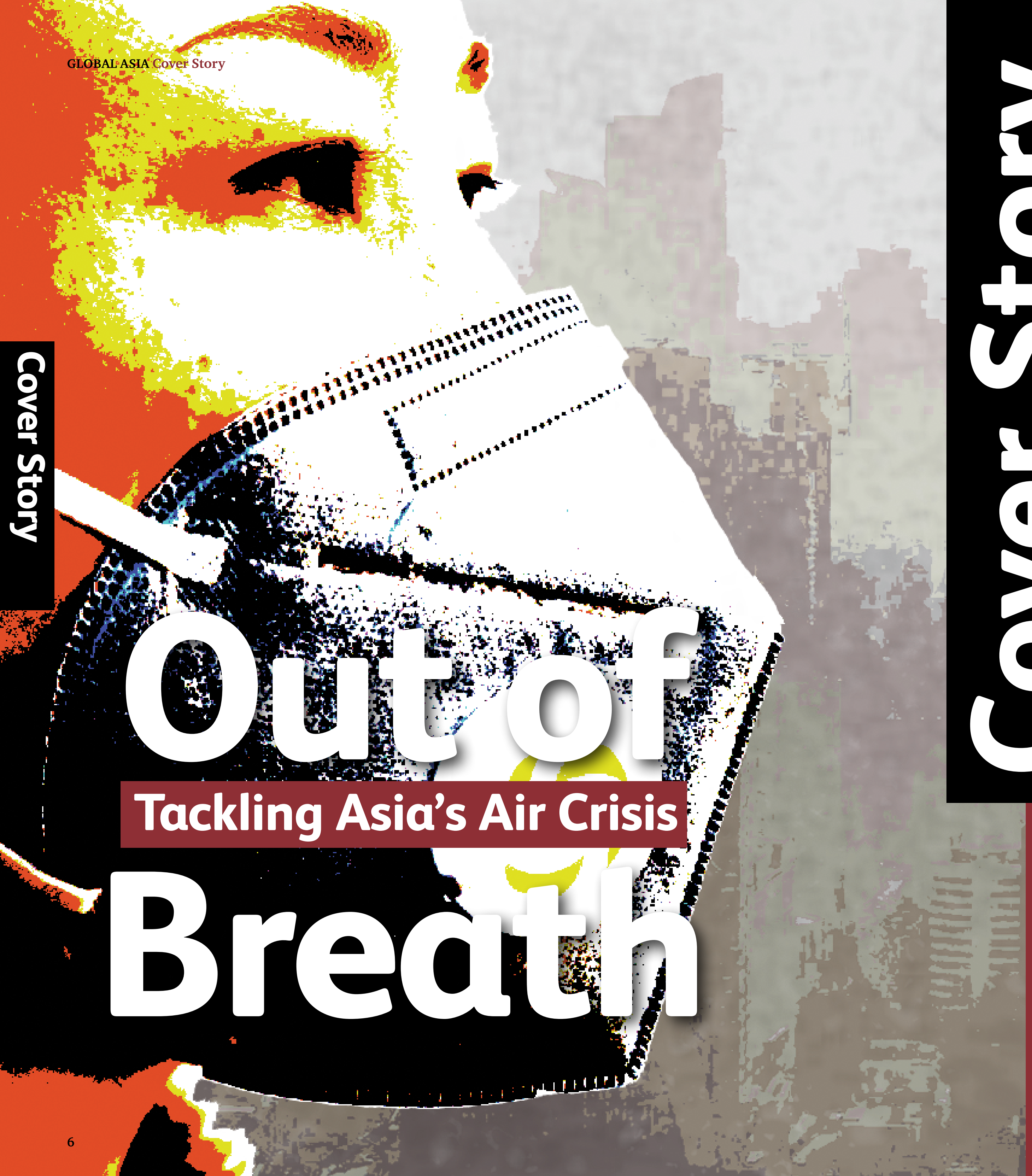


Cover Story

Out of Breath

Tackling Asia's Air Crisis

Cover Story

Asia's extraordinary economic growth since the Second World War has come at an enormous price to the environment, and above all, on its air.

For this cover package, Associate Managing Editor John Delury and Editorial Board member Peter Hayes assembled an international team of experts to look at the challenges posed. In particular, we sought to look at both the science and the policy-making behind the problems.

