SAND AND DUST STORMS IN THE MIDDLE EAST AND NORTH AFRICA (MENA) REGION

Sources, Costs, and Solutions

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WORLD BANK GROUP
Environment, Natural Resources & Blue Economy

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SOURCES, COSTS, AND SOLUTIONS

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This report was prepared by Menaal Ebrahim under the guidance of Craig Meisner, Senior Environmental Economist of the World Bank.

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ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AEMET	Meteorological State Agency of Spain
AI	Aerosol Index
APINA	Air Pollution Information Network for Africa
ASEAN	Association of Southeast Asian Nations
AUD	Australian Dollar
CAWAS	Centre for Atmosphere Watch and Services (China)
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CNY	Chinese Yuan
COPD	Chronic Obstructive Pulmonary Disease
DALYs	Disability-Adjusted Life Years
ECMWF	European Center for Medium-range Weather Forecasting (UK)
FAO	Food & Agriculture Organization
GDP	Gross Domestic Product
IARS	Inertial Altitude Reference System
IASI	Infrared Atmospheric Sounding Interferometer
ICAO	International Civil Aviation Organization
IHME	Institute of Health Metrics and Evaluation
ITU	International Telecommunication Union
IUCN	International Union for Conservation of Nature
KMA	Korea Meteorological Administration
km^2	Square kilometers
MENA	Middle East and North Africa
MODIS	Moderate Resolution Imaging Spectroradiometer
NIES	National Institute for Environmental Studies (Japan)
NWS	National Weather Service (USA)
$PM_{2.5}$	Particulate Matter (diameter less than 2.5 microns)
PM_{10}	Particulate Matter (diameter less than 10 microns)
PEF	Peak Expiratory Flow
PPP	Purchasing Power Parity
RAPIDC	Regional Air Pollution in Developing Countries
RC	Regional Centre
SA	Source Apportionment
SACEP	South Asia Cooperative Environment Programme
SCS	Soil Conservation Service (USA)
SDS	Sand and Dust Storm
SDS-WAS	Sand and Dust Storm Warning Advisory and Assessment System
SMS	Short Message Service
UAE	United Arab Emirates
UAV	Unmanned Aerial Vehicle
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme

UNESCAP	United Nations Economic and Social Commission for Asia and Pacific
UNESCWA	United Nations Economic and Social Commission for Western Asia
UN-Habitat	United Nations Human Settlement Programme
UNITAR	United Nations Institute for Training and Research
USD	United States Dollars
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WSN	Wireless Sensor Network

EXECUTIVE SUMMARY

Dust storms are capable of transporting sediment over thousands of kilometers, but due to the Middle East and North Africa (MENA) region's proximity to the Sahara Desert, the region is one of the dustiest in the world. Dust storms are transboundary, which has important implications for their mitigation, as effects are felt in different countries and even regions than their source of origin. North African dust is transported to as far away as the Amazon Forest, North America, Europe, and China. The Sahara Desert is undoubtedly the biggest dust source, as its dust emissions are about four times as much as Arabian deserts. North Africa, the Middle East, South West Asia, and North East Asia are the regions with the highest dust frequencies and highest Aerosol Index (AI) values. The highest density of dust sources in the Middle East is found in northern Iraq between the Tigris and Euphrates rivers and along the Syria-Iraq border. Dust sources in the region are also generally found in areas with extensive desert cover, low population densities, and sparse agriculture concentrated along river valleys. In terms of occurrences of dust storms, Sudan, Iraq, Saudi Arabia, and the Persian Gulf report the greatest number of dust storms overall.

While natural sources such as the Sahara are the main contributors to dust storms in MENA, land-use changes and human-induced climate change has added anthropogenic sources as well. There are about three times as many natural dust sources as anthropogenic dust sources, however due to land use changes in the past few decades, anthropogenic sources have increased. Most North African dust storms originate from natural sources such as the Sahara, but there are some anthropogenic sources too. For instance, Southern Sahel, the Atlas Mountains, and the Mediterranean coast sources are overwhelmingly anthropogenic. The Middle East region also experiences dust storms from a mix of natural and anthropogenic sources. The Aral Sea is an active dust source, as well as dry riverbeds in Saudi Arabia. There is a cluster of anthropogenic and hydrologic sources along the Jordan River, particularly on the east side. In addition, Iran has prominent dust sources such as large salty lakes and deserts, but the northwestern part is anthropogenic. Although much dust in the Middle East derives from local sources, substantial amounts of dust come from the Sahara.

Like sources, drivers of sand and dust storms are also natural and anthropogenic, as both wind speed and land management can cause them. Wind erosion is the main driver of sand storms and dust emissions in all systems. Essentially, erodibility of surface material coupled with aridity that limits protective effects of vegetation is a natural driving factor of sand and dust storms. For instance, the major dust storm event in 2015 in the Middle East has been attributed to the wind and arid conditions in the area rather than man-made factors. However, there are many man-made drivers of wind erosion too. Human-induced land degradation is a driver of wind erosion and a major contributor toward sand and dust storms, as it exposes degraded and dry surfaces with a long wind fetch. Besides resource use and management in drylands, practices that disrupt the hydrology and protection provided by land in general also contribute to sand and dust storms. In addition, land management practices that result in deforestation and clearance of vegetation will lead to an increase of wind velocity, as well as reduce the entrapment of particles. The complementary piece titled *'Sustainable Land Management and Restoration in the Middle East and North Africa Region—Issues, Challenges, and Recommendations'* provides details on land degradation severity, drivers, and impacts and provides insights into the human-induced drivers of dust storms in MENA.

Dust deposition has wide-ranging health impacts, such as causing and aggravating asthma, bronchitis, respiratory diseases, and infections and lung cancer. Populations far from the source regions are exposed to a wide range of air quality–related health problems when long-range atmospheric transport carries dust. For instance, African dust transported to the Caribbean and Florida has deteriorated air quality standards in those areas and makes up half of South Florida's airborne particles in the summer. Poor air quality and dust cause numerous health problems, both near the dust storm and thousands of kilometers away. Inhalation of fine particles can cause or aggravate diseases such as asthma, bronchitis, emphysema, and silicosis. Chronic exposure can be linked to respiratory disease, lung cancer, and acute lower respiratory infections.

Apart from devastating health impacts, dust also impacts the environment, agriculture, transport, and infrastructure. For the environment, dust can have both negative and positive effects. Dust storms have some positive global impacts due to their transboundary nature and the importance of dust in global climate and terrestrial and biogeochemical cycling. For instance, dust fertilizes and sustains both oceans and forests, playing a huge part in the earth's biogeochemical cycles. While dust boosts primary productivity of oceans, it could have damaging effects on coral reefs. In addition, dust has been also associated with leading to and exacerbating climatic events such as storms, droughts, and the melting of glaciers. Dust deposition and dust storms are also associated with many other costs such as crop damage, livestock mortality, infrastructure damage, and interruption of transport.

Globally, welfare losses from dust are approximately 3.6 trillion USD, where costs are about 150 billion USD and over 2.5 percent of Gross Domestic Product (GDP) on average in MENA. Dust storm costs range from negative health impacts to reducing crop yields to lowering property values to steering talented workers away from polluted places. The World Health Organization estimates that 7 million people die from poor air quality every year, which is at least partly attributed to dust. A study prepared by the World Bank and the Institute of Health Metrics and Evaluation (IHME) calculated welfare losses from ambient $PM_{2.5}$ pollution for each country, where welfare losses represent the cost of premature mortality. Global welfare losses from premature mortality are large and increasing from 2.2 trillion in 1990 to 3.6 trillion USD in 2013. For MENA, dust concentration and storms cost MENA over 150 billion USD annually and over 2.5 percent of GDP for most countries in the region. According to the UN, about 13 billion USD are lost every year from dust storms alone in the MENA region and welfare losses from $PM_{2.5}$ alone were about 141 billion USD in 2013. The biggest welfare losses were incurred by Egypt, Iran, and Pakistan.

Besides investing in early warning systems, governments all over the world are designing policies to mitigate the impact of sand and dust storms, both at national and regional levels. Devastating impacts from sand and dust storms in the Americas, MENA region, and East Asia have encouraged governments to enforce many large-scale initiatives and plans. In many instances, these initiatives also tackle land degradation, terrestrial biodiversity, and climate change mitigation. However, policies designed to mitigate the wider impacts of sand and dust storms, including many that are transboundary, are geographically patchy and have a much shorter history. Regional and international cooperation among countries will lead to greater understanding of the transportation paths of dust storms, particle content, and their impacts. Eventually, regional action will also lead to reduced the occurrence of dust storms. Recent years have seen some regional air pollution policies emerge, but more collaboration is needed and should be sustained.

TRENDS AND SOURCES OF DUST STORMS IN MENA

Sand and dust storms (SDS) are complex events with transboundary impacts. Sand and dust storms result from the erosion and transport of mineral sediments from land. Sand particles are larger than dust, but both are typically associated with dryland areas and can occur anywhere where there are dry unprotected sediments.[1] They could lift large quantities of dust particles into the air and transport them hundreds or thousands of kilometers away.[2] SDS occur because of interlinked direct and indirect drivers, divided into natural and anthropogenic sources. Concern on sand and dust storms is growing considering their huge impacts on the economy, human health, and the environment.

DUST HOT SPOTS AND TRENDS

The MENA region, which neighbors the Sahara Desert, is the dustiest region in the world. Nine regions contribute to the total global production of desert dust: North Africa (Sahara), South Africa, the Arabian Peninsula, Central Asia, Western China, Eastern China, North America, South America and Australia.[3, 4] North Africa, the Middle East, South West Asia, and North East Asia are the regions with the highest dust frequencies, as observed from synoptic weather reports (Figure 1).[5] Similarly, in terms of Aerosol Index (AI) hot spots, the Sahara and Asian deserts are dominant, whereas AI values are low in the Southern Hemisphere and the Americas.[6] The dust observed in the Caribbean is transported dust from the Sahara, while the dust observed in Mexico may be partly related to the dust activities in the Chihuahua Desert.[7, 8] The Sahara Desert is undoubtedly the biggest dust source, as its dust emissions are about four times as much as Arabian deserts.

Dust can travel thousands of kilometers, as North African dust is transported as far as the Caribbean. Dust storms are capable of transporting sediment over thousands of kilometers. Dust storms are transboundary, which has important implications for their

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[1] Middleton and Goudie, Desert Dust in the Global System.

[2] Zoljoodi, Didevarasl, and Saadatabadi, "Dust Events in the Western Parts of Iran and the Relationship with Drought Expansion over the Dust-Source Areas in Iraq and Syria."

[3] Prospero et al., "Environmental Characterization of Global Sources of Atmospheric Soil Dust Identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) Absorbing Aerosol Product."

[4] Tanaka and Chiba, "A Numerical Study of the Contributions of Dust Source Regions to the Global Dust Budget."

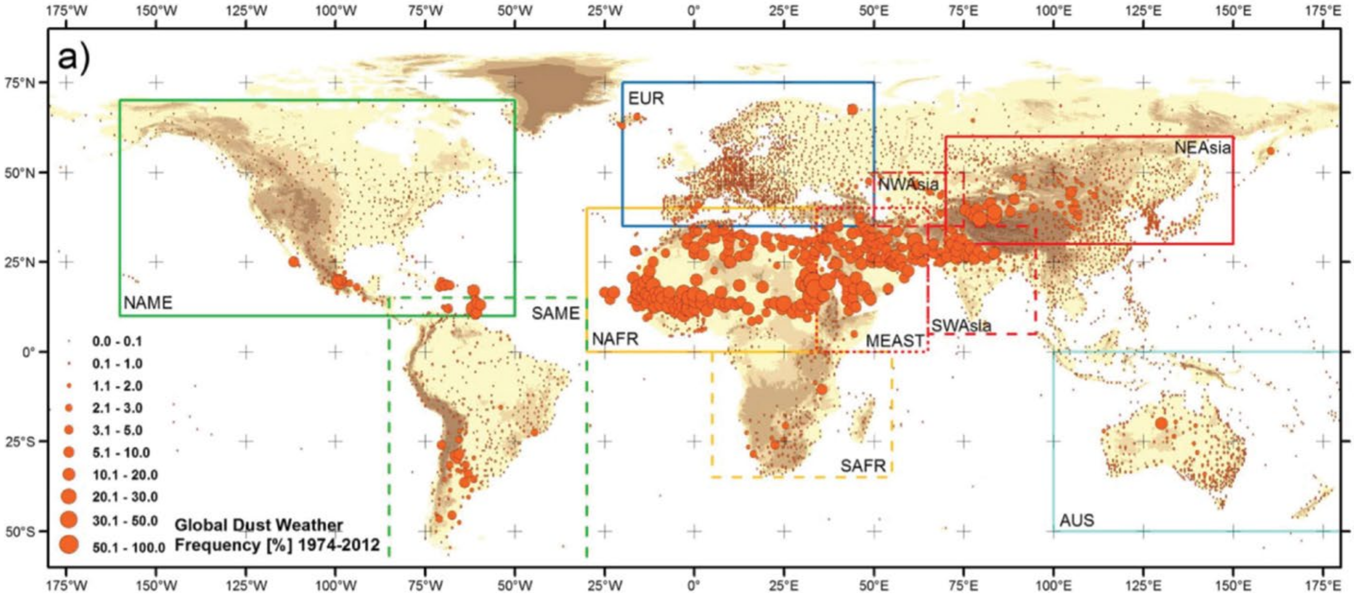
[5] Shao, Klose, and Wyrwoll, "Recent Global Dust Trend and Connections to Climate Forcing."

