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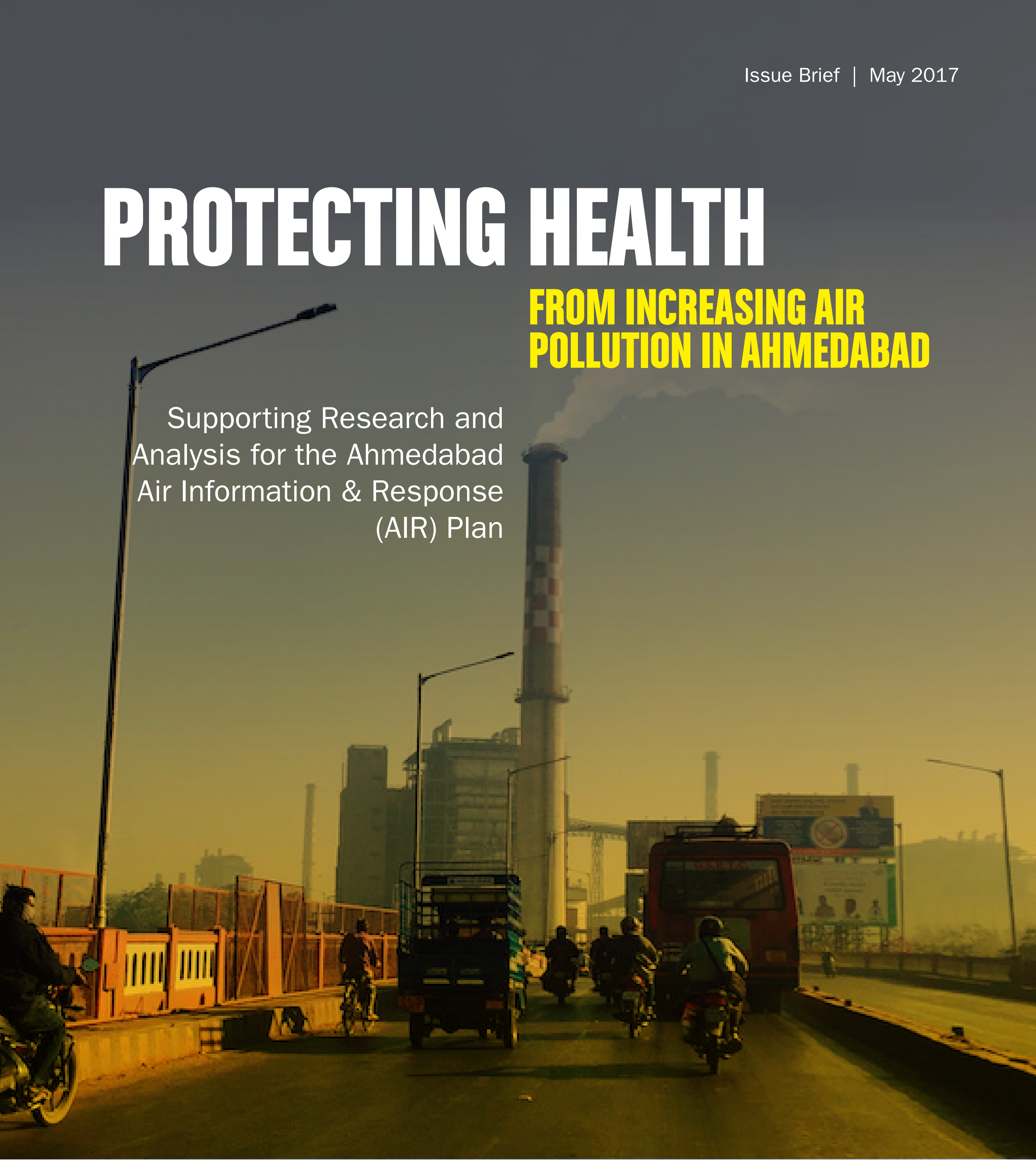
PROTECTING HEALTH

FROM INCREASING AIR POLLUTION IN AHMEDABAD

Supporting Research and Analysis for the Ahmedabad Air Information & Response (AIR) Plan



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SAFAR-Ahmedabad
Air Quality and Weather Monitoring Stations

IITM

About the Partners

Ahmedabad Municipal Corporation

The Ahmedabad Municipal Corporation (AMC) is the municipal governing body of Ahmedabad, responsible for the city's civic infrastructure and administration. Led by its mayor and commissioner, the AMC has pioneered community health strategies and an early warning system for extreme heat events to protect its residents. www.egovamc.com

Indian Institute of Tropical Meteorology, Pune & Indian Meteorological Department – SAFAR

The System of Air Quality and Weather Forecasting and Research (SAFAR) was developed by the Indian Institute of Tropical Meteorology, Pune and the Indian Meteorological Department as a major national initiative, for greater metropolitan cities in India to provide location specific information on air quality in near real time and one-three day advance forecasts. The program was created by the Indian Ministry of Earth Sciences (MoES) and collaborates with the India Meteorological Department (IMD) and National Centre for Medium Range Weather Forecasting (NCMRWF). http://safar.tropmet.res.in

Indian Institute of Public Health, Gandhinagar

The Indian Institute of Public Health, Gandhinagar (IIPH) was launched by the Public Health Foundation of India (PHFI), and is a leader on public health education, advocacy and research on public health. IIPH advances the mandate of equity in public health, applying strategy, resources and networks to the issues and practice of public health in India. IIPH's programs aim to make education and research activities relevant to India in content and context. www.phfi.org

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Natural Resources Defense Council

The Natural Resources Defense Council (NRDC) is one of the most effective environmental groups, combining 1.3 million members and online activists with the expertise of more than 350 scientists and other professionals. NRDC is a leader in public health research, policy, and advocacy—including building resilience in local communities and fighting climate change. In 2009, we launched our India Initiative focused on climate change and clean energy with projects on climate health and clean energy. With our partners, we advocate for increased policy development and implementation to protect communities from environmental threats. www.nrdc.org

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Cover image: Ahmedabad's Chimanbhai Patel Bridge and Sabarmati Power Plant by Dr. Abhiyant Tiwari

Executive Summary

Air pollution is a major global public health risk in cities across the world. It is one of the highest-ranking environmental health challenges in the world, especially in developing countries like India. Ahmedabad is one of India's largest and fastest growing cities with a population over 7.3 million. The World Health Organization (WHO) urban air quality database, and several international and Indian studies have identified Ahmedabad as one of the most polluted cities in the world. In an effort to protect local communities from rising air pollution levels, the Ahmedabad Municipal Corporation (AMC) is developing an air quality index (AQI) with the technical expertise of the Indian Institute of Tropical Meteorology, Pune (IITM) and SAFAR (System of Air Quality and Weather Forecasting And Research).

With rising air pollution levels and deadly health risks, leading cities have developed clean air programs using the AQI. The AQI is the key tool in programs for protecting communities and triggering response actions. AQI programs started in the 1970s and are now in over 100 cities across Asia, Australia, Europe, North America and South America. AQI programs can be nationally-led, such as in Beijing; city-led, such as in Mexico City; or hybrid, such as in Los Angeles. Often, as is the case with the United States, it can take decades to align national, regional, state, and city programs, but it is important to launch the systems to protect public health before the crisis worsens. National systems benefit from federal initiatives and funds, and often have easier access to and facilitated communications with other agencies. Because of the local-nature of air pollution, city-based systems often have a deeper understanding of pollution drivers, the extent to which policies have worked in the past and better community outreach. Cities also have the ability to move quickly on advancing air pollution programs and solutions.

To support the AQI in protecting citizen health in Ahmedabad, the Indian Institute of Public Health Gandhinagar (IIPH-G) and the Natural Resources Defense Council (NRDC) are working with the AMC on information, education, and communication strategies for the new AQI launched in Ahmedabad. The combined efforts of government agencies, health professionals, and community leaders can serve to effectively inform the public about rising air pollution health risks in India, and how to take steps to protect community and individual health.

This issue brief serves to make key recommendations for the AMC in developing a city-wide health risk communication plan based on the AQI. This issue brief has two parts. The first part focused on Ahmedabad and the AQI system with three sections: the first section covers air pollution and associated health impacts in Ahmedabad, the second section covers the AQI, and the third section covers the elements of applying a successful AQI. The second part focuses on the health impacts of air pollution and international practices on health risk communication.

PART I

Ahmedabad Focused Discussions and Air Quality Index Systems

Section 1: Air Pollution and Health

Health Effects of Air Pollution

Air pollution is a major global public health risk in cities across the world. It is one of the highest-ranking environmental health challenges in the world, especially in developing countries like India.[1] In the World Health Organization's (WHO) 2014 urban air quality assessment, 13 of the top 20 most polluted cities for the worst fine particulate air pollution, are located in India.[2] The Indian government found that in 2010, average concentrations of particulate matter (PM) in the air of 180 Indian cities were about six times higher than WHO standards.[3]

Increasing Concern over Particulate Matter Health Effects

Over the past decade, research in air pollution epidemiology has increasingly focused on the harmful effects of exposure to particulate matter (PM). PM is mixture of solids and liquids in the air that can be emitted directly or formed by chemical reactions in the atmosphere.

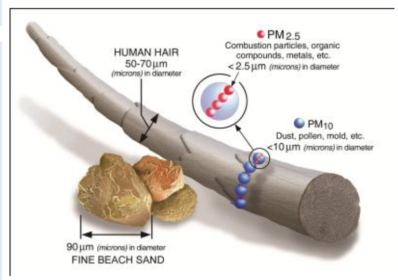

Illustration of the small size of fine particulate matter (PM2.5)

PM_{10} is made up of coarse particles that are 2.5 to 10 micrometers in diameter. $PM_{2.5}$ is made up of finer particles that are 2.5 micrometers in diameter or smaller. PM_{10} comes primarily from motor vehicles, dust and construction and $PM_{2.5}$ comes from many types of combustion, including vehicles, power plants, industry, waste burning, agricultural burning and cooking. Particles less than or equal to 10 micrometers in diameter are so small that they can get into the lungs, potentially causing serious health problems. Ten micrometers is less than the width of a single human hair. Because of its tiny size, $PM_{2.5}$ can rapidly penetrate deep into airways, lungs and the respiratory system causing adverse health effects, even in low pollutant concentrations.[4]

Exposure to $PM_{2.5}$ is linked to heart and lung disease and heart attacks. Other health effects associated with exposure to $PM_{2.5}$ are increased respiratory symptoms, irregular heartbeat, non-fatal heart attacks, development of chronic bronchitis, and decreased lung function.[5] The most vulnerable populations to air pollution are the very young, the elderly, and those with preexisting cardiovascular conditions and asthma, and air pollution affects lung development.[6] A prominent study conducted in North American cities showed that a 10 µg/m^3 increase in PM_{10} was associated with an increase in all-cause mortality of about 0.3% to 0.5%.[7]

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[1] United Nations Environment Programme, Year Book 2014, *Chapter 7 Air Pollution: World's Worst Environmental Health Risk*, 2014 http://www.unep.org/yearbook/2014/PDF/chapt7.pdf (accessed January 12, 2017).

[2] World Health Organization, Global Health Observatory Data Repository, *Ambient (Outdoor) Air Pollution Database, by Country and City*, 2014.

[3] Michael Greenstone and Rohini Pande, "India's particulate problem." *New York Times*, February 9, 2014, http://www.nytimes.com/2014/02/10/opinion/indias-particulate-problem.html (accessed December 2, 2016).

[4] World Health Organization Regional Office for Europe, *Global Air Quality Guidelines Update*, 2005,http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf (accessed December 2, 2016).

[5] C. A. Pope III et al., "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution," *JAMA: The Journal of the American Medical Association* 287, no. 9 (2002): 1132–41.

[6] Hassan N.A. et al., "Impact of climate change on air quality and public health in urban areas," *Asia Pac Journal of Public Health* (2015); Public Health Foundation of India, *Ambient Air Pollution and Public Health: A Call to Action*, March 2014.

[7] Samet J.M. et al, "Morbidity and mortality from air pollution in the United States," The National Morbidity, Mortality, and Air Pollution Study, Research Report 94, Health Effects Institute, Cambridge, MA (2000); Vichit-Vadakan, N., N. Vajanapoom, and B. Ostro, "The Public Health and Air Pollution in Asia (PAPA) Project: Estimating the Mortality Effects of Particulate Matter

A wealth of epidemiological research, carried out by both Indian and international experts, over the past two decades indicates that both acute and chronic exposure to ambient air pollution is associated with adverse health effects. Fine particulate matter or $PM_{2.5}$ (particles of aerodynamic diameter of 2.5 microns or smaller) is consistently implicated as the most damaging pollutant to human health. The WHO recently estimated that ambient air pollution contributes to 3.2 million premature deaths and 76,163,000 disability adjusted life years annually, largely due to the impacts of cardiovascular disease.[8] Of this staggering total, two-thirds of the burden falls in Asia, where $PM_{2.5}$ concentrations are highest.[9] Estimates are that 92% of the world's population lives in places where the mean annual air quality levels are above WHO ambient air quality guidelines for fine particulate matter ($PM_{2.5}$).[10] While air quality standards vary in coverage and stringency across countries and global regions, the WHO guidelines provide reference points and health risks.[11]

According to scientific studies in India, several cities and regions suffer from polluting emissions and resulting poor air quality. Data collected by the Central Pollution Control Board (CPCB) in 2010 showed that 82% of 360 monitored sites across India exceed national air quality standards for particulate matter.[12] A 2013 study conducted by the Centre for Science and Environment (CSE) found that very few Indian cities (only two, Malapuram and Pathanamthitta in Kerala) had "low" air pollution concentration according to national standards.[13]

High levels of pollution are taking a toll on public health in India.[14] A 2010 study by the Institute for Health Metrics and Evaluation (IHME) estimated 695,000 deaths in India resulted from air pollution, with a loss of 18.2 million healthy years of life.[15] The same study discovered substantial increases in the following illnesses due to air pollution: ischemic heart disease; chronic obstructive pulmonary disorder; lower respiratory infections; bronchitis; and cancers of the trachea and lungs.

Exposure to ambient concentrations of fine PM ($PM_{2.5}$) is the sixth leading risk factor for disease and early death in South Asia and the ninth worldwide.[16] While larger particles (PM_{10}) are typically blocked from deposition by our natural defense mechanisms (e.g., coughing, sneezing, or swallowing) and mid-range particles are typically inhaled and exhaled, fine and ultra-fine particles can penetrate deep into the lungs and alveolar sacs after inhalation.[17] An analysis of pollution estimates by the Centre for Science and the Environment in Delhi suggests that 141 Indian cities experience PM_{10} pollution levels exceeding

in Bangkok, Thailand," *Environmental Health Perspectives* 116, no. 9 (2008): 1179–1182; International Energy Agency, *Word Energy Outlook Special Report on Energy and Air Pollution*, 2016, http://www.worldenergyoutlook.org (accessed December 2, 2016).

[8] Lim, S.S., et al., "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010," *The Lancet* 380, no. 9859 (December 2012): 2224–60, doi:10.1016/S0140-6736(12)61766-8.

[9] Cohen, Aaron J., et al. "Urban air pollution." *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors* 2 (2004): 1353-1433.

[10] World Health Organization, "WHO releases country estimates on air pollution exposure and health impact," News Release, September 27, 2016,http://www.who.int/mediacentre/news/releases/2016/air-pollution-estimates/en/ (accessed December 2, 2016).

[11] International Energy Agency, *Word Energy Outlook Special Report on Energy and Air Pollution*, 2016,http://www.worldenergyoutlook.org.

[12] Central Pollution Control Board, "National Ambient Air Quality Status & Trends in India – 2010," 2012.

[13] Centre for Science and Environment, "Burden of Disease: Outdoor Air Pollution Among Top Killers," February 13, 2013, http://www.cseindia.org/userfiles/briefing_note13feb.pdf (accessed November 28, 2016).

[14] Balakrishnan K, Rajarathnamet U, et al., "Public Health and Air Pollution in Asia (PAPA): Coordinated Studies of Short-Term Exposure to Air Pollution and Daily Mortality in Two Indian Cities" Health Effects Institute, Research Report 157, March 2011.