A short package of essays on an issue of this complexity cannot hope to be comprehensive, but we do aim to highlight key issues and how they might be addressed. One major conclusion is that air pollution in Asia is a problem that cries out for regional cooperation, precisely because it is transboundary in nature, as numerous authors in this cover package point out.

ESSAYS BY

Desert Dust: Its Perils and Its Importance

By Nick Middleton

In Northeast Asia, it is well known to South Koreans and Japanese: the annual yellow haze, a blanket of sand dust emanating from China's Gobi Desert. This ritual plague covers the region and sends people indoors to escape dangerous, if natural, pollutants.

Desert dust spread is part of a global phenomenon that regularly plays out across a large swathe of the world, from West Africa to Northeast Asia. It merits further study because, while it imperils human health, it also has benefits for the wider planet, writes Nick Middleton.

THE STRING OF DESERTS and semi-deserts stretching almost continuously from the Atlantic coast of West Africa through the Middle East and Central Asia to the Gobi Desert of China and Mongolia is often called the "Dust Belt." It's an extensive region marked by strong, turbulent winds that frequently result in severe dust storms. The millions of tiny soil particles raised during these storms have all sorts of implications. Dust adversely affects air quality and human health, and can impact transport, agriculture, manufacturing and electricity generation. These consequences extend far beyond the arid landscapes because, once lifted high into the atmosphere, dust is often transported over thousands of kilometers. Understanding the composition, transport and effects of this dust is therefore of critical importance.

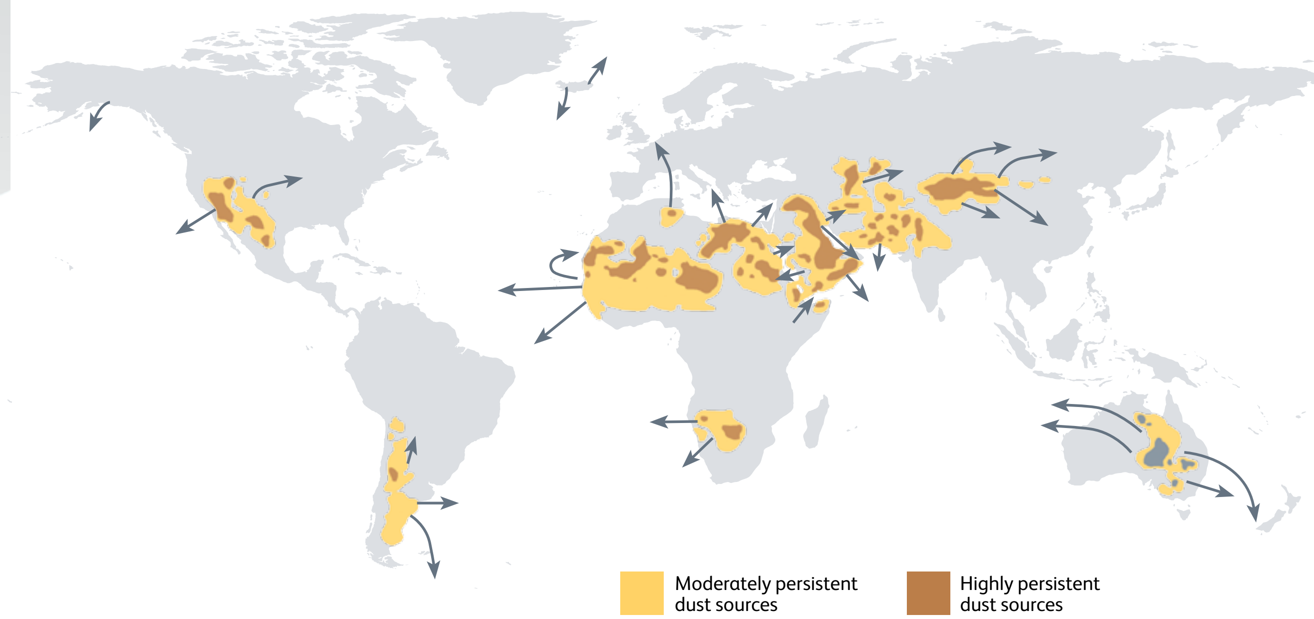
THE NATURE OF DESERT DUST

Globally, an estimated two billion tons of dust are emitted from the world's deserts every year. The greatest sources are in the Sahara, but the Asia-Pacific region is the second largest in terms of emissions, with more than half a billion tons of dust per year (see figure 1). This material is mainly composed of fragmented sand grains, or quartz. Other constituents commonly include a mixture of minerals, clays, salts, micro-organisms, traces of plant matter, and often anthropogenic pollutants of various kinds, including pesticide residues and fertilizers.

