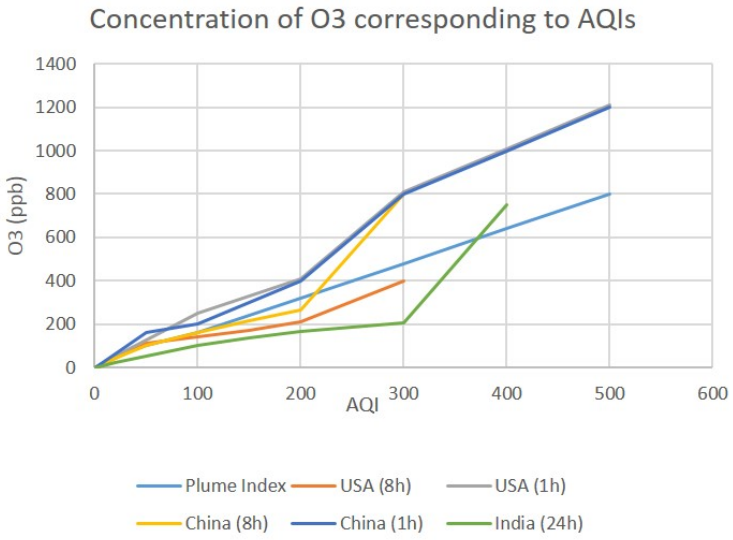

Figure 2:: How the Plume Index compares with other AQIs for O3

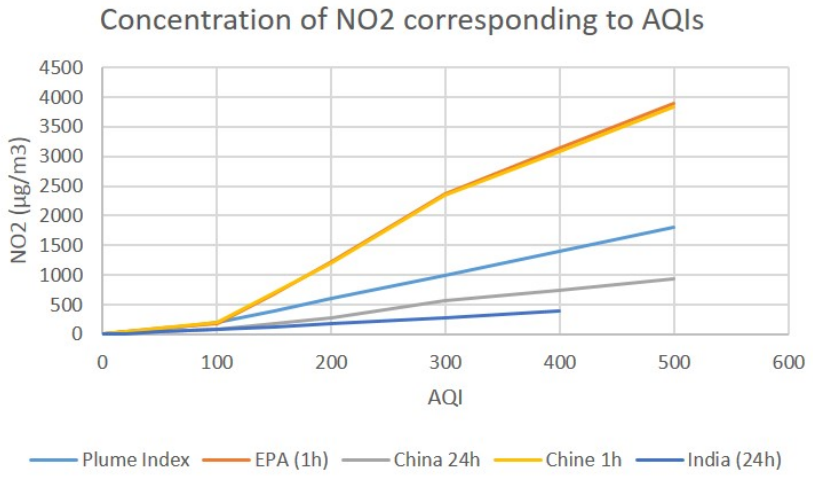

Figure 3: How the Plume Index compares with other AQIs for NO2

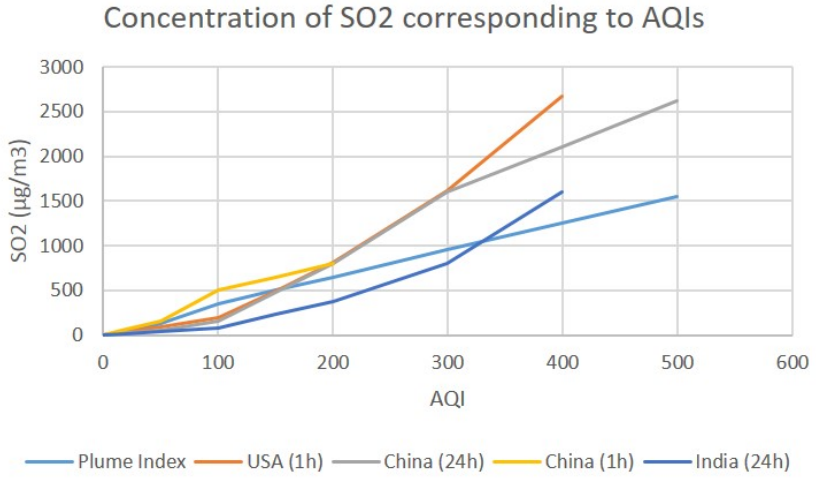

Figure 4: How the Plume Index compares with other AQIs for SO2

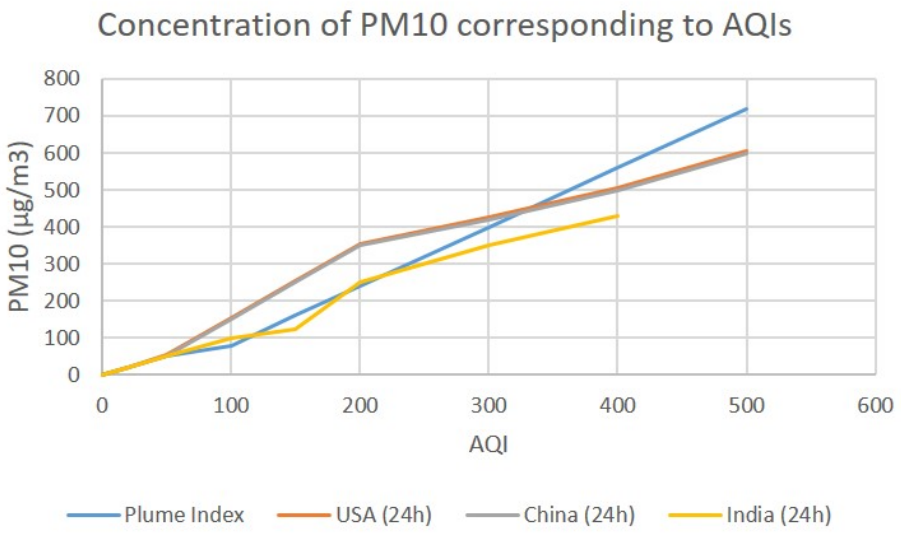

Figure 5: How the Plume Index compares with other AQIs for PM10

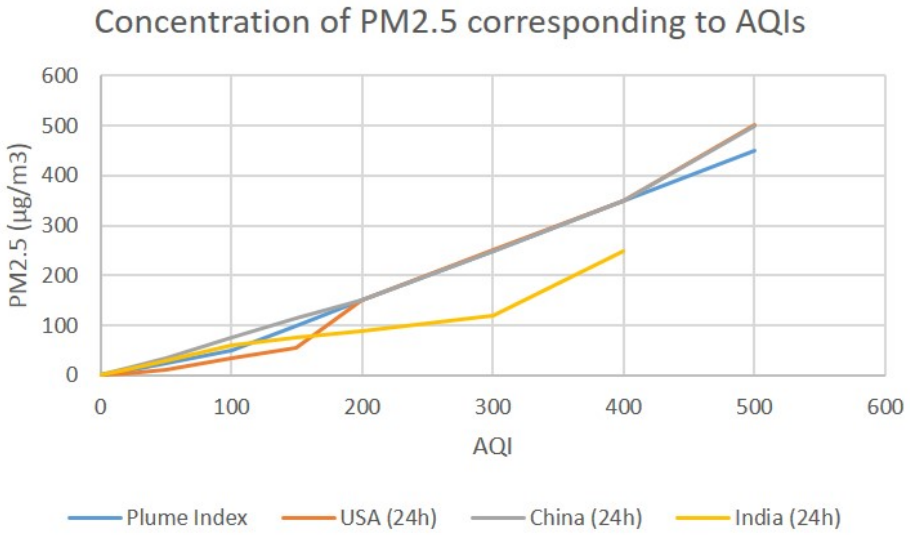

Figure 6: How the Plume Index compares with other AQIs for PM2.5

5. Conclusion

To overcome the variability of Air Quality Indices, regarding both the structure of those indices and their levels, this article proposes an Air Quality Index called the Plume Index, with 7 differents levels : fresh air, moderate pollution, high pollution, very high pollution, excessive pollution, extreme pollution, airpocalypse. Five pollutants are taken into accounts : ozone, nitrogen dioxide, sulfur dioxide, PM10 and PM2.5 ; these are the pollutants which are measured in most cities and can reach harmful levels. As often as possible, the thresholds (summarised in Table 3) are based on health recommendations.

Polluant	PI = 20	PI = 50	PI = 100	PI = 150	PI=200	PI=300
Ozone	50	100	160	240	320	480
NO_2	40	80	200	400	600	1000
SO_2	20	125	350	500	650	950
PM10	20	50	80	160	240	400
PM2.5	10	25	50	100	150	250

Table 3: Thresholds of the Plume Index for each pollutant.

Future works could study the impacts of pollutants on health at high urban levels, to provide a background for the highest thresholds of the index.

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