[6] Middleton and Goudie, Desert Dust in the Global System.

[7] Prospero, "Long-Range Transport of Mineral Dust in the Global Atmosphere."

[8] Liu et al., "CALIPSO Lidar Observations of the Optical Properties of Saharan Dust."

FIGURE 1: GLOBAL PATTERN OF DUST FREQUENCY ESTIMATED FROM THE SYNOPTIC PRESENT WEATHER RECORDS FOR THE PERIOD OF JANUARY 1974 TO DECEMBER 2012



Source: Shao et al., 2013.

mitigation, as effects are felt in different countries and even regions than their source of origin. For instance, dust from China can reach the European Alps, after being transported across the Pacific and Atlantic Oceans over 13 days.[9] Dust from Central Asia and China reaches Korea, Japan, the Pacific Islands, and North America.[10] Based on estimates made by Tanaka and Chiba (2006), Figure 2 shows the geographical distribution of the desert dust atmospheric loads, in mg m^{-2}.[11] North African dust is transported to as far away as the Amazon Forest, North America, Europe, and China. The westward dust movement from the Sahara is the largest flow, accounting for 30–50 percent of the output. For example, transport to the Caribbean, where 20 million tons of Saharan dust are deposited annually, typically takes 5 to 7 days.

While dust emissions have generally been high and increased over the last century, the past two decades have not seen a rise in emissions from the North Africa region. Simulations suggest that global annual dust emissions have increased by 25 to 50 percent over the last century due to a combination of land use and climate changes. Sand and dust storm frequency and severity have increased in recent decades in some areas but decreased in other areas. However, a recent analysis by Shao et al. (2013) revealed that over the period 1984–2012, the global mean of near-surface dust concentration decreased at 1.2 percent per year (Figure 3).[12] This decrease is mainly due to reduced dust activities in North Africa, accompanied by reduced activities in Northeast Asia, South America, and South Africa. This could be attributed to recovery of vegetation because of rainfall following the droughts in the 1980s, leading to a reduction in wind.[13] However other studies conclude that a reduction in wind cannot be directly linked to changes in land use.[14]

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[9] Grousset et al., "Case Study of a Chinese Dust Plume Reaching the French Alps."

[10] Middleton and Goudie, Desert Dust in the Global System.

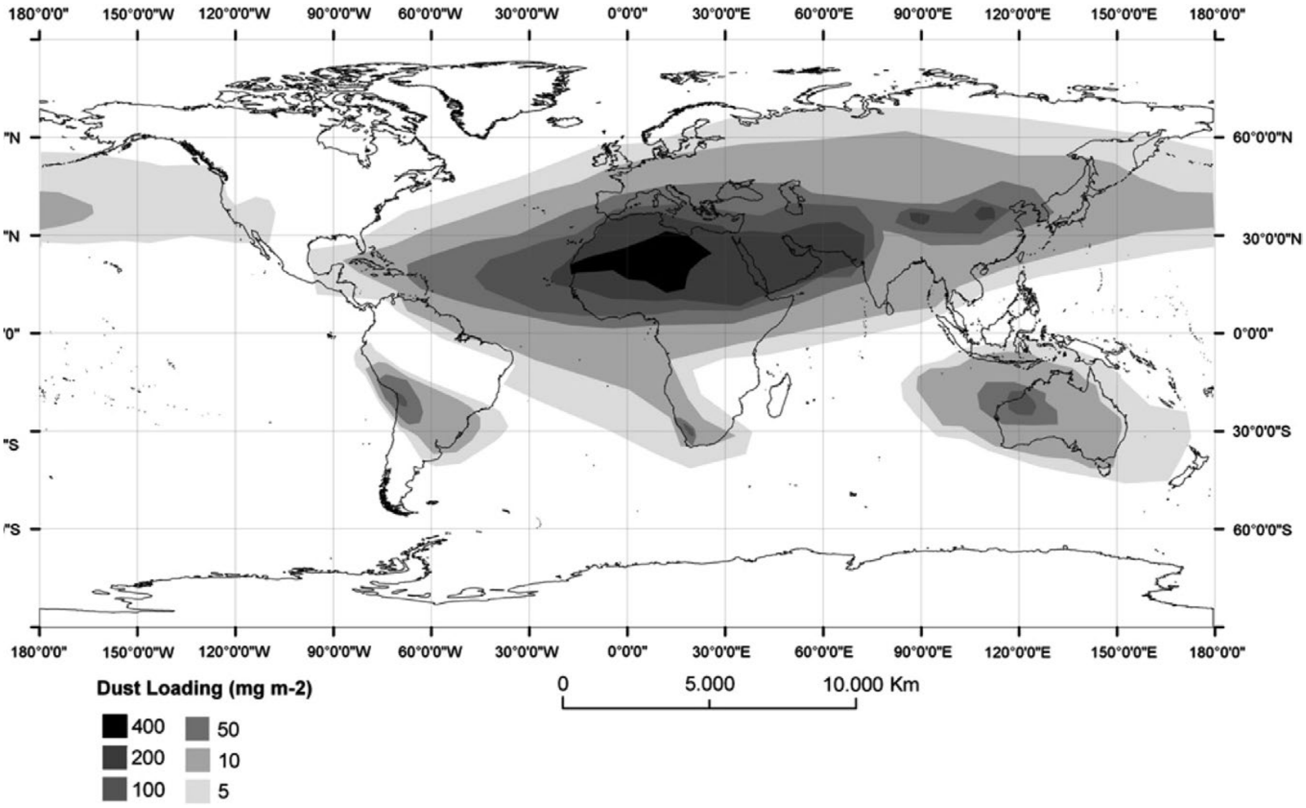
[11] Tanaka and Chiba, "A Numerical Study of the Contributions of Dust Source Regions to the Global Dust Budget."

[12] Shao, Klose, and Wyrwoll, "Recent Global Dust Trend and Connections to Climate Forcing."

[13] Cowie, Knippertz, and Marsham, "Are Vegetation-Related Roughness Changes the Cause of the Recent Decrease in Dust Emission from the Sahel?"

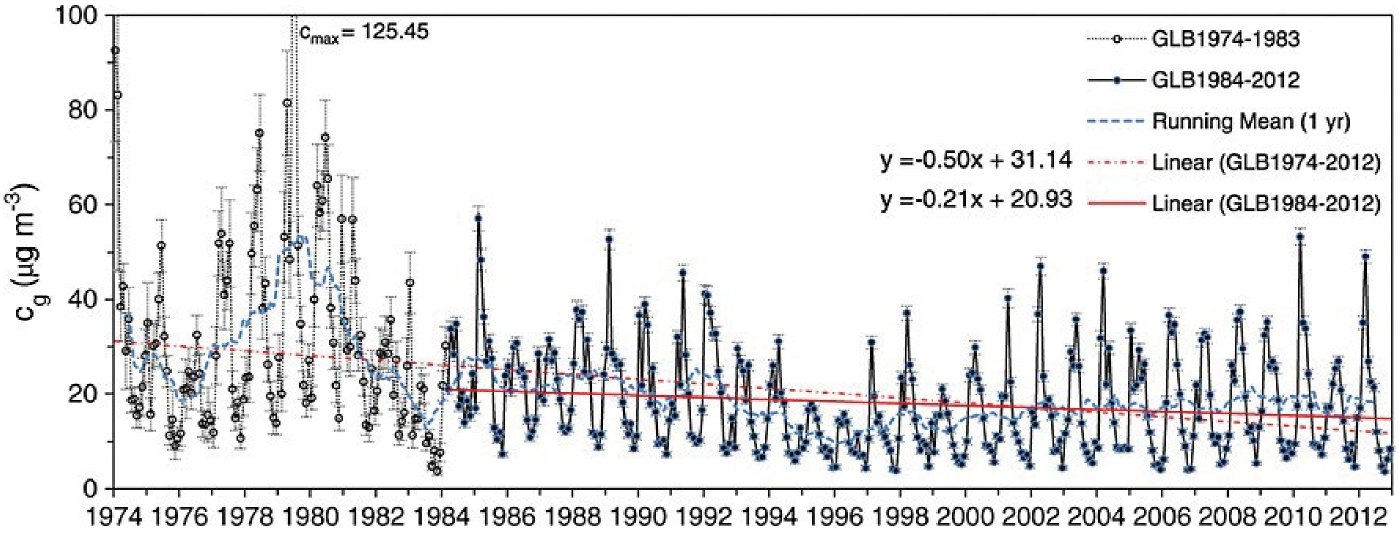
[14] Ridley, Heald, and Prospero, "What Controls the Recent Changes in African Mineral Dust Aerosol across the Atlantic?"

FIGURE 2: GEOGRAPHIC DISTRIBUTION OF THE DUST ATMOSPHERIC LOAD



Source: De Longueville et al., 2010.[15]

FIGURE 3: TIME SERIES OF GLOBAL MONTHLY MEAN DUST CONCENTRATION AND THE CORRESPONDING 95% CONFIDENCE INTERVAL (IN ERROR BARS) FOR THE PERIOD 1974–2012



Source: Shao et al., 2013.

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[15] De Longueville et al., "What Do We Know about Effects of Desert Dust on Air Quality and Human Health in West Africa Compared to Other Regions?"

Countries in the Middle East experience varying frequencies of dust storms depending on the time of year. The Middle East region is a notable dust hot spot, especially during the summer months when the dust storms in the region are often associated with Shamal winds.[16] Sudan, Iraq, Saudi Arabia, and the Persian Gulf report the greatest number of dust storms overall.[17] In the summer months, Iran, Iraq, Syria, the Persian Gulf, and the southern Arabian Peninsula experience the most dust storms. In western Iraq and Syria, Jordan, Lebanon, northern Israel, northern Arabian Peninsula, and southern Egypt they occur mainly in the spring, while in southern Israel and in the Mediterranean parts of northern Egypt, they occur in winter and spring.[18]

Sand and dust storms in MENA are determined by numerous climate systems and pathways. There are a variety of climate systems that govern the distribution of sand and dust storm events in the MENA region such as the Siberian, polar, and monsoon cyclones, and the depressions in the non-summer months. In MENA, most of dust storm systems can be classified into Summer Shamal and frontal dust storms.[19] Shamal dust storms usually occur across Iraq, Kuwait, western part of Khuzestan plain, and some parts of Arabian Peninsula, whereas frontal dust storms occur across Jordan, Israel, and the northern Arabian Peninsula.[20] There are six main sand and dust storm paths dominated by the climate in MENA (Figure 4). The first path originates from the Mediterranean Sea passing over Cyprus and enters Syria. The second path is under the control of a high-pressure system over east of Europe.[21] The third path comes from south of the Mediterranean Sea or coastal of northern Africa and always strikes south of Syria or the north border of Jordan and Saudi Arabia. The fourth path is from north of Africa which usually passes across Egypt, north of the Red Sea, and blows toward southeast in Saudi Arabia.[22] The fifth path is also located in the depressions in north of Africa. The last path originates from Sistan Plain at the Iran–Afghanistan border which is controlled by anticyclone over central Asia. Air masses from the Mediterranean Sea are important factors for the generation of sand and dust storms which cover about 70 percent dust storm events.[23]

SOURCES AND DRIVERS OF SAND AND DUST STORMS

SOURCES OF SAND AND DUST STORMS

Sand and dust storm sources and drivers are both natural and anthropogenic. There is need to distinguish drivers of sand and dust storms from natural sources, which supply most of the global dust emissions and anthropogenic sources. However natural ecosystems are increasingly being subject to human pressure, which may intensify their importance as source areas in the future.[24] Although there is currently much uncertainty on the magnitude of human activity on sand and dust storms, disturbance of natural systems through human pressure is highly likely to increase in the coming decades, including through human-induced climate change.