The grain size of dust is, by definition, small. Sedimentologists define a dust particle as having a diameter less than 62.5 microns (a micron is a thousandth of a millimeter — for reference, a human hair is about 80 microns in width). Gravity sees the smaller dust particles travel furthest.

FIGURE 1 GLOBAL DUST SOURCES AND TRAJECTORIES

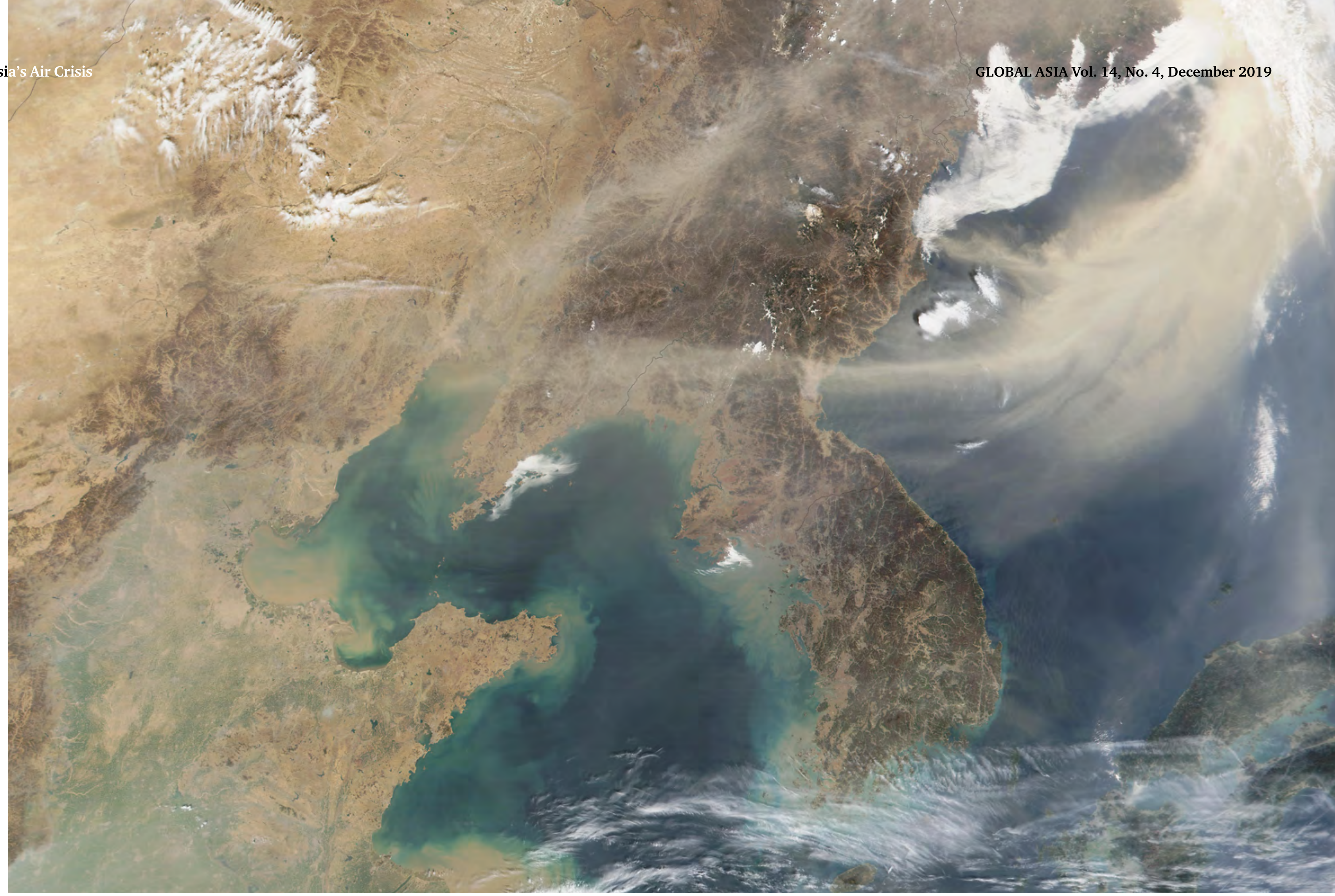
Source: Adapted from Daniel R. Muhs et al., "Identifying Sources of Aeolian Mineral Dust: Present and Past," in Knippertz P, Stuut J-B W, eds., *Mineral Dust: A Key Player in the Earth System* (Springer, 2014)



