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Effect of Humidity, Temperature and Size of Particles in AQI (Air Quality Index) in Northern India

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ABSTRACT: An air quality index (AQI) is an indicator developed by government agencies^[1] to communicate to the public how polluted the air currently is or how polluted it is forecast to become.^{[2][3]} As air pollution levels rise, so does the AQI, along with the associated public health risk. Children, the elderly, and individuals with respiratory or cardiovascular problems are typically the first groups affected by poor air quality. When the AQI is high, governmental bodies generally encourage people to reduce physical activity outdoors, or even avoid going out altogether. When wildfires result in a high AQI, the use of masks such as N95 respirators outdoors and air purifiers incorporating HEPA filters indoors are also encouraged.^[4]

KEYWORDS-air,quality,index,AQI,pollution,levels,health,northern,India

I. INTRODUCTION

Computation of the AQI requires an air pollutant concentration over a specified averaging period, obtained from an air monitor or model. Taken together, concentration and time represent the dose of the air pollutant. Health effects corresponding to a given dose are established by epidemiological research.^[5] Air pollutants vary in potency, and the function used to convert from air pollutant concentration to AQI varies by pollutant. Its air quality index values are typically grouped into ranges. Each range is assigned a descriptor, a color code, and a standardized public health advisory.^[1,2,3]

The AQI can increase due to an increase of air emissions. For example, during rush hour traffic or when there is an upwind forest fire or from a lack of dilution of air pollutants. Stagnant air, often caused by an anticyclone, temperature inversion, or low wind speeds lets air pollution remain in a local area, leading to high concentrations of pollutants, chemical reactions between air contaminants and hazy conditions.^[6]



Signboard in Gulfport, Houston, Texas, indicating an ozone watch

On a day when the AQI is predicted to be elevated due to fine particle pollution, an agency or public health organization might:

- advise sensitive groups, such as the elderly, children, and those with respiratory or cardiovascular problems, to avoid outdoor exertion.^[7]



- declare an "action day" to encourage voluntary measures to reduce air emissions, such as using public transportation.^[8]
- recommend the use of masks outdoors and air purifiers indoors to keep fine particles from entering the lungs^[9]

During a period of very poor air quality, such as an air pollution episode, when the AQI indicates that acute exposure may cause significant harm to the public health, agencies may invoke emergency plans that allow them to order major emitters (such as coal burning industries) to curtail emissions until the hazardous conditions abate.^[10]

Most air contaminants do not have an associated AQI. Many countries monitor ground-level ozone, particulates, sulfur dioxide, carbon monoxide and nitrogen dioxide, and calculate air quality indices for these pollutants.^[11]

The definition of the AQI in a particular nation reflects the discourse surrounding the development of national air quality standards in that nation.^[12] A website allowing government agencies anywhere in the world to submit their real-time air monitoring data for display using a common definition of the air quality index has recently become available.^[13]

The National Air Quality Index (NAQI) was launched in New Delhi on September 17, 2014, under the Swachh Bharat Abhiyan.^{[25][26][27][28]}

The Central Pollution Control Board along with State Pollution Control Boards has been operating National Air Monitoring Program (NAMP) covering 240 cities of the country having more than 342 monitoring stations.^[29] An Expert Group comprising medical professionals, air quality experts, academia, advocacy groups, and SPCBs was constituted and a technical study was awarded to IIT Kanpur. IIT Kanpur and the Expert Group recommended an AQI scheme in 2014.^[30] While the earlier measuring index was limited to three indicators, the new index measures eight parameters.^[31] The continuous monitoring systems that provide data on near real-time basis are installed in New Delhi, Mumbai, Pune, Kolkata and Ahmedabad.^[32]

There are six AQI categories, namely Good, Satisfactory, Moderate, Poor, Severe, and Hazardous. The proposed AQI will consider eight pollutants (PM₁₀, PM_{2.5}, NO₂, SO₂, CO, O₃, NH₃, and Pb) for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed.^[33] 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. Likely health impacts for different AQI categories and pollutants have also been suggested, with primary inputs from the medical experts in the group. The AQI values and corresponding ambient concentrations (health breakpoints) as well as associated likely health impacts for the identified eight pollutants are as follows:

