



Delhi's

BY MEERA SUBRAMANIAN

India's capital scrambles to tackle its epic pollution problems.

On winter nights, New Delhi burns with innumerable fires. Flames flicker along pavements and street corners, where the destitute huddle to stay warm and cook their suppers, while night watchmen stand guard next to their own small blazes outside private homes. The rising plumes of smoke mingle with exhaust and dust stirred up by overloaded trucks that rumble down roads blanketed in fog. The mixture melds into a nearly opaque substance that leaves a metallic taste on the tongue. Overhead, there is not a single star to be seen.

With dawn comes a hint of warmth, but the sunlight remains hidden by haze. A hopelessly optimistic sign — “Make Delhi Pollution-Free” — is lashed to a metal cage that protects a young sapling, its withered leaves caked with dust.

The grime is the most obvious part of the pollution that plagues India's capital region and its 25 million people. Less discernible are the airborne particles smaller than 2.5 micrometres in diameter, known as $PM_{2.5}$ — the most harmful size range. Just a fraction of the diameter of a human hair and astoundingly aerodynamic, $PM_{2.5}$ can penetrate deep into the body, reaching the recesses of the lungs. The particles are a nasty amalgam of pollutants both natural and increasingly anthropogenic, generated from sources within the city's boundaries and hundreds of kilometres away. The World Health Organization (WHO) declares that no amount of this pollutant is safe to breathe.

Two years ago, Delhi had the highest $PM_{2.5}$ levels of 1,600 cities surveyed by the WHO. Last month, in an updated and expanded inventory¹, Delhi retained its status as the most polluted of the world's largest cities, with an annual $PM_{2.5}$ average of 122 micrograms per cubic metre ($\mu g m^{-3}$) — three times the permitted Indian standard and greatly exceeding the WHO standard of $10 \mu g m^{-3}$. The pollution, which comes mainly from combustion of wood, coal, gas, diesel and

A brown cloud of pollutants hangs over the outskirts of New Delhi.



deadly air

ROBERTO SCHMIDT/AFP/GETTY

crop residue, is worst in the winter, when wood-burning peaks and cold-weather inversions trap pollutants close to the ground and cause spikes in the daily average of above $600 \mu\text{g m}^{-3}$. Late last year, the levels prompted the Delhi High Court to declare the city a “gas chamber”.

The observed $\text{PM}_{2.5}$ amounts are estimated to cause as many as 16,000 premature deaths and 6 million asthma attacks² in Delhi annually, shaving around 6 years off the life expectancy of city residents³. Although the WHO data have brought attention to Delhi, the problem is global: according to the agency, particulate pollution affects more people than any other pollutant on Earth.

AIR PATROL

Delhi, like Beijing, Mexico City, London and Los Angeles, is struggling to reduce pollution, even as its population swells. Researchers and the government are trying to construct a detailed breakdown of the different pollution sources, and authorities are experimenting with ways to mitigate the damage, from restricting when people can drive to shutting down power plants. But India faces unique challenges. Its population is concentrated in the north, an area geographically prone to pollution, and its people have aspirations for development. There is a growing middle class hungry to own cars, and one-fifth of the population merely wants access to basic electricity. Those facts threaten to compromise Delhi's efforts to improve environmental quality.

“The reality is that the pollution in Delhi is very complex. There are a lot of sources. It varies from season. It varies by time of day. It varies by neighbourhood,” says Namit Arora, a member of the pollution task force of the Delhi Dialogue Commission, a government initiative in the

city. But he insists that the city can make progress. “We can act, and we need to act, on multiple fronts simultaneously.”

Delhi is trying to do just that. Long before it was saddled with the mantle of having some of the world's worst air, the city and the Supreme Court of India took several steps to alleviate pollution. Vehicle emissions came down in the early 2000s, thanks to decisions to remove lead from petrol, improve vehicle-emission standards and pull old commercial vehicles off the roads. Around the same time, the city implemented a monumental conversion of the public-transportation fleet, including buses and the city's zippy three-wheel auto-rickshaws, away from gasoline and diesel engines to ones fuelled by cleaner compressed natural gas. In 2002, the Delhi Metro subway system opened its first line, improving public-transportation options. All but two of the coal-based thermal power plants in the city were converted to natural gas, and many industries, including brick kilns, were moved beyond Delhi's bounds.