The exact composition of dust reflects the surface sediments in the source area. Sources of this material can be divided into naturally dry, sparsely vegetated areas such as the Taklimakan Desert, and regions such as the Aralkum, the salty patch of former lake bed in Central Asia exposed as the Aral Sea has shrunk due to excessive diversion of water for human use. Not all sources fit into this neat classification, however, because mismanagement is easily exposed when natural conditions take a turn for the worse. A farmer's field, or a stretch of rangeland grazed by livestock, can become a dust source at any time if overused, but is particularly prone to erosion by wind during a drought.

Soil particles picked up by the wind can quickly become a choking dust cloud, obscuring the horizon and, in the worst cases, reducing visibility at ground level to zero. Much of this dust is lifted far above the surface, where it is carried huge distances in high-level winds. In Korea, the arrival of yellow dust haze from mainland Asia is such a common phenomenon they have a name for it: *Hwang Sa*. In Japan, it's known as *Kosa*.

Dust from Northeast Asia is frequently transported out over the Pacific Ocean and regularly reaches North America, a journey that takes several days. Traces of Asian dust have also been found in ice and snow cores in Greenland and the European Alps. In 2009, a team led by researchers from Kyushu University in Japan reported tracking Asian dust that was transported more than one full circuit around the globe. Soil material uplifted during a storm in China's Taklimakan Desert was carried more than 8 km above the Earth's surface, where it took 13 days to encircle the planet. When the dust reached the northwestern Pacific for the second time, it fell to earth over the ocean.



A satellite image from April 2002 shows dust blowing from East Asia eastward across North Korea over the Sea of Japan, also known as the East Sea (top right). Meanwhile, haze is evident over eastern China (lower left, in greyish tones).

Photo courtesy of MODIS Land Rapid Response Team, NASA/GSFC

IMPACT ON SOCIETY

Dust blown from a farmer's field usually leaves the soil impoverished. The finer, lightest particles are most easily removed, damaging soil structure. Nutrients and seeds often disappear in the process. A wind storm during the early months of crop growth can easily kill seedlings, exposing roots and bombarding the young plants with abrasive particles. The loss of topsoil due to wind erosion has a measurable effect on crop yields.

Dust blowing in the wind also brings a wide range of adverse effects to anyone in its path. Poor visibility can result in the closure of airports and more frequent road traffic accidents. Associated strong winds may bring down trees and damage housing. A series of severe dust storms in northern India in May 2018 killed more than 125 people and injured many more.

Dirty air harms health. Particle size is the main determinant of where dust comes to rest in the respiratory tract once inhaled, and a distinction is commonly made between particles <10 microns (PM_{10}) in diameter, which can penetrate the lungs, and those with diameter <2.5 microns ($PM_{2.5}$) which penetrate deep into lung tissue. Many epidemiological studies show associations between dust exposure and increases in mortality and hospital admissions due to respiratory and cardiovascular diseases. The effects of desert dust outbreaks on asthma incidence has also attracted considerable research in several parts of the world.

Most countries set air quality guidelines indicating acceptable atmospheric concentrations of particulate matter, but these limits are frequently exceeded, sometimes by orders of magnitude, during dust storms. The World Health Organization's air quality guidelines indicate a 24-hour average of 25 micrograms per cubic meter for $PM_{2.5}$ as the maximum acceptable atmospheric concentration. That level is commonly exceeded in Dalanzadgad, a notoriously dusty town in Mongolia's Gobi Desert. A severe dust storm at Dalanzadgad can bring an hourly maximum $PM_{2.5}$ concentration of more than 2,500 micrograms per cubic meter.

Even dust that has travelled great distances in the wind can still occur at concentrations that exceed air quality standards. Dust blown from the Gobi Desert frequently surpasses safe levels in Japan some 2,000 km distant. Mongolian dust has also broken air quality guidelines 3,000 km away in Taiwan. An extreme dust event in 1998 resulted in dangerous concentration levels of particulates several days later on the west coast of the US, more than 16,000 km from the Gobi.

Other health effects of desert dust are traced to a wide variety of fungi, bacteria and viruses, some capable of causing disease in plants and animals as well as people. In Sahelian Africa, also known as the Meningitis Belt, epidemics of meningococcal meningitis appear to be related to Saharan dust intrusions brought by the seasonal Harmattan winds. Dust transported from Asian deserts has been linked to cases of Kawasaki disease — which causes an inflammation of the blood vessels and can result in heart disease — in Japan and Hawaii.