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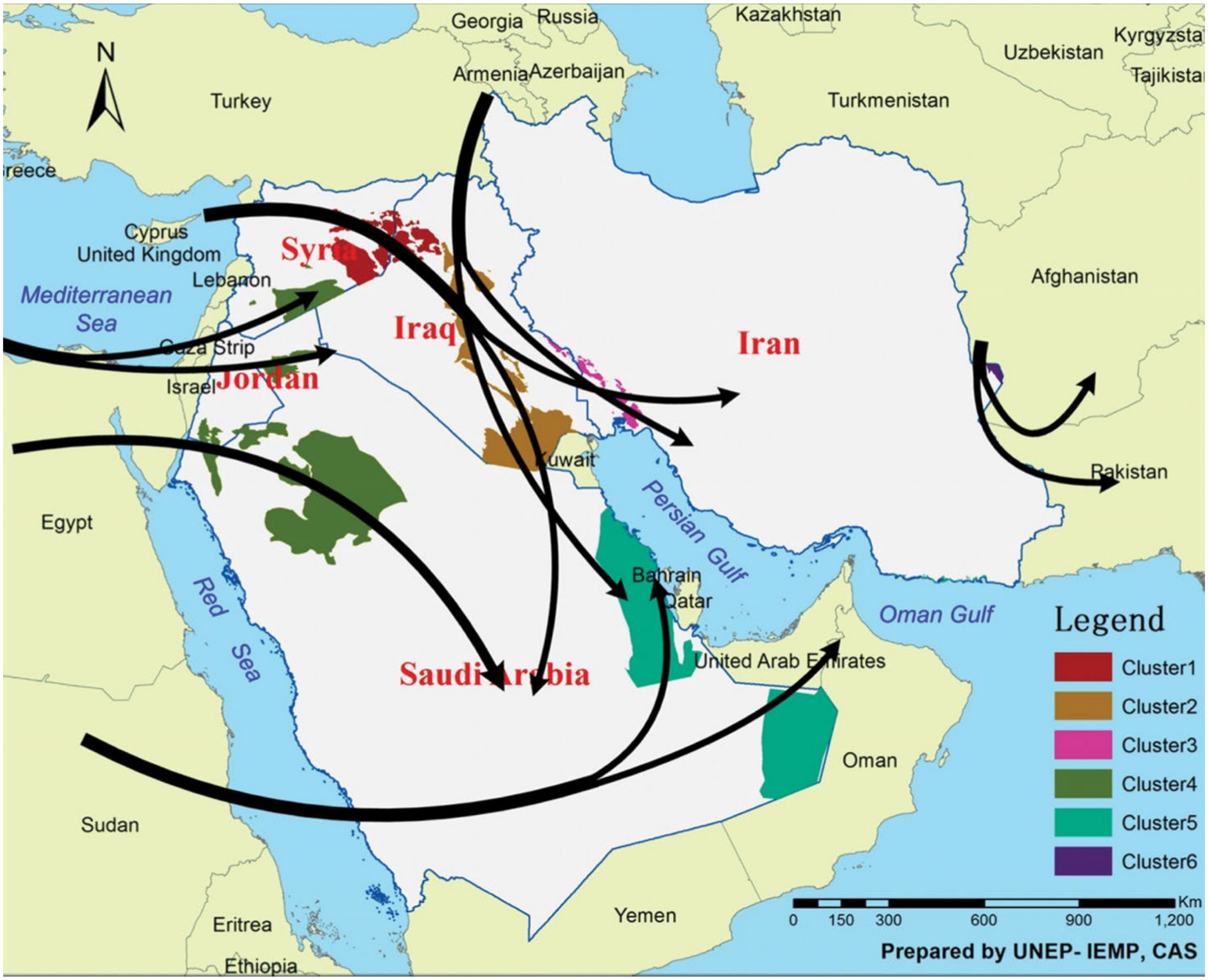
[16] Choobari, Zawar-Reza, and Sturman, "The Global Distribution of Mineral Dust and Its Impacts on the Climate System."
[17] Furman, "Dust Storms in the Middle East."
[18] Ibid.
[19] Hamidi, Kavianpour, and Shao, "Synoptic Analysis of Dust Storms in the Middle East."
[20] Middleton, "Dust Storms in the Middle East."
[21] Hamidi, Kavianpour, and Shao, "Synoptic Analysis of Dust Storms in the Middle East."
[22] Wilderson, "Dust and Sand Forecasting in Iraq and Adjoining Countries."
[23] Cao et al., "Identification of Dust Storm Source Areas in West Asia Using Multiple Environmental Datasets."
[24] Assessment, Millennium Ecosystem.

FIGURE 4: SAND AND DUST STORMS PATH AND SOURCE CLUSTERS IN MENA

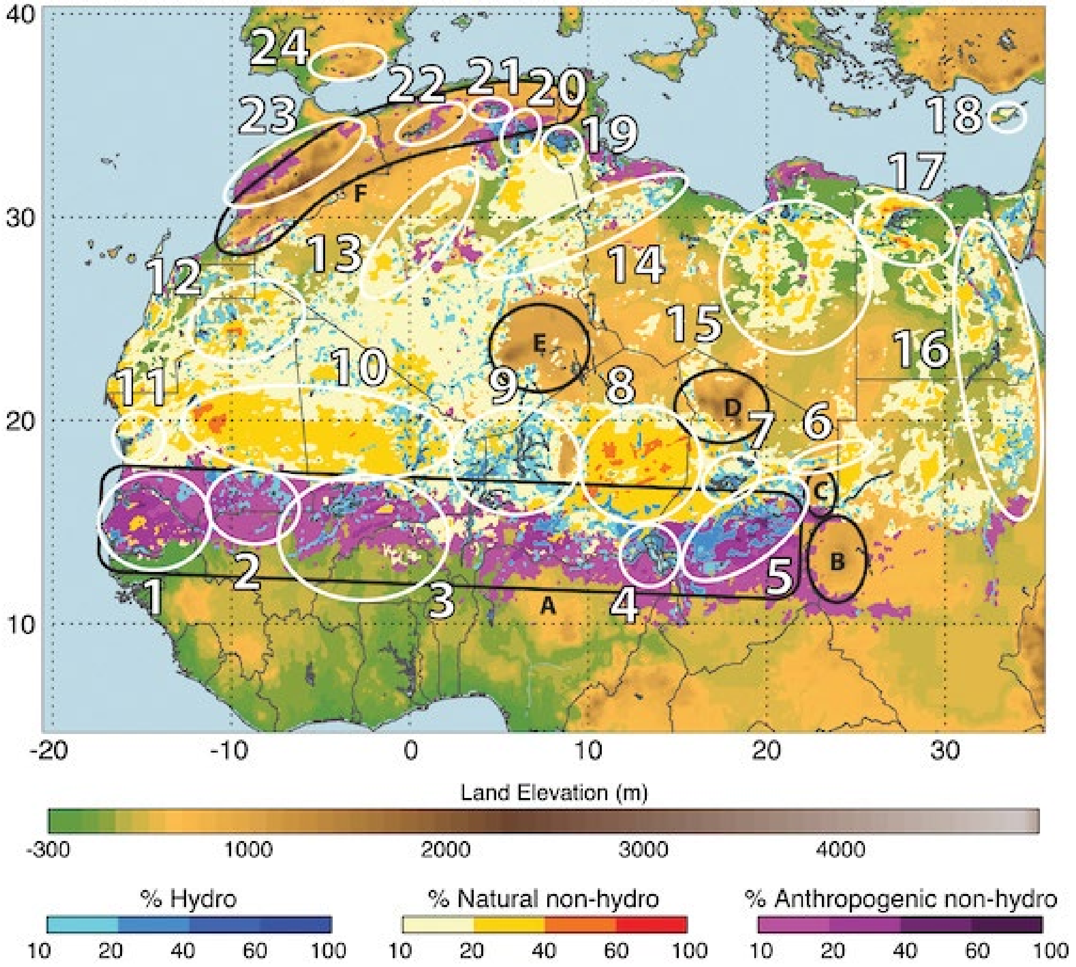


Source: Cao et al., 2015.

Globally, there are about three times as many natural dust sources as anthropogenic dust sources; however, due to land use changes in the past few decades, anthropogenic sources have increased. There are three dust source types: hydrologic, dust linked to various water features as discussed above; natural, dust emitted from land surfaces where land use is less than 30 percent; and anthropogenic, sources where land use exceeds 30 percent. North Africa accounts for 55 percent of global dust emissions with only 8 percent being anthropogenic, mostly from the Sahel. Hydrologic dust sources (e.g., ephemeral water bodies) account for 31 percent worldwide; 15 percent of them are natural while 85 percent are anthropogenic. Overall, natural dust sources globally account for 75 percent of emissions and anthropogenic sources account for the rest.

Most North African dust comes from natural sources such as the Sahara, with some anthropogenic sources. Southern Sahel sources are overwhelmingly anthropogenic (locations 1 to 5), whereas the Sahara is the most significant natural

FIGURE 5: DISTRIBUTION OF THE PERCENTAGE NUMBER OF DAYS PER YEAR WITH DUST OPTICAL DEPTH > 0.2 OVER NORTH AFRICA



Source: Ginoux et al., 2012.[25]

source (locations 6 to 11) (Figure 5). This could be explained by the fact that agricultural and grazing activities in regions with some rainfall are confined to relatively localized areas around point sources of water, and most agricultural and grazing activity takes place in wetter areas.[26] Analysis of thousands of years of dust deposition in the mouth of the Senegal River showed a sharp increase in deposition after the advent of commercial agriculture in the Sahel, about 200 years ago.[27] The sources in the Atlas Mountains (locations 20 to 23) and along the Mediterranean coast (e.g., location 19) are also mostly anthropogenic. Outside the Sahel, the major sources are natural.[28] These include major depressions, large basins with sand seas, ephemeral lakes, and the Nile River Basin.

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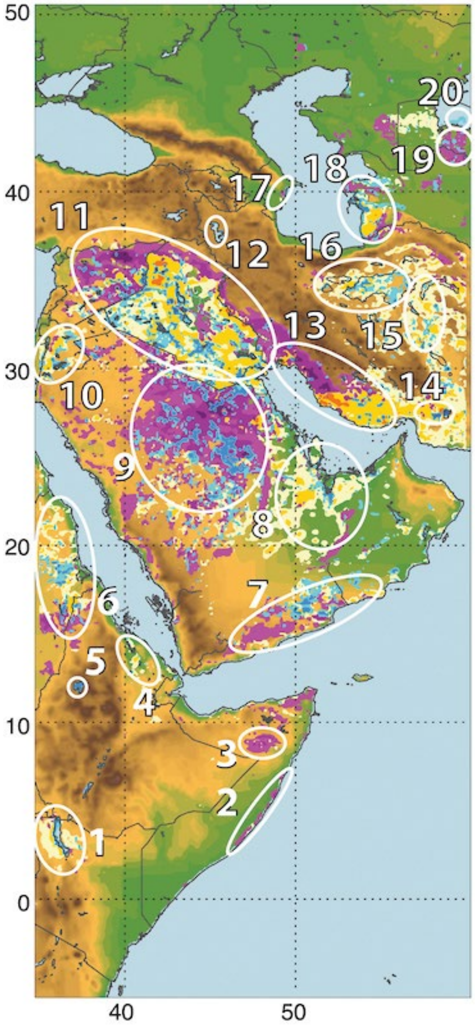
[25] Ginoux et al., "Global-Scale Attribution of Anthropogenic and Natural Dust Sources and Their Emission Rates Based on MODIS Deep Blue Aerosol Products."