[15] Institute for Health Metrics and Evaluation, "The Global Burden of Disease 2010: Generating Evidence and Guiding Policy," 2013; Guttikunda, S.K., R. Goel, and P. Pant, "Nature of Air Pollution, Emissions Sources, and Management in Indian Cities," *Atmospheric Environment* 95 (2014): 501-510.

[16] Lim, S.S., et al., "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010," *The Lancet* 380, no. 9859 (December 2012): 2224–60, doi:10.1016/S0140-6736(12)61766-8.

[17] Oberdörster, G., E. Oberdörster, and J. Oberdörster, "Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles," *Environmental Health Perspectives* 113, no. 7 (March 22, 2005): 823–39, doi:10.1289/ehp.7339.

the 2009 national standards of 60 µg/m^3, itself a far more generous standard than the corresponding WHO annual air quality guideline of 20 µg/m^3.[18]

Pollutant	Averaging Time	Indian National Standard, 2009	WHO Guideline Values	WHO-Interim Target 1	WHO-Interim Target 2	WHO-Interim Target 3
PM_{10} (µg/m^3)	Annual 24-hour	60 100	20 50	30 75	50 100	70 150
$PM_{2.5}$ (µg/m^3)	Annual 24-hour	40 60	10 25	15 37.5	25 50	35 75

Table 1: Indian National Ambient Air Quality Standards (NAAQS) for PM_{10} and $PM_{2.5}$, and corresponding World Health Organization guideline values and interim targets

Importantly, fine particulate matter pollution in parts of India is expected to worsen in the coming decades due to continuing urban expansion and the country's heavy reliance on coal for electricity generation.[19] By 2030, high levels of fine particulate matter are projected to pervade across most of the country, with concentrations in the Ganges Valley increasing to more than 150 µg/m^3.[20]

After particulate matter, ground-level ozone (O_3) and its nitrogen oxide (NO_X) precursors are the next priority pollutants in India. The WHO estimates that 19 cities experience NO_2 levels that exceed the national annual standard (40 µg/m^3), a level at which adverse health effects, particularly impaired lung development in infants, are still likely.[21] Importantly, many cities are out of compliance for both PM_{10} and NO_2. After NO_2 and O_3, sulfur dioxide (SO_2) is the priority next target for mitigation, as one city currently exceeds the annual (50 µg/m^3) standard and moderate levels are observed in eleven additional cities.

Key Air Pollution Sources in Ahmedabad

Ahmedabad, Gujarat

- Area: 466 square kilometers
- Population: 7.3 million
- Population Density: 11,948 per square kilometer
- Climate: Semi-Arid
- Average Rainfall: 782 millimeters per year
- Relative Humidity: 60 percent

Ahmedabad is one of India's largest and fastest growing cities with a population over 7.3 million.[22] The WHO urban air quality database, and several international and Indian studies have identified Ahmedabad as one of the most polluted cities in the world. New Delhi, Beijing and other Asian cities are at the top of this list and grappling with increasing air pollution levels.

[18] Health Effects Institute, "Burden of Disease: Outdoor Air Pollution among Top Killers," 2013, http://www.cseindia.org/userfiles/briefing_note13feb.pdf; Central Pollution Control Board, "National Ambient Air Quality Standards," November 18, 2009, http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php; World Health Organization, *Air Quality Guidelines: Global Update 2005: Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide* (Copenhagen, Denmark: World Health Organization, 2006).

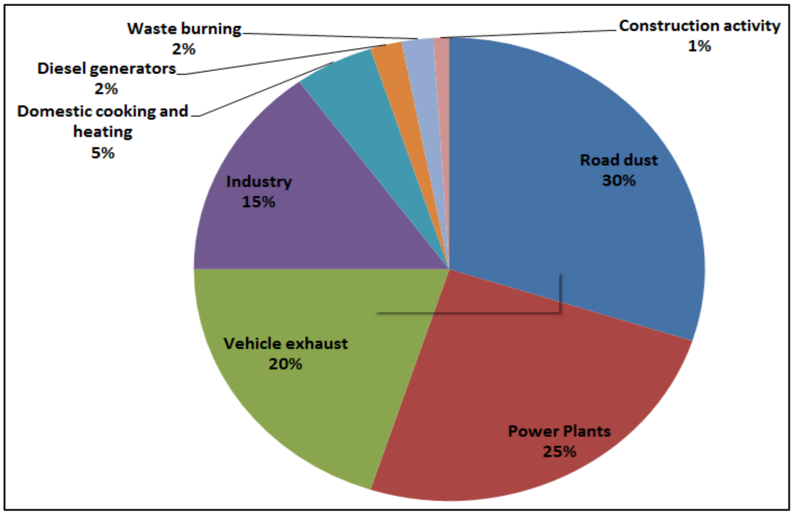
[19] Ramanathan, K., and The Energy and Resources Institute, *National Energy Map for India: Technology Vision 2030 Summary for Policy-Makers*, TERI, 2003.

[20] Purohit, P., M. Amann, and R. Mathur, "GAINS-Asia: Scenarios for Cost-Effective Control of Air Pollution and Greenhouse Gases in India," 2010, http://gains.iiasa.ac.at/gains/reports/GAINS-Asia-Methodology-20081205.pdf.

[21] World Health Organization, *Air Quality Guidelines*.

[22] World Health Organization, *Global Ambient Air Interactive Map*, 2016.http://maps.who.int/airpollution/ (accessed December 2, 2016).

In 2010, the Government of India, through the Ministry of Environment, Forests and Climate Change (MOEFCC), issued a memorandum that declared Ahmedabad and other key cities as critically polluted areas. The MOEFCC directed industries to take necessary pollution control measures, adopt clean technology, reduce waste or face penalties. Taking a cue from the central government's orders, the Gujarat Pollution Control Board (GPCB) in Gandhinagar is actively working with the city of Ahmedabad to address air pollution through a city clean air program.[23]



Major contributors to PM10 in Ahmedabad (S. Guttikunda et al 2012)
Source: http://shaktifoundation.in/wp-content/uploads/2014/02/urban%20air%20pollution%20analysis%20-%20india%206%20cities%202011%2009%2013.pdf

Air pollution is emitted from several local sources in Ahmedabad. Available studies suggest that rapid urban growth has led to increase in air pollution from vehicle-related emissions and stationary sources in Ahmedabad. From 2001 to 2011, the number of vehicles, including motorcycles and scooters, doubled in Ahmedabad, while the population grew by 58%.[24] Ahmedabad has two thermal coal-fired power plants: the 800 MW Gandhinagar plant and the 400 MW Sabarmati plant, one of the oldest in India. The city also has almost 3,000 industrial units including 855 chemical factories, 511 foundries and 380 textile plants among others.[25] The surrounding low-efficiency brick kilns and trash burning also contribute to air pollution in the city.

A major 2012 study by Urban Emissions, a research organization, evaluated air quality in six Indian cities: Ahmedabad, Surat, Rajkot, Pune, Indore and Chennai.[26] The study examined pollution levels and sources and then modeled emissions, with a focus on PM_{10}. The study found that the major sources for PM_{10} in Ahmedabad are: 30% road dust; 25% power plants; 20% vehicle exhaust; 15% industry; 5% domestic cooking and heating; 2% diesel generator sets; 2% waste burning and 1% construction activities.

[23] Gujarat Central Pollution Control Board, http://www.gpcb.gov.in/About-Board1.htm (accessed December 2, 2016).

[24] Parth Shastri, "Vehicle population grew at double the rate than human population in Ahmedabad," *Economic Times*, January 15, 2014, http://economictimes.indiatimes.com/industry/vehicle-population-grew-at-double-the-rate-than-human-population-in-ahmedabad/articleshow/28827664.cms (accessed December 2, 2016); Ahmedabad RTO Regional Transportation Office, 2014.

[25] Gujarat Pollution Control Board, December 2016 presentation.

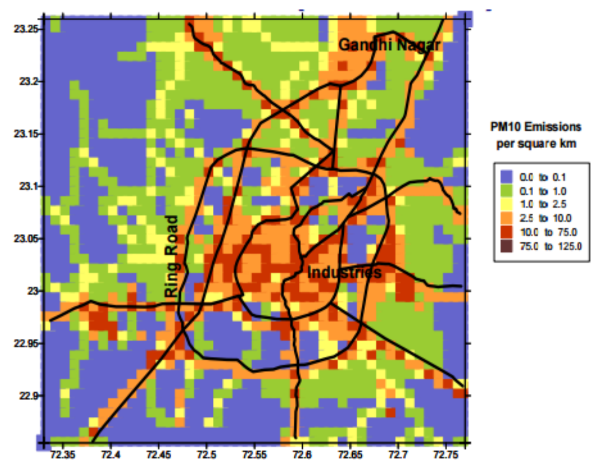
[26] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016); Ahmedabad RTO Regional Transportation Office, 2014; Parth Shastri, "Vehicle population grew at double the rate than human population in Ahmedabad," *Economic Times*, January 15, 2014, http://economictimes.indiatimes.com/industry/vehicle-population-grew-at-double-the-rate-than-human-population-in-ahmedabad/articleshow/28827664.cms (accessed December 2, 2016).

Transportation

Direct vehicle exhaust is a dominant source of air pollution in Ahmedabad. Vehicles, especially two-wheelers and diesel-based trucks, account for over 20% of PM_{10} pollution in Ahmedabad.[27] Two-wheeler motor vehicles including mopeds, scooters and motorcycles, all with a mix of two- and four- stroke engines, have grown rapidly in Ahmedabad and make up the largest number of passenger kilometers travelled as well as the most rapidly growing fleet of vehicles. An estimated 30-40% of two-wheelers in Ahmedabad have two-stroke engines, which are considered to be less fuel-efficient than four-stroke models. As in most Indian cities, Ahmedabad bans heavy-duty vehicles during daytime hours. However, the number of light-duty vehicles on the roads during the day and number of heavy-duty vehicles in the night, have increased rapidly. A GIS analysis carried out by Urban Emissions for PM_{10} emissions shows that motorcycles and automobiles as the primary vehicular emission sources in the city center; trucks remain mostly confined to the highways.[28] Further, while Ahmedabad, like other large cities in India, uses the National Fuel Policy's Bharat emission and fuel regulations, compliance is a challenge in the city. [29]

Road Dust in Ahmedabad

Road dust from automobiles, two-wheelers, trucks and other vehicles is a major problem in Ahmedabad, and other cities. Road dust accounts for over 25% of PM_{10} levels in Ahmedabad.[30] Direct vehicle exhaust is the largest contributor of $PM_{2.5}$ and road dust is the largest contributor for PM_{10}, according the 2012 Urban Emissions study.[31] Road-carpeting using asphalt or tar can reduce road dust resuspension – a major contributor to PM_{10} and $PM_{2.5}$. Road carpeting is a cheaper and faster option than building concrete roads. However, asphalt roads often inhibit water penetration into the earth and are easily damaged by extreme weather and rain. Melting asphalt also produces greenhouse gases, and VOCs and carbon monoxide (CO) are emitted during the paving process.



PM10 emissions per square km in Ahmedabad. Source: https://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf

Thermal Power Plants in Ahmedabad

Ahmedabad's electricity grid is supplied by two thermal power stations, both coal-fired. The first, the Sabarmati 400 MW power station is situated on the Sabarmati river and the second, larger 800 MW power station in Gandhinagar. The Sabarmati plant is one of the oldest power stations in India, operating since 1934. Based on available data, stack location, consumption and production rates, the Urban Emissions study found that the Ahmedabad power plants are a "major source" of emissions.[32] The Urban Emissions dispersion models found high emissions levels related to the plants for both PM_{10} and $PM_{2.5}$.

[27] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016).

[28] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016).

[29] Diesel Net, *Emissions Standards Review for India*, 2016,https://www.dieselnet.com/standards/in/ (accessed December 2, 2016).

[30] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016).

[31] *Ibid*.

[32] Urban Emissions, *Urban Air Pollution Analysis in India*, September 2011, http://shaktifoundation.in/wp-content/uploads/2014/02/urban%20air%20pollution%20analysis%20-%20india%206%20cities%202011%20%2009%2013.pdf (accessed December 2, 2016).

Three additional studies found concentrations of SO_2, NO_X, suspended particulate matter, and mercury surrounding the Gandhinagar plant.[33] While not directly linked to the Ahmedabad thermal plants, studies on thermal plants in India and internationally show higher pollution levels, including particulate matter, SO_2, and mercury among others. In addition, communities living near thermal plants experience higher rates of chronic respiratory illness, asthma, cancer and premature death.[34]

Brick Kilns, Construction, Diesel Generators, Cooking Fuels and Waste Burning

The brick kilns surrounding Ahmedabad contribute to 6-15% percent of the city's emissions because of inefficient baking methods, the use of coal and biomass burning as fuel sources, soil transfer from the quarries to the manufacturing kilns, and heavy-duty vehicles used for transport. Burning of coal and biomass results in high emissions of NO_X, PM, CO, and CO_2.[35] With rapid urbanization, construction practices for buildings, roads and infrastructure also contribute to air pollution. Diesel generators, often used for back-up power and for telecom towers, are another growing source of pollution. Domestic cooking and heating emissions, especially from low-income communities that use coal and biomass as fuel can contribute to air pollution. Waste burning, including from the Pirana dumpsite, is another major source of pollution.[36] Waste management programs need to be improved, and domestic waste is often burned, leading to PM, toxic, and carcinogenic emissions.

Ahmedabad Wind and Weather

Ahmedabad's inland location, as well as its dry and hot climate can worsen air pollution in the city.[37] Wind patterns, rainfall and temperatures all affect long-lived pollutants in a region with air pollution flowing into and out of the city.[38] In Ahmedabad, winds blow mainly from the southwest in the summer and the northeast in the winter. Based on initial examination of thermal plants, the Sabarmati power plant is in the city and can directly impact air quality while the Gandhinagar power plant is located on the northeastern edge of Ahmedabad and can impact winter air pollution levels. Rainfall also contributes to the rate of removal and resuspension from all air pollution sources.

Air Pollution Levels and Health Effects in Ahmedabad

While SO_2, NO_X, O_3, ammonia (NH_3), CO, coarser particles (PM_{10}), fine particles ($PM_{2.5}$), lead (Pb), arsenic (As), nickel (Ni), benzene and benzo-a-pyrene are all major pollutants, PM_{10} and $PM_{2.5}$, are the primary pollutants of concern and most frequently monitored in Ahmedabad, because they can penetrate deeply into the respiratory tract and pose grave health risks.

Since at least 2008, Ahmedabad has exceeded both WHO standards and India's air quality standards for particulate matter. The WHO Global Ambient Air map reports annual mean concentrations of 100 $\mu g/m^3$ for $PM_{2.5}$ and 83 $\mu g/m^3$ for PM_{10},[39] in Ahmedabad for 2013 and 2012, respectively.[40] PM_{10} levels in Ahmedabad exceeded permissible limits for all five years between 2008 and 2012, exceeding the national

[33] Mukherjee, S., and D. Chakraborty *Environmental Scenario in India: Successes and Predicaments* (Routledge, 2013); Pirrone, N., and R. Mason, *Mercury fate and transport in the global atmosphere* (Dordrecht, The Netherlands: Springer, 2009); Garg, A. et al., "Sub-region (district) and sector level SO_2 and NO_X emissions for India: assessment of inventories and mitigation flexibility," *Atmospheric Environment* 35, no. 4 (2001): 703-713.

[34] Guttikunda S.K. and R. Goel, "Health Impacts of Particulate Pollution in a Megacity—Delhi, India." *Environmental Development* 6 (2013): 8-20; World Health Organization, *Air Quality Standards Report*; World Health Organization, *Quantification of the Health Effects of Exposure to Air Pollution*, 2000; Analitis, A., et al., "Short-term Effects of Ambient Particles on Cardiovascular and Respiratory Mortality," *Epidemiology* 17, no. 2 (2006): 230-3; Health Effects Institute, *Outdoor Air Pollution and Health in the Developing Countries of Asia: A Comprehensive Review*, 2010; World Health Organization, "Seven Million Premature Deaths Annually Linked to Air Pollution," News Release, March 25, 2014.