These efforts reaped big gains, yet they have been offset by the incessant growth of the megacity. Since 2000, Delhi's population has nearly doubled. And the number of vehicles has almost tripled, from 3 million to more than 9 million, according to the government.

Determining what creates hazardous $\text{PM}_{2.5}$ is a crucial step in reducing it, yet past studies have varied markedly because they have used different methods and relied on limited data. Filling some of the gaps is a report released in January by the Indian government and the Indian Institute of Technology (IIT) Kanpur⁴, which took a more comprehensive approach to investigating the causes of Delhi's poor air quality. Some sources contribute throughout the year, such as pollution from vehicles, diesel generators, construction dust, biomass and

coal combustion and industries. Others are seasonal: dry summer dust blowing in from nearby deserts, autumn crop burning and Diwali holiday fireworks, and the warming fires that make the city glow come winter (see 'Poison stew').

Vehicle emissions are constant, and with all those belching tailpipes in sight every day, they often capture the attention of pollution-fighting officials. In January, Delhi implemented an odd-even programme that allowed car owners to drive only every other day, as dictated by their vehicle's number plate. When the 15-day experiment came to a close, a few hundred Delhiites took to the streets to praise the initiative and rally for continued efforts. Families, musicians, passionate teenagers, costumed 20-somethings and activists all gathered near Jantar Mantar, a cluster of monuments built in the 1700s to study skies that were then crowded with visible stars. But over the temporary stage set up for the event, an air monitor showed that $PM_{2.5}$ levels were hovering around $184 \mu g m^{-3}$, a level that warrants staying indoors to reduce exposure.

Although levels remained well above acceptable during the odd-even experiment, several researchers declared it a success in both lowering emissions and, perhaps more importantly, raising public awareness. "People are willing to display the civic sense we thought didn't exist here," says Arora, who was at the demonstration wearing a shirt emblazoned with the words "Help Delhi Breathe" and an image that was half flower bloom, half gas mask.

Still, government officials and researchers admit that this approach has limited long-term potential because of how difficult it is to enforce the ban. During January's trial, people were already talking about buying a second car as a workaround. After the odd-even effort was repeated in April, the government estimated that there were half a million more vehicles on the roads than during January's trial, according to local media, which suggests that people were skirting the rules.

The odd-even policy gets a lot of attention, "but that is not the solution," says Ashwani Kumar, who was secretary of the environment of the Delhi Pollution Control Committee (DPCC) at the time. "A typical democratic society cannot depend on a 'don'ts' approach," he says. Making it more expensive and inconvenient to drive a car, for example, would naturally spur people to use public transportation. "It has to be based on incentive and disincentive; otherwise, it's easy to find loopholes and descend into a quagmire of corruption."

GOING PUBLIC

Although parts of Delhi's public-transportation system are impressive, others are lacking. The Delhi Metro is an efficient, extensive electric-rail system with more than 200 kilometres of lines, and it continues to expand. But the Indian media has reported that the government's plans to increase the number of buses in Delhi have been plagued by delays, and that a pilot programme for dedicated bus lanes was met with so much public resistance that the lanes are now being dismantled.

"If the public-transportation system is robust, and it's made safe and comfortable and reliable, people will automatically switch," says Sarath Guttikunda, director of the independent research group UrbanEmissions.info, which is registered in Delhi.

Nudging people onto buses and subways will deal with only part of the transportation pollution problem. Although vehicles as a group contribute up to about one-quarter of $PM_{2.5}$ in Delhi⁵, the fraction generated by heavy-duty freight trucks is twice that of cars. To ease the impact of the estimated tens of thousands of trucks that move through the city daily, the Supreme Court has implemented new taxes on them, and Delhi is adding bypass highways.

The other crucial ingredient is the type of fuel that goes into vehicles. Given that diesel engines produce much more particulate matter than ones that run on petrol, the rising percentage of luxury diesel cars is a troubling trend. To try to stem the sales, the government temporarily banned registration of diesel vehicles with larger engines earlier this year, according to Indian media.