[26] Prospero et al., "Environmental Characterization of Global Sources of Atmospheric Soil Dust Identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) Absorbing Aerosol Product."

[27] Mulitza et al., "Increase in African Dust Flux at the Onset of Commercial Agriculture in the Sahel Region."

[28] Prospero et al., "Environmental Characterization of Global Sources of Atmospheric Soil Dust Identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) Absorbing Aerosol Product."

FIGURE 6: DISTRIBUTION OF THE PERCENTAGE NUMBER OF DAYS PER YEAR WITH DUST OPTICAL DEPTH > 0.2 OVER THE MIDDLE EAST



Source: Ginoux et al., 2012.

The Middle East shows a complex mixture of natural and anthropogenic sources. The Aral Sea was formerly one of the largest lakes in the world (area 68,000 km^2) but is now reduced to 10 percent of its original size. Large areas of the Aral Sea are now active dust sources, in agreement with in situ measurements.[29] There is an extensive area of anthropogenic sources, mixed with hydrologic sources, in Saudi Arabia (location 9) essentially aggregated around the dry riverbeds (Figure 6). The dust from the region between the Tigris and Euphrates is mapped as natural in Iraq and anthropogenic in Syria. There is a cluster of anthropogenic and hydrologic sources along the Jordan River, particularly on the east side (location 10). Iran has prominent dust sources such as large salty lakes and deserts, but the northwestern part is anthropogenic. Although much dust in the Middle East derives from local sources, substantial amounts of dust come from the Sahara.

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[29] Wiggs et al., "The Dynamics and Characteristics of Aeolian Dust in Dryland Central Asia."

DRIVERS OF SAND AND DUST STORMS

Wind erosion is the main natural driver of dust storms, which is also dependent on other climate and land characteristics. Wind is the main driver of sand storms and dust emissions in all systems. Specific synoptic meteorological conditions that produce winds vary in different regions.[30] Globally about 32 million km^2 of land is susceptible to wind erosion, with 17 million km^2 having high or very high susceptibility.[31] Erodibility of surface material coupled with aridity that limits protective effects of vegetation is what usually defines natural dust sources and dust storms. For instance, the major dust storm event in 2015 in the Middle East has been attributed to the wind and arid conditions in the area rather than man-made factors.[32] Besides wind speed, other land form characteristics also determine wind erosivity (Table 1). Considering these factors, the biggest dust sources are therefore usually inland drainage basins or depressions in arid areas, such as the Bodele Depression in the Sahara and the Taklamakan Desert in China.[33, 34]

TABLE 1: KEY PHYSICAL FACTORS INFLUENCING WIND EROSION

Climate	Sediment or Soil	Vegetation	Landform
Wind speed (+)	Soil type	Type	Surface roughness
Wind direction	Particle composition	Coverage (–)	Slope (–)
Turbulence (+)	Soil/sediment structure	Density	Ridge
Precipitation (–)	Organic matter (–)	Distribution (+/–)	
Evaporation (+)	Carbonates (–)		
Air temperature	Bulk density		
Air pressure (+)	Degree of aggregation (–)		
Freeze-thaw action	Surface moisture (–)		

Source: UNEP, WMO, UNCCD, 2016; Shi et al., 2004; Middleton and Goudie, 2006.[35]

(+) indicates that the factor reinforces wind erosion, whereas (–) indicates that the factor has a protective effect, reducing wind erosion. (+/–) indicates the effect can be positive or negative depending on the processes involved.

While climatic factors directly cause dust storms, there are several human-induced factors that can alter those climatic factors. Human-induced land degradation is a driver of wind erosion and a major contributor toward sand and dust storms, as it exposes degraded and dry surfaces with a long wind fetch. Besides resource use and management in drylands, practices that disrupt the hydrology and protection provided by land in general also contribute to sand and dust storms. For instance, demand for water for urban areas or irrigation disturbs the hydrology of ephemeral lakes and playas. Building roads and other infrastructure that blocks the inflow of drainage waters is another contributor to the drying up of playas.[36] Poor standards of crop management (e.g., related to soil fertility, seed quality, tillage, planting, and pest and disease control) that result in poor vegetation growth and soil cover increase risk of wind erosion. In addition, land management practices that result in deforestation and clearance of vegetation will lead to an increase of wind velocity,

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[30] Knippertz and Stuut, "Mineral Dust."

[31] Eswaran, Lal, and Reich, "Land Degradation."

[32] Parolari et al., "Climate, Not Conflict, Explains Extreme Middle East Dust Storm."

[33] Bullard et al., "Preferential Dust Sources."

[34] Thomas, Arid Zone Geomorphology.

[35] UNEP, WMO, UNCCD., "Global Assessment of Sand and Dust Storms."

[36] Gill, "Eolian Sediments Generated by Anthropogenic Disturbance of Playas."

BOX 1: INDIRECT HUMAN-INDUCED FACTORS THAT CONTRIBUTE TO SAND AND DUST STORMS

- Population increase and economic globalization leading to increased demands for food, feed, and other products
- Failure of policy to recognize noneconomic ecosystem functions
- Policies that unwittingly encourage unsustainable land management
- Land use change to less sustainable uses
- Use of prime agricultural land for urban development and waste disposal, thereby increasing pressure on marginal land
- Subsistence farming
- Lack of access to rural credit, extension services, and markets
- Poverty
- Insecure land tenure
- Migration to fragile land
- Climate change
- War and insecurity

Source: UNEP, WMO, UNCCD, 2016.

as well as reduce the entrapment of particles. The complementary piece titled *'Sustainable Land Management and Restoration in the Middle East and North Africa Region—Issues, Challenges, and Recommendations'* provides details on land degradation severity, drivers and impacts and offers insights into the man-made drivers of dust storms in MENA. There are also many other indirect drivers of sand and dust storms, such as population increase, weak land tenure, poverty, conflict, and climate change (Box 1).

IMPACTS OF INCREASED DUST CONCENTRATION AND DUST STORMS

Dust deposition has vast health, environmental, and economic impacts. Dust can contribute to numerous human health problems globally, especially in arid and semiarid regions. Inhalation of fine particles can cause or aggravate diseases such as asthma, bronchitis, emphysema, and silicosis. Chronic exposure can be linked to respiratory disease, lung cancer, and acute lower respiratory infections. For the environment, dust can have both negative and positive effects. Dust affects the climate system and can lead to intensifying drought conditions, but it also increases precipitation and provides nutrients to terrestrial ecosystems. In addition to health and environmental impacts, there are other short-term costs of dust such as crop damage, livestock mortality, infrastructure damage, and interruption of transport. Longer term costs include health problems, soil erosion, and disruption of global climate regulation. Monetizing these impacts can translate to hundreds of million dollars just from a single dust storm.

HEALTH IMPACTS OF DUST DEPOSITION

Dust storms often affect human life and health not only in the drylands but also in downwind regions. As discussed in the previous chapter, dust emitted from the North Africa region reaches as far as the rest of Africa, Middle East, Europe, Asia, the Caribbean and the Americas, impacting air quality in those regions too. Dust from Asia is shown to contribute to aerosol loadings in western North America.[37] African dust transported to the Caribbean and Florida has deteriorated air quality standards in those areas and makes up half of South Florida's airborne particles in the summer.[38] Therefore, populations far from the source regions are exposed to a wide range of air quality related health problems.

Air quality, which is impacted by dust, is very poor in MENA. Airborne dust particles, whether of natural origin and/or partially human from bush fires or practices that lead to desertification, affect human health through their impact on local and regional air qualities.[39, 40] Airborne mineral dusts are respirable within size ranges of particles equal to or less

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[37] Fairlie, Jacob, and Park, "The Impact of Transpacific Transport of Mineral Dust in the United States."

[38] Prospero and Mayol-Bracero, "Understanding the Transport and Impact of African Dust on the Caribbean Basin."

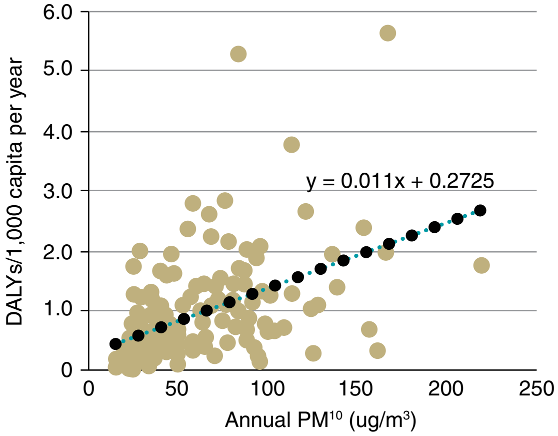
[39] Anuforom et al., "Inter-Annual Variability and Long-Term Trend of UV-Absorbing Aerosols during Harmattan Season in Sub-Saharan West Africa."

[40] Sassen et al., "Saharan Dust Storms and Indirect Aerosol Effects on Clouds."

than a diameter of 2.5 microns ($PM_{2.5}$) and coarse particles equal to or less than 10 microns (PM_{10}), as defined by the US Environmental Protection Agency. In the United States today, the following standards apply: the acceptable annual mean values of $PM_{2.5}$ and PM_{10} are respectively 15 $\mu g\ m^{-3}$ and 50 $\mu g\ m^{-3}$ and the mean values over 24 h exceeding respectively 65 $\mu g\ m^{-3}$ and 150 $\mu g\ m^{-3}$ are considered to exceed the standards.[41] Dust concentrations in the MENA region can reach well beyond these acceptable levels. Studies have shown that dust storms in the Middle East are characterized by high concentrations of particles with 2 to 20 μm diameter size, with more than 85 percent of them being less than 10 μm in diameter.[42, 43]

Increased dust concentrations can adversely affect health and even lead to death. Ambient fine particulate matter ($PM_{2.5}$) exposure is currently considered the leading environmental risk factor globally. Fine particulate matter can come from a variety of sources and its determination can be ascertained through a source apportionment (SA) study.[44] Locations susceptible to high dust concentrations will have a larger contribution and in general will have a larger impact on premature mortality.[45, 46] WHO's environmental burden of disease dataset that compiles PM_{10} levels and Disability Adjusted Life Years (DALYs) (which considers years lost to mortality) in all countries, shows a positive correlation between the two (Figure 7). It is estimated that $PM_{2.5}$ exposure contributed to 4.1 million premature deaths in 2016.[47] The situation is worse in areas that are prone to frequent dust events. Compared to other regions, MENA has one of the highest average $PM_{2.5}$ and PM_{10} levels.[48] Within MENA, populations in Iraq, Egypt, and Pakistan suffer disproportionately more in terms of premature deaths—as many as 30,000 deaths can be attributed to bad air quality (Figure 8).

FIGURE 7: GLOBAL PM_{10} LEVELS AND DALYs



Source: Authors' calculations based on WHO—Environmental burden of disease, 2004.

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[41] Prospero, "Assessing the Impact of Advected African Dust on Air Quality and Health in the Eastern United States."

[42] Perdue et al., "The Surgical Significance of Persian Gulf Sand."

[43] Draxler et al., "Estimating PM_{10} Air Concentrations from Dust Storms in Iraq, Kuwait and Saudi Arabia."

[44] The WHO maintains a database on source apportionment studies for particulate matter in the air (PM_{10} and $PM_{2.5}$) at https://www.who.int/quantifying_ehimpacts/global/source_apport/en/

[45] Perez et al., "Coarse Particles from Saharan Dust and Daily Mortality."

[46] Samoli et al., "Does the Presence of Desert Dust Modify the Effect of PM_{10} on Mortality in Athens, Greece?"

[47] Gakidou et al., "Global, Regional, and National Comparative Risk Assessment of 84 Behavioural, Environmental and Occupational, and Metabolic Risks or Clusters of Risks, 1990–2016."

[48] World Health Organization, "Environmental Burden of Disease: Country Profiles."

