Breathless in the Megacity

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Smog over Mumbai: The air in some mega cities contains enough contaminants to cause thousands of extra deaths.Air pollution in India's capital alone claims around 10,000 lives each year. Credit: IndianInsights / Romana Chapman

Megacities offer the enticing prospect of employment and the benefits of an urban infrastructure – but they also expose their inhabitants to high levels of air pollution. Together with an Indian Partner Group of the Max Planck Institute for Chemistry in Mainz, Bhola Ram Gurjar is analyzing this pollution and how badly it is affecting the health of city dwellers.

Bhola Ram Gurjar is always fascinated to observe the object of his research from a plane. An environmental engineer by trade, he grew up on a farm where millet was cultivated and sheep were raised. The farm was in a village with no electricity, near Ranthambore forest, a tiger reserve in Western India. Today, Gurjar's interest lies in megacities – cities with ten million inhabitants or more. Whenever he approaches Delhi, Tokyo or New York by air, time and again, he is amazed by the sprawling extent of these conurbations, the tightly packed buildings, traffic arteries, industrial areas and patches of green.

"Modern cities are among mankind's greatest achievements," says Gurjar. But for all the advantages that cities offer, they also have serious disadvantages. The air in some of these vast hubs of human activity is extremely polluted. "Cities are great habitats," Gurjar continues, "but they can be better still if we get a grip on problems like this." As an environmental engineer and associate professor at the Indian Institute of Technology in Roorkee, he would like to do his part.

Pointers to improve air quality

At first glance, Roorkee doesn't really seem the ideal place to study air pollution and its consequences for megacities. Situated in the foothills of the Himalayas, the town has less than 150,000 inhabitants – tiny, by Indian standards. Nor is there much industry here to pollute the environment. Bhola Ram Gurjar's desktop, however, is brimming over with air quality data – data that provides tangible evidence of the air pollution in Beijing, New Delhi, Los Angeles and 15 other megacities.

xTo improve the quality of the air in megacities, Gurjar has teamed up with Jos Lelieveld, Director at the Max Planck Institute for Chemistry in Mainz. Together they developed Ri-MAP (Risk of Mortality-Morbidity due to Air Pollution), a mathematical model that estimates how many additional lives a given degree of air pollution will claim, relative to a

clean atmosphere. The computer program can help the authorities in megacities around the world to clean up their polluted air. It enables them to take targeted action based on reliable data, rather than mere supposition, to reduce the levels of particularly harmful contaminants.

Overshadowed by the disaster in Bhopal

Gurjar arrived at the analysis of air quality and its effects on health by a somewhat circuitous route. Almost 30 years ago, he received a government grant that enabled him to enroll at a school of engineering in Jodhpur. He still remembers studying by the light of a kerosene lamp in his village of Daulatpura in Rajasthan. His decision to specialize in civil engineering was prompted largely by chance. “I was so delighted by the idea of studying engineering that it didn’t seem to matter which branch I chose.

The boy sitting next to me filling out his form chose civil engineering, so I did too,” Gurjar recalls.

His first job after receiving his engineering degree was on a construction site in Western India, building a runway. However, he found the task of cooperating with construction firms andthe bureaucracy involved in public sector building projects so frustrating that he returned almost immediately to the academic world. He first completed a master’s degree at his college, then a Ph.D. at the IIT in New Delhi.

It was while studying at the IIT in the 1990s that he began to specialize in the evaluation of environmental risks. He was interested in air pollutants even back then, not least because memories were still fresh in India of what at the time was the worst industrial disaster in history: in December 1984, a leaking storage tank in Bhopal had allowed toxic methyl isocyanate gas to escape, killing at least 2,500 people.

Megacities are becoming increasingly relevant

The accident sensitized Gurjar, too, to the dangers of airborne contaminants. He thus set up a risk assessment study in which he compared the cancer rates in certain Indian states with the levels of potentially carcinogenic substances recorded by the local environmental authorities.

On the very day on which he was awarded his doctorate from the IIT in New Delhi, Gurjar learned from a scientist from the US that Jos Lelieveld was recruiting postdoctoral researchers for his department. The group specialized in atmospheric chemistry, and Lelieveld himself had studied the interrelationship between atmospheric chemistry and climate. He investigated the effects of the Indian monsoon on pollution transports and the capacityof the atmosphere to clean itself and remove the contaminants.

Gurjar applied and was accepted for a three-year postdoctoral research scientist's position – but he encountered a dilemma. He simultaneously had an offer for a Ford Foundation fellowship for studies at the Harvard School of Public Health. Gurjar recalls that Lelieveld sent him a single-page analysis in a leading scientific journal that pointed out that the Max Planck Society had more publications in the field of atmospheric chemistry than Harvard. He now admits that there was another reason he picked Germany over Harvard. The Ford Foundation fellowship was just enough for him to travel alone to the US. The pay as a post doc at the Max Planck Institute for Chemistry was also sufficient to bring his wife along to Germany.