[35] World Health Organization, *Air Quality Guidelines: Global Update 2005: Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide*, 2006.

[36] Paul John, "Mount Pirana casts toxic shroud," *Times of India*, November 8, 2016, http://timesofindia.indiatimes.com/city/ahmedabad/Mount-Pirana-casts-toxic-shroud/articleshow/55308874.cms (accessed December 2, 2016).

[37] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016); Urban Emissions, *Urban Air Pollution Analysis in India*, September 2011, http://shaktifoundation.in/wp-content/uploads/2014/02/urban%20air%20pollution%20analysis%20-%20india%206%20cities%202011%2009%2013.pdf (accessed December 2, 2016).

[38] Daniel J. Jacob, *Introduction to Atmospheric Chemistry* (Princeton, N.J: Princeton University Press, 1999).

[39] World Health Organization, *Global Ambient Air Interactive Map*, 2016, http://maps.who.int/airpollution/ (accessed December 2, 2016).

[40] Ahmedabad's yearly averages for PM for 2014-15: state program (SAMP), S. No. 14-15; national program (NAMP), S. No. 22-18.

standards in India, which are less restrictive than the WHO guidelines, by 30–50%.[41] Similarly, studies show that $PM_{2.5}$ levels in Ahmedabad also exceed national standards.[42]

In addition to PM, O_3, NO_X, CO and polycyclic aromatic hydrocarbons (PAH) are also of concern in Ahmedabad. According to pollution experts, Ahmedabad's high $PM_{2.5}$ and O_3 levels, pose serious health risks, such as more premature deaths, increased hospitalizations and emergency room visits for respiratory and cardiovascular illnesses, allergic effects and increased risks of bacterial or fungal infection and fibrosis.[43]

In 2010, Ahmedabad experienced over 4,900 premature deaths attributed to excessive ambient air pollution, as estimated by recent research.[44] Deteriorating air quality in Ahmedabad has also resulted in serious health concerns including increased morbidity, especially affecting vulnerable populations.

Section 2: AQI and Health Advisories

Building Citizen Awareness with the AQI

An Air Quality Index, or the AQI, is a tool that communicates information on air quality in qualitative terms (for example, good, satisfactory, poor) which makes citizens aware of associated health impacts and facilitates greater public participation in air quality improvement efforts. It is employed by cities, states, and countries around to the world to communicate present and future health risks of air pollution to residents. The AQI communicates simplified air pollution information based on data collected through national monitoring systems that may not always be collected or reported in a form that is understood easily by the public. Additionally, the AQI also provides detailed data on how to protect health from air pollution and to guide pollution-reducing policies and regulations.[45]

The AQI provides an index number for reporting daily air quality, on a scale from 0 to 500. The higher the AQI value, the greater the level of air pollution that day, and the greater the potential health concerns. Typically, AQI values of 100 correspond to the national air quality standard for each pollutant, so AQI values of 100 or less are generally considered satisfactory. An AQI value of 50 would represent good air quality with low risks to public health, but an AQI value of 300 would represent air quality so hazardous that even healthy people may feel its respiratory effects.[46] The AQI serves as a communication bridge to members of the public that can summarize complex air quality information in a single number and associated color code. AQIs have variations in different locations and settings (see AQI figure below), but most AQI systems have two common characteristics:

- a table with different levels of air pollution and health risks, ranging from minimal to severe; and
- color-coding to distinguish these levels, also known as "breakpoints"

The breakpoints distinguishing different AQI levels are tied to the wealth of scientific, epidemiologic evidence that links air pollution to adverse health effects among specific vulnerable populations. As such, the communication of AQI information to members of the public also depends on the identification of specific target audiences that are especially vulnerable to air pollution.

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[41] World Health Organization, *Global Urban Ambient Air Pollution Database*, 2016, http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ (accessed September 27, 2016).

[42] World Health Organization, *Global Urban Ambient Air Pollution Database*, 2016, http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ (accessed September 27, 2016); Dey, S. et al., "Variability of outdoor fine particulate ($PM_{2.5}$) concentration in the Indian Subcontinent," *Remote Sensing of Environment* (2012): 153-161.

[43] B Sengupta, "Ahmedabad ranks among India's most polluted cities," *Times of India*, December 15, 2015, http://timesofindia.indiatimes.com/city/ahmedabad/Ahmedabad-ranks-among-Indias-most-polluted-cities/articleshow/50181733.cms (accessed December 2, 2016); American Lung Association, "Health Effects of Ozone and Particle Pollution," 2016.

[44] Guttikunda, S.K. and P. Jawahar, "Application of SIM-Air Modeling Tools to Assess Air Quality in Indian Cities," *Atmospheric Environment* 62 (2012), http://www.cobenefit.org/cop18/pdf/DRI/2012-10-AE-AP-in-Six-Indian-Cities.pdf (accessed December 2, 2016).

[45] Central Pollution Control Board, *Non-Attainment*, 2008, http://cpcb.nic.in/Non_attainment.php (accessed September 27, 2016).

[46] United States Environmental Protection Agency, *AQI: A Guide to Air Quality and Your Health*, EPA-456/F-14-002, February 2014, https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf (accessed December 2, 2016).

An AQI summarizes a rating for the quality of the air city residents are breathing, and an associated level of potential health impacts. In situations where multiple air pollutants are monitored concurrently, the AQI typically reflects the air quality and associated health effects for the most dominant pollutant. The AQI is calculated through an analysis of local weather and outdoor air pollution data. AQI values tend to vary seasonally, and depending on the time of day. For example, ground-level O_3 tends to be higher in the hotter summer months, because heat and sunlight increase O_3 formation. Ozone smog also often peaks in the afternoon to early evening hours.

Air quality indices and air quality monitoring are done all around the world, with different agencies responsible in different areas. For instance, in India, the air quality monitoring network is coordinated on the national level by the CPCB and the Indian Institute of Tropical Meteorology (IITM) network called SAFAR (System of Air Quality and Weather Forecasting And Research).[47] In Mexico City, on the other hand, the AQI/Air Quality Management system is run by the municipality.[48]

Monitoring Air Pollution in Ahmedabad

There are more than 20 monitoring stations in Ahmedabad operated and managed by several entities. Of the stations, 15 are operated by the GPCB, six by the AMC, one by Torrent Power and several others by the Gujarat Environmental Management Institute. IITM, Pune is installing eight new ambient air quality monitoring stations for the new SAFAR AQI system in Ahmedabad in collaboration with the AMC.

List of GPCB Ambient Air Quality Monitoring Stations in Ahmedabad

1. Cadila Laboratory, Narol
2. LD Engineering College, Navrangpura
3. Shardaben Hospital, Saraspura
4. RC Technical School, Mirzapur
5. Behrampura Referral Hospital, Bodakdev
6. Jodhpur Urban Health Centre, Satellite
7. Ashram Road, Nehrubridge
8. Police Chowky, Naroda
9. Mukesh Industries, Narol
10. SP Ring Road, Odhav
11. Centre of Excellence, VIA, Gujarat Industrial Development Corridor, Vatva
12. Rakhiyal WDS, Rakhiyal
13. Dyno Wash, Pirana Dumpsite, Narol
14. Sola Pumping Station, Sola
15. Maninagar (continuous monitoring)

The GPCB Ambient Air Quality Monitoring (AAQM) stations in Ahmedabad report results from 7-10 days of monitoring and measure SO_2, NO_X, O_3, NH_3, CO, PM_{10}, $PM_{2.5}$, Pb, As, Ni, benzene and Benzo-a-pyrene. These monitoring stations record data twice a week, for at least 104 samples per year (as per CPCB guidelines). Three more AAQM stations are maintained in Gujarat Industrial Development Corridor (GIDC) areas for monitoring of VOCs only. As of June 2011, one continuous AAQM station is operated by the GPCB at Maninagar. The monitoring results from the AAQM stations are periodically unavailable because of technical difficulties.

Ambient air and meteorological data are submitted by the local meteorological department to the CPCB for compilation and reporting. GPCB also collects ambient air pollution data from all stations once each week for 12 hours, and calculates annual air pollution averages for each year from that data. These results from 2014-2015 are displayed on GPCB's website for nine stations in the city of Ahmedabad both under the National Air Quality Monitoring Program and the State Air Quality Monitoring Program (Table 2).

Table 2: Status of Ambient Air Quality Monitoring (AAQM) from the National Air Quality Monitoring Program (NAMP) Project and the State Air Quality Monitoring Program (SAMP) – Yearly Average (2014-2015) [all parameters in $\mu g/m^3$]

[47] Central Pollution Control Board, *About National Air Quality Index*, 2008, http://cpcb.nic.in/About_AQI.pdf (accessed September 28, 2016); Indian Institute of Tropical Meteorology, *SAFAR Monitoring Network*,http://safar.tropmet.res.in/MONITORING%20SYSTEM-10-3-Details (accessed September 27, 2016). More general information on SAFAR can be found online at: http://safar.tropmet.res.in/.

[48] Mexico City-Harvard Alliance for Air Quality and Public Health, *Data*,https://www.hsph.harvard.edu/cdmx/resource-library/data-reports/ (accessed September 20, 2016).

	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	SO_2 (µg/m^3)	NO_X (µg/m^3)	O_3 (µg/m^3)	NH_3 (µg/m^3)	CO (mg/m^3)	Pb (µg/m^3)	As (ng/m^3)	Ni (ng/m^3)	Benzene (µg/m^3)	Benzo-a-pyrene (ng/m^3)
Indian NAAQS (Annual)	**60**	**40**	**50**	**40**	**100**	**100**	**2 (8-hr)**	**0.5**	**6**	**20**	**5**	**1**
National Air Quality Monitoring Program												
Cadila, Narol	91	33	13.6	20.9	12	10.2	1.42	0.09	<1.0	2.1	1.8	<0.5
LD Engg. College	83	29	12.4	20	11.3	9.5	1.28	0.08	<1.0	1.3	1.4	<0.5
Shardaben Hospital	83	30	12.3	19.5	12.4	9.8	1.36	0.07	<1.0	1.4	2.1	<0.5
R.C. Tech. High School	84	30	12.3	19.4	12.1	9.7	1.28	0.08	<1.0	1.4	1.6	<0.5
Behrampura Referral Hospital	85	31	12.9	20.05	12.7	10.3	1.4	0.07	<1.0	1.5	1.5	<0.5
Bhagavathi Estate	93	37	13.8	21.1	11.6	10.6	1.59	0.1	<1.0	1.8	1.9	<0.5
Reliable Products	92	32	13.4	20.7	12	10.2	1.48	0.07	<1.0	1.4	1.8	<0.5
State Air Quality Monitoring Program												
Nehru Bridge	95	36	14.9	22.3	12.6	9.8	1.63	0.19	<1.0	2.3	2.7	<0.5
Satellite Road	80	29	13.9	20.8	12.8	10.4	1.28	0.08	<1.0	1.5	1.7	<0.5

The AMC operates stations in six different locations in the city as listed below.

List of AMC Ambient Air Quality Monitoring Stations in Ahmedabad

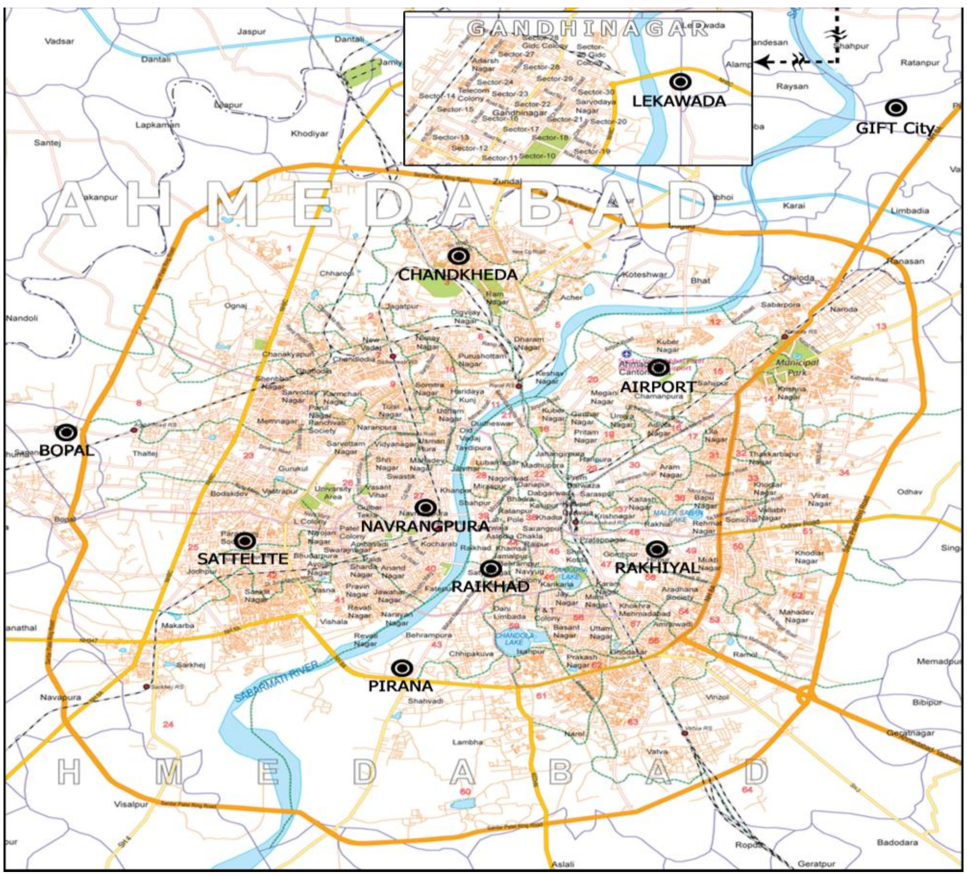
1. Nava Vadaj Circle
2. Narol Cross Road
3. Paldi Bus Station
4. Pakwan Cross Road
5. Income Tax Road
6. Panchwati

In addition to multiple monitoring entities, the AQI reporting for Ahmedabad can come from various sources and agencies, including the GPCB. For example, in New Delhi, the AQI readings are available from the CPCB, SAFAR, the United States Embassy monitor, and other international sources such as the World Air Quality Index Network[49] or AQICN.

Multiple monitoring systems provide complementary methods and more information to help evaluate future meteorological or air quality conditions, and the health risks they pose. Multiple AQI systems ultimately provide a breadth of information that can inform more health-protective air quality management decisions, as in Ahmedabad where two sources of temperature forecasts (the Indian Meteorological Department and a piloted Georgia Tech system) were used during preparation of the city's Heat Action Plan.

The System of Air Quality and Weather Forecasting and Research[50] (SAFAR) AQI

To protect public health and improve air quality the AMC is partnering with IITM, Pune to develop a new AQI for the city. Currently, SAFAR's AQI operates in: New Delhi, Pune, and Mumbai with plans to expand to Ahmedabad in 2016-2017. This AQI is an independent effort of the MoES and differs from the AQI implemented by the CPCB under the Ministry of Environment, Forests and Climate Change. For Ahmedabad, SAFAR will install and operate an air quality monitoring network with eight stations across the city of Ahmedabad.