FIGURE 8: ANNUAL PM_{10} CONCENTRATION, DEATHS, AND DALYs IN MENA COUNTRIES

Country	Population ('000)	*Annual PM_{10} [$\mu g/m^3$]	**Urban Population (%)	Deaths per Year	DALYs[a] /1000 Capital per Year
Afghanistan	24,076	27	16	400	0.3
Egypt	71,550	136	32	15,500	2
Iran	68,669	68	42	9,100	1.0
Iraq	27,456	167	58	10,300	6
Israel	6,574	53	80	1,400	1.1
Jordan	5,371	69	49	700	1.1
Kuwait	2,617	129	74	300	1.1
Lebanon	3,965	43	74	400	1.6
Libyan Arab Jamahiriya	5,799	121	85	1,800	3
Morocco	30,152	27	37	900	0.2
Oman	2,479	124	36	300	1.1
Pakistan	155,333	165	27	30,000	2.0
Qatar	764	57	65	<100	0.4
Saudi Arabia	23,047	91	40	2,500	1.1
Syrian Arab Republic	18,389	89	38	1,800	0.9
Tunisia	9,996	46	30	800	0.6
United Arab Emirates	3,947	109	70	200	0.7
Yemen	20,478	82	15	1,100	0.7

Source: WHO—Environmental burden of disease, 2004.

*Urban-population-weighted average particulate matter less than 10 microns in diameters [mg/m^3] (estimates or monitored, when available).

**Percentage of urban population living in cities >100,000 and national capital.

[a] For Outdoor Air Pollution, DALYs consist only of years of life lost to premature mortality (YLL).

RESPIRATORY/ASTHMA

Respiratory illnesses are one of the main health impacts of dust. Airborne dust particles are transported via air inhaled through the nose or mouth and passed via the trachea to the lung tissues. Exposure to dust therefore contributes to respiratory disorders such as asthma, tracheitis, pneumonia, aspergillosis, allergic rhinitis, and nonindustrial silicosis.[49] Dust has been strongly linked to Chronic Obstructive Pulmonary Disease (COPD), which is an umbrella term used to describe progressive lung diseases including emphysema, chronic bronchitis, and refractory (non-reversible) asthma. In Hong Kong, it was found that dust events had a significant adverse impact on emergency hospital admissions for COPD.[50] Epidemiological studies have also shown that increases in allergic rhinitis and daily admissions and clinical visits for allergic diseases such as asthma coincided with Asian dust storms.[51, 52] Pneumonia admissions have also been significantly associated with Asian dust storms in Taipei.[53] Desert dust also deteriorates pulmonary function. Recent studies have shown

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[49] Derbyshire, "Natural Minerogenic Dust and Human Health."

[50] Tam et al., "Effect of Dust Storm Events on Daily Emergency Admissions for Respiratory Diseases."

[51] Chang et al., "Correlation of Asian Dust Storm Events with Daily Clinic Visits for Allergic Rhinitis in Taipei, Taiwan."

[52] Kanatani et al., "Desert Dust Exposure Is Associated with Increased Risk of Asthma Hospitalization in Children."

[53] Cheng et al., "Consequences of Exposure to Asian Dust Storm Events on Daily Pneumonia Hospital Admissions in Taipei, Taiwan."

significantly reduced Peak Expiratory Flow (PEF) values and more increased PEF variability during dust days than during the control days in Korea.[54, 55, 56]

There is strong evidence on the adverse impacts of dust on asthma. Asthma is one of the world's leading noncommunicable diseases, and it affects about 334 million people each year.[57] There is plenty of evidence that shows dust causes or exacerbates asthmatic conditions. Exposure to dust particles transported globally from desert storms is associated worldwide with increased hospital admissions for childhood asthma and bronchitis, for example in Japan, Trinidad, and Texas.[58, 59, 60] The highest prevalence of asthma has been reported in areas with desert dust storms events such as the MENA region.[61, 62] In Greece, Saharan dust events have been associated with a 2.5 percent increase in pediatric asthma hospital admissions.[63] Similarly, in Kuwait, dust storms led to an 8.4 percent increase in daily emergency asthma admissions over a period of five years, which was particularly evident among children.[64] In Qatar, asthma cases are reported to increase by 30 percent during and shortly after very windy conditions.[65]

CARDIOVASCULAR

Studies have found a positive correlation between dust events and cardiovascular illnesses, such as ischemic heart disease, cerebrovascular disease, and hypertension among others. Epidemiological studies have found positive relations between cardiovascular mortality and morbidity and dust storms. For instance, in Taiwan, a study of 39 Asian dust storm events found drastic increases in cardiopulmonary emergency visits when ambient PM_{10} concentrations were high and estimated that cardiovascular diseases, ischemic heart diseases, and cerebrovascular diseases during the Asian dust events increased by 26 percent, 35 percent, and 20 percent per event, respectively, compared to the pre-dust periods in Taiwan.[66] Another study in China found a significant association between dust events and hypertension in men in Minqin China, and that the association of dust events and cardiovascular hospitalization was stronger in spring than in winter.[67] There are some studies that have quantified cardiovascular health problems in MENA as well. The 2005 dust storm in Baghdad, Iraq, led to nearly 1,000 cases of suffocation.[68] In Iran, dust storms caused a 1 percent increase in cardiovascular morbidity.[69]

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[54] Gwack et al., "Effects of Asian Dust Events on Diurnal Variation of Peak Expiratory Flow Rate in Children with Bronchial Asthma and Healthy Children."

[55] Yoo et al., "Acute Effects of Asian Dust Events on Respiratory Symptoms and Peak Expiratory Flow in Children with Mild Asthma."

[56] Hong et al., "Asian Dust Storm and Pulmonary Function of School Children in Seoul."

[57] Global Asthma Network, "Global Asthma Report."

[58] Kanatani et al., "Desert Dust Exposure Is Associated with Increased Risk of Asthma Hospitalization in Children."

[59] Gyan et al., "African Dust Clouds Are Associated with Increased Paediatric Asthma Accident and Emergency Admissions on the Caribbean Island of Trinidad."

[60] Grineski et al., "Hospital Admissions for Asthma and Acute Bronchitis in El Paso, Texas."

[61] Al Frayh et al., "Increased Prevalence of Asthma in Saudi Arabia."

[62] Bener et al., "Genetic and Environmental Factors Associated with Asthma."

[63] Samoli et al., "Acute Effects of Air Pollution on Pediatric Asthma Exacerbation: Evidence of Association and Effect Modification."

[64] Thalib and Al-Taiar, "Dust Storms and the Risk of Asthma Admissions to Hospitals in Kuwait."

[65] Teather et al., Examining the Links between Air Quality, Climate Change and Respiratory Health in Qatar.

[66] Chan et al., "Increasing Cardiopulmonary Emergency Visits by Long-Range Transported Asian Dust Storms in Taiwan."

[67] Meng and Lu, "Dust Events as a Risk Factor for Daily Hospitalization for Respiratory and Cardiovascular Diseases in Minqin, China."

[68] Middleton and Goudie, Desert Dust in the Global System.

[69] Delangizan and Jafari Motlagh, "Dust Phenomenon Affects on Cardiovascular and Respiratory Hospitalizations and Mortality: A Case Study in Kermanshah, during March-September 2010–2011."

OTHER INFECTIONS

Infectious diseases, such as meningitis, conjunctivitis, and eye and skin infections, are also known to be linked to increased dust concentrations. Meningococcal meningitis, also known as cerebrospinal meningitis, caused by the bacterium Neisseria meningitides, can cause large epidemics with fatality rates among cases.[70] The largest epidemic occurs in the African "meningitis belt," a semiarid region spanning the Sahel from Senegal in the west to Ethiopia in the east, which has the highest rate of the disease.[71] Dust storms from the Sahara and meningitis outbreaks are highly correlated and are perhaps linked through the Neisseria bacteria that need iron-laden dust to grow and become viral.[72] Dust has also been linked to conjunctivitis, which is an inflammation of the conjunctiva and other ocular surfaces because of the reaction to an allergen.[73] Exposure to desert dust could also lead to itchy eyes and skin rashes.[74] Lastly, Asian dust is widely suspected to be an important factor in the pathogenesis of atopic dermatitis, which could be due to the fungi, mites, and other allergens contained in dust.[75]

ENVIRONMENTAL IMPACTS OF DUST

Besides many of the negative impacts, dust fertilizes oceans and forests. Dust storms have some positive global impacts due to their transboundary nature and the importance of dust in global climate and terrestrial and biogeochemical cycling.[76] For instance, dust fertilizes and sustains both oceans and forests, playing a huge part in the earth's biogeochemical cycles.[77] Saharan dust fertilizes the Amazon forest, by replacing the phosphorous it loses from the basin. Similarly, Hawaiian rain forests receive nutrient inputs from dust from central Asia, which may sustain forest productivity over long time periods.[78]

While dust boosts primary productivity of oceans, it could have damaging effects on coral reefs. Dust provides nutrients to the surface and seabed of oceans, boosting primary productivity such as phytoplankton growth.[79] Changes in dust fluxes to the ocean have the potential to modify ocean biogeochemistry.[80] Research has suggested that dust deposition trends have increased ocean productivity by an estimated 6 percent in the past century.[81] However, there is also a possibility that microorganisms, nutrients, trace metals, and organic contaminants deposited in the dust on land and in oceans may play a role in the complex changes occurring on coral reefs worldwide.[82] For instance, dust originating from Africa and Asia could therefore be adversely affecting coral reefs and other downwind ecosystems in the Americas.

Dust has been also associated with leading to and exacerbating climatic events such as storms, droughts, and the melting of glaciers. Dust can affect climate by

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[70] UNEP, WMO, UNCCD, "Global Assessment of Sand and Dust Storms."

[71] World Health Organization, "Meningococcal Meningitis."

[72] Noinaj, Buchanan, and Cornelissen, "The Transferrin–Iron Import System from Pathogenic N Eisseria Species."

[73] Zhang et al., "A Systematic Review of Global Desert Dust and Associated Human Health Effects."

[74] UNEP, WMO, UNCCD, "Global Assessment of Sand and Dust Storms."

[75] Lee and Lee, "Effects of Asian Dust Events on Daily Asthma Patients in Seoul, Korea."

[76] Ravi et al., "Aeolian Processes and the Biosphere."

[77] Goudie, "Dust Storms."

[78] Chadwick et al., "Changing Sources of Nutrients during Four Million Years of Ecosystem Development."

[79] Jickells et al., "Air-Borne Dust Fluxes to a Deep Water Sediment Trap in the Sargasso Sea."

[80] Aumont, Bopp, and Schulz, "What Does Temporal Variability in Aeolian Dust Deposition Contribute to Sea-Surface Iron and Chlorophyll Distributions?"

[81] Mahowald et al., "Observed 20th Century Desert Dust Variability."

[82] Garrison et al., "African and Asian Dust."

its effect on biogeochemical cycles, especially through effects on the ocean temperature and primary productivity and through indirect mechanisms from the dusts' chemical reactivity.[83] Therefore, extreme events such as floods and droughts can be influenced by dust. For instance, dust has been linked to modifying tropical storms and cyclone intensities.[84] Dust can also cause drought intensification, as dust loadings effect absorption and scattering of solar radiation and can alter the Earth's radiative balance.[85] Dust can affect precipitation indirectly too, through effects on convective activity due to altered temperature gradients. Glacial melt has also been linked to dust, as the deposition of mineral dust on glaciers has the potential to lower their surface albedo and speed up their melting.[86]

Dust deposition and storms are both a cause and symptom of land degradation. Wind erosion is one of the main land degradation processes, especially in dryland regions.[87] Wind erosion removes finer soil particles, which constitute the most active soil component in retaining nutrients and organic matter, resulting in soil degradation. The eroded material may damage crops and vegetation due to abrasion and sand burying young plants.[88] Dust deposition has played a role in soil formation in many parts of the world, often at large distances from desert margins. The most striking example is the influence of aeolian processes on the formation of loess soils (unconsolidated silt), which occur extensively in North and South America, Central Asia, and China.[89] Aeolian processes have also contributed to forms of land degradation, such as soil salinization and alkalinity, through accumulation of soluble salt, and reduction of soil acidity through addition of carbonates.[90] Thus dust entrainment (particle lifting by wind erosion) during dust events leads to long-term soil degradation, which is essentially irreversible.