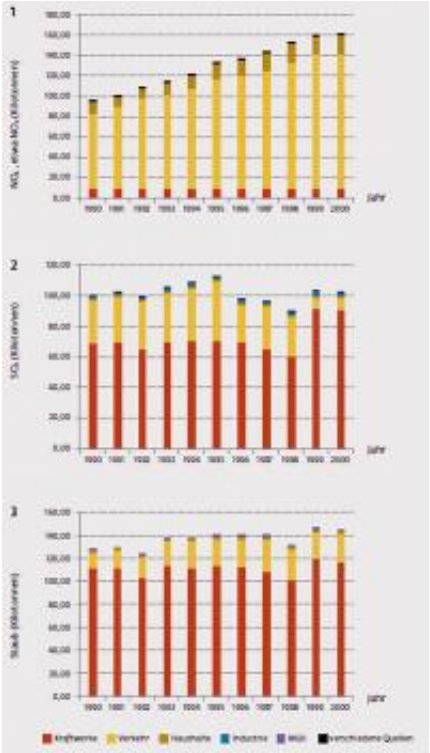
When he arrived in Mainz, Lelieveld offered him the chance to choose any research topic he liked. "That was something of a surprise," says Gurjar. In India, it is usual for a mentor to tactfully but firmly direct his protégés toward a particular subject. "I decided to study the air pollution

in megacities, and Lelieveld evidently shared my enthusiasm for the topic."

The importance of megacities, they both believed, would steadily increase, not least in research. And indeed the number of conurbations with more than ten million inhabitants has risen from just 2 in 1950, when only Tokyo and New York passed this threshold, to 20 at the beginning of the 21st century. According to some forecasts, the number of city dwellers worldwide will reach five billion by 2030, by which time 8 out of 10 megacities will be found in Asia and Africa.

Airborne pollutants trigger many diseases

As a consequence of this development, more and more people will be breathing air that is hazardous to their health. The problems vary from city to city. Every megacity is shrouded in its own characteristic air pollution, generated by high traffic densities and various industrial activities. In varying proportions, the air contains considerablequantities of carbon monoxide, sulfur dioxide, oxides of nitrogen, particulates – such as soot – and organic compounds such as those released in the combustion of fossil fuels. Some megacities generate more exhaust fumes than entire countries. In Beijing, for example, a total of 2.7 million tons of carbon monoxide are released into the air – more than Portugal – yet Beijing occupies only a fifth of the area covered by Portugal.



Sources of pollution in Delhi: Bhola Ram Gurjar and his colleagues have investigatedthe emissions given off by power stations, traffic, domestic households, industry,agriculture and garbage. Oxides of nitrogen, such as NO2, originate mainly from thesteadily growing volume of traffic (1). The narrow black bars represent a combinationof sources not depicted individually (1 and 2). Most sulfur dioxide is emitted by powerstations (2). Between 1996 and 1998, emissions declined with the introduction of low-sulfurdiesel, and because in 1998 the power stations burned less fuel. Meanwhile, however,the growing volume of traffic has cancelled out the improvements. Power stations arethe main source of particulates (3). Reduced capacity utilization, as occurred in 1992and 1998, noticeably reduces the concentration of particulates. Credit: Designergold / nach Vorlagen des MPI für Chemie

The resulting concentrations of exhaust fumes are certainly not conducive to good health. They have long been associated with respiratory diseases such as asthma, but in recent years, links have been established between air pollution and other illnesses ranging from

cardiovascular diseases to breast cancer.

Five years ago, researchers at the University of New York, Mount Sinai School of Medicine and the University of Michigan produced results indicating that particulates with a diameter of 2.5 micrometers can cause arteriosclerosis, which in turn is a risk factor for heart disease. Scientists at the Fritz Haber Institute of the Max Planck Society reported two years ago that particulates less than 20 nanometers in size can provoke even greater inflammation than larger micro-particles. And just recently, experts at the Institute for Cancer Epidemiology in Copenhagen showed that long-term exposure to even low levels of air pollution increases the risk of serious chronic obstructive pulmonary disease, an affliction that makes it hard to breathe.

It is becoming steadily clearer that there is a risk associated not just with highly polluted air, to which even short-term exposure can be harmful. Even low concentrations of contaminants can cause damage if individuals are exposed to them over long periods. As an analogy, one could compare this with the passive smoking of cigarettes.

The airborne contaminants that people breathe in with their city air and how these affect their health is a natural extension of what Bhola Ram Gurjar focused on during his three-year stay in Mainz. During this period, he compiled an emissions inventory for the Indian capital of New Delhi, where the number of vehicles on the roads has burgeoned in recent decades, while the city's infrastructure has failed to keep pace. Between 1971 and 2001, the overall length of the road network grew by a factor of 3.5, from 8,380 kilometers to 28,508 kilometers. Yet over the same timescale, the number of vehicles on the roads increased 20-fold: from 180,000 to almost 3.5 million.
"The inventory helped us to eliminate some false interpretations regarding the sources of the air pollution," says Gurjar. In the 1990s, public transportation and private traffic were regarded as the main cause

of the contaminants in Delhi's air. However, Gurjar's analysis showed that up to 80 percent of sulfur dioxide and particulate emissions in the city were contributed by coal-fired power stations.

