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Online: Air pollution – global problem needs local fixes
Find the particles most dangerous to health in each locale and lower those, urge Xiangdong LI and colleagues.

Each year more than 4 million people die early because of air pollution, according to the World Health Organisation (WHO). The main culprits are fine particles 2.5 micrometers or less in diameter ($PM_{2.5}$). These can penetrate deep into the lungs, heart and bloodstream, where they cause diseases and cancers.

But those numbers may be underestimated or overestimated. They assume that these particles are the same the world over. They are not. $PM_{2.5}$ is a cocktail of chemicals (hydrocarbons, salts and other compounds given off by traffic, stoves and industry) plus other natural components such as dust and microbes. The mix --- and its toxicity --- varies from place to place, in ways that are not tracked, understood or managed.

For example,[1] in Asia, soot from residential heating and cooking is the biggest source of $PM_{2.5}$. In Europe, Russia, Turkey, Korea, Japan and the eastern USA agricultural emissions including ammonia are the leading source. Desert dust boosts air pollution in northern Africa, the Middle East and Central Asia. Which is most dangerous?

Levels of $PM_{2.5}$ alone thus only give a rough guide to the toxicity of the air in a particular place.[2] Researchers and policymakers need to rethink methods for assessing health risks and regulatory measures for reducing those risks. Reducing $PM_{2.5}$ by the same amount in different places will not deliver the same health benefits in all. To protect millions more lives, scientists need to help governments and municipalities find out what the most toxic constituents are and mitigate them first.

Unequal toxicities

Evidence is mounting of geographic differences in health responses to air pollution. For example, while the death tolls are high in China and India --- industrialising cities are heavily polluted and lots of people live there ---- the risks to city dwellers in Europe and the US are greater. Europeans and Americans are more likely to die from heart disease and from acute respiratory attacks than those in China, when exposed to similar levels of $PM_{2.5}$.[3]

Risks from dirty air vary between cities. Londoners and New Yorkers are at greater risk of dying than inhabitants of Beijing when smog concentrations surge. Dirty air in Milan is more likely to generate reactive species of oxygen (free radicals) that stress the body than in Lahore or Los Angeles.[4] Chinese cities in the east fare worse than those elsewhere in the country.[3] Beijing's winter smog is more deadly than that in Guangzhou much farther south.[5]

Cell and animal studies --- it is unethical to test toxicity directly on humans --- back up these findings. For example, mice exposed for 24 hours to $PM_{2.5}$ from California[6] had more inflamed lungs that animals exposed to similar concentrations in air sourced from China. The difference may reflect higher levels of organic carbon and copper in Californian traffic fumes, although it's hard to translate findings from animal models to humans.

Mixtures of air pollutants may be more toxic than their constituents in isolation. For example, the combined effects of outdoor and indoor air pollution and tobacco smoke may lead to 2-3 times more premature deaths globally than the WHO currently estimates.[1]

Few studies of the health impacts of air pollution consider these variations. Most simply look at masses of $PM_{2.5}$ particles and assume a single recipe. For example, the Global Burden of Disease project captures health risks in one 'exposure-response' function, which the WHO also uses**.** This derives the likelihood of someone who has inhaled a certain mass of $PM_{2.5}$ dying later from a related disease, based on hundreds of epidemiological studies, mostly done in Europe and the US.

But we know very little about how actual smog affects health. Some substances are known toxins when inhaled. For example, transition metals including iron and copper readily produce oxygen free radicals that damage the body. Links have been reported, for example, in Canadian cities between prenatal exposure to free radicals in $PM_{2.5}$ and low birth weight.[7] On the other hand, sulphates, nitrates and ammonia are much more common but less harmful than metals.

Some toxins remain to be discovered. For example, toxic metals and poly-aromatic hydrocarbons (PAHs) accounted for less than 40% of $PM_{2.5}$'s potential to generate oxygen free radicals in Beijing and Guangzhou in the winter of 2013.[4] What explains the rest?

Possibilities include 'secondary organic aerosols' derived from photochemical reactions of organic compounds like isoprene (which is produced by many plants and animals and found in natural rubber). Other 'humic' organics are released from soil and coal. Plasticizers (such as bisphenols and phthalates) affect the endocrine system. But the toxicities of all these substances in air remain to be assessed.

Biological components like bacteria and fungi are rarely considered in health studies. These may be poisonous in themselves or interact with other chemicals to affect health.[8] Pathogens and allergens need to be evaluated. Floating in Beijing's wintertime smog, for example, is a common bacterium that can cause pneumonia (*Streptococcus pneumonia*) and a fungal allergen (*Aspergillus fumigatus*) that may invade the airways of immune-deficient patients. Compounds in the cell walls of bacteria (endotoxins) may induce inflammation. Other products of fungi (mycotoxins) can lead to respiratory conditions and infections.

The list is long. But the most important question is: which toxins are most dangerous in a given location and thus most urgent to mitigate?