ECONOMIC COSTS OF DUST

There are countless short-term and long-term impacts of dust pollution. Impacts range from negative health impacts to reducing crop yields to lowering property values to steering talented workers away from polluted places. As discussed in the previous section, sand dust affects crops and soil negatively. Sandblasting and burial of seedlings have an immediate negative effect on yields, and the loss of nutrient rich topsoil affects productivity in the long term.[91] During dust storms, labor productivity and household incomes drop sharply, and millions of people are unable to reach work, and factories and offices close. Additionally, continued incidence of dust storms can also result in migration. Because of the Dust Bowl in the 1930s, millions of hectares of farmland became useless, and hundreds of thousands of people were forced to leave their homes.[92] Other short-term impacts include livestock mortality, infrastructure and transportation damage, and cost of clearing up sand (Table 2, Box 2).

Global welfare losses from premature mortality are huge and increased from 2.2 trillion in 1990 to 3.6 trillion in 2013. Quantifying and monetizing dust impacts is difficult, as costs are wide-ranging and methods to calculate them are complex. Very few

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[83] Singh et al., "Enhancement of Oceanic Parameters Associated with Dust Storms Using Satellite Data."

[84] Evan et al., New Evidence for a Relationship between Atlantic Tropical Cyclone Activity and African Dust Outbreaks.

[85] Highwood and Ryder, "Radiative Effects of Dust."

[86] Oerlemans, Giesen, and van den Broeke, "Retreating alpine glaciers: increased melt rates due to accumulation of dust (Vadret da Morteratsch, Switzerland)."

[87] Middleton and Goudie, Desert Dust in the Global System.

[88] Ravi et al., "Aeolian Processes and the Biosphere."

[89] Muhs et al., "Identifying Sources of Aeolian Mineral Dust: Present and Past."

[90] Middleton and Goudie, Desert Dust in the Global System.

[91] Behzad, Mineta, and Gojobori, "Global Ramifications of Dust and Sandstorm Microbiota."

[92] Lee, Gill, and Mulligan, "The 1930s Dust Bowl."

TABLE 2: SHORT-TERM AND LONG-TERM IMPACTS OF SAND AND DUST STORMS

Short-term	Long-term
Immediate human health problems (e.g., respiratory problems) and mortality	Cumulative human health problems (e.g., bronchitis, cardiovascular disorders)
Annual and perennial crop damage	Soil erosion and reduced soil quality
Livestock mortality	Soil pollution through deposition of toxic biological materials (fungi, bacteria), heavy metals, or salts
Infrastructural damage (e.g., buildings, electricity and telephone structures, power facilities, solar farms, machinery, greenhouses)	Disruption of global climate regulation (through feedbacks involving global warming, ocean productivity and CO_2 production, precipitation changes, global ice volume, sea level, hydrological cycle, and vegetation cover)
Costs of clearing sand and dust from infrastructure (e.g., roads, airports, dams, irrigation canals, flood control structures, ditches, power facilities)	Migration
Interruption of transport (air, road, rail) and communications; air and road traffic accidents	Decrease in household income
Decline in labor productivity; office and business closure	

Source: Middleton and Goudie, 2006.

studies have attempted to assess all costs associated with dust or a dust storm in a specific country (Box 2). However, just quantifying some of the most immense costs provides a magnitude of how big the dust problem is. The most significant is the cost of deaths and premature mortality. The World Health Organization (WHO) estimates that 7 million people die from poor air quality every year, which is at least partly attributed to dust. A study prepared by the World Bank and the Institute of Health Metrics and Evaluation (IHME) calculated welfare losses from ambient $PM_{2.5}$ pollution for each country, where welfare losses represent the cost of premature mortality.[93] Globally, welfare losses increased from about 2.2 trillion to 3.6 trillion from 1990 to 2013 (Table 3). Interestingly, while Europe and North America have had the much higher welfare costs than other regions, they have not risen much over the years. On the other hand, welfare costs have at least doubled in all other regions.

Dust concentration and storms cost MENA over 150 billion USD annually and over 2.5 percent of GDP for most countries in the region. The costs of dust pollution and dust storms are significant in MENA. According to the UN, about 13 billion USD are lost every year due from dust storms alone in the MENA region.[94] Additionally, welfare losses from $PM_{2.5}$ were about 141 billion USD in 2013 in the MENA region, and an average of 2.5 percent of the GDP in MENA countries (Table 4).[95] However, countries in MENA incur different costs depending on $PM_{2.5}$ concentrations and the development level of the country. In absolute terms, the biggest welfare losses were incurred by Egypt, Iran, Pakistan, and Saudi Arabia. However, considering the economies, Egypt, Lebanon, Pakistan, and Yemen lost over 3 percent of their GDPs due to $PM_{2.5}$ in 2013.

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[93] World Bank and IHME, "The Cost of Air Pollution."

[94] UNEP, "Sand and Dust Storms."

[95] World Bank and IHME, "The Cost of Air Pollution."

BOX 2: ECONOMIC COST CASE STUDIES

The direct economic losses from the dust storm in May 1993 in China reached 550 million CNY.[96] Driven by a cold air current from Siberia, a severe sandstorm occurred in northwest China in early May 1993. It moved southward from May 4 to 6, 1993, affecting a total area of 1.1 million square km. A total of 85 people died and 264 were injured, mostly primary school children, 4,412 houses were destroyed, and 120,000 animals died or went missing. About 373,333 million hectares of crops were destroyed, over 2,000 km of irrigation ditches were buried, 16,300 ha of fruit trees were damaged, and thousands of greenhouses and plastic mulching sheds were broken; ground transportation (train and highways) was suspended, and telecommunications facilities were severely damaged in some areas. Many water resource back-up facilities, such as reservoirs, dams, catchments, underground canals, and flood control installations were filled up with sand silts.

In 2002, Korea was estimated to have incurred costs of USD 4.6 billion, about 0.8 percent of its GDP from yellow dust.[97] These costs included medical expenses, opportunity costs, and industrial damage. The air transportation industry recorded sale losses due to flight cancellations caused by dust storms of USD 0.6 million. The total socioeconomic cost from yellow dust damage in South Korea in the year of 2002 is estimated at US$3,900 million at a minimum and US$7,300 million at a maximum, with an average of US$5,600 million, which is equivalent to 0.8% of GDP and US$117.00 per South Korean inhabitant.

A large dust storm called Red Dawn that passed over the eastern coast of Australia on 23 September 2009 is estimated to have cost AUD$299 million (with a range of AUD$293–A$313 million).[98] Most of the costs were associated with household cleaning and associated activities. The study demonstrates some, but not all, of the major economic costs associated with wind erosion in Australia. Given the annual average cost of dust storms, the study suggested that AUD$9 million per year would be a conservative estimate of the level of investment required in rural areas for dust mitigation strategies, based on improved land management that could be justified to achieve a positive impact on soil conditions and reduce economic losses in rural towns and the more populous coastal cities.

TABLE 3: WELFARE LOSSES FROM AMBIENT $PM_{2.5}$ BY REGION (2011 US$ BILLIONS—PPP ADJUSTED)

Region	1990	1995	2000	2005	2010	2013
East Asia and Pacific	273	366	458	668	1,065	1,387
Europe and Central Asia	1,247	1,172	1,129	1,232	1,188	1,170
Latin America and Caribbean	43	47	55	71	100	122
Middle East and North Africa	62	69	86	105	130	141
North America	483	503	527	518	451	431
South Asia	48	63	85	123	203	256
Sub-Saharan Africa	20	20	24	32	39	44
Total	**2,176**	**2,240**	**2,364**	**2,749**	**3,176**	**3,551**

Source: World Bank and IHME, 2016.

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[96] Wang et al., “Analysis on the Formative Causes of Sand-Dust Storms in the Northwest China during 3–12 April 1994.”
[97] Jeong, “Socio-Economic Costs from Yellow Dust Damages in South Korea.”
[98] Tozer and Leys, “Dust Storms–What Do They Really Cost?”

TABLE 4: MEAN ANNUAL $PM_{2.5}$, AND TOTAL DEATHS AND LOSSES FROM POLLUTION BY COUNTRY

Country	Mean Annual $PM_{2.5}$ ($\mu g/m^3$)	Total Deaths	Losses in US Million Dollars (PPP-adjusted)	% of GDP Equivalent
Algeria	19.26	7,845	9,186	1.84%
Bahrain	43.63	188	836	1.47%
Egypt	36.41	39,118	33,912	3.85%
Iran	31.89	21,680	32,070	2.6%
Iraq	32.57	10,372	14,793	2.89%
Israel	25.78	2,201	7,639	3.03%
Jordan	25.64	1,055	1,083	1.47%
Kuwait	49.13	547	3,820	1.44%
Lebanon	23.56	1,816	2,808	3.78%
Morocco	17.36	7,034	4,158	1.73%
Oman	30.35	655	2,725	1.8%
Pakistan	46.18	156,191	54,295	6.69%
Qatar	38.36	110	1,222	0.44%
Saudi Arabia	54.12	6,285	32,038	2.17%
Tunisia	16.35	3,792	3,514	3.01%
UAE	40.95	900	5,761	1.02%
West Bank and Gaza	26.36	1,006	309	1.65%
Yemen	36.19	13,442	3,229	3.45%

Source: World Bank and IHME, 2016.

PREVENTATIVE ACTIONS, INTERVENTIONS, AND POLICIES AGAINST SAND AND DUST STORMS

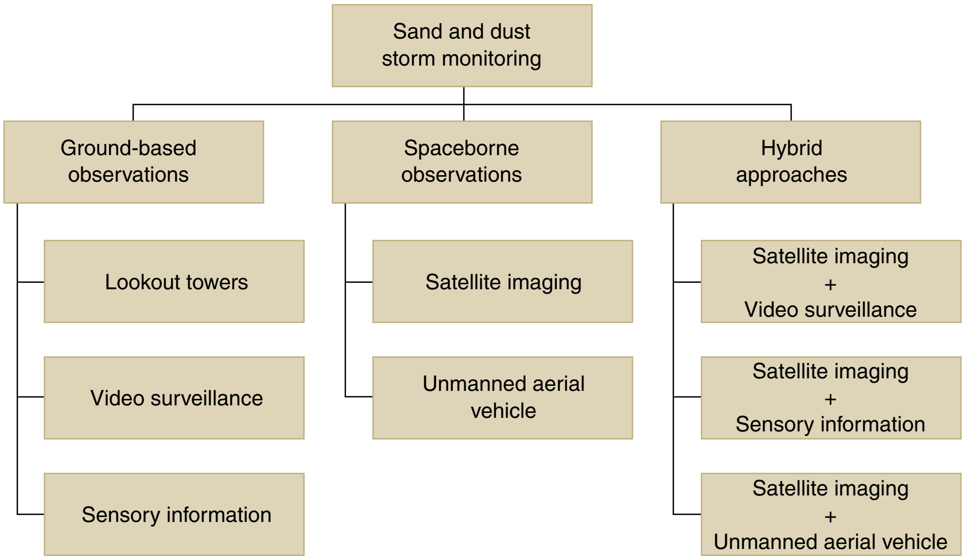
Investment in prediction technologies, interventions against wind erosion, and regional air pollution policies can significantly reduce the high costs associated with sand and dust storms. As previously mentioned, about 13 billion USD in GDP are lost every year due to dust storms in the MENA region. Additionally, dust pollution is also linked with many adverse health impacts such as strokes, heart disease, lung cancer, and respiratory diseases like asthma. Preventative and mitigating interventions addressing sand and dust storms are therefore imperative. While dust storms and dust emissions mostly originate from natural sources and are dependent on wind, there are still actions that can be taken to lessen the impacts. Investing in early warning and prediction systems can be extremely beneficial, as it can better prepare economies and significantly lower the damages from sand and dust storms. Additionally, while most dust transport is linked to natural sources, anthropogenic drivers are becoming increasingly threatening too. Government policy addressing these barriers, especially on a transboundary level, should also be prioritized.

EARLY WARNING SYSTEMS FOR DUST STORM PREDICTION

Early warning systems can reduce many unexpected costs that result from sand and dust storms. Early warning systems at the national and regional levels could prepare people for dust storms and reduce costs. Some major costs include crop losses, adverse health impacts, and infrastructure damage. It gives people time to take cover, seal doors, and vacate streets which prevent car accidents. It would also reduce flight disruption costs, as airlines can activate programs to reschedule or cancel flights before passengers arrive at the airport. Warnings would also give farmers time to bring in livestock and equipment, and allow them to harvest most of a crop if necessary.