The results made it clear that what the megacities needed was an emissions inventory. In an article in the journal ATMOSPHERIC ENVIRONMENT, Gurjar and Lelieveld thus called for an international program to gather data on air pollution emissions and estimate their local and global effects.

The two researchers also practiced what they preached: Shortly after the article was published, Bhola Ram Gurjar returned to India and took up a position at the Indian Institute of Technology in Roorkee. There, he and Lelieveld established a Max Planck Partner Group to study air quality in megacities. Such Partner Groups enable scientists from abroad, when they return home, to continue with the joint research and existing projects first initiated at a Max Planck institute.

An additional 15.000 deaths in Karachi

The scientists first studied the emissions in the world's 18 largest megacities and ranked them in order of air quality. The figures measured in 2000 showed that Tokyo, Beijing, and Shanghai had the highest emissions of carbon monoxide, while Beijing, Shanghai and Los Angeles recorded the highest emissions per inhabitant.

The highest concentration of sulfur dioxide was found in Dhaka, followed by Beijing and Shanghai. The levels in each of these three megacities exceeded the standards recommended by the World Health Organization (WHO). Moscow, Beijing and Jakarta claimed the dubious record for the highest concentrations of nitrogen dioxide, while the inhabitants of Karachi, Cairo, Dhaka and Delhi suffered the worst particulate pollution.

But Gurjar and Lelieveld were not satisfied simply with drawing up a pollution ranking table. They wanted to rank these megacities by the actual impact of these contaminants on the health of their populations. Ri-MAP is the result of their continuous research collaboration – a model that combines various data: the population of a megacity, the air quality and the risk to human health presented by each hazardous substance in the air. Based on a set of ratios of concentration to effect, the model predicts the number of additional deaths in each city that can be attributed to individual airborne contaminants.

The resulting table for the 18 megacities in which the researchers analyzed the quality of the air shows where the air is most dangerous to breathe. Karachi has the highest number of additional deaths due to air pollution, almost 15,000 per year. Some 14,700 people die each year as a consequence of Dhaka's polluted air, 14,100 in Cairo, 11,500 in Beijing and 10,500 in New Delhi.

Which pollutant must be reduces first?

In Los Angeles, New York and Tokyo, in contrast, the effects of air pollution have long since ceased to be so drastic. Here, the number of additional deaths is less than 500 per year. "The analysis shows a clear trend: the health risk presented by air pollution is greater in the megacities of the developing world than in the industrialized countries," says Bhola Ram Gurjar.

The researchers admit that the figures do not reflect any absolute certainties. The current model assumes that the entire population of a megacity is exposed to the same degree of airborne pollution. Furthermore, the model also uses annual averages of individual pollutants. In the future, however, the researchers intend to take account of monthly, weekly or even daily fluctuations in the concentrations of contaminants, as well as the number of people who are directly exposed

to these substances.

“The estimates of risk may not be perfect, but we believe that they can be helpful in establishing guidelines for pollution control,” says Gurjar. The model breaks down the health risks in order of pollutants: it considers the relative risk – that is, the probability of disease or death – if the concentration of one contaminant rises by one point on the Ri-MAP scale. The resulting figures show for each contaminant how steeply it increases the mortality rate due to respiratory or cardiovascular diseases, or how many hospitalizations it prompts due to chronic obstructive pulmonary disease. In both Karachi and Dhaka, around 2,100 deaths are attributable to respiratory diseases. “The city authorities could even use such approximate values as a basis for decisions on which pollutant to reduce first.”

Analysis to include heavy metals and ozone

New Delhi became a test city for the Ri-MAP model. Analysis revealed that the number of additional deaths due to air pollution rose steeply between 1998 and 2002. Then, in 2003, the rate suddenly declined, remained constant for a few years, and is now once again rising steadily.

“The steep decline in 2003 could be attributable to the fact that that was the year in which the city authorities converted all of their public transport service buses from diesel to run on compressed natural gas,” Gurjar explains. “Since then, however, the steep growth in the overall number of vehicles has cancelled out this improvement.” Gurjar and Lelieveld are now keen to broaden their research to include other pollutants, such as heavy metals, ozone and minute particulates that can penetrate the human lung. At some point, Gurjar continues, the estimates of risk generated by the model should be compared against epidemiological data from the megacities. “Correlating the Ri-MAP figures directly like that with actual death statistics is the toughest test of

such a model," says Gurjar.

If the model's predictions were to be confirmed by such a comparison, it is likely that city administrators would have faith in the forecasts. The results of the model calculations would then demonstrably offer a reliable basis on which to plan the measures needed to make the air healthier to breathe. Not only would there be health benefits the fantastic views of these megacities, seen from above from an approaching aircraft, would also be less clouded by smog – perhaps even to the point where they could be enjoyed in aweinspiring clarity.

Provided by Max-Planck-Gesellschaft