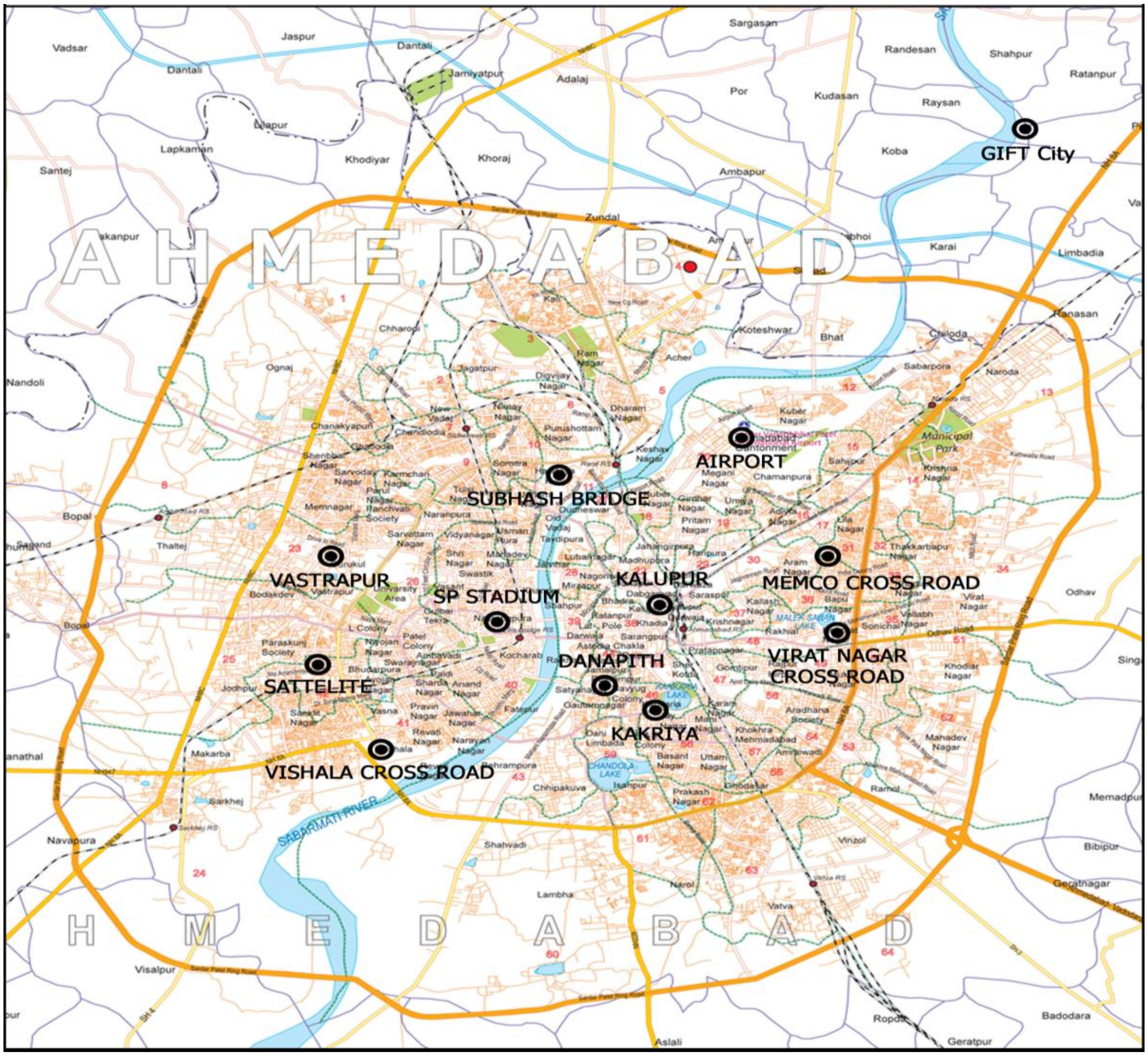


SAFAR Air Quality and Monitoring Stations in Ahmedabad (Source: IITM, SAFAR)

[49] The World Air Quality Index site (WAQI), 2016. Information at https://aqicn.org/contact/.

[50] Indian Institute of Tropical Meteorology, *SAFAR Monitoring Network*, 2016, http://safar.tropmet.res.in/MONITORING%20SYSTEM-10-3-Details (accessed September 27, 2016).

As part of the Government of India through IITM, Pune, SAFAR provides location-specific information on air quality in near real-time and forecasts one-two days in advance.[51] This information is combined with an early warning system of weather parameters. SAFAR was developed by IITM, Pune along with the Indian Meteorological Department (IMD). The objective of the SAFAR project is to engage the public and spread citizen awareness about local air quality issues. SAFAR is designed to inform locally-relevant air pollution control measures and systematic actions to reduce health risks associated with air pollution exposure.



SAFAR Digital Display Boards Network in Ahmedabad (Source: IITM - SAFAR)

According to SAFAR, "SAFAR sensors are established within city limits, about 3 meters from the ground, and represent specific microclimates of the city such as industrial, residential, background concentrations, urban complex, and agricultural zones. Sensors are always operational and record data in 5 minute intervals and undergo a rigorous quality check and assurance." SAFAR systems monitor PM_1,

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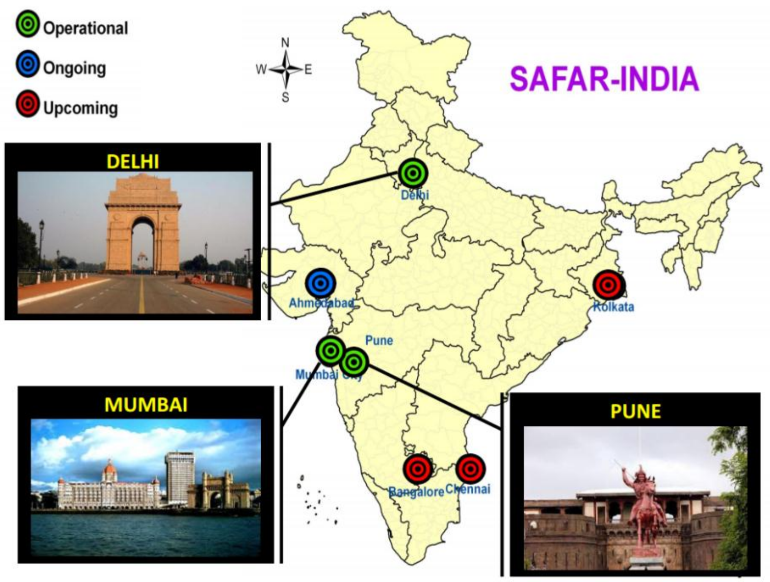
[51] Indian Institute of Tropical Meteorology, *SAFAR Forecast Modelling and Supercomputing*, 2016, http://safar.tropmet.res.in/FORECASTING-46-4-Details (accessed December 2, 2016).

$PM_{2.5}$, PM_{10}, O_3, CO, NO_X (NO, NO_2), SO_2, black carbon, methane (CH_4), non-methane hydrocarbons (NMHC), VOCs, benzene, and mercury. Monitored meteorological parameters include UV radiation, rainfall, temperature, humidity, wind speed, and wind direction. This is the first network in India that continuously monitors all these air pollution and weather parameters, and maintains a current database with robust quality control and quality assurance measures.[52]

Map of cities where SAFAR is operational in 2016, and cities to where it plans to



SAFAR's AQI Scale

SAFAR uses an AQI system in which the reported AQI is the highest AQI value from among the criteria pollutants being measured and reported for the time period in question. SAFAR calculates its AQI in two parts: first by forming sub-indices and individual AQI readings for each air pollutant; and second, by determining the health-relevant breakpoints of these sub-indices. [53] Breakpoints are decided by each country's National Ambient Air Quality Standards (NAAQS), in conjunction with epidemiological studies describing the relation between air pollution exposures and adverse health risks. Different air pollutants pose health risks to different sensitive groups, when their AQI exceeds 100. The raw concentration measurements from monitoring stations are converted into separate AQI sub-index values for each air pollutants that comprise the AQI. The highest of these sub-index AQI values determines the overall AQI value for the day.

When the AQI is above 100, in some countries, agencies also report which groups are especially vulnerable or sensitive to that pollutant—for example, children, or people with asthma or heart disease. If two or more individual air pollutants have AQI values over 100, all sensitive groups should be reported. For example, if a city's AQI is 140 for particle pollution and 105 for O_3, the AQI value that day would be announced as 140 for particle pollution, and also note that O_3 smog levels are also high, alerting groups

[52] Indian Institute of Tropical Meteorology, *SAFAR Forecast Modelling and Supercomputing*, 2016, http://safar.tropmet.res.in/FORECASTING-46-4-Details (accessed December 2, 2016).

[53] SAFAR also uses a segmented linear function to relate the actual concentrations of each pollutant to a non-dimensional number (the AQI). A linear segmented function uses straight-line segments to join discrete coordinates. In this case, the discrete coordinates are the AQI breakpoints. The following equation converts the concentration of key air pollutants to its respective AQI value:

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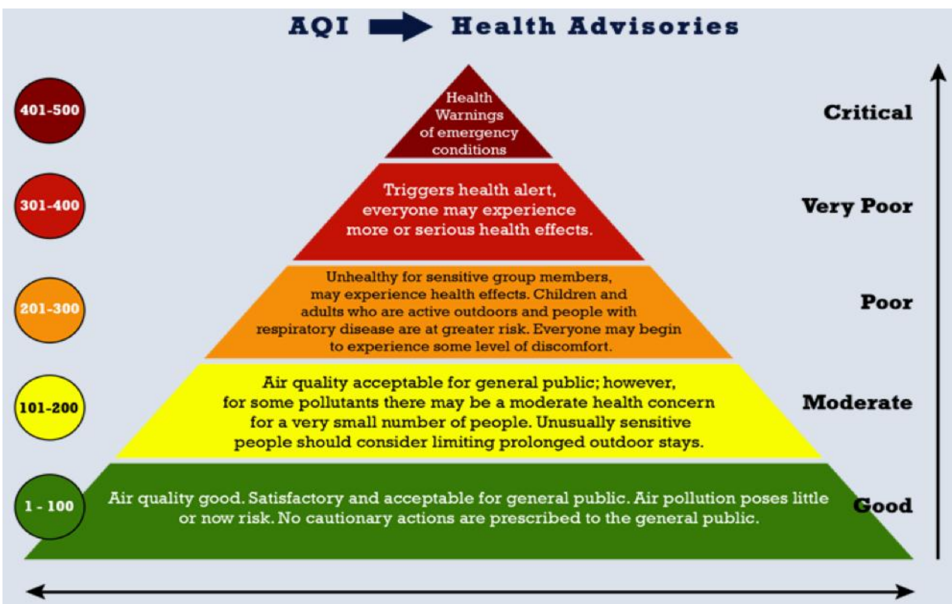
This equation, used to convert measured pollutant concentration data to its corresponding AQI, is taken from Dr. Gufran Beig (2015). *System of Air Quality Forecasting and Research*. Annual Report, Geneva: World Meteorological Organization.

sensitive to either particle or O_3 pollution about how to protect their health.[54] Some countries provide not only information on each day's AQI, but also forecasts for the next day's AQI. This helps people plan their outdoor activities for times when air quality is better, in order to protect their health.

The AQI categories and health breakpoints for five of the eight pollutants that comprise SAFAR's AQI are shown in Table 2 below. Eight pollutants go into SAFAR's AQI, with sub-indices and health breakpoints calculated for each: PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb. These eight pollutants have short-term standards, up to 24 hours, under the India NAAQS.[55] However, breakpoints are only established for the five main pollutants.

Description	AQI	PM10 µg/m³ 24 hr avg	PM2.5 µg/m³ 24 hr avg	CO ppm 8 hr avg	O3 ppb 24 hr avg	NO2 ppb 24 hr avg
Good + Satisfactory	0-100	0-100	0-60	0-1.7	0-50	0-43
Moderate	101-200	101-250	61-90	1.8-8.7	51-84	44-96
Poor	201-300	251-350	91-120	8.8-14.8	85-104	97-149
Very Poor	301-400	351-430	121-250	14.9-29.7	105-374	150-213
Severe	401-500	431-550	251-350	29.8-40	375-450	214-750

Table 3: AQI tiers for five of the eight criteria air pollutants of SAFAR's AQI in



SAFAR's AQI scale: AQI index value ranges are shown on the left; associated public health impacts in the middle; and air quality descriptors on the right; SAFAR (2013), available at http://pune.safar.tropmet.res.in/AQI.aspx

[54] United States Environmental Protection Agency, *AQI: A Guide to Air Quality and Your Health*, EPA-456/F-14-002, February 2014, https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf (accessed December 2, 2016).

[55] Indian Institute of Tropical Meteorology, *SAFAR Air Quality Index*, 2016, http://safar.tropmet.res.in/AQI-47-12-Details (accessed December 2, 2016).

SAFAR uses five AQI categories: Good + Satisfactory, Moderate, Poor, Very Poor, and Severe (or "Critical" in the graphic above). Each of these categories is based on ambient concentration values of air pollutants and their likely health impacts (known as *health breakpoints*).[56] The SAFAR AQI additionally incorporates a more comprehensive data set and a more advanced health assessment model which considers statistics on health data for different diseases including hospital visits, admissions, mortality data and weather conditions.[57]

Disseminating AQI Forecasts

There are different means to access air pollution and health impact information from SAFAR's AQI, which is currently in four cities with more on the way.

The SAFAR website at http://safar.tropmet.res.in/[58] provides the daily AQI and the associated health impacts for the cities of Delhi, Pune, and Mumbai, along with the next day's forecast. In addition to the website, people can download the SAFAR-Air app on their smart phones. Users currently rate SAFAR highly on the Google Play App Store and reviews applaud the efforts being made by SAFAR. Most comments express interest in a widget version to be available as well.[59] Those without smartphones can also access AQI information through a toll-free telephone number twice a day. SAFAR also uses a Digital Display Board System that displays current air quality data to citizens by setting up large LED screens in populated areas in each of the cities.

SAFAR also issues warnings in advance of projected major pollution events. In the case of extreme air quality and weather emergencies, SAFAR uses radio/TV, email and SMS service alerts for registered users.[60] For example, SAFAR issued a warning to the residents of Delhi advising them to stay indoors for Diwali in 2015.[61]

Key Sources of Air Quality Monitoring and Reporting

India's CPCB is in charge of a network of 400 ambient air quality monitoring stations across 130 cities in India. These stations are operated by the respective State Pollution Control Boards (SPCBs) that measure ambient levels of criteria air pollutants such PM_{10}, $PM_{2.5}$, SO_2, NO_2, and O_3. There are current efforts to connect the existing CPCB monitoring network with continuous monitoring data collected at additional cities across India in conjunction with SPCBs.[62] The CPCB also has a smart phone app called "Sameer" for the National AQI (NAQI).[63]

A third AQI system, the World Air Quality Index (or WAQI[64]) project, based in China, provides a World Air Quality System that reports air quality in cities across Asia. In recent years, there has been a fourth source of air pollution information, from the US Embassies and Consulates in India.[65] The Embassy network uses the US EPA's NowCast method to measure and disseminate information about daily fine particle ($PM_{2.5}$) concentrations from the prior 24 hours and converts raw $PM_{2.5}$ readings into an AQI value that can help inform health-related decisions. Embassies in New Delhi, Chennai, Hyderabad, Kolkata and Mumbai have been reporting as part of this network. The SAFAR AQI system, the CPCB network, the World AQI and the group of United States embassies that have been reporting $PM_{2.5}$ are all indications of

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[56] Indian Institute of Tropical Meteorology, *SAFAR Air Quality Index*, 2016, http://safar.tropmet.res.in/AQI-47-12-Details (accessed December 2, 2016).

[57] Gufran Beig, *GAW Report No. 217, System of Air Quality Forecasting and Research (SAFAR-INDIA)*, World Meteorological Organization, 2015.

[58] For current AQI information from SAFAR, access the webpage at: http://safar.tropmet.res.in/map_data.php?city_id=3&for=current.

[59] Indian Institute of Tropical Meteorology, SAFAR Monitoring Network, 2016, http://safar.tropmet.res.in/MONITORING%20SYSTEM-10-3-Details (accessed December 2, 2016); A *widget* is an on-screen, easy to see source on information that is available without logging into or opening an app. Examples of widgets are the clock display and the weather display.

[60] Gufran Beig, *GAW Report No. 217, System of Air Quality Forecasting and Research (SAFAR-INDIA)*, World Meteorological Organization, 2015.

[61] Pritha Chatterjee, "Delhi: Don't Step out this Diwali," *Indian Express*, November 10, 2015, http://indianexpress.com/article/delhi/dont-step-out-this-diwali/ (accessed September 28, 2016).

[62] Central Pollution Control Board, *About National Air Quality Index*, 2008, http://cpcb.nic.in/About_AQI.pdf (accessed September 28, 2016).

[63] Google Play, Sameer, 2016, https://play.google.com/store/apps/details?id=com.cpcb&hl=en (accessed September 28, 2016).