AQI category, pollutants and health breakpoints									
AQI category (range)	PM ₁₀ (24hr)	PM _{2.5} (24hr)	NO ₂ (24hr)	O ₃ (8hr)	CO (8hr)	SO ₂ (24hr)	NH ₃ (24hr)	Pb (24hr)	Colour
Good (0–50)	0–50	0–30	0–40	0–50	0–1.0	0–40	0–200	0–0.5	Deep Green
Satisfactory (51–100)	51–100	31–60	41–80	51–100	1.1–2.0	41–80	201–400	0.5–1.0	Light Green
Moderate (101–200)	101–250	61–90	81–180	101–168	2.1–10	81–380	401–800	1.1–2.0	Yellow
Poor (201–300)	251–350	91–120	181–280	169–208	10–17	381–800	801–1200	2.1–3.0	Orange
Severe (301–400)	351–430	121–250	281–400	209–748	17–34	801–1600	1200–1800	3.1–3.5	Red
Hazardous (401–500)	430+	250+	400+	748+	34+	1600+	1800+	3.5+	Maroon



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 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.
Severe (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.
Hazardous (401–500)	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

II. DISCUSSION

In November, satellites often observe large clouds of smoke and heightened fire activity in northwestern India as farmers burn excess paddy straw after the rice harvest—a practice called stubble burning. November 2022 followed this pattern.

When the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi NPP satellite captured this natural-color image on November 1, 2022, a plume of smoke curled from northeastern Pakistan to the Indian states of Punjab, Haryana, and Uttar Pradesh. Use the slider tool to see the locations of active fires observed by VIIRS that afternoon.[5,7,8]

Many farmers, particularly in the states of Punjab and Haryana, use fire as a fast, cheap way to clean up and fertilize fields before planting winter crops. However, a surge of smoke in the heart of the densely populated Indo-Gangetic Plain often contributes to a sharp deterioration of air quality across the region, including in the capital city of Delhi.

The air quality index rose as high as 424 on November 1, 2022, according to India’s Central Pollution Control Board, enough to put it into the “severe” category. The high pollution levels prompted a halt in construction in Delhi and calls for people to work from home.

Smoke from crop fires is not the only contributor to the hazy skies in the region. Influxes of dust sometimes arrive from the Thar Desert to the west, as happened on October 31. An array of other human-caused sources of air pollution come from cities, including motor vehicle fumes, industrial and construction activity, fireworks, and fires for heating and cooking.

Measurements of particulate matter, including the small particles known as PM_{2.5}, can be used as a proxy for air quality. According to one analysis of Delhi’s air pollution, stubble burning contributed 14 percent of PM_{2.5} in Delhi on November 1. Prior to the start of widespread crop fires, the percentage ranged from 1 to 3 percent.[9,10,11]

Geography and weather also exacerbate the region’s air quality problems. Temperature inversions are common in November and December as air rolls off the Tibetan Plateau and mixes with smoky air from the Indo-Gangetic plain. An inversion can function like a lid, with the warm air trapping pollutants near the surface and helping hem pollutants in between the Himalayan Mountains to the north and the Vindhya Mountains to the south.

The crop-burning season is just beginning and typically continues for two to three weeks. Hiren Jethva, a senior research scientist with University of Maryland, Baltimore County and Morgan State University, uses satellite observations to monitor the fires each year. Based on measurements of the “greenness,” or Normalized Difference Vegetation Index (NDVI), of the rice crop during the summer, he expects NASA’s Aqua satellite will observe about 15,000 fires by late-November, which would make this the 5th most active season since 2002 (following 2021, 2020, 2016, and 2012). As of November 2, Aqua had detected about 2,000 fires.[12,13,15]



III. RESULTS

In northern India, Air pollution caused over 1.7 million premature deaths in the country in 2019. The entire population of India is exposed to unhealthy levels of ambient PM 2.5 – the most harmful pollutant - emanating from multiple sources, according to the World Bank.

With rapid urbanization and industrial growth, the problem of air pollution is only going to increase in the coming years. Hence, it necessitates the need to track air pollution levels.

National Air Quality Index (AQI)-northern-India transforms complex air quality data of eight pollutants into a single number (index value), nomenclature and colour.[17,18,19]

National Air Quality Index (AQI) was launched on 17 October 2014 to disseminate information on air quality in an easily understandable form for the general public. The measurement of air quality is based on eight pollutants, namely,

- Particulate Matter (size less than 10 µm) or (PM₁₀),
- Particulate Matter (size less than 2.5 µm) or (PM_{2.5}),
- Nitrogen Dioxide (NO₂),
- Sulphur Dioxide (SO₂),
- Carbon Monoxide (CO),
- Ozone (O₃),
- Ammonia (NH₃), and
- Lead (Pb)

for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed. It may be noted that ambient air quality standards are specified separately in India for around 12 pollutants including the 8 that constitute the Air Quality Index. AQI has six categories of air quality. These are: Good, Satisfactory, Moderately Polluted, Poor, Very Poor and Severe. The AQI values and corresponding ambient concentrations (health breakpoints) for the identified eight pollutants are as follows:[20,21,22]