Next steps

First, the focus of air pollution studies should shift to measuring the health effects, not just emissions from sources and atmospheric chemistry.[9] This must involve diverse experts from molecular biology and toxicology to health sciences and economics. Researchers should rank sources of $PM_{2.5}$ in order of toxicity. And examine the toxicity of mixed samples of real air.

That knowledge must be translated into local measures to control the most hazardous types of pollution. For example, efforts to reduce emissions from residential energy might be the best way to reduce premature deaths from air pollution in China and India; China's shift in wintertime heating energy from coal to natural gas thus needs to be evaluated. Similarly, clean fuel and energy efficiency measures might be prioritized in the US. And inorganic emissions from agriculture should be addressed in rural areas.

As a first step, hotspot countries should be identified in the WHO data where there are particular health concerns arising from $PM_{2.5}$ pollution (**Figures 1 and 2**). Niger, India, Egypt, Nepal should be included as they have high levels of particulates and high death rates. $PM_{2.5}$ in Nigeria, Chad, Yemen, Sierra Leone and Cote D'lvoire might be targeted as being particularly hazardous due to their relatively high baseline death rates, which can be further exacerbated by medium to low concentrations of $PM_{2.5}$.

The WHO, UNEP and the World Bank should fund a network of flagship stations to monitor the chemistry of air at key locations, starting with these hotspots and expanding to others. *In situ* cell and animal studies should also be placed across cities. Methodologies will need to be standardized for studies of cells, animals and humans. For cell-based assays, the toxicities of $PM_{2.5}$ mixtures could be quantified relative to the impacts of other chemicals, as is done in water quality assessments for example.[4]

Data from different locations and seasons should be openly shared and synthesized in a global toxicity database, such as that run by the WHO. This could also collect personalized air quality data, for example from wearable sensors, and determine links between individual exposure to pollutants and health conditions.

More data should be collected on people's behaviours and perceptions, to find out how human activity determines exposure to air pollution.[10] For example, such data may be translated into personalised air quality and health management. Smart travel alerts could be produced for sensitive individuals to help them avoid hazardous exposures, for example when traffic emissions are high or weather conditions are likely to form haze.

We call for efforts to reduce the health impacts of air pollution to be high on the agendas of major conferences this year. Sessions at the International Aerosol Conference, European (EGU) and American Geophysical Union (AGU), the China India Association of Atmospheric Scientists (CIAAS), the International Society of Environmental Epidemiology (ISEE) and others should pave the way for the research collaborations needed.

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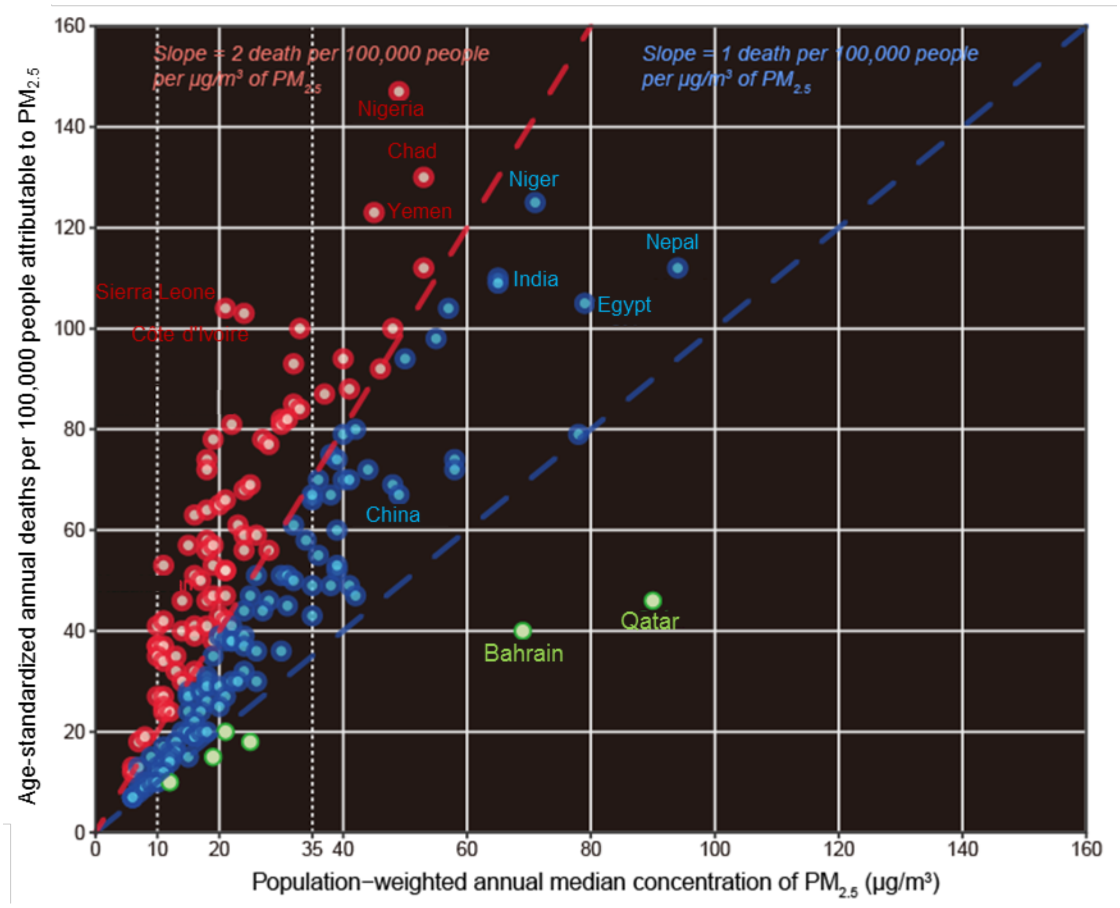