Sand and dust storms can be predicted by ground-based technologies, spaceborne observations, or a combination of both. There are many types of sand and dust storms with respect to spatial and temporal coverage. The physical parameters of a dust storm include its optical depth, concentration, particle size distribution, and land surface cover below it.[99] The main issues in developing a system for dust storm detection and prediction include defining data requirements, modeling dust, and designing an effective prediction technique. Such systems require data on dust and other environmental changes, which can be obtained in two ways: ground-based observations and spaceborne observations.[100] The ground-based observations can be made through lookout towers, video surveillance, and sensory information gathered by radars, lidars, Wireless Sensor Networks (WSNs), etc. The spaceborne observations are typically obtained through satellite imaging, and sometimes through unmanned aerial vehicle (UAV), etc.[101] However, hybrid approaches make use of both types of observations for better performance. Figure 9 classifies the most commonly used technologies for sand and dust storm detection and prediction.

FIGURE 9: TECHNOLOGIES FOR SAND AND DUST STORM MONITORING



Source: Akhlaq et al., 2012.

Latest satellite technologies have provided reliable and high-quality data for dust detection. Satellite instruments, particularly the Moderate Resolution Imaging Spectroradiometer (MODIS), have revolutionized the scientific community's ability to understand the spatial extent, pathways, and source area of dust storms. Coupling satellite images with Weather Research and Forecasting (WRF) modelling provides a tool for more accurate forecasting. Other systems such as the Inertial Altitude Reference System (IARS) and the Infrared Atmospheric Sounding Interferometer (IASI), have the potential to provide good quality dust information as well.[102, 103] A reliable Internet connectivity set up to access, download, and transfer data from satellite-borne sensors and terrestrial meteorological stations is key to the success of this time-critical activity.

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[99] El-Askary et al., "Introducing New Approaches for Dust Storms Detection Using Remote Sensing Technology."
[100] Ma et al., "New Dust Aerosol Identification Method for Spaceborne Lidar Measurements."
[101] Akhlaq, Sheltami, and Mouftah, "A Review of Techniques and Technologies for Sand and Dust Storm Detection."
[102] Klüser, Martynenko, and Holzer-Popp, "Thermal Infrared Remote Sensing of Mineral Dust over Land and Ocean."
[103] Hilton et al., "Hyperspectral Earth Observation from IASI."

In addition to weather services and media, warnings can be communicated through text alerts and websites that are quicker and reach larger populations. Early warnings of dust hazards can be communicated through a variety of means, including media coverage and Short Message Service (SMS) alerts. In South Korea, warnings of yellow dust events transported across the Korean peninsula from China and Mongolia are issued by the Korea Meteorological Administration (KMA) using local media and Short Message Service (SMS) text alerts issued to users who register on their air quality alert website. Similarly, the National Weather Service (NWS) in the USA also provides dust storm warnings via SMS.[104] The KMA has provided text message alerts since at least 2006, and the USA just began this system in the summer of 2012 as part of a severe weather alert initiative. Although an SMS alert system may not work in developing nations due to poor network connectivity in some areas, it is still a good model for quick and digestible information that can reach a large population. Another example of an early warning platform that updates frequently is a website hosted by the National Centre of Meteorology and Seismology in the United Arab Emirates (UAE), which updates warnings every three hours and provides dust and visibility conditions to the public and local media.[105]

The World Meteorological Organization (WMO) launched a sand and dust storm warning system that aims to deliver reliable dust storm forecasts through a network of research organizations all over the world. The WMO provides global coordination of monitoring, prediction, and warning systems for sand and dust storms. In 2007, the WMO endorsed the launching of the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS). It aims to improve the ability of countries to deliver quick and high-quality sand and dust storm forecasts and knowledge to users through an international partnership of research and operational organizations (Table 5).[106] The SDS-WAS works as a network of research, operational centers, and users which is organized through regional nodes.[107] Three regional nodes are currently in operation: (i) Northern Africa, Middle East, and Europe, (ii) Asia and Central Pacific, and (iii) Pan-America. The SDS-WAS regional node for Northern Africa, Middle East, and Europe is coordinated by a Regional Centre (RC) set in Barcelona, Spain, and aims to facilitate user access to observational and forecast products and other sources of basic information related to airborne dust. Its web portal (NA-ME-E 2016) provides users with the information needed to monitor dust events and to issue operational predictions and warning advisories related to the dust content in the atmosphere.[108]

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[104] NOAA, "Mobile Weather Warnings on the Way! National Oceanic and Atmospheric Administration."

[105] NCMS, "Warnings. National Centre of Meteorology and Seismology."

[106] Terradellas, Nickovic, and Zhang, "Airborne Dust."

[107] Nickovic et al., "Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Science and Implementation Plan."

[108] Terradellas, Baldasano, and Cuevas Agulló, "Regional Center for Northern Africa, Middle East and Europe of the WMO Sand and Dust Storm Warning Advisory and Assessment Sytem."

TABLE 5: INSTITUTIONS AND ORGANIZATIONS WITH DUST FORECASTING PROGRAMS

Name	Location	Coverage
Japan Meteorological Society	Japan	Global
The Meteorological State Agency of Spain (AEMET) and Barcelona Supercomputing Centre	Spain	North Africa, Middle East, Europe, Asia
Centre for Atmosphere Watch and Services (CAWAS), Chinese Meteorological Agency	China	East Asia, Central Pacific
National Observatory of Athens, University of Athens	Greece	North Africa, Middle East, Europe, Asia
National Research Council	Italy	North Africa, Middle East, Europe, Asia
South east European Climate Change Center	Serbia	North Africa, Middle East, Europe, Asia
Finnish Meteorological Institute	Finland	North Africa, Middle East, Europe, Asia
Korean Meteorological Administration	Korea	East Asia
University of Tel Aviv	Israel	North Africa, Middle East, Europe
Egyptian Meteorological Authority	Egypt	North Africa, Middle East, Europe, Asia
Naval Research Laboratory, National Aeronautics and space Administration, National Centers for Environmental Prediction	USA	Global
Research Institute for Applied Mechanics, Kyushu University in cooperation with the National Institute for Environmental Studies (NIES)	Japan	East Asia, Central Pacific
Laboratoire de Meteorologie Dynamique	France	Africa, Europe, Atlantic, Central Asia
European Center for Medium range Weather Forecasting (ECMWF), Met Office	UK	Global
World Meteorological Organization (WMO)	Switzerland	Global network of regional models

Source: WMO, 2011[109], UNEP, WMO, UNCCD, 2016[110]

TECHNICAL INTERVENTIONS

Agricultural practices, such as residue management, tillage, shelterbelts, and agroforestry, are effective against wind erosion and decreasing dust transport. To prevent dust transport and dust storms, soil exposure to wind must be managed. This can be done by protecting the soil with live or dead vegetation or minimizing the time and area of the soil that has little cover. Additionally, adding windbreaks and adopting agroforestry in agricultural land can also reduce wind erosion Cropping, residue management, shelterbelts, and reduced tillage practices are especially helpful for preventing wind erosion. Reduced or no tillage, and other practices that minimize soil disturbance and maximize residue on the soil are included under 'conservation agriculture'. Such practices also reduce the time that

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[109] WMO, "Organizations Delivering SDS Forecasts. World Meteorology Organization."

[110] UNEP, WMO, UNCCD (2016). Global Assessment of Sand and Dust Storms. United Nations Environment Programme, Nairobi

the soil is unprotected in dry seasons. Other good management practices include use of quality planting material, optimal plant density, appropriate soil and crop nutrient management, and adequate pest and disease control.

Maintaining crop residue successfully protects the soil from erosion. Maintaining enough vegetative cover is often referred to as the "cardinal rule" for controlling wind erosion.[111] Crop residues as a cover help stabilize the soil by reducing soil water loss and erosivity. For example, Michels et al. (1995) showed that covering the soil with 2,000 kg per ha of millet residues provides enough protection from sand storms.[112] Mulching—the practice of leaving some residual crop material such as leaves, stalks, and roots, on or near the surface—is a commonly used agronomic technique. It is successful in reducing erosion and in reducing the loss of water from fields by decreasing evaporation. Research shows that vertical residues are also very effective for controlling soil loss during wind, as they can trap more snow than horizontal stems for instance.[113, 114]

Windbreaks such as shelterbelts reduce wind speed and provide other agricultural benefits as well. Windbreaks are structures that reduce wind speed and are commonly associated with a natural vegetative barrier against wind.[115] These types of barriers can inhibit wind erosion by reducing the travel distance of wind across a field. Fences or walls placed at right angles to erosive winds can reduce wind erosion, or windbreaks may be created from living plants such as trees or bushes, in which case they are known as shelterbelts. Reductions in wind velocity are achieved both upwind, for 2–5 times the height of the windbreak, and downwind, extending 10–30 times of the windbreak height.[116] Shelterbelts produce many benefits for farmers, such as decreased soil erosion, increased crop yields, reduced livestock stress, control of drifting snow, building maintenance, and energy savings.[117] Other benefits include increased soil and air temperatures, reduced pest and disease problems, and an extended growing season in sheltered areas.

Agroforestry, along with providing other ecosystem services, offers windbreaks in agriculture land.[118] Agroforestry includes linear arrangements of trees and shrubs around fields and homesteads, along roadsides, on soil conservation contours within fields, and in riparian areas. Scattered trees are especially important for protecting croplands in dryland areas. Poor farmers who are mostly concerned with crop yields will not prioritize wind erosion as much.[119] However, introducing agroforestry will provide economic incentives as well as protection against wind erosion.

NATIONAL AND REGIONAL GOVERNMENT POLICIES

Besides investing in early warning systems, governments all over the world are designing policies to mitigate the impact of sand and dust storms, both at national and regional levels. Devastating impacts from sand and dust storms in the

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[111] Skidmore, "Wind Erosion Climatic Erosivity."

[112] Michels et al., "Wind and Windblown Sand Damage to Pearl Millet."

[113] Bilbro and Fryrear, "Wind Erosion Losses as Related to Plant Silhouette and Soil Cover."

[114] Nielsen, Hinkle, and Lyon, "Wind Velocity, Snow and Soil Water Measurements in Sunflower Residues."

[115] Rosenberg, Blad, and Verma, Microclimate.

[116] Cornelis and Gabriels, "Optimal Windbreak Design for Wind-Erosion Control."

[117] Forman and Baudry, "Hedgerows and Hedgerow Networks in Landscape Ecology."

[118] Young, "Agroforestry for Soil Conservation."

[119] Sterk, "Causes, Consequences and Control of Wind Erosion in Sahelian Africa."

BOX 3: UN-INTERAGENCY RESPONSE TO SDS

The United Nations Coalition on Combatting SDS was launched at COP 14. The UN Coalition was established in response to the United Nations General Assembly resolution 72/225 in 2017 through the efforts made by UNEP. Currently 15 members of the coalition include: UNEP, WMO, UNCCD, UNITAR, ICAO, UNDP, UN-Habitat, WHO, ESCAP, ESCWA, IUCN, FAO, World Bank, ITU, and UNECE. The key objectives of the coalition include:

- Prepare a global response to SDS, including a strategy and an action plan, which could result in the development of a United Nations system-wide approach to addressing SDS. Identifying entry points to support SDS-affected countries and regions in the implementation of cross-sectoral, and transboundary risk reduction and response measures for SDS.
- Provide a forum for engaging with partners and enhancing dialogue and collaboration among affected countries and the UN system agencies at global, regional, and subregional levels.
- Provide a common platform for exchange of knowledge, data, information, and technical expertise and resources for strengthening preparedness measures and strategies for risk reduction, consolidated policy, innovative solutions, advocacy and capacity building efforts, and fund-raising initiatives.
- Identify, mobilize, and facilitate access to financial resources for joint responses to sand and dust storms, including through new and innovative resources and mechanisms.

Four main cross-cutting work areas will be addressed by the coalition:

- Facilitation of information exchange among stakeholders (e.g., data collection, knowledge sharing, and innovative solutions)
- Capacity building and training
- Mobilizing resources and fund-raising initiatives
- Advocacy and awareness raising

For more information see: https://unemg.org/our-work/emerging-issues/sand-and-dust-storms/

Source: UN Environment Management Group, 2019.