AQI Category, Pollutants and Health Breakpoints								
AQI Category (Range)↓	→ Categories for the various readings of the pollutant based on the health breakpoints or health impacts							
	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	0.5 –1.0
Moderately polluted (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	10-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

The AQI Index values and their associated health impacts are as follows:

AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people.
Moderately polluted (101–200)	May cause breathing discomfort to 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
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 impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

AQI is considered as ‘One Number- One Colour-One Description’ for the common man to judge the air quality within his vicinity. The formulation of the index was an initiative under Swachh Bharat Mission (Cleanliness Mission), based on the recommendations of IIT Kanpur and the Expert Group formed in this regard. The earlier measuring index in this regard was limited to three indicators, while the current measurement index had been expanded with five additional parameters.[23,25,27]

Construction of the AQI
 Based on the measured ambient air concentrations, corresponding standards and likely health impact (known as health breakpoints), a sub-index is calculated for each of the pollutants. A sub-index is a linear function of concentration (e.g. the sub-index for PM_{2.5} will be 51 at concentration 31 µg/m³, 100 at concentration 60 µg/m³, and 75 at concentration of 45 µg/m³)

The formula for calculating a sub index is as follows:
 Sub Index for a pollutant = Upper limit of the previous AQI category to which the pollutant’s current reading would have fallen +[(current reading – upper limit of the previous reading category of the pollutant)* (width or interval of the AQI category for the current level of reading / width or interval of the current reading category of the pollutant)]

Eg.For PM_{2.5} reading coming at a concentration of 150 µg/m³, the sub index for PM_{2.5} would be = 300+[(150-120)*100/130] = 323

For PM_{2.5} reading coming at a concentration of 45 µg/m³, the sub index for PM_{2.5} would be = 30+[(45-30)*50/30] = 75

The worst sub-index reflects overall AQI. For instance, if the sub index of PM_{2.5} =75, SO₂ = 63, NO₂ =38 then the AQI will be 75 which is the same as the value of the sub index of PM_{2.5}.

The excel sheet for calculating AQI, as uploaded by CPCB, may be seen here.[28,29,30]

The live city wise readings on AQI can be seen here.

The Sub-indices for individual pollutants at a monitoring location are calculated generally using its 24-hourly average concentration value (8-hourly in case of CO and O₃) and health breakpoint concentration range (e.g. AQI at 6 am on a day will incorporate data from 6am on previous day to the current day). However, all the eight pollutants may not be monitored at all the locations. Hence, overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either PM_{2.5} or PM₁₀. Else, data are considered insufficient for calculating AQI. But the sub-indices for monitored pollutants are calculated and disseminated, even if data are inadequate for determining AQI. Further, a minimum of 16 hours’ data is considered necessary for calculating sub index.[31,32,33]

AQI index values can vary depending on the time of the day. AQI reflects the status of the worst pollutant in that city. i.e. higher reading in one city can be due to high concentration of PM whereas in some other city it may be due to SO₂. Even if the other 7 pollutants have a benign reading, if one pollutant is in the “poor” category then AQI will be in the “poor” category.

The web-based system designed to provide AQI on real time basis is an automated system that captures data from monitoring stations (at present available only for 10 cities but it is planned for 46 cities which has over 1 million population and to 20 state capitals) on a continuous basis without human intervention, and displays AQI based on running average values. For manual monitoring stations, an AQI calculator is developed wherein data can be fed manually to get AQI value.[39,50,51]

International comparison of air quality
 WHO also measures air quality across major cities of the globe which may be seen here. The WHO database contains results of ambient (outdoor) air pollution monitoring from almost 1600 cities in 91 countries. Air quality is represented



by annual mean concentration of particulate matter (PM₁₀ and PM_{2.5}, i.e. particles smaller than 10 or 2.5 microns). The world's average PM₁₀ levels by region range from 26 to 208 µg/m³, with a world's average of 71 µg/m³. [35,37,38]

IV. CONCLUSIONS

Ambient air quality refers to the condition or quality of air surrounding us in the outdoors. National Ambient Air Quality Standards are the standards for ambient air quality set by the Central Pollution Control Board (CPCB) that is applicable nationwide. The CPCB has been conferred this power by the Air (Prevention and Control of Pollution) Act, 1981.

Ambient Air Quality Standards in India

The Air (Prevention and Control of Pollution) Act 1981 was enacted by the Central Government with the objective of arresting the deterioration of air quality. The Air (Prevention and Control of Pollution) Act 1981 describes the main functions of the Central Pollution Control Board (CPCB) as follows:

- To advise the Central Government on any matter concerning the improvement of the quality the air and the prevention, control and abatement of air pollution.
- To plan and cause to be executed a nation-wide programme for the prevention, control and abatement of air pollution.
- To provide technical assistance and guidance to the State Pollution Control Board.
- To carry out and sponsor investigations and research related to prevention, control and abatement of air pollution.
- To collect, compile and publish technical and statistical data related to air pollution; and [52,53,55]
- To lay down and annul standards for the quality of air

The mandate provided to the CPCB under the Air (Prevention and Control of Pollution) Act empowers it to set standards for the quality of air.