[64] World Air Quality Index, 2016, https://aqicn.org/contact/ and http://aqicn.org/city (accessed December 2, 2016).

[65] U.S. Embassy and Consulates in India, *Air Quality Data*, 2016,https://in.usembassy.gov/embassy-consulates/new-delhi/air-quality-data/ (accessed December 2, 2016).

the great interest in addressing air pollution and improving air quality in India. As the experience from other countries over the past forty years shows, the time it takes for the various expert agencies and key players to refine and coordinate these complementary national and local AQI systems is time well-spent, with the overarching goal of better protections for public health and improving air quality.

Section 3: Elements of Effective AQI Systems and Recommendations for Ahmedabad's Air Information & Response (AIR) plan

AQI systems that have been effectively communicated to air pollution-affected communities are based on a strong foundation of scientific evidence on air pollution-health effects, well-designed monitoring programs, and agency and public coordination that communicates the evidence base to affected communities. The dual goals of protecting public health from air pollution and improving air quality are strengthened by effective AQI systems, which provide the evidence base for municipal or state agencies to take action on air pollution.

From the evidence base provided by AQI systems in India and globally, six of the key elements of successful, effective AQI systems include:

- Robust, streamlined interagency coordination;
- Strong communication channels and direct involvement with the general public, and with communities vulnerable to air pollution's effects: schoolchildren, older adults, people with respiratory or cardiovascular ailments, outdoor workers, people who engage in sports outdoors;
- Strategic policy interventions that can reduce air pollution from its sources;
- Scientific studies that expand local air pollution-health evidence base;
- Media engagement and outreach;
- Capacity building among health professionals on air pollution and health.

The following section describes some features of these elements, many of which SAFAR and AMC have underway.

Interagency Coordination

Municipal Coordination

Interagency coordination at the municipal level is a central element to an effective AQI. Combating air pollution requires professionals and experts in many areas such as scientists, data analysts, engineers, law-makers, politicians, economists, health officials, accountants, and many more. Furthermore, the fact that air pollution can arise from many different sources such as industry, transportation, and agriculture, makes it an interagency issue.

As domestic and international experiences have shown, interagency coordination plays a pivotal part in reducing air pollution as well as informing and protecting the public from its effects. The Ahmedabad Heat Action Plan (HAP) development by AMC and partners at IIPH-G, NRDC and others, showed the importance of frequent interagency communications, and the establishment of a Nodal Officer who is responsible for being the main point of contact across all agencies.[66] An important part of the HAP planning process was creating a map of the agencies and groups already involved in responding to heat emergencies, so that an agreed-upon, inclusive communications framework could be developed. For communicating the AQI and days with unhealthy air quality to key groups, creating that type of communications and coordination map will be very useful. Citywide programs such as Smart Cities or

[66] Knowlton K., et al., "Development and Implementation of South Asia's First Heat-Health Action Plan in Ahmedabad (Gujarat, India)," ***Int. J. Environ. Res. Public Health*** **11**, no. 4 (2014): 3473-3492; doi:10.3390/ijerph110403473http://www.mdpi.com/1660-4601/11/4/3473.

state wide plans for sustainable development goals could be useful for comprehensive planning that includes strategies to combat sources of air pollution.

Regional and State-Level Coordination

Air pollution is often not a localized problem, especially since pollutants and emissions are affected by regional and long-range pollution transport. Since air pollution can affect large geographic areas as well as concern many different sectors, statewide coordination of agencies is an effective mechanism to combat air pollution. One international example of a regional cooperation is the Southern California Association of Governments (SCAG). SCAG's Transportation Conformity Working Group (TCWG) works to facilitate interagency coordination for to ensure that approved infrastructure projects conform to air quality goals and targets in Southern California.[67] Specifically, the group meets monthly to address and resolve regional issues regarding transportation conformity focusing on PM_{10} and $PM_{2.5}$ hot spots in non-attainment areas. The TCWG developed a "PM Conformity Hot Spot Analysis–Project Summary Form for Interagency Consultation" to help provide information to SCAG on whether a proposed project needs a detailed PM air pollution "hot spot" analysis.

Often, development of specific projects can have profound impacts on air quality during construction in addition to long-term effects on air quality. Interagency discussions on the project's potential impacts on air quality have been effective in addressing air-related issues and working out ways to mitigate the project's impact on air quality. For example, one Memorandum of Agreement (MOA) from the US, the Washington State MOA on Fugitive Dust, could be relevant for some of Indian cities' long range pollution problems.[68] In addition, the MOA outlines roles for both agencies and deadlines for deliverables such as training programs for best management practices for controlling fugitive dust[69].

Interagency coordination is a necessary and productive tool to address the broad problem of air pollution. The examples above are only a snapshot of many efforts to foster interagency coordination in the United States.

Strong Communication Channels

Ensuring that the AQI is communicated effectively to reach communities is vital to protecting public health. The AQI should be easy to associate with health effects and provide additional information relating to potential health symptoms and advice as to what action to take. Improvements in air quality depend on the support of citizens who are well-informed about local and national air pollution problems and about the progress of mitigation efforts. Many air pollution guidelines consider the importance of alerts when air pollution becomes serious and action needs to be taken.[70]

The public should be involved in developing risk communication from the outset and can contribute to the assessment and management of risk. Involving the public as stakeholders helps establish effective communication and reciprocal exchange of information and is conducive to finding innovative solutions, thus moving away from one-way communication models.[71] Essential elements for effective risk communication are information quality, transparency, the simplicity and coherence of the message, receptivity to public concerns and timing. Communication approaches should be participatory and integrate sociological methods into traditional public health-oriented ones. While this may increase effort and cost, it is useful in managing controversy, when and if it develops during high air pollution

[67] SCAG, *Transportation Conformity Working Group*, 2016, http://www.scag.ca.gov/programs/Pages/TCWG.aspx (accessed October 12, 2016).

[68] PTI, "Nearly 60 pc of PM 2.5 pollutants in Delhi from outside: Study," *Indian Express*, October 5, 2016, http://indianexpress.com/article/delhi/nearly-60-pc-of-pm-2-5-pollutants-in-delhi-from-outside-study/ (accessed October 12, 2016).

[69] Puget Sound Clean Air, Washington State Department of Transportation, *Memorandum of Agreement- Fugitive Dust*, 1999.

[70] Shooter, D. and P. Brimblecombe, "Air quality indexing," *Int. J. Environment and Pollution* 36 (2009): 305–323.

[71] World Health Organization Regional Office for Europe, *Health and environment: communicating the risks*, 2013, http://www.euro.who.int/__data/assets/pdf_file/0011/233759/e96930.pdf (accessed December 2, 2016).

emergencies.[72] Including organizations who advocate for the health of people with particular illnesses can help reach some of the most health-vulnerable people, for example organizations who represent people with asthma or those with other respiratory diseases, or groups representing patients with heart disease. Including air pollution as part of environmental education programs can increase awareness among school children, who are particularly vulnerable to the health impacts.

SAFAR currently uses multiple approaches to reach the public with their AQI alerts, as discussed above, including its website, the SAFAR-app for smart phones, toll-free telephone numbers, email alerts, and digital display boards.[73] Even with all these multiple, complementary pathways, there are more promotion options available, worthy of continued discussion by AMC for possible adoption in Ahmedabad.

Some cities offer phone SMS messages or text sign-ups like the NotifyNYC system in New York City that helps make the public aware of emergencies of all types (heat, air pollution, accidents, etc.) or planned large-scale activities.[74] The air pollution School Flags Program from the US EPA uses the color coding of the AQI to fly highly visible flags in school areas, corresponding to the day's air quality, since schoolchildren are especially vulnerable to air pollution. The program also has informational materials for teachers, students and parent on air pollution and health protection.[75]

The US EPA has developed a number of other outreach tools that could potentially be adapted for use in India. There are online brochures, games, and videos on different aspects of air pollution and health protection.[76] There is also online access to trainings and tools for teachers, weathercasters and health care providers. An online "Air Compare" tool lets people compare the air quality of different US cities, or find out about air quality trends in specific areas.[77] People can also access web cameras online, to see real-time pictures of visibility at locations across the US.[78]

Combating air pollution can also be done by the public on a citizen-to-citizen basis. For example, New York States' *Clean Air NY Public Education Campaign* (CANY) focuses on marketing and outreach programs that educate New Yorkers on manageable changes that residents can make in their transportation choices to reduce their vehicular miles traveled and affect air quality. This includes Air Quality Action Day notifications by the New York State Department of Transportation (NYSDOT) when $O_3$and PM levels are expected to be at levels that could threaten the health of sensitive populations. The Program Advisory Committee for CANY includes members from state, regional, and local health departments, transportation councils, and city and state governments.

Media Engagement and Outreach

The media in India has been covering the nation's deteriorating air quality, and has a very critical role to play in raising public awareness of air pollution's effects on health.[79] For example, in March 2015, *India Today* published an article titled "Choking on the Truth: How the Air that Sustains our Life is also Slowly Killing Us." [80] The story paints a vivid image of the reality faced by Delhi's 25 million residents,[81] who

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[72] *Ibid*.

[73] Indian Institute of Tropical Meteorology, SAFAR Monitoring Network, 2016, http://safar.tropmet.res.in/MONITORING%20SYSTEM-10-3-Details (accessed December 2, 2016).

[74] NYC Office of the Mayor, *Notify NYC*, 2016, https://a858-nycnotify.nyc.gov/notifynyc/(S(ttpex4myempjed1cmve0jcz5))/About.aspx (accessed December 2, 2016).

[75] United States Environmental Protection Agency, *AirNow Air Quality Flag Program*, 2016, https://www.airnow.gov/index.cfm?action=flag_program.educational (accessed December 2, 2016).

[76] United States Environmental Protection Agency, *AQI Brochure*, 2014, https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf (accessed December 2, 2016); United States Environmental Protection Agency, *Air Quality Index (AQI) Basics*, 2016, https://airnow.gov/index.cfm?action=aqibasics.aqi (accessed December 2, 2016).

[77] United States Environmental Protection Agency, *Air Compare*, 2016, https://www3.epa.gov/aircompare/ (accessed December 2, 2016).

[78] United States Environmental Protection Agency, *AirNow Visibility Cameras*, 2016, https://airnow.gov/index.cfm?action=airnow.webcams (accessed December 2, 2016).

[79] TNN, "Deadline for Cleaner Fuel Across India Moved Up: Javadekar," *Times of India*, June 5, 2015; Sushmi Dey, "Air Pollution is World's Top Environmental Health Risk, WHO Says," *Times of India*, June 2, 2015; Ambika Pandit, "Congress Writes to Delhi CM on Air Pollution," *Times of India*, June 4, 2015; Praveen Jose, "Dubious Air Quality Data Mars Gurgaon's Pollution Fight," *Times of India*, June 7, 2015; TNN, "Air Pollution Chokes City's Lungs," *Times of India*, June 4, 2015; Priyangi Agarwal, "Vehicular Emissions Increase Air Pollution in City: Experts," *Times of India*, June 4, 2015; Sushmi Dey, "Air Pollution Causes 8m Deaths/Yr," *Times of India*, May 19, 2015.

[80] Amulya Gopalakrishnan, "Choking on the Truth: How the Air that Sustains Our Lives is also Slowly Killing Us," *India Today*, March 16, 2015.

[81] Yoshita Singh, "Delhi Now Second Most Populous City in World," *Indian Express*, July 12, 2014.

are subject to the city's pervasive smog and discusses scientific and statistical studies that have confirmed the dangers associated with prolonged exposure to airborne pollutants.

In April 2015, *The Indian Express* published, "Death by Breath: What's Happening to Delhi Air will have You Gasping for Breath."[82] The article investigates Delhi's deteriorating air quality in spite of the growing evidence base on the effects of pollution. Over the past years, PM levels rose to 316 µg/m^3 in 2015, which are almost 16 times the WHO air quality standards. In the article, Dr. Randeep Guleria, head of respiratory medicine at the All India Institute of Medical Science (AIIMS), explained:

> *"What is most worrying is that 10-15 years ago, when air pollution levels had come down, our average OPD attendance and admissions in respiratory medicine at AIIMs saw about a 20% decline. We seem to have lost out on our own achievements."*

Involving the media in efforts to raise public awareness and reduce air pollution is essential.

Build Capacity among Health Professionals

AQI reporting to the public provides important information about potentially unhealthy air pollution days, and gives people ways to reduce their air pollution exposures. Besides the various means of directly communicating from SAFAR's AQI through the AMC's information dissemination channels and the media to the members of the public, health professionals can provide specific information on personal health risks of air pollution information. As trusted messengers and health experts, and people who are on the front lines of advising, diagnosing and treating respiratory and cardiovascular illnesses worsened by air pollution, local health professionals can encourage vulnerable people to take health-protective actions. A study[83] among nearly 34,000 people showed that receiving advice from a health professional to reduce outdoor activity during poor air quality periods dramatically increased the impact of media alerts and AQI reports, especially among people with asthma. While 31% of adults with asthma reportedly reduced their outdoor activity after hearing a media AQI alert, 75% of people reduced time outdoors after hearing advice from a health professional. Medical and health professionals should consider routinely advising patients, especially those with asthma and other respiratory or cardiovascular illness, to avoid strenuous outdoor activity when the AQI is high.

In addition to supporting individual patients' health, the same health professionals have the research and clinical practice expertise that informs local interventions and policy strategies to reduce air pollution sources. Building capacity and engagement among health professionals to cope with air pollution's health effects and advocate for policies to improve air quality benefits everyone.

Scientific Studies and Research

Critical to advancing a health-based plan is robust scientific studies and research. Ahmedabad's program on reducing heat vulnerability shows that developing local scientific studies to build a local evidence base on environment-health connections provide the foundation for taking action.[84] Some of the types of scientific studies that could serve to build this evidence base include:

- Epidemiologic studies to examine possible relationships between levels of daily air pollution and respiratory hospitalizations or emergency department visits in Ahmedabad;
- Comparing data from air quality monitoring sites that are near schools, and evaluating school children's' respiratory health;

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[82] Web Desk, "Death by Breath: What's Happening to Delhi Air Will Have You Gasping for Breath," *Indian Express*, April 4, 2015.

[83] Wen, X-J., L. Balluz, and A. Mokdad, "Association between media alerts of Air Quality Index and change of outdoor activity among adult asthma in six states, BRFSS, 2005," *J. Community Health* 34 (2009):40-46.

[84] Shah Azhar, G., et al., *Heat-related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave*, PLOS ONE 9, no. 9 (2014): e109457.

- Studying the long-term effects of air pollution exposures amongst pregnant mothers and their newborns, and estimating the long-term effects and costs to society;
- Describing the range of air pollution exposures among highly-exposed outdoor workers, such as traffic police.

Policy Interventions

Another key element of a health-based air response plan is to develop a range of policy interventions that aim to reduce air pollution. For example, a road space rationing plan in Delhi in January 2016,[85] in which odd versus even license plates had access to roadways on alternate days, resulted in uncertain effects on air quality overall but may be attempted again. Plans to reduce vehicle, industrial, construction, agricultural and other air pollution sources will be a necessary complement to air pollution monitoring and health risk communication, under systems like the AQI.

Other programs like planting trees in order to reduce fine particulate air pollution have shown promising results, at least in modeling studies. One recent modeling study estimated that tree planting could appreciably lower both $PM_{2.5}$ concentrations and urban temperatures.[86] By combining several of these approaches, air pollution sources can be reduced at the same time that AQI programs help people adjust their behavior to protect themselves from current levels of air pollution.

Key Recommendations

Based on the above elements, and discussions with key stakeholders, the AMC can pilot its air pollution health risk communication activities as per the following recommendations:

Recommendation 1: *Build public awareness through information, education and communication on air pollution and engaging with media*

Recommendation 2: *Develop activities that target specific groups that are particularly vulnerable to the health effects of air pollution*

Recommendation 3: *Strengthen interagency coordination to lay the foundation for an air pollution early warning system in Ahmedabad*

Recommendation 4: *Build capacity in public and private sector medical professionals to recognize and treat air pollution related illness*

Recommendation 5: *Work with state agencies such as the GPCB to integrate with their efforts in reducing sources of air pollution*

[85] Express Web Desk, "Delhi's odd even rule ends today: A look-back at the last 15 days," *Indian Express*, January 15, 2016, http://indianexpress.com/article/cities/delhi/delhis-odd-even-rule-ends-today-a-look-back-at-the-last-15-days/ (accessed December 2, 2016).