Delhi's emissions standards for vehicles are more stringent than those in the rest of India, but they still lag far behind those in Europe. And

the discrepancy between city and national standards means that many vehicles operating in Delhi spew emissions from lower standard vehicles and fuel obtained beyond city limits.

Yet all this attention on vehicles is somewhat misplaced because they are not the biggest source of particulate pollution. "If the goal is to reduce PM, we need to go beyond traffic," says atmospheric scientist Pallavi Pant of the University of Massachusetts–Amherst, who studies Delhi's air quality.

Just a few steps away from the busy roads, on a broken stretch of pavement, a woman tends a cooking pot perched on three stones, a wood fire burning below. Across South Asia, more than one-quarter of the outdoor air pollution comes from these traditional stoves⁶. In urban



Ever-present construction and smoke-belching vehicles are major contributors to air pollution.

As it seeks cleaner air, Delhi has to confront the desperate desire for development.

CHRIS STOWERS/PANOS

Delhi, only about one in ten households still relies on smoky stoves that use wood, dung or kerosene, but they still contribute a substantial part of the city's $PM_{2.5}$ burden. One study found⁷ that the emissions from fires used domestically for cooking and warmth rival those from the electricity sector, from brick kilns and from industry.

Delhi's government and the country's Supreme Court have tried to limit some of these sources, but there is one major factor that they cannot control: the city's location, far from the cleansing breezes of the ocean. From the west, smoke from agricultural crop burning and dust storms from the Thar Desert blow into the city. And from the north, cold fronts sweep down from the Himalayas, locking pollutants in with winter weather inversions. When it comes to air pollution, the city is "geographically disadvantaged", says M. P. George, an environmental scientist with the DPCC.

Although Delhi can't fend off desert dust storms, it can control construction dust generated by its never-ending building spree. Officials are attempting to decrease air pollution from construction by improving and enforcing rules, such as requirements to cover building sites and trucks to stop dust from blowing away.

The problems that Delhi faces also afflict other cities in the region, creating a vast brown cloud that in satellite images seems to smother much of South Asia. About one-third of Delhi's particulate pollution comes from sources outside the city, according to the IIT-Kanpur study⁴.

"It's not just a Delhi problem; it's a regional problem," says Milind Kandlikar, who researches development and environmental issues at the University of British Columbia in Vancouver, Canada. India's northern

cities have come to dominate the WHO's list of most-polluted cities, with half of the top 20 all located in the region. Delhi's efforts will falter unless the rest of the country also steps up, says Kandlikar. "Everybody else has to be involved. This is not going to go away easily."

But political conflicts are threatening the chances for broad-scale pollution-control efforts. There is currently a fractious tension between the national government, run by Prime Minister Narendra Modi's Bharatiya Janata Party, and Delhi's ruling Aam Aadmi Party — a situation that hinders efforts to develop a unified strategy to deal with air pollution. In lieu of any cooperation, the Supreme Court continues to have an integral role in improving air quality by directing the govern-

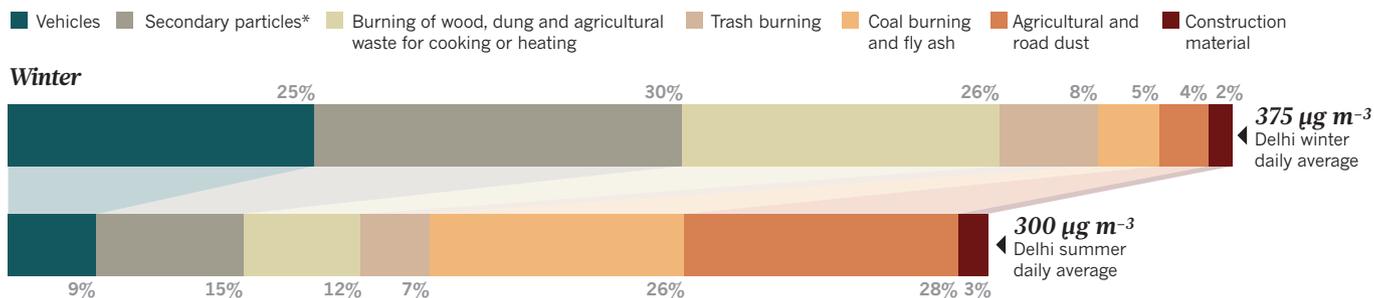
ment to restrict emissions from sources such as vehicles and power plants. "My reading is that the politicians are often grateful to the courts for acting, because many of these measures are unpopular," says Arora. With so many sources of air pollution, city officials would ideally like to know which programmes will work best — so the Delhi Dialogue Commission task force recruited IBM Research-India to develop computer models to forecast pollution levels.

