Food and Agriculture Organization of the United Nations

Sand and dust storms

A guide to mitigation, adaptation, policy and risk management measures in agriculture




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Foreword

The world's drylands are commonly affected by sand and dust storms (SDS) that occur when strong, turbulent winds erode small particles from soil surfaces with little or no vegetation cover. While such storms are important for ecosystem functioning, they are associated with numerous, frequently transboundary impacts. SDS adversely affect the yields and productivity of crops, trees, pastures and livestock. Wind erosion can result in the loss of nutrients, seeds and fertilizer, and can damage crop tissues by sandblasting. In addition, seedlings may be buried by sediments. Poor air quality associated with SDS is hazardous to honeybees. Soil material lifted into the atmosphere during SDS events contain many microorganisms such as bacteria, fungi and viruses. Plant and animal diseases have been dispersed in this way, some between continents. In fact, by directly affecting 11 of the 17 Sustainable Development Goals, SDS undermine efforts to achieve the 2030 Agenda for Sustainable Development. The growing impact of SDS urged the UN General Assembly in 2017 to pass a resolution requesting UN agencies to consider launching an inter-agency process to develop a global response to SDS. Subsequently, the United Nations Coalition on Combating Sand and Dust Storms was established in September 2019.

Drylands host a very significant proportion of major agricultural activities, including most rangelands and some 40 percent of global cropland. Just as SDS have numerous direct negative impacts on agriculture, agriculture is probably the most important anthropogenic driver of SDS – via unsustainable land and water management practices, desertification and land degradation. – but SDS also have numerous direct negative impacts on agriculture. Conversely, SDS frequency may decline when fields and rangelands are subject to successful wind erosion control practices. Hence agriculture is key to mitigating SDS sources and impacts globally when sustainable practices and risk reduction measures are implemented. We have a broad understanding of how society interacts with the global dust cycle, but significant data and information gaps remain in our knowledge of the linkages to agriculture. Hence, greater joint efforts are needed to reduce the risks associated with SDS and develop tools and measures that help mitigate the impact of SDS on agriculture, food systems and livelihoods of people.

This publication is designed to help fill some of those gaps. It is the product of an FAO inter-regional technical cooperation programme "Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture (TCP/INT/3802)". It represents the work of national and international experts, research organizations, government personnel and FAO staff from headquarters – the Land and Water Division (NSL) and the Office of Emergencies and Resilience (OER) – and the six partnering countries – Algeria, China, Islamic Republic of Iran, Iraq, Kuwait, and Mongolia – over the period 2020-2022.

The report aims to consolidate and synthesise existing knowledge of agriculture as a source of SDS, and of how SDS impact agricultural production, as well as mitigation, risk reduction and adaptation measures, both at local and national policy levels. In addition, the report presents the results of several case studies especially commissioned for this programme. The conclusions and recommendations enhance our understanding of SDS and suggest how farmers, herders, local administrators, and governments can act to reduce SDS risks and their adverse impacts. The benefits of such actions are expected to extend to other sectors of society at all levels.

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Abbreviations

AEZ	agroecological zone
ARF	Agricultural Risk Fund
CA	conservation agriculture
DRM	disaster risk management
DRR	disaster risk reduction
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
GEE	Google Earth Engine
GIS	geographic information system
LDN	land degradation neutrality
LP	linear programming
MWH	micro water harvesting
NDVI	normalized difference vegetation index
SDG	Sustainable Development Goal
SDS	sand and dust storm(s)
Sendai Framework	Sendai Framework for Disaster Risk Reduction 2015–2030
SDS-WAS	sand and dust storm warning advisory and assessment system
SFM	Sendai Framework Monitor
SLM	sustainable land management
UNCCD	United Nations Convention to Combat Desertification
WMO	World Meteorological Organization

Executive summary

Sand and dust storms (SDS) are common in drylands when strong, turbulent winds erode small particles from soil surfaces with little or no vegetation cover. Dust generated in SDS is often raised high into the atmosphere and transported over great distances, frequently across international boundaries. Such storms are important for ecosystem functioning, but they also create numerous hazards to society, in agriculture and other socioeconomic sectors. These hazards threaten the achievement of 11 of the 17 Sustainable Development Goals (SDGs).