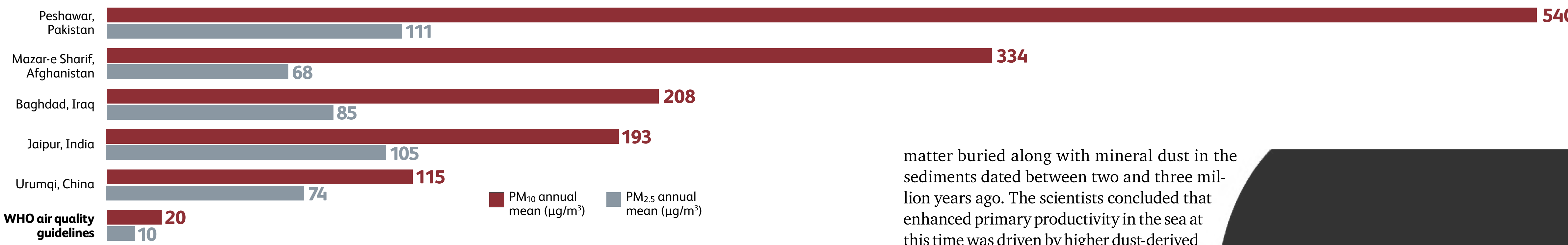
The deposition of dust can cause other problems. A layer of fine particles settling on a photovoltaic solar panel inevitably reduces the amount of electricity the panel produces by as much as 20 percent. Calcium-rich dust from a desert area with limestone geology can result in a more serious problem. If the dust becomes wet from early morning dew, the calcium in the dust hardens like cement, rendering the solar panel useless. Deserts may be blessed with abundant sunshine, making them ideal locations for solar power production, but the presence of dust can seriously reduce this potential.

ENVIRONMENTAL EFFECTS

It is important to keep in mind the fact that many dust storms are entirely natural in their occurrence. Although some of their effects are negative for human society, the occurrence of dust storms is simply part of how our planet works. For instance, dust particles in the atmosphere have numerous implications for weather and cli-

FIGURE 2 MEAN ANNUAL ATMOSPHERIC CONCENTRATIONS OF PARTICULATE MATTER IN SELECTED DESERT SETTLEMENTS IN ASIA AND THE MIDDLE EAST

Source: World Health Organization Ambient Air Pollution Database, accessed December 2019.



mate. Their presence affects the radiation balance and helps to create clouds by providing nuclei on which water vapor can condense to form raindrops. The intensity of the Indian summer monsoon is significantly affected by the concentrations of desert dust over the Arabian Sea, West Asia and the Arabian Peninsula. The dust helps to warm the atmosphere and aids the flow of moisture over India.

The deposition of dust also contributes to soil formation, ocean sedimentation and the health of ecosystems on land and at sea. The long-term beneficial aspects of dust deposition are evident in China on the Loess Plateau, an important farming region for many centuries. Nutrients blown from a soil surface may represent a loss to a farmer, but the nutrients bring benefits wherever they land. Dust carried in winds from the Bodélé Depression, an ancient desiccated lake bed in the West African country of Chad, has been identified as a key source of phosphorus — a vital nutrient for plant growth — in the Amazon rainforest.

Iron is another common constituent of desert dust that is essential for all life forms, albeit in small quantities. Deposition of iron-rich dust on the ocean surface stimulates the growth of phytoplankton, single-celled photosynthetic microbes that form the base of the marine food web.

The fertilizing effect of desert dust on the ocean surface is not fully understood. One aspect still unclear is how iron carried on dust particles from the Earth's surface, where the iron is usually insoluble, becomes available for use in the biological process of photosynthesis. Complex chemical processes appear to change the dust particles during atmospheric transport. Dust remains in transit for periods lasting from hours to weeks, and during this time, it is exposed to sunlight and acidic compounds such as sulfuric acid and nitric acid. These acids initiate chemical reactions that can modify the solubility of iron carried on particles. Interestingly, there is evidence to suggest that these reactions associated with atmospheric acidification are enhanced in areas where desert dust mixes with industrial pollution. Dust that has passed through industrial regions is better able to fuel phytoplankton growth when it reaches the oceans.