odd-even schemes, and the Delhi government has teamed up with the University of Chicago's Delhi-based academic centre to launch a design competition called the Urban Labs Innovation Challenge: Delhi, which aims to crowdsource ideas for improving air and water quality. In March, it received hundreds of submissions, including ideas for promoting rooftop solar panels and creating viable alternatives to burning waste and crops. Prize money of up to US\$300,000 will fund design pilots.

In Delhi and around the world, citizens, governments and researchers are all demanding more air-quality data, which indicates an interest in knowing the enemy. Information from government monitors is publicly available, but the interfaces are often clunky. This has given rise

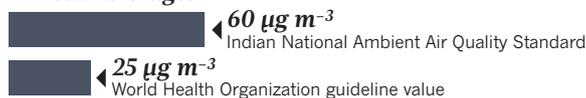
Poison stew

Delhi has the highest particulate air-pollution readings of any megacity. A study released this year by the Indian Institute of Technology Kanpur⁴ found that different sources dominate in winter and summer for particles smaller than 2.5 micrometres, known as PM_{2.5}.



*Formed mostly from sulfur dioxide and NO_x produced principally from vehicles, industry and power generation.

24-hour averages:



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"The idea is to create a simulation framework which will allow them to evaluate different policies and see their impact before they actually implement them," says Ashish Verma, a senior manager with IBM's Smarter Planet team in Delhi. Although the modelling is still in progress, early results reinforce how important the weather is. This suggests that air-pollution controls might be most effective if they take advantage of specific weather conditions, for example, by closing power plants or limiting traffic during the worst pollution-trapping weather inversions.

CITIZEN ACTION

As it seeks cleaner air, Delhi has to confront the country's desperate desire for development, which includes providing electricity to the roughly 240 million people who still lack it. India pledged to expand its renewable energy capacity aggressively, as part of the national plan that it submitted during the United Nations climate-treaty negotiations last year. But the plan also defends India's right to use fossil fuels, stating that "in order to secure reliable, adequate and affordable supply of electricity, coal will continue to dominate power generation in future".

Both the climate plan and government officials such as Kumar insist that India need not follow conventional modes of development that rely on fossil fuels. "There is no way we can adopt the technology trajectory of the developed countries who continue to be the biggest polluters in terms of per capita," Kumar says. But it is not clear whether India will be able to leap-frog past the most polluting forms of energy.

One encouraging sign in Delhi is that air quality is now part of an active city-wide conversation. Full-page newspaper ads solicit citizen input on

to new alternatives such as IndiaSpend, an independent media outlet that also conducts 'sensor journalism', in which readings from its own pollution monitors are made available in a user-friendly format. The sheer increase in global monitoring — the WHO's database doubled in two years because many more cities had begun to monitor their air — offers an opportunity for more-comprehensive studies going forward, including in regions that have previously been neglected.

Meanwhile, concerns about pollution are hard to escape. In upscale Delhi markets, vendors hawk air masks and purifiers, and parents can purchase nebulizers decorated with cute animals to appeal to children with asthma. Doctors have been known to advise patients with lung ailments to leave the city. "Picking up a life is not so easy," pleads one mother. "What are we supposed to do?"

Many Delhiites tend to swing between despair and hope — just as the skies go through their own cycles. By late March, the weather starts to shift and the winds pick up. It's as if the city's windows are thrown open, allowing fresh breezes to blow through. July brings the monsoon rains and washes much of the danger out of the sky, down towards the Yamuna River, which carries some of the burden away. For a few months, citizens can step into the night, tilt their heads back and once again enjoy the stars overhead. ■

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