A widely accepted estimate is that 25 percent of global dust emissions comes from anthropogenic sources and 75 percent from natural sources. Agriculture is one of the main anthropogenic drivers of SDS, by disturbing soils and/or changing the land cover that otherwise protects soil surfaces. Farming operations on cropland that can enhance wind erosion include activities associated with land preparation, cultivation and harvest. Abandoned cropland can also readily become a source of SDS. In addition, water bodies that shrink due to excessive water use for agriculture can create new SDS sources. On rangeland, trampling by livestock can destroy soil crusts and excessive grazing can reduce vegetation cover.

The yields and productivity of crops, trees, pastures and livestock are adversely affected by SDS. Wind erosion can result in the loss of nutrients, seeds and fertilizer, and can damage crop tissues by sandblasting. In addition, seedlings may be buried by sediments. Poor air quality associated with SDS is hazardous to honeybees. Soil material lifted into the atmosphere during SDS events contain many microorganisms such as bacteria, fungi and viruses. Plant and animal diseases have been dispersed in this way, some between continents.

There are still considerable uncertainties around the quantification of many of these impacts on agriculture, although their effects are direct and indirect, on-site and off-site, and long-term and short-term. Our knowledge of SDS impacts on agriculture has been enhanced by research commissioned as part of the Food and Agriculture Organization of the United Nations (FAO)'s technical cooperation programme "Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture." A severe two-day cold wave SDS event in Mongolia in March 2021 resulted in 87 percent of herder households in one Gobi Desert district reporting deaths among their herds. Some 16 percent of all livestock perished in the district, a loss valued at USD 1.2 million. The total value of livestock lost in this SDS was estimated to be USD 69.3 million. Econometric analysis in Iraq demonstrates a statistically significant negative impact of SDS on crop yields for cereals, dates and other fruits and vegetables. Losses due to an additional SDS day range from 0.7 percent to 2.8 percent, with the greatest impacts on vegetables and dates.

Extreme SDS events are recognized as severe natural hazard-induced disasters. Sizeable losses in the agricultural sector also occur due to the cumulative effects of numerous short wind erosion events with moderate wind velocities. FAO has developed a damage and loss assessment methodology to monitor disaster impacts on agriculture. The tool is used as part of the Sendai Framework Monitor Indicator C-2 to report direct agricultural loss attributed to disasters and the corresponding SDG Indicator 1.5.2. The tool is instrumental also to monitor SDS impacts on agriculture.

Drought typically increases SDS activity, exacerbating the risk to agriculture. Atmospheric dust emitted over large areas during periods of drought may also create a land–atmosphere feedback that prolongs drought conditions. Higher SDS emissions are consistent with climate change projections, indicating the expansion of global drylands, increased aridity and worsening drought conditions. The adverse impacts of SDS are likely to become even more severe in the future unless appropriate interventions are made.

Agriculture is a major driver of SDS, but it is also part of the solution to combat SDS risks and mitigate their impacts, through implementation of resilient and sustainable agricultural good practices. SDS should be addressed as part of national multihazard disaster risk reduction (DRR) and disaster risk management strategies linked to the Sendai Framework for Disaster Risk Reduction 2015–2030.

Efforts are growing to support SDS-affected countries in promoting sustainable land and water management, land-use planning, agroforestry, shelterbelts, afforestation/reforestation programmes, and the forest and landscape restoration mechanism, which all contribute to SDS source and impact mitigation in agriculture.

This Guide provides a database of more than 150 high-impact, context-specific practices (technical and non-technical) to reduce SDS sources and impacts on the agricultural sector at the local level. This database can be searched using filters to identify the most suitable practices per context according to multiple attributes. The longlist of practices has also been refined to produce a selection of 15 good practices to reduce SDS source and impacts on the agricultural sector. This shortlist of practices considers functionality, scaling, costs and cobenefits. These good practices have been chosen to cover a range of agroecological zones. The top four good practices are described in separate, detailed fact sheets followed by an evaluation of their economic cost, upscaling potential and effectiveness. A more concise assessment of good practices 5–15 is given in table format.

The adoption and upscaling of appropriate sustainable land management (SLM) and disaster risk reduction (DRR) good practices for SDS source and impact mitigation at local and landscape levels should be complemented by the strengthening of well-coordinated risk monitoring and early warning systems to enable anticipatory actions to minimize impacts of SDS events.