Americas, MENA region, and East Asia have encouraged governments to enforce many large-scale initiatives and plans. In many instances, these initiatives also tackle land degradation, terrestrial biodiversity, and climate change mitigation. However, policies designed to mitigate the wider impacts of sand and dust storms, including many that are transboundary, are geographically patchy and have a much shorter history. Regional and international cooperation among countries will lead to a greater understanding of the transportation paths of dust storms, particle content, and their impacts. A new United Nations Coalition on Combatting Sand and Dust Storms has recently been launched with the goal of raising awareness, capacity building, and mobilizing resources to respond to SDS (Box 3). Eventually, regional action will also lead to reduced occurrence of dust storms. Recent years have seen some regional air pollution policies emerge, but more collaboration is needed and should be sustained.

Large-scale disasters like the dust bowl in the USA in the 1930s motivated several government initiatives and policies against sand and dust storms. Even though the Dust Bowl in the 1930s in the USA had devasting impacts all around, one silver lining was the government's increased participation in soil conservations and land management issues. For instance, the Soil Conservation Service (SCS), created in 1935, identified areas in need of remediation using aerial photography surveys and detailed soil maps.[120] They acquired abandoned lands, which are dust storm sources, and used them for demonstration projects on terracing and contour plowing. Other government agencies provided subsidies to encourage improved plowing methods and funded planting of shelterbelts on many private lands. Similar interventions by the government also occurred in Canada. Some farmland was converted to rangelands, subsidies were offered to families willing to abandon farms in dry areas, and farmers were encouraged to build shelterbelts and adopt soil conservation.[121]

In addition to government initiatives after a dust storm disaster, several countries have developed government policies to mitigate the impacts of sand and dust storms. In China, one of the most ambitious projects to combat desertification and control dust storms is an afforestation project called the Three Norths Forest Shelterbelt program or the Great Green Wall, which is to be completed by 2050.[122] Other projects in China include the Grain-for-Green program, which is designed to convert cropland to forest and grassland and the Beijing-Tianjin Sand Source Control program, which includes various interventions that conserve cropland and grazing lands and prevent erosion.[123, 124] China also has a National Action Plan to implement the United Nations Convention to Combat Desertification (UNCCD), drawn up in 1996 and revised in 2003, and is the first country to establish a national desertification monitoring initiative as a follow-up action. In a similar initiative to the Great Green Wall of China, the African Union, with the support of the World Bank, is establishing a Great Green Wall of trees and shrubs along the southern edge of the Sahara Desert. The project aims to reforest 15 million hectares along a 15 km-wide, 7,775 km-long belt, from Dakar to Djibouti.

Northeast Asia and West Asia have developed Regional Action Plans on sand and dust storms, which aim to monitor dust storms and invest in mitigation strategies. The Regional Master Plan for the Prevention and Control of Dust and Sandstorms in Northeast Asia is a project involving the governments of China, Japan, Mongolia, and South Korea.[125] It was jointly initiated and conducted by the Asian Development Bank (ADB), the UNCCD, the United Nations Economic and Social Commission for Asia and Pacific (UNESCAP), and United Nations Environment Programme (UNEP). The plan's aims are two-fold—to establish a regional monitoring, forecasting, and early warning network for dust storms in Northeast Asia and to invest in strengthening mitigation measures against root causes of dust storms in the regional source areas. Another regional master plan is the West Asia Regional Master Plan to Combat Sand and Dust Storms, which is coordinated by UNEP and WMO Regional Offices for West Asia Iran.[126, 127] The plan includes Bahrain, Iran, Iraq, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, Syria, Turkey, and the UAE. There are also several other global and regional air pollution agreements and policies that are addressing dust pollution and dust storm monitoring (Box 4).

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[120] McLeman et al., "What We Learned from the Dust Bowl: Lessons in Science, Policy, and Adaptation."

[121] Marchildon et al., "Drought and Institutional Adaptation in the Great Plains of Alberta and Saskatchewan, 1914–1939."

[122] Wang et al., "Has the Three Norths Forest Shelterbelt Program Solved the Desertification and Dust Storm Problems in Arid and Semiarid China?"

[123] Lei, Shangguan, and Rui, "Effects of the Grain-for-Green Program on Soil Erosion in China."

[124] Dalintai, Yanbo, and Jianjun, "The Eurasian Steppe."

[125] Diallo, "United Nations Convention to Combat Desertification (UNCCD)."

[126] Cuevas, Establishing a WMO Sand and Dust Storm Warning Advisory and Assessment System Regional Node for West Asia.

[127] UNEP, "West Asia Regional Master Plan to Combat Sand and Dust Storms. United Nations Environment Programme."

BOX 4: REGIONAL AIR POLLUTION POLICIES

The Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia is an intergovernmental agreement to tackle regional air pollution problems, established in 1998 by the South Asian countries at a meeting of the South Asia Cooperative Environment Programme (SACEP) Governing Council.

Regional Air Pollution in Developing Countries (RAPIDC) aims to facilitate the development of agreements/protocols to implement measures which prevent and control air pollution.

The Air Pollution Information Network for Africa (APINA) was formed in 1997 and acts as a link between different networks and programs on air pollution in Africa.

The governments of the ten ASEAN (Association of Southeast Asian Nations) member countries signed the ASEAN Agreement on Transboundary Haze Pollution in 2002. The agreement is the first regional agreement that binds a group of countries to tackle transboundary haze pollution resulting from land and forest fires.

China—South Korea—Japan joint sand and dust storm cooperation within the Asia Node of SDSWAS. China—South Korea—Mongolia joint sand and dust storm monitoring. Mongolia and Kazakhstan are associated partners of the Asia Node of SDS-WAS.

The Convention on Long-Range Transboundary Air Pollution (CLRTAP) is intended to protect humans and the environment against air pollution and to gradually reduce and prevent air pollution, including long-range transboundary air pollution exchange.

Source: Shepherd et al., 2016.

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GLOSSARY

Aerosol A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 micrometres (µm), that resides in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin.

Aerosol index An indicator that detects the presence of UV-absorbing aerosols such as dust and soot.

Agroforestry The intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits.

Albedo The proportion of the incident light or radiation that is reflected by a surface.

Alkalinity The accumulation of sodium ions on exchange surfaces of soils, resulting in high pH values and often collapse of soil structure due to dispersion of clays.

Allergic rhinitis Hay fever, a type of inflammation in the nose which occurs when the immune system overreacts to allergens in the air.

Anthropogenic As a result of human activity.

Anticyclone A weather system with high atmospheric pressure at its center, around which air slowly circulates in a clockwise (northern hemisphere) or counter-clockwise (southern hemisphere) direction. Anticyclones are associated with calm, fine weather.

Aspergillosis A condition in which certain fungi infect the tissues, especially the lungs.

Biogeochemical cycles The fluxes of chemical elements among different parts of the earth: from living to non-living, from atmosphere to land to water, and from soils to plants.

Cerebrovascular diseases A group of conditions that affect the circulation of blood to the brain, causing limited or no blood flow to affected areas of the brain.

Chronic Obstructive Pulmonary Disease The name for a collection of lung diseases including chronic bronchitis, emphysema, and chronic obstructive airways disease.

Clay Soil or sediment particles of diameter less than 2 microns.

Cyclone A system of winds rotating inward to an area of low atmospheric pressure, with a counter-clockwise (northern hemisphere) or clockwise (southern hemisphere) circulation; cyclones are associated with tropical storms.

Deposition Settling of dust onto the land surface through natural settling of particles from the atmosphere (dry) or in precipitation (wet).

Desertification When individual land degradation processes, acting locally, combine to affect large areas of drylands (UNEP 2007).

Dust bowl An area of land where vegetation has been lost and soil reduced to dust and eroded, especially as a consequence of drought or unsuitable farming practice.

Dust haze Dust which resides in the atmosphere from a previous dust storm.

Dust storm The result of terminal winds raising large quantities of dust into the air and reducing visibility at eye level (1.8 meters) to less than 1,000 meters.

Emphysema A condition in which the air sacs of the lungs are damaged and enlarged, causing breathlessness.

Entrainment The process of particle lifting by the agent of wind erosion.

Ephemeral water body A water body that dries up periodically.

Erodibility The inherent yielding or non-resistance of soils and sediments to wind erosion.

Erosivity A measure of the capacity of wind to cause soil or sediment erosion.

Fetch The length of unobstructed terrain over which the wind flows.

Hydrologic Associated with water bodies that dry out during some periods, including shorelines, river beds, ephemeral water bodies, and inland water features.

Ischemic heart disease Also known as coronary artery disease, a group of diseases that includes: stable angina, unstable angina, myocardial infarction, and sudden cardiac death.

Land Degradation Neutrality A policy supported by the UNCCD to maintain or improve the amount of healthy and productive land resources over time and in line with national sustainable development. It is incorporated into the Sustainable Development Goal target 15.3.

Lidar A detection system that works on the principle of radar but uses light from a laser.

Loess Sediment formed by the accumulation of wind-blown silt.

Meningococcal meningitis A bacterial infection that results in swelling and irritation (inflammation) of the membranes covering the brain and spinal cord; also known as cerebrospinal meningitis.

Micron A unit of millionth of a meter, or micrometer (μm).

Mineral dust Atmospheric aerosols originated from the suspension of minerals constituting the soil, being composed of various oxides and carbonates.

Mitigation of climate change Efforts to reduce or lessen climate change through, for example, reduction in greenhouse gas emissions.

Mitigation of sand and dust storms Efforts to reduce anthropogenic causes of SDS and to lessen the negative impacts of SDS on human well-being.

Monsoon A seasonal prevailing wind in the region of South and Southeast Asia, blowing from the southwest between May and September and bringing rain (the wet monsoon), or from the northeast between October and April (the dry monsoon).

Natural ecosystem An ecosystem that occurs as it would without the influence of human beings. Natural ecosystems include deserts, grasslands, natural forests, lakes, and rivers.

Normalized Vegetation Difference Index A measure of green vegetation cover calculated from satellite image data.

Phytoplankton Microscopic marine plants. Phytoplankton provide the base of several aquatic food webs.

Playa Flat-bottomed depressions commonly found in interior desert basins and as "sabkhas" adjacent to coasts within arid and semiarid regions; in some locations, these are periodically covered by water to form playa lakes, some of which are saline. Ephemeral, salt, or dry lakes are referred to as playas and playa lakes in North America; salinas, saladas, and salars in South America; chotts (shatts, shotts); sebkhas or sabkhas in the Middle East; boinkas in Australia; pans in southern Africa; or kavir, or gol in Asia.

Primary productivity The rate at which plants and other photosynthetic organisms produce organic compounds in an ecosystem.

Radiative balance The relationship between the amount of energy reaching the earth and the amount leaving it.

Reduced or no tillage A practice of minimizing soil disturbance and allowing crop residue or stubble to remain on the ground instead of being removed, burned, or incorporated into the soil. Reduced tillage practices may progress from reducing the number of tillage passes to stopping tillage completely (no or zero tillage).

Risk factor A factor that raises the probability of an adverse outcome.

Salinization Accumulation of water-soluble salts in soil.

Sand Soil or sediment particles of diameter greater than 63 microns.

Sediment Naturally occurring material that is broken down by processes of weathering and erosion, and is subsequently transported by the action of wind, water, or ice, and/or by the force of gravity acting on the particles.

Shelter belt Planting of one or more rows of trees or shrubs in such a manner as to provide shelter from the wind and to protect soil from erosion.

Silicosis Lung fibrosis caused by the inhalation of dust containing silica.

Silt Soil or sediment particles of diameter between 2 and 63 microns.

Soil The unconsolidated mineral or organic matter on the surface of the earth that has been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on parent material over a period of time. A product-soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics.

Soil conservation contours The practice of tilling sloping land or leaving strips of land untilled along lines of consistent elevation in order to conserve rainwater and to reduce soil losses from surface erosion.

Soil cover The degree to which soil is covered and protected by vegetation, organic litter layers, or mulches.

Source apportionment The practice of deriving information about pollution sources and the amount they contribute to ambient air pollution levels.

Surface roughness Character of a surface that produces drag on wind; results in turbulent flow with efficient transfer of matter and energy.

Sustainable land management Practices and technologies that aim to integrate the management of land, water, biodiversity, and other environmental resources to meet human needs, while ensuring the long-term sustainability of ecosystem services and livelihoods.

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