[86] The Nature Conservancy, "Urban trees can save tens of thousands of lives by reducing air pollution and temperature," News Release, October 31, 2016, http://www.nature.org/newsfeatures/pressreleases/urban-trees-can-save-tens-of-thousands-of-lives-globally.xml (accessed December 2, 2016).

PART II

International Practices, Standards and Climate Change

Section 1: International Best Practices on Using the AQI

With rising air pollution levels and deadly health risks, leading cities have developed clean air programs. The AQI is the key tool in the programs for protecting communities and trigger action. AQI programs started in the 1970s and are now in over 100 cities across Asia, Australia, Europe, North America and South America. Three key cities – Beijing, Los Angeles, and Mexico City – offer experiences with AQI systems that are instructive in protecting public health and improving air quality.

AQI programs can be nationally-led, such as in Beijing; city-led, such as in Mexico City; or hybrid, such as in Los Angeles. Often, as is the case with the United States, it can take decades to align national, regional, state, and city programs, but it is important to launch the systems to protect public health before the crisis worsens. National systems benefit from federal initiatives and funds, and often have easier access and facilitated communications with other agencies. Because of the local-nature of air pollution, city-based systems often have a deeper understanding of pollution drivers, the extent to which policies have worked in the past, and a better community outreach. Cities also have the ability to move quickly on advancing air pollution programs and solutions.

Beijing, China

Air Pollution in Beijing

Beijing and many cities in China are plagued by some of the worst air pollution in the world. As highlighted during the 2008 Olympics, air pollution has skyrocketed in Beijing in the past decade with more vehicles, massive industrialization, increased coal combustion, heavy urbanization, and low-efficiency. To protect public health, Beijing's AQI has been a central means for notifying communities and driving action. The AQI regularly hits record highs ranging from 200 to 400, which is much higher than the WHO recommended level of 25 – and often called "airpocalypse".

Air pollution in Beijing (thenanfang.com)

In Beijing, vehicle emissions accounted for 31% of the city's $PM_{2.5}$ levels and coal plants accounted for 22.4% in 2014[87]. Beijing plans to add 30 AQI stations in places like schools in addition to its 35 operational stations[88]. China and Beijing have recently instituted measures to reduce air pollution such as decommissioning and retrofitting coal-fired boilers and banning dirty cars from the road. Over the past three years, Beijing has experienced a drop in $PM_{2.5}$, PM_{10}, NO_2 and SO_2 emissions but an increase in levels of CO and O_3.[89] Overall, air pollution levels in Beijing and many other cities in China remain alarming high, especially for $PM_{2.5}$.[90]

[87] Zhang, L., Y. Liu, and L. Hao, "Contributions of Open Crop Straw Burning Emissions to PM2. 5 Concentrations in China," *Environmental Research Letters* 11, no. 1 (2016): 014014.

[88] Carlos Barria, "China's smoggy capital to double air monitoring stations," *Reuters*, February 22, 2016, http://www.reuters.com/article/us-china-pollution-idUSKCN0VV0Y1 (accessed September 20, 2016).

[89] Clean Air Asia, *China Air 2016: Air Pollution Prevention and Control Progress in Chinese Cities*, 2016.

[90] Didi Kirsten Tatlow, "China Air Quality Study Has Good News and Bad News," *New York Times*, March 30, 2016; Xuan Liang, Shuo Li, Shuyi Zhang and Hui Huang, and Song Xi Chen, Peking University, Air Quality Assessment Report (2): A Statistical Analysis of Air Pollution in Five Chinese Cities, Peking University, 2016

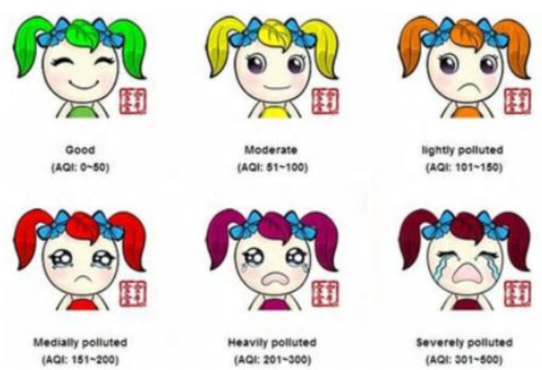
Beijing AQI and Community Outreach Examples[91]

China's AQI system consists of both a national and local network. Both networks have the following four types of stations: monitoring, assessment, control, and background. Beijing enhanced AQI reporting focused on $PM_{2.5}$ in 2013, after the United States Embassy started reporting air pollution levels. The Ministry of Environment website releases hourly concentration values for six pollutants: SO_2, NO_2, CO, O3, PM_{10}, and $PM_{2.5}$ on their website and through tweets. The Ministry of Environment also issues quarterly data and annual reports that summarize and analyze the results of air quality information at the national level.

China amended its NAAQS in February 2012 and prescribed its first limits for $PM_{2.5}$ and ozone. The standards are comparable to WHO's interim target. In addition, China also plans for regional air pollution collaborations in its Five Year Plan for Air Pollution and further integration of $PM_{2.5}$ and O3 reporting at more stations.

The enhanced AQI and worse air pollution levels spurred several levels of action in Beijing and China focused on community outreach:

- Massive public outreach via radio, media and print
- Hourly website reports
- Smartphone apps to report hourly levels, including Twitter
- Red flag programs for schools, and school closures
- Increased availability and distribution of masks and air filters
- Built domes for indoor playgrounds and fields with air purifiers
- Blue Skies and Clean Skies programs
- Increased hand-held and individual monitoring and reporting



Air Quality Index graphics by the Shanghai Environmental Monitoring Centte

Air Quality Index graphics by the Shanghai Environmental

[91] Wan, Wei, and K. Patdu, "A New Era in Air Quality Monitoring in China," *Environmental Technology*, September 2013, http://www.envirotech-online.com/articles/air-monitoring/6/wei_wan_kaye_patdu/a_new_era_in_air_quality_monitoring_in_china/1478/.

For example, for major international events such as the 2008 Olympics or the Asia-Pacific Economic Cooperation (APEC) summit, with the aim of getting to a "Blue Sky", China stopped production in all factories within 125 miles of Beijing; banned half of the vehicular traffic; closed schools, government offices, and banks so workers stayed home; issued orders for no licenses for weddings, no new passports, no fresh product delivery and no cremations.[92]

Beijing Measures to Combat Air Pollution[93]

China and Beijing have a series of programs to improve air quality, such as decommissioning and retrofitting coal plants and removing older, dirty cars from the road. As part of the overall program, China has an "Action Plan for Air Pollution Prevention and Control." The Plan involves performance assessments of measures; environmental regulations; mechanisms for regional cooperation; monitoring of air quality as a focus for major events, such the Olympics and international summits.

China and Beijing also have focused programs on:

- motor vehicles with a registration, inspection and restriction program
- pollution from coal-fired boilers and industrial sources to encourage retrofits
- special inspection for air pollution
- remote sensing for straw burning
- energy-saving low carbon development
- heavy pollution emergency management plans
- integrated monitoring programs
- increased hospital, health, medical and monitoring programs

Los Angeles, California, United States

Air Pollution in Los Angeles

Los Angeles has suffered from high levels of pollution since World War II with massive growth of both population and vehicles. The South Coast Air Basin is plagued by photochemical smog[94] and London-type smog.[95] In the 1970s, Los Angeles had the worst air pollution in the United States and remains the worst in 2016 for O_3.[96] While Los Angeles is still ranked highly amongst the cities with the most pollution, local governmental efforts have reduced high level alerts from 100 to less than 10 per year.[97]

[92] Oliver Wainwright, "Inside Beijing's airpocalypse – a city made 'almost uninhabitable' by pollution,"*Guardian U.S. Edition*, December 16, 2014, https://www.theguardian.com/cities/2014/dec/16/beijing-airpocalypse-city-almost-uninhabitable-pollution-china.

[93] Ministry of the Environmental Protection, *Report on the State of the Environment in China*, May 19, 2015, http://english.sepa.gov.cn/Resources/Reports/soe/soe2011/201606/P020160601592064474593.pdf (accessed September 21, 2016).

[94] Photochemical smog results from the emission of hydrocarbons and nitrogen oxides in the presence of sunlight leading to the formation of ozone.

[95] London-type smog results from the burning of coal or other raw material in the presence of a strong temperature inversion. Jacobson, M. *Air Pollution and Global Warming: History, Science, and Solutions* (Cambridge University Press, 2012).

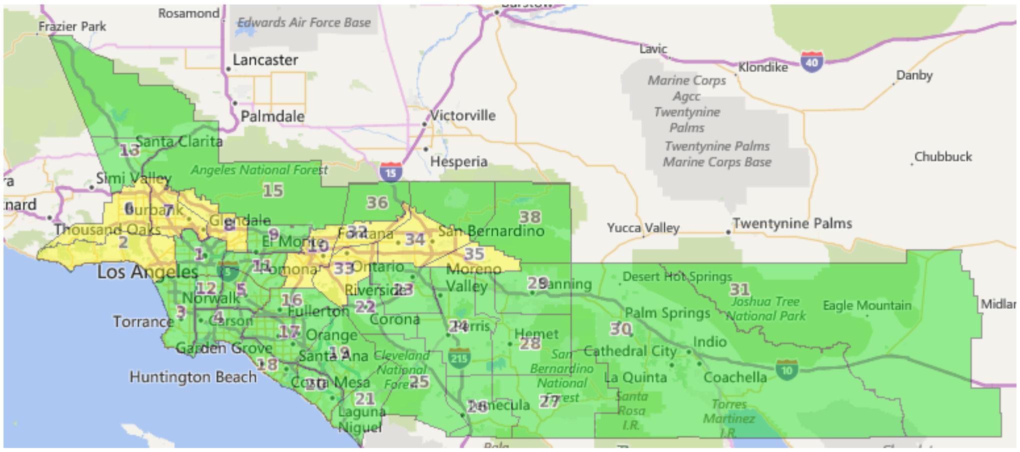
[96] Associated Press, "Los Angeles and Bakersfield top list of worst air pollution in the nation," *Los Angeles Times*, April 20, 2016, http://www.latimes.com/local/lanow/la-me-air-pollution-report-20160420-story.html.

[97] UCLA Center for Clean Air, *UCLA Air Quality Management Training Program*, 2016, http://www.environment.ucla.edu/cleanair/air-quality-management-training-program (accessed October 4, 2016).

Los Angeles AQI and Community Outreach Examples[98]

The Los Angeles AQI has been upgraded through the years and is a key tool for the city's air quality program. Combining programs by state, local, and federal agencies, including the Environmental Protection Agency's (EPA) AirNow program, the South Coast Air Quality Management District and Air Now have websites to regional maps of California that color-code the geographical areas with their respective air-pollution levels.

The Los Angeles AQI systems provide hourly AQI readings throughout the region. The AQI measures: ground-level O_3, PM, CO, SO_2, and NO_2, as consistent with the EPA AirNow program.



Air Quality Map of LA regions from the AQMD website (green indicates good air quality and yellow indicates

A series of activities have been conducted in the Los Angeles region over the years that are triggered by the AQI to protect the health of citizens:

- Alert system, including health alerts for "bad air days"
- Smart phone app data for neighborhood info
- Television, radio, and print media outreach
- School closure program
- "Check before you burn" program for wood burning outdoors
- Vehicle checks program
- Community-based programs to raise awareness, including the school flag program announcing the AQI via color-coded flags on a daily basis
- Medical and health professional engagement

[98] Wan, Wei, and K. Patdu, "A New Era in Air Quality Monitoring in China," *Environmental Technology*, September 2013, http://www.envirotech-online.com/articles/air-monitoring/6/wei_wan_kaye_patdu/a_new_era_in_air_quality_monitoring_in_china/1478/.

Working toward clean air in Los Angeles has taken several decades. Key activities toward clean air include:

- Increased local monitoring for ambient, vehicle, smoke stacks, ports, and fence-line
- Stronger vehicle standards in California, requiring catalytic converters on automobiles, eliminating lead in gasoline, and moving polluting industries away from the city
- Stronger emissions controls on ports, refineries, and industrial sources
- Banning emission of dense smoke and implementing office of Air Pollution Control (1945, Los Angeles County Board of Supervisors)
- Requiring major industrial emitters to obtain emission permits, regulating open burning in garbage dumps, emission of $SO_2$from refineries, emissions from industrial gasoline storage tanks (1940-1950, Los Angeles air Pollution Control District)
- Banning the use of over 300,000 backyard trash incinerators (1954, Los Angeles Air Pollution Control District)
- Merging of Orange, Riverside, and San Bernardino air pollution control districts with LA into South Coast Air Quality Management District (1977)

Free informational materials from Sparetheair.com; **http://www.sparetheair.com/publications.cfm and Air Quality and Outdoor Activity Guidance for Schools; US EPA, Air Quality Flag Program** **https://www.airnow.gov/index.cfm?action=flag_program.**

Air Quality Index	Outdoor Activity Guidance
green GOOD	Great day to be active outside!
yellow MODERATE	Good day to be active outside! Students who are unusually sensitive to air pollution could have symptoms.*
orange UNHEALTHY FOR SENSITIVE GROUPS	It's OK to be active outside, especially for **short activities** such as recess and physical education (PE). For **longer activities** such as athletic practice, take more breaks and do less intense activities. Watch for symptoms and take action as needed.* Students with asthma should follow their asthma action plans and keep their quick-relief medicine handy.
red UNHEALTHY	For **all outdoor activities**, take more breaks and do less intense activities. Consider moving **longer or more intense activities** indoors or rescheduling them to another day or time. Watch for symptoms and take action as needed.* Students with asthma should follow their asthma action plans and keep their quick-relief medicine handy.
purple VERY UNHEALTHY	Move **all activities** indoors or reschedule them to another day.

AirNow in the USA

The primary purpose of AirNow is to support the EPA's AQI Program, as well as real-time reporting and forecasting by hosting and distributing ambient air quality monitoring data and forecasts. The AirNow program is the national repository of real time air quality data and forecasts for the US, and enables timely and accessible AQI information to the public, media outlets, other federal agencies, and to the research community.

Features of AirNow in the US include 1) Year round 24/7 coverage delivering real-time data (O_3 & PM) for 50 states, six Canadian provinces and 24 U.S. national parks; 2) Next-day AQI forecasts for over 400 cities in the summer and 300 cities year-round; 3) Data processing/management to public dissemination in approximately one hour

The EPA calculates the AQI for five criteria pollutants regulated by the Clean Air Act under the United States' NAAQS. AirNow reports on two of these pollutants, ground-level $O_3$and airborne particles ($PM_{2.5}$ and PM_{10} considered jointly as combined PM), that pose the greatest threat to human health in the US. AirNow data management converts raw air quality data to the AQI and shows hourly formation and movement of ground level $O_3$and combined PM with the AQI colors.

The AQI focuses on health effects one may experience within a few hours or days. The AQI converts raw measurements for the five pollutants into a separate AQI value for each pollutant (shown below for PM), based on health-related risk thresholds for each pollutant based on the epidemiologic literature . Then the highest of these AQI values is reported as the AQI value for that day.

AirNow-International

AirNow-International (AirNow-I) is a stand-alone, international version of the EPA's AirNow, and is working with countries and regions around the world to inform the public about air quality. Using the AirNow-I system, air quality agencies can provide real-time air quality information to local residents. By participating in a community of users, they can share information and learn from colleagues around the world. AirNow also works with U.S. Embassy posts in China, India and elsewhere to provide AQI readings to protect the health of staff and inform the local community about air quality.