Desert dust's fertilizing effect in the oceans has a history stretching back into geological time. Dust particles can be identified in seabed sediments to provide a natural archive of processes through Earth's history. A sediment core drilled from the North Pacific Ocean floor has been studied recently by scientists from the Chinese Academy of Sciences who reconstructed the links between iron supplied in Asian dust and marine productivity in the Sea of Japan, known in Korea as the East Sea, over the last four million years. They found particularly large amounts of organic matter buried along with mineral dust in the sediments dated between two and three million years ago. The scientists concluded that enhanced primary productivity in the sea at this time was driven by higher dust-derived iron supply from Central Asia which, in turn, was probably driven by the growth of the Northern Hemisphere ice sheets during glacial times.

When phytoplankton produce new organic material by photosynthesis in the sunlit upper levels of the ocean, they use carbon dioxide from the atmosphere in the process. Hence, the fertilizing effect of iron-rich dust helps to reduce atmospheric carbon dioxide concentrations. Realization of this natural mechanism by which carbon is "sequestered" into the oceans has led to the suggestion that deliberate fertilization of the ocean surface with iron could be one way to draw down the rising levels of carbon dioxide associated with the burning of fossil fuels. Ocean iron fertilization is the best-studied of several proposed "geo-engineering" approaches to mitigating the effects of global climate change.

DEALING WITH DUST HAZARDS

When and where desert dust presents hazards to society, there are many ways in which these threats can be mitigated. Protecting soil surfaces from winds is a long-established approach, and maintaining sufficient vegetation cover is often referred to as the "cardinal rule" for controlling wind erosion.

China's government has expended huge efforts planting trees across northern parts of the country, both to control dust storms and to combat

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desertification. The largest of these ambitious afforestation projects is the Three Norths Forest Shelterbelt program (also known as the Great Green Wall), begun in 1978, but not due for completion until 2050. But assessments of these projects in remediating desertification in general, and specifically in preventing dust storms, do not all agree. Many studies have noted improved vegetation cover in northern China, but tree survival rates are typically low and several researchers point to warmer temperatures and greater rainfall as being more important drivers of greening trends in the region.

Nevertheless, such afforestation projects continue. Since 2005, South Korea has provided bilateral aid money to help fund the Great Green project, a large-scale planting scheme in the Gobi Desert in Mongolia. Similarly, in Uzbekistan, the government has initiated an extensive planting scheme in the Aralkum.

Planting trees is not always the answer. Straddling the border between southeastern Iran and Afghanistan, the Hamoun Basin is another strong source of desert dust when its marshy lakes become dry during times of drought, but also when water is taken from rivers for agriculture and municipal use. As a consequence, the Iranian border town of Zabol is frequently cited as among the dustiest places on Earth. Its air quality future depends on the governments of Iran and Afghanistan striking a deal on water use in the region.

Co-operation between governments and their meteorological services has resulted in regular forecasts of transboundary dust events in northeast Asia. Under the umbrella of the World Meteorological Organization, a United Nations body, dust forecasts for the region are produced using an ensemble of computer models from China, Japan and South Korea.

Use of these forecasts is a national affair. The Korea Meteorological Administration has a public information system to warn citizens of possible health effects when Asian dust arrives from the continent. There are two levels of notice:

- Advisory, issued when the hourly average PM_{10} concentration is expected to exceed 400 micrograms per cubic meter for over 2 hours.
- Warning, issued when the hourly average PM_{10} concentration is expected to exceed 800 micrograms per cubic meter for over 2 hours.

During a warning, groups seen as particularly at-risk — the old, the young and those with respiratory diseases — are prohibited from going outside. Kindergarten and elementary schools are closed, and outdoor sports events rescheduled. Such alerts are a simple, effective way of reducing harmful health impacts. Analysis of a severe dust event that swept across eastern Australia in September 2009 concluded that the health impacts were minor because of the public health messages sent to subscribers by SMS and email, alerts that also received widespread media coverage.

Dust storms do not result in the kind of significant damage to infrastructure and loss of life usually associated with natural hazards, such as earthquakes or typhoons. Yet, the cumulative effects on society can be significant, because they occur more frequently than most other hazards. The resulting disruption to economic and social activity is a growing concern. Acknowledging that these atmospheric phenomena represent a severe obstacle to sustainable development in affected countries and the well-being of their people, the UN General Assembly has adopted resolutions on combating sand and dust storms each year since 2015. Governments and international organizations are being urged to do more to combat the effects of this particular form of dirty air.

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