Figure 1. Country-specific data on age-standardised annual deaths attributable to outdoor $PM_{2.5}$ exposure per 100,000 people in relation to population-weighted annual median $PM_{2.5}$ concentrations (Data sourced from the WHO, 2018; available online at: https://www.who.int/airpollution/data/en/)

Note: The slopes (number of annual deaths per unit $PM_{2.5}$ concentration increase) categorise countries into three areas (green: slope < 1; blue: 1 <= slope < 2; and red: slope >= 2).

- Toxicity is high in countries like Nigeria, Chad, Yemen, Sierra Leone, Cote D'lvoire where high baseline mortality can be further exacerbated by medium or even low $PM_{2.5}$ pollution;
- Toxicity is high in places like Niger, India, Egypt, and Nepal where mixed sources add to high pollution of $PM_{2.5}$; and
- Toxicity may be low in places with high levels of $PM_{2.5}$ from natural origins, such as Bahrain and Qatar.

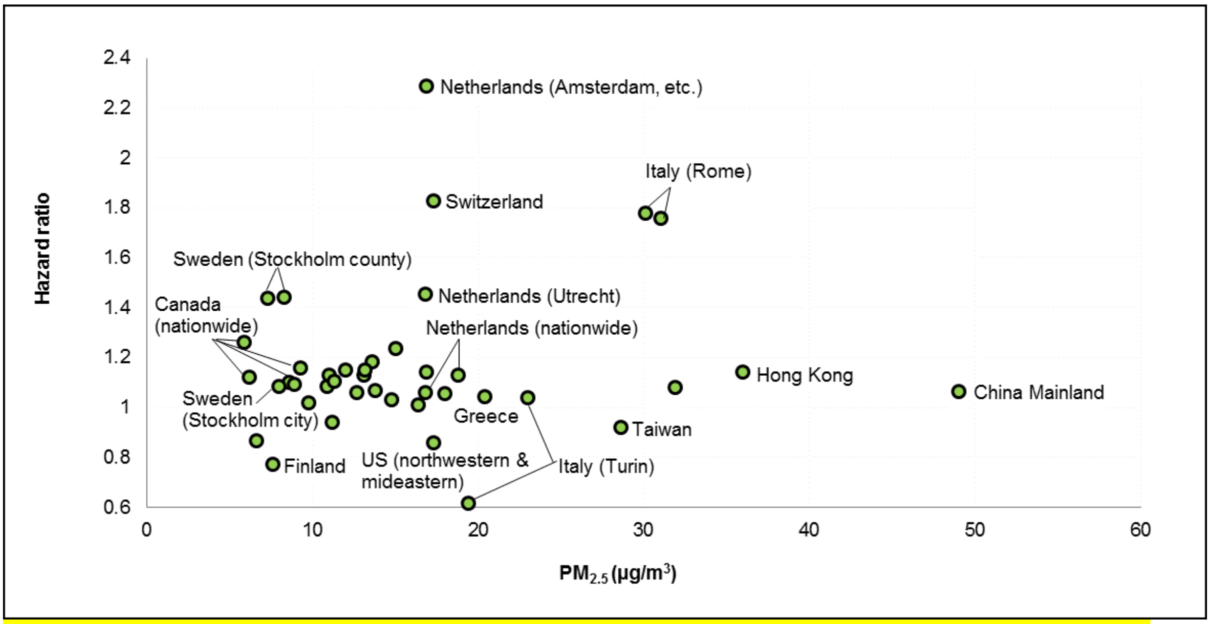

Figure 2. Country-specific $PM_{2.5}$ levels and hazard ratios (*i.e.,* increase in death risks per increase of 10 μg/m^3 $PM_{2.5}$) derived from available cohort studies (Data sourced from Ref 2 and references therein).

- Toxicity may be relatively low in places with high levels of $PM_{2.5}$ pollution, such as China; and
- Toxicity may be relatively high in urbanised/industrialised regions (for example in the Netherlands) even though the pollution levels of $PM_{2.5}$ are relatively low.