The current National Ambient Air Quality Standards were notified on 18 November 2009 by the Central Pollution Control Board.

Table 1: National Ambient Air Quality Standards[Northern-India]

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and Other Areas	Ecologically Sensitive Area (notified by Central Government)
Sulphur Dioxide (SO ₂), µg/m ³	Annual* 24 hours**	50 80	20 80
Nitrogen Dioxide (NO ₂), µg/m ³	Annual* 24 hours**	40 80	30 80
Particulate Matter (size less than 10 µm) or PM ₁₀ µg/m ³	Annual* 24 hours**	60 100	60 100
Particulate Matter (size less than 2.5 µm) or PM _{2.5} µg/m ³	Annual* 24 hours**	40 60	40 60
Ozone (O ₃) µg/m ³	8 hours* 1 hour**	100 180	100 180
Lead (Pb) µg/m ³	Annual* 24 hours**	0.50 1.0	0.50 1.0
Carbon Monoxide (CO) mg/m ³	8 hours* 1 hour**	02 04	02 04
Ammonia (NH ₃) µg/m ³	Annual* 24 hours**	100 400	100 400



Benzene (C ₆ H ₆) μg/m ³	Annual*	5	5
Benzo(a)Pyrene (BaP)- particulate phase only, ng/m ³	Annual*	1	1
Arsenic(As), ng/m ³	Annual*	6	60
Nickel (Ni), ng/m ³	Annual*	20	20
<p>* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals. ** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring. Source: National Ambient Air Quality Standards, Central Pollution Control Board Notification in the Gazette of India, Extraordinary, New Delhi, 18th November, 2009</p>			

Prior to the November 2009 standards, India had set Air Quality standards on 11 April 1994, and this was later revised on 14 October 1998. The 2009 standards further lowered the maximum permissible limits for pollutants and made the standards uniform across the nation. Earlier, less stringent standards were prescribed for industrial zones as compared to residential areas.

Further, a new National Air Quality Index (AQI) has been launched in October 2014 to disseminate information on air quality in an easily understandable form for the general public. The measurement of air quality is based on eight pollutants, namely, PM₁₀, PM_{2.5}, NO₂, SO₂, CO, O₃, NH₃, and Pb for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed and the worst reading in these pollutants represents the AQI for that city.[57,58,59]

International Standards

The 2005 World Health Organization's "WHO Air quality guidelines" offer global guidance on thresholds and limits for 4 key air pollutants that pose health risks - particulate matter (PM), ozone (O₃), nitrogen dioxide (NO₂) and sulfur dioxide (SO₂).

Guideline values prescribed by WHO are

- PM_{2.5}
10 μg/m³ annual mean
25 μg/m³ 24-hour mean
- PM₁₀
20 μg/m³ annual mean
50 μg/m³ 24-hour mean
- O₃
100 μg/m³ 8-hour mean
- NO₂
40 μg/m³ annual mean
200 μg/m³ 1-hour mean
- SO₂
20 μg/m³ 24-hour mean
500 μg/m³ 10-minute mean

The WHO Guidelines indicate that by reducing particulate matter (PM₁₀) pollution from 70 to 20 micrograms per cubic metre (μg/m), air pollution-related deaths can be cut by around 15%^[11]. Indian Standards are slightly less stringent as compared to WHO guidelines. However, the world's average PM₁₀ levels by region range from 26 to 208 μg/m³, with a world's average of 71 μg/m³ as per WHO estimates published in 2014.

Many countries have their own Ambient Air Quality Standards prescribed for their territories. The Clean Air Act in the US requires the Environment Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS). Two types of Ambient Air Quality Standards are identified in the Clean Air Act: Primary standards provide public health

protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly and Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.^[2] NAAQS has been set for six pollutants in the US, namely, carbon monoxide, lead, nitrogen dioxide, ozone, particle pollution and sulphur dioxide. The values for these pollutants may be seen here.

The European Union has also developed legislations on air quality standards. The pollutants for which the standards are specified are: PM_{2.5}, sulphur dioxide (SO₂), nitrogen dioxide (NO₂), PM₁₀, lead (Pb), carbon monoxide (CO), Benzene, Ozone, Arsenic (As), Cadmium (Cd), Nickel (Ni), Polycyclic Aromatic Hydrocarbons.[60,61]

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