At the policy level, a multihazard, multisectoral and multiactor risk management approach is appropriate because of the linkages between SDS and risks such as drought, desertification and land degradation. Relevant national policies that can help to mitigate anthropogenic SDS source areas are those related to sustainable land and water management, integrated landscape management, and climate change mitigation and adaptation. Sand and dust storms must be mainstreamed into national and local DRR, as well as sectoral laws, policies, plans and strategies, which should be informed by multihazard risk and vulnerability assessment and actionable risk information. Relevant institutions require specific mandates and clearly defined roles and responsibilities to address SDS as outlined in DRR and sector-specific legislation and policy frameworks, so that their mandates are enforced, and clear synergies are established. Effective SDS risk management requires preventative and anticipatory risk management approaches. Integrated legislation and policy actions, adequate budget and an enabling environment are needed to facilitate the large-scale application of SDS source and impact mitigation actions. Short-term responses need to be linked to, and/or complemented by, long-term resilience building actions if we are to achieve sustainable development.

Given the frequent transboundary impact of SDS, risk-informed planning and implementation of well-coordinated actions is needed at national, regional and interregional levels. There is also a need to foster knowledge exchange among countries on good SDS policies and practices.

The specific recommendations of this Guide are followed by a series of annexes offering further information, guidance and examples.


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1 Overview of sand and dust storms

Key messages

Sand and dust storms (SDS) are often transboundary in nature. Such storms threaten the achievement of 11 of the 17 Sustainable Development Goals (SDGs). They are therefore attracting increasing concern from governments and the international community.

Societies frequently demand action on SDS during an SDS event, but commonly disregard the long-term solutions needed to comprehensively combat the adverse effects of SDS.

A dust storm or sand storm is an ensemble of small particles lifted above the land surface by a strong, turbulent wind that reduces visibility to less than 1000 m. Many of the impacts of SDS are also felt during less-intense events.

A widely accepted estimate is that 25 percent of global dust emissions comes from anthropogenic sources and 75 percent from natural sources.

Agriculture is one of the main anthropogenic drivers of SDS. Yet, it is also part of the solution to combat SDS risks and mitigate their impacts, through implementation of resilient and sustainable agricultural good practices.

Higher SDS emissions are consistent with climate change projections, indicating the expansion of global drylands, increased aridity and worsening drought conditions (increased frequency, severity and duration). Such storms should therefore be addressed as part of national multihazard disaster risk reduction (DRR) and disaster risk management (DRM) strategies linked to the Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework), the Paris Agreement and Transforming our World: The 2030 Agenda for Sustainable Development.

Action should be taken now. The adverse impacts of SDS are likely to become even more severe in the future unless appropriate interventions are made.

Sand and dust storms occur when strong, turbulent winds erode small particles from dryland surfaces with little or no vegetation cover. Such conditions are found most frequently in deserts and semi-deserts, where SDS are common, although they can occur in almost any environment. Dust generated in SDS is often raised high into the atmosphere and transported over great distances, frequently across international boundaries. Sand and dust storms are important for ecosystem functioning, with a wide range of effects on the Earth's system but these extreme climate events also create numerous hazards to society, in agriculture and other socioeconomic sectors. These hazards threaten the achievement of 11 of the 17 SDGs and have made SDS an issue of increasing concern to governments and the international community (Figure 1.1).

The agricultural sector is one of the main anthropogenic drivers of SDS, via poor land and water management, desertification and land degradation. In turn, SDS also have direct adverse impacts on agriculture, resulting in the loss of crops, trees and livestock or significant decreases in their production, thus also causing land degradation.

The socioeconomic impacts associated with SDS fall disproportionately on those with the least capacity to cope, including people who are dependent upon subsistence agriculture, living in poverty and suffering from malnourishment. Climate change projections indicate the expansion of drylands, increased aridity and worsening drought conditions (increased frequency, severity and duration) in global drylands, and consequently less vegetation cover (Mirzabaev *et al.*, 2022). The adverse impacts of SDS are likely to become even more severe in the future unless appropriate interventions are made.

In some regions, especially naturally dry zones, dust storms occur more frequently than most other types of natural hazard. Their impacts on society are severe, widespread and often transboundary. However, many aspects of this emerging DRM issue are understudied and poorly understood. This is a situation that weakens the capacity of policymakers and society to tackle the issue. An additional challenge is that societies demand action during an SDS event, but frequently disregard the long-term solutions needed to comprehensively combat the adverse effects of SDS.

This publication highlights the impacts of SDS on agriculture. It identifies a range of high-impact practices, which are location and context specific, to reduce SDS sources and impacts on the agricultural sector at local and policy levels. The overall global knowledge base on SDS mitigation and adaptation in the agricultural sector is therefore enhanced.

Figure 1.1 | Impacts of SDS on 11 of the 17 SDGs

1 NO POVERTY	Sand and dust storms can adversely impact poverty in a community in numerous ways, not least because SDS often represent a form of dryland degradation or desertification.
2 ZERO HUNGER	Sand and dust storms can cause damage to crops and livestock, as well as to agricultural infrastructure, negatively affecting food quality/quantity and food security.
3 GOOD HEALTH AND WELL-BEING	Air pollution caused by SDS poses a serious threat to human health. Many studies link dust exposure with increases in mortality and hospital admissions due to respiratory and cardiovascular diseases.
6 CLEAN WATER AND SANITATION	Dust deposition can compromise water quality because desert dust is frequently contaminated with microorganisms, salts and/or anthropogenic pollutants.
7 AFFORDABLE AND CLEAN ENERGY	Dust deposition can reduce power output from solar panels. Sand and dust particles can also damage energy infrastructure due to erosion, particularly on wind turbines.
8 DECENT WORK AND ECONOMIC GROWTH	The economic impact of SDS is considerable, affecting multiple economic sectors.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Power, water, road and other important infrastructure failures can occur because of SDS, causing interruptions to the provision of critical community services. These impacts can affect the sustainability and resilience of infrastructure and businesses.
11 SUSTAINABLE CITIES AND COMMUNITIES	Sand and dust storms can severely impact cities and other communities, hampering their efforts to become inclusive, safe, resilient and sustainable.
13 CLIMATE ACTION	Climate change, including changes in temperature and precipitation levels (and consequently vegetation cover), is modifying SDS hazard levels and increasing associated risks. Sand and dust storms may also have climatic feedbacks (e.g. making drought more prolonged).
14 LIFE BELOW WATER	Life below water is directly and indirectly affected by SDS in both positive and negative ways. Sand and dust deposition in coastal areas can adversely affect coral reef ecosystems and may have an impact on algal blooms.
15 LIFE ON LAND	Wind erosion in SDS source areas contributes to land degradation, undermining the resilience of communities.

Source: Adapted from **The Asian and Pacific Centre for the Development of Disaster Information Management.** 2021. *Sand and dust storms risk assessment in Asia and the Pacific*. Tehran.

1.1 Sand and dust storm definitions

The World Meteorological Organization (WMO) defines a dust storm or sand storm as an ensemble of small particles lifted to great heights by a strong and turbulent wind (WMO, 2017). Visibility is thus reduced at ground level to 1000 m or less, a limit widely adopted in the literature (UNEP, WMO and UNCCD, 2016). However, the distinction between sand storms and dust storms is not clear cut since there is a continuum of particle sizes in any storm, comprising particles that are clay sized (<4 µm in diameter), silt sized (4–62.5 µm) and sand sized (62.5 µm to 2 mm).

Larger particles entrained from the land surface are usually deposited within kilometres of the source, whereas finer particles can be lifted to considerable altitudes and transported great distances (>1000 km) by high-altitude winds. This long-distance transport results in individual dust events affecting huge areas, in some cases more than 1 million km^2 (Middleton *et al.*, 2021). Sand storms, however, typically have more localized effects, including sand dune encroachment.

Not all dust- or sand-raising events result in a full-blown storm with visibility less than 1000 m. Indeed, dust events are commonly classified according to visibility using the categories shown in Table 1.1. Throughout this publication, the emphasis is on SDS, but it is important to note that many of the impacts of SDS are also felt during the less-intense events shown in Table 1.1. For this reason, knowledge, understanding and examples of soil erosion by wind in its broad sense are included, incorporating events in all the categories shown in Table 1.1.

Table 1.1 | Classification of dust events

Dust event	Description	Visibility
Dust whirl (or dust devil)	Whirling column of dust moving with the wind; usually narrow, less than 30 m high and dissipating after travelling a short distance	Not applicable
Dust haze (or dust in suspension)	Widespread dust in suspension, not raised at or