Mexico City, Mexico

Figure 3: Air Pollution in Mexico City

In 1992, WHO called Mexico City the most polluted city in the world. Since then Mexico City has made tremendous progress in understanding the city's sources and characteristics that led to these high air pollution levels. Through strategic planning, regulations and policy, Mexico City was able to make vast improvements in air quality; an impressive feat considering the city was undergoing rapid urbanization at the same time. Mexico City still struggles with episodes of persistent high levels of $O_3$and particulates. Currently ranked the 30^{th} worst city for air quality by WHO due heavily to diesel-related transport emissions, it is estimated that vehicles are responsible for 81 % of nitrogen oxides and 46% of VOCs in Mexico City.[99] The major industries with potential to impact air quality in the city are chemicals, iron, steel, petroleum, mining, and textiles.[100]

Mexico City AQI and Community Outreach Examples

Mexico City has a 10-year air quality management development program called "Proaire".[101] Combining monitoring programs from city and national levels, Mexico City's system is a typical AQI with levels of 0-50 (Good), 51-100 (Regular), 101-150 (Bad), 151-200 (Very Bad), and >200 (Extremely Bad). The AQI is similar to SAFAR's in that the index setting pollutant is also advertised on the website as well as health effects associated with over-exposure to that pollutant.

The Mexico City AQI system reports hourly averages for PM_{10}, $PM_{2.5}$, CO, SO_2, NO_X, NO, and O_3 on the web.[102] Mexico City also employs several atmospheric modeling and meteorological networks for additional information such as wind direction, speed and pressure.[103] SIMAT has 34 monitoring stations throughout the city that measure a variety of the above listed pollutants.[104]

The objectives of Mexico City's air monitoring program are to:

1. Evaluate the compliancy of Mexican Official Norms (NOM) of environmental health in Mexico City and its associated areas.
2. Evaluate the state of air quality with respect to the concentration of criteria pollutants.
3. Quantify contaminant exposure levels of different populations.
4. Warn at-risk populations about future air-pollution spikes and inform them of the associated health risks.
5. Publish time-sensitive information regarding the activation or deactivation of alerts based on human-harming levels of air pollution.
6. Inform the general population in an effective way regarding the status of air quality.
7. Collect information for evaluation of spatial distribution and transport of atmospheric pollutants.
8. Generate reliable data for evaluation of strategies to advance clean air strategies in Mexico City and its associated area.
9. Evaluate historical tendencies of criteria pollutants in Mexico City and its associated area[105].

Key community outreach examples for Mexico City include:

- Alert system to warn communities

[99] Lucas Davis, "Driving Restriction and Air Quality in Mexico City," Resources for the Future Blog, August 18, 2008, http://www.rff.org/blog/2008/driving-restriction-and-air-quality-mexico-city (accessed September 20, 2016).

[100] United Nations Environment Programme, *Air Quality Policies*, 2015, http://www.unep.org/transport/airquality/Mexico.pdf (accessed December 2, 2016).

[101] Eric Anderson, *Audit of Ambient Air Monitoring Stations for the Sistema de Monitoreo Atmosferico de la Ciudad de Mexico*, Audit, Ciudad de Mexico: EPA Systems, Secretaria del Medio Ambiente, 2013; Riojas-Rodriguez, H., et al., "Health impact assessment of decreases in PM_{10} and ozone concentrations in the Mexico City Metropolitan Area. A basis for a new air quality management program," *Salud Publica Mex* 56, no. 6 (2014): 579-91.

[102] Cuidad de México, *Índice de Calidad del Aire*, 2016,http://www.aire.cdmx.gob.mx/default.php?opc=%27ZaBhnmI=%27&dc=Zw== (accessed September 20, 2016).

[103] Estrucplan Online, *SIMAT: REDDA - Red de Depósito Atmosférico*, November 19, 2009, http://www.estrucplan.com.ar/Producciones/entrega.asp?IdEntrega=2631 (accessed September 20, 2016).

[104] Mexico City-Harvard Alliance for Air Quality and Public Health, *Data*, https://www.hsph.harvard.edu/cdmx/resource-library/data-reports/ (accessed September 20, 2016).

[105] Gobierno de la Ciudad de Mexico, *El monitoreo de la calidad del aire*, http://www.aire.cdmx.gob.mx/default.php?opc=%27ZaBhnmI=%27 (accessed September 20, 2016).

- Web access: Real-time information on air quality and UV-radiation levels from the government's air quality home page (http://www.aire.cdmx.gob.mx/default.php). The home page has information (about the city's AQI, associated health impacts and which pollutant set the AQI) for individual stations throughout the city. The website contains multiple links to information regarding background information on each pollutant as well as information on how to stay healthy with regards to air pollution and UV exposure. The website also includes a "kids" link which leads to interactive pages that have tutorials on air contamination and UV exposure targeting younger audiences.

- Twitter (@Aire_CDMX) on an hourly basis: Every hour the Twitter account reports the air quality level and index for every station. The account has233,000 followers as of February 2017.

- Smartphone App: the air quality on a user's phone via SIMAT's app (available on both android and iOS). The app reports real-time data (AQ level and index, UV radiation exposure) from the nearest Air Quality Monitoring (AQM) station based on the user's location. In addition to the reported data, the app also provides recommendations for health protection such as protective clothing recommendations for UV exposure levels, recommended Sun Protection Factor (SPF) levels for sunblock, and recommendations on how long to limit your time outside based on the levels of air pollution. The app is also paired with the city's bike share program to show the user how close he/she is to a bike share station and the availability of bikes.

Mexico City Measures to Combat Air Pollution

One of the most important Proaire measures from the 2002-2010 action plan was its intention to reduce emissions from the transportation sector. Part of this plan involved Mexico City's adoption of a bus rapid transit system. A recent national study concluded that CO, hydrocarbon, and PM exposure was reduced by about 50%when the modern diesel buses replaced the gasoline mini-buses that were traditionally used in the city.[106] Some other efforts include requiring catalytic converters on automobiles, eliminating lead in gasoline, and moving polluting industries away from the city.

Key elements include:

- Institution of a driving restriction program

- Strengthening vehicle inspection and maintenance programs

- Reducing sulfur content in diesel fuel

- Substituting natural gas for fuel oil in industry and power plant

- Mexico City recently banned 40% of cars in a "hoy no circula" or "no circulation" (HNC) program that bans certain cars from driving on certain days of the week. It works similarly to an odd/even program implemented in many other cities where license plates ending in certain numbers are prohibited from driving on certain days. This came in response to a spike in O_3 AQI to 161 (national level is 150)[107]. Unfortunately, the HNC program had unintended consequences: citizens bought older, dirtier cars and took taxis (exempt from HNC) for transport. Further, clean, hybrid, or electric vehicles are not given HNC exemptions leading to no incentive for citizens to purchase these vehicles. In

[106] Molina, L., et al., , "Air Quality, weather and climate in Mexico City," *World Meteorological Organization* (2009): 48-53.

[107] "Mexico City bans 40% of cars again over air pollution," *Phys.org*, May 3, 2016, http://phys.org/news/2016-05-mexico-city-cars-air-pollution.html (accessed September 20, 2016).

the 1990s in an effort to spur the Mexican economy, the government also issued an HNC exemption for domestically-produced cars. [108]

- Longer-term, national regulatory action for clean vehicle standards similar to that of the rest of North America.
- Mexico City has recently announced its commitment to renovate its bus system to become soot-free.
- Mexico City will join a select few cities that implement rigorous urban transport policy.[109]
- Increased health research.[110]

It took Mexico City many institutional reforms to foster effective interagency coordination. With city leadership the program developed into a more coordinated effort.

[108] Paulina Segarra and Ajnesh Prasad, "How corruption is hurting Mexico City's efforts to tackle air pollution," *The Conversation*, May 5, 2016, http://theconversation.com/how-corruption-is-hurting-mexico-citys-efforts-to-tackle-air-pollution-57517 (accessed September 20, 2016); Mexico City-Harvard Alliance for Air Quality and Public Health, *Air Quality Surveillance*, https://www.hsph.harvard.edu/cdmx/about-us/air-quality-surveillance/ (accessed September 20, 2016).

[109] Ray Minjares and Kate Blumberg, "Mexico City commits to a soot-free urban bus fleet," *International Council on Clean Transportation*, July 28, 2016, http://www.theicct.org/blogs/staff/mexico-city-soot-free-urban-bus-fleet-commitment (accessed October 4, 2016).

[110] Mexico City-Harvard Alliance for Air Quality and Public Health, *Data*,https://www.hsph.harvard.edu/cdmx/resource-library/data-reports/ (accessed October 3, 2016).

Section 2: Air Pollution Standards, Economic Development and Climate Change

India's Ambient Air Quality Standards

With the goal of providing for the control of air pollution, India's first ambient air quality standards were adopted in 1982 by the CPCB and revised in 1994 and 2009. NAAQS have been established for twelve pollutants for various time horizons (see table below). Permitted concentrations are allowed to be higher in industrial, residential, rural and other specified areas than in ecologically sensitive areas.

Under the Air (Prevention and Control of Pollution) Act of 1981, under the Ministry of Environment, Forests and Climate Change (MOEFCC), the CPCB and SPCBs are responsible for establishing air quality standards and monitoring. The Air Act mandates the CPCB and SPCBs to: (1) establish national ambient air quality standards for criteria pollutants, (2) assist the government in planning future environmental prevention and control strategies, (3) carry out research to better understand environmental issues, (4) undertake nationwide air sampling to ascertain the ambient air quality in India and identify problem areas, and (5) conduct air quality inspections in areas of concern.[111] SPCBs can set more stringent standards than the existing national standards in their respective states.

Compared to WHO ambient air quality guidelines, India's air quality standards are less stringent. For example, the WHO recommends a 24-hour mean $PM_{2.5}$ limit of 25 µg/m^3, while the corresponding Indian standard is 60 µg/m^3.

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and Other Areas	Ecologically Sensitive Area (notified by Central Government)
Sulfur Dioxide (SO_2),	Annual* 24 hours**	50 µg/m^3 80	20 µg/m^3 80
Nitrogen Dioxide (NO_2),	Annual* 24 hours**	40 µg/m^3 80	30 µg/m^3 80
PM_{10} (particulate matter less than 10 µm in diameter) µg/m^3	Annual* 24 hours**	60 µg/m^3 100	60 µg/m^3 100
$PM_{2.5}$ (particulate matter less than 2.5 µm in diameter)	Annual* 24 hours**	40 µg/m^3 60	40 µg/m^3 60
Ozone (O_3)	8 hours* 1 hour**	100 µg/m^3 180	100 µg/m^3 180
Lead (Pb)	Annual* 24 hours**	0.5 µg/m^3 1.0	0.5 µg/m^3 1.0
Carbon Monoxide (CO)	8 hours* 1 hour**	2 mg/m^3 4	2 mg/m^3 4
Ammonia (NH_3)	Annual* 24 hours**	100 µg/m^3 400	100 µg/m^3 400

[111] The Air (Prevention and Control of Pollution) Act, 1981, http://www.moef.nic.in/legis/air/air1.html.

Benzene (C_6H_6)	Annual*	5 µg/m^3	5
Benzo(a)Pyrene (BaP)-particulate phase only,	Annual*	1 ng/m^3	1 ng/m^3
c(As),	Annual*	6 ng/m^3	60 ng/m^3
Nickel (Ni),	Annual*	20 ng/m^3	20 ng/m^3
* 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. Figure: National Ambient Air Quality Standards as published in the Gazette of India, 18 November 2009. Retrieved from Central Pollution Control Board site at: http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php.			

Table 4: India's National Ambient Air Quality Standards

Exposure to ambient concentrations of fine PM is the sixth leading risk factor for disease and early death in South Asia and the ninth worldwide.[112] While larger particles are typically blocked from deposition by our natural defense mechanisms (e.g., coughing, sneezing, or swallowing) and mid-range particles are typically inhaled and exhaled, fine and ultrafine particles can penetrate deep into the lungs and alveolar sacs after inhalation.[113] An analysis of pollution estimates by the Centre for Science and Environment (CSE) in Delhi suggests that 141 Indian cities experience PM_{10} pollution levels exceeding the 2009 national standards of 60 µg/m^3, itself a far more generous standard than the corresponding WHO annual air quality guideline of 20 µg/m^3.[114]

Pollutant	Averaging Time	Indian National Standard, 2009	WHO Guideline Values	WHO-Interim Target 1	WHO-Interim Target 2	WHO-Interim Target 3
PM10 (µg/m^3)	Annual 24-hour	60 100	20 50	30 75	50 100	70 150
PM2.5 (µg/m^3)	Annual 24-hour	40 60	10 25	15 37.5	25 50	35 75

Table 5: Indian National Ambient Air Quality Standards (NAAQS) for PM_{10} and $PM_{2.5}$, and corresponding WHO guideline values and interim targets

Importantly, fine particulate matter pollution in parts of India is expected to worsen in the coming decades due to continuing urban expansion and the country's heavy reliance on coal for electricity generation.[115] By 2030, high levels of fine particulate matter are projected to pervade across most of the country, with concentrations in the Ganges Valley increasing to more than 150 µg/m^3.[116]

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[112] Lim, S.S., et al., "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010," *The Lancet* 380, no. 9859 (December 2012): 2224–60, doi:10.1016/S0140-6736(12)61766-8.

[113] Oberdörster, G., E. Oberdörster, and J. Oberdörster, "Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles," *Environmental Health Perspectives* 113, no. 7 (March 22, 2005): 823–39, doi:10.1289/ehp.7339.

[114] Health Effects Institute, "Burden of Disease: Outdoor Air Pollution among Top Killers," 2013, http://www.cseindia.org/userfiles/briefing_note13feb.pdf; Central Pollution Control Board, "National Ambient Air Quality Standards," November 18, 2009, http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php; World Health Organization, *Air Quality Guidelines: Global Update 2005: Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide* (Copenhagen, Denmark: World Health Organization, 2006).

[115] Ramanathan, K., and The Energy and Resources Institute, *National Energy Map for India: Technology Vision 2030 Summary for Policy-Makers*, TERI, 2003.

[116] Purohit, P., M. Amann, and R. Mathur, "GAINS-Asia: Scenarios for Cost-Effective Control of Air Pollution and Greenhouse Gases in India," 2010, http://gains.iiasa.ac.at/gains/reports/GAINS-Asia-Methodology-20081205.pdf.

After PM, O_3 and its NO_X precursors are the next priority pollutants in India. The WHO estimates that 19 cities experience NO_2 levels that exceed the national annual standard (40 µg/m^3), a level at which adverse health effects, particularly impaired lung development in infants, are still likely.[117] Importantly, many cities are out of compliance for both PM_{10} and NO_2. Nitrogen oxides, along with VOCs, are central to the chemical formation of ground-level O_3, a secondary pollutant, in the atmosphere and the major component of smog pollution. After fine particulate matter, O_3 is the second most damaging air pollutant to human health. This gas inflames the respiratory tract, aggravates lung diseases such as asthma, and increases lung susceptibility to infection. After NO_2 and O_3, SO_2 is the priority next target for mitigation, as one city currently exceeds the annual (50 µg/m^3) standard and moderate levels are observed in 11 additional cities. SO_2 exposure aggravates asthma and other respiratory and cardiovascular diseases.

Economic Development and Air Pollution

With the rapid pace of economic growth at above 8% and increasing energy demand, under a business as usual scenario, air pollution and related health issues will balloon in India.[118] With increasing city pollution and urbanization, air pollution exposure is expected to shift away from indoor air towards problems of ambient PM and O_3 in cities.[119]

India's electricity sector is highly reliant on coal and domestic deposits contain relatively high levels of sulfur, exacerbating aerosol emissions and requiring more solid fuel to be burned to return the same amount of usable energy. In the absence of a more aggressive shift to cleaner energy, demand for electricity is expected to increase emissions of SO_2, NO_X, and carbon particles, worsening ambient concentrations of PM and O_3. Similarly, economic growth in India is also expected to increase the share of two-wheelers and automobiles on already congested roadways: between 1951 and1991, the population of Delhi expanded fourfold while vehicle registrations skyrocketed by a factor of more than fifty.[120]

Although fleet emission standards are steadily improved, the number of new vehicle owners may overwhelm these gains and contribute to increasing nitrogen oxide emissions from the transportation sector and exacerbate the smog of O_3 pollution. Under a business as usual scenario analyzed by the GAINS model, estimates of emission increases between 2005 and 2030 show: SO_2 emissions grow by factor of five, NO_X by a factor of three, VOCs by 27%, and $PM_{2.5}$ by 30% [121]. Under this future scenario, power generation continues to be the major driver of SO_2 and NO_X, while biomass burning is implicated in increases in VOC and $PM_{2.5}$ pollution.

However, tools such as the AQI can help protect public health. Decisions to shift to cleaner energy technologies for thermal power plants and vehicle sources as well as reducing crop burning and other practices can lower air pollution. The Indian government, along with state and city governments, is certainly focusing on sustainable development with an emphasis on clean energy. Still, more comprehensive programs are required to control air pollution while allowing for economic growth, as major economies around the world have proven. Shifting to cleaner sources of energy, such as solar energy and wind energy, and adopting large scale energy efficiency programmes can help lower air pollution.

[117] World Health Organization, *Air Quality Guidelines*.

[118] Purohit, P., M. Amann, and R. Mathur, "GAINS-Asia: Scenarios for Cost-Effective Control of Air Pollution and Greenhouse Gases in India."

[119] World Health Organization, *Air Quality Guidelines*.

[120] Goyal, P., "Present Scenario of Air Quality in Delhi: A Case Study of CNG Implementation," *Atmospheric Environment* 37, no. 38 (December 2003): 5423–31, doi:10.1016/j.atmosenv.2003.09.005.

[121] Purohit, P., M. Amann, and R. Mathur, "GAINS-Asia: Scenarios for Cost-Effective Control of Air Pollution and Greenhouse Gases in India."

Indoor Air Pollution and Ambient Air Pollution

Exposures to indoor air pollution stemming from the incomplete combustion of solid fuels are substantial in developing countries and complicate health impact assessments attempting to isolate exposures to ambient pollution. While the magnitude of indoor $PM_{2.5}$ health effects is well-established, there are fewer studies on the specific sources and chemical and biological properties of $PM_{2.5}$ which are most hazardous and how the composition of indoor air pollution compares to ambient pollution. Current evidence indicates that about a quarter of ambient air pollution India may stem from indoor combustion of solid fuels. Therefore, intervention efforts to mitigate ambient air pollution should consider the potential for environmental and health gains from promoting cleaner fuels for cooking and heating in rural areas.

Climate Change: Multiplier Effects on Air Quality

Rising levels of air pollution due to climate change rank high among future health concerns. [122] In addition to the effects of economic growth on the demand for electricity and road transportation, climate change is expected to directly and indirectly exacerbate surface concentrations of PM and O_3. The chemical formation of O_3 in the atmosphere is temperature dependent, and as a result climate change and higher surface temperatures are expected to worsen O_3 pollution in India. This current-day effect of a changing climate will be a particularly important policy concern in cities such as Delhi and Ahmedabad, which are already polluted and getting hotter because of climate change. [123]

The chemical formation of O_3 in the lower atmosphere, typically limited by ambient NO_X concentrations, can also be VOC-limited under highly polluted conditions. The hydrocarbon-limited situation presents particular challenges for air quality managers, as NO_X emission controls cause an increase in O_3 concentrations due to the non-linear dependence of O_3 on precursor emissions.[124] Just as a decline in surface cyclones is expected to increase the frequency of stagnant air masses in the United States, global climate modeling suggests similar patterns for mid-latitudes worldwide[125]. These findings support the view that O_3 and PM pollution will remain an important air quality threat in India even if emissions do not drastically rise in the future.

Future estimates of PM pollution are less certain, given the complex components of this pollutant and weak correlation between ambient PM concentrations and local meteorological conditions [126]. Fine particle pollution also influences meteorology itself. Over the past decade, long-range transport of air pollution has emerged as an important pattern explaining trans-oceanic and trans-continental aerosol plumes of atmospheric brown clouds that absorb and reflect radiation from the sun, causing both atmospheric warming (and an exacerbated greenhouse effect) as well as surface cooling (through an atmospheric dimming effect). For South Asia in particular, expected changes in north-south gradients in sea surface temperatures will inhibit summer monsoon circulation and thus decrease rainfall over land [127]. As a result of this reduced rainfall, particle pollution will persist.

Given India's large population and rising levels of prosperity, energy demand is expected to increase

[122] Patz, J.A,, et al., "The Potential Health Impacts of Climate Variability and Change for the United States: Executive Summary of the Report of the Health Sector of the US National Assessment.," *Environmental Health Perspectives* 108, no. 4 (2000): 367; Intergovernmental Panel On Climate Change, Working Group II, "Climate Change 2014: Impacts, Adaptation, and Vulnerability," 2014, http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap11_FGDall.pdf.

[123] Jacob D.J., and D. A. Winner, "Effect of Climate Change on Air Quality," *Atmospheric Environment* 43, no. 1 (2009): 51–63; Central Pollution Control Board, "Indian NAAQS."

[124] Daniel J. Jacob, *Introduction to Atmospheric Chemistry* (Princeton, N.J: Princeton University Press, 1999).

[125] L. J. Mickley et al., "Effects of Future Climate Change on Regional Air Pollution Episodes in the United States," *Geophysical Research Letters* 31, no. 24 (2004): L24103; Jacob and Winner, "Effect of Climate Change on Air Quality."

[126] Jacob, Daniel J., and Darrel A. Winner, 2009, Effect of climate change on air quality. Atmospheric Environment 43(1): 51-63.

[127] Ramanathan, V., and Y. Feng, "Air Pollution, Greenhouse Gases and Climate Change: Global and Regional Perspectives," *Atmospheric Environment* 43, no. 1 (2009): 37–50.

more than fivefold by 2030[128]. Increasingly, air conditioning is seen as both a method to relieve exposure to oppressive summer heat, but also a status symbol of economic advancement. Researchers estimate that air conditioning sales are growing 20% annually and that the cooling demands of Mumbai alone in a warmer world (home to 18.4 million people), are exacerbating polluting emissions[129].

[128] Ramanathan, K., and Shahid Hasan. *Privatization of electricity distribution: the Orissa experience*. The Energy and Resources Institute (TERI), 2003; partially available online: https://books.google.com/books/about/Privatization_of_electricity_distributio.html?id=ce0AAQAAQBAJ.

[129] Michael Sivak, "Potential Energy Demand for Cooling in the 50 Largest Metropolitan Areas of the World: Implications for Developing Countries," *Energy Policy* 37, no. 4 (April 2009): 1382–84, doi:10.1016/j.enpol.2008.11.031.

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Video Resources on Air Pollution

Increase of Air Pollution In Naroda, Ahmedabad

(Duration: 1:04 minutes)
Sandesh News, November 2, 2016

Air Pollution Gets Dangerously High During Diwali Celebrations in Ahmedabad

(Duration: 2:44 minutes)
Ahmedabad City Guide, November 12, 2016.

Air Pollution in Delhi Dangerously High; 1,700 Schools to Remain Shut today

Duration: 15:47 minutes)
IndiaTV, November 5, 2016.

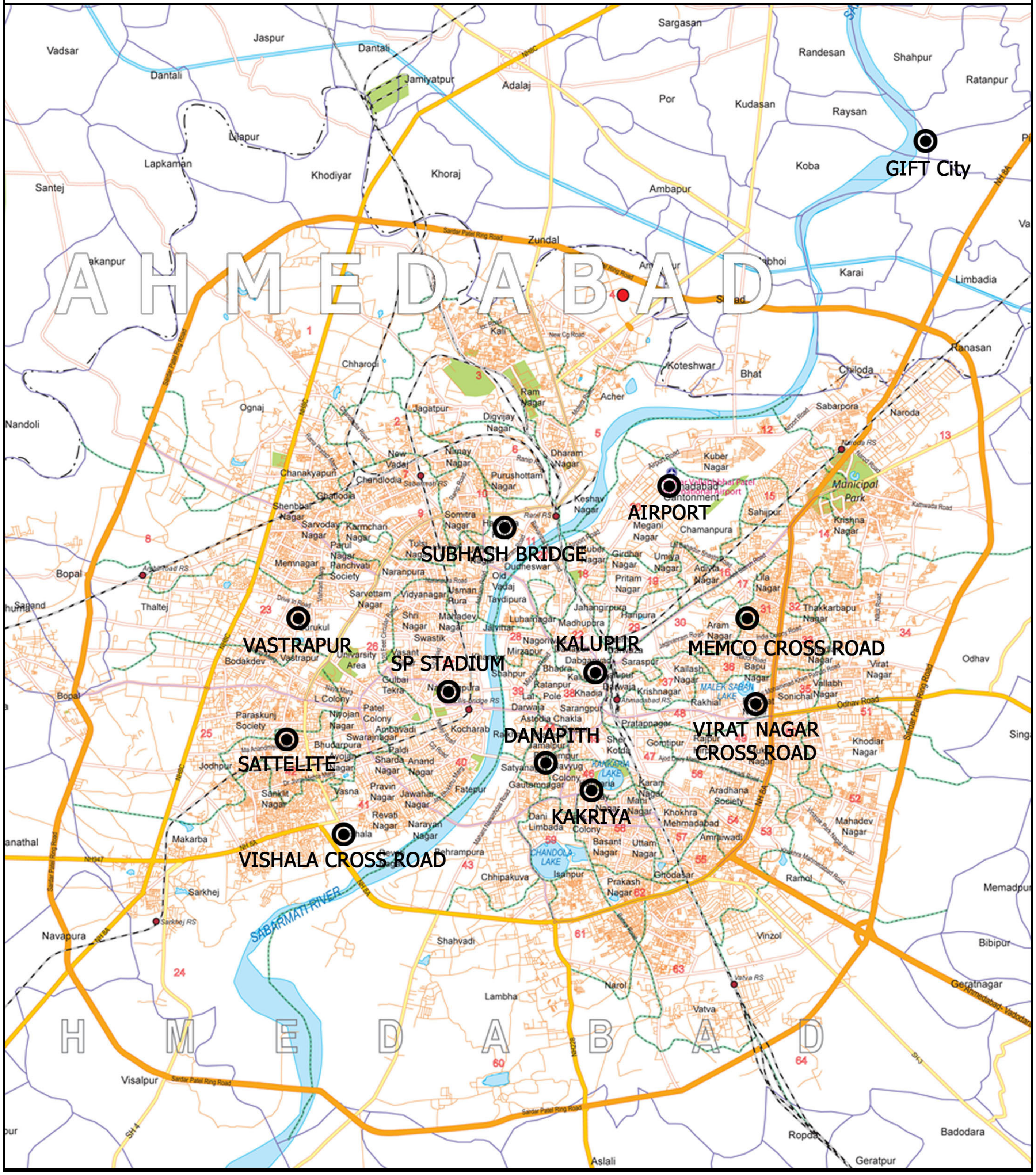
Conclusion

Dangerous air pollution levels threaten the health of tens of millions of Indians living in cities across the country. While awareness about air pollution and its effects is increasing, major gaps remain in communicating the health risks of air pollution, including gaps in connecting the dots between climate change and its effects on air pollution and human health.

The use of AQI has been applied globally in more than a dozen countries as a powerful means to communicate air pollution levels and associated health risks to the public. Air pollution alerts can help the public and policy makers to take precaution and preventive measures in the short-term with a longer-term view to address the sources of air pollution. The objective of the SAFAR AQI project is to build national and community response capability by providing risk knowledge, monitoring and warnings, dissemination and communication and response capability. By interpolating and analyzing meteorological data, air quality monitoring data and health data, patterns can emerge that can offer useful information to hospitals to make the early warning system for a specific region stronger and making communities more aware about the health risks of impending high pollution events.

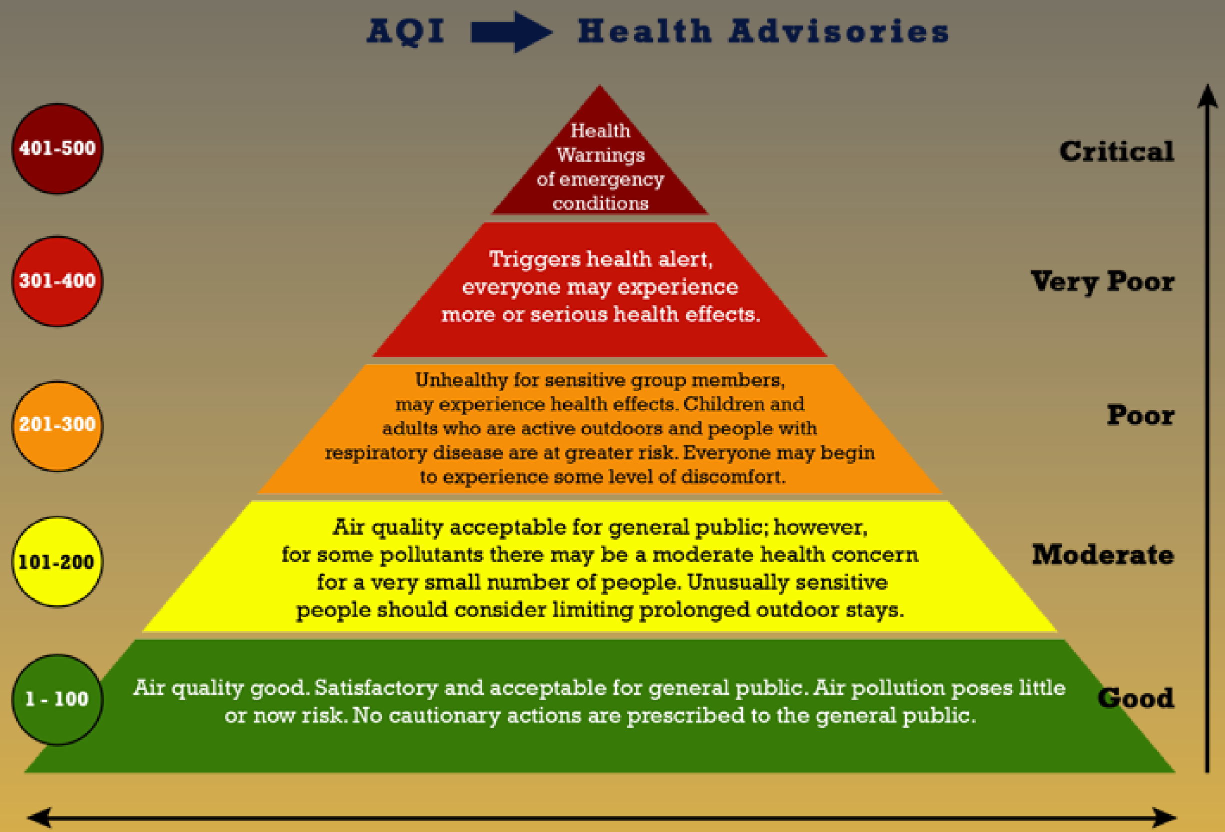
The international experience on improving air quality in a region starts with increased monitoring that allows for clear health risk communication. Access to information increases awareness about air pollution that leads to greater acceptance of air pollution as a serious health risk needing action. This process ultimately leads to an increased focus on air quality action through policy measures and behavioral changes, resulting in reduced air pollution levels and better citizen health.

SAFAR-Ahmedabad
Digital Display Boards Network



Description	AQI	PM10 µg/m³ 24 hr avg	PM2.5 µg/m³ 24 hr avg	CO ppm 8 hr avg	O3 ppb 24 hr avg	NO2 ppb 24 hr avg
Good + Satisfactory	0-100	0-100	0-60	0-1.7	0-50	0-43
Moderate	101-200	101-250	61-90	1.8-8.7	51-84	44-96
Poor	201-300	251-350	91-120	8.8-14.8	85-104	97-149
Very Poor	301-400	351-430	121-250	14.9-29.7	105-374	150-213
Severe	401-500	431-550	251-350	29.8-40	375-450	214-750

SAFAR's color coded AQI tiers for five criteria air pollutants for India.



SAFAR's AQI scale with AQI index value ranges, associated public health impacts in the middle; and air quality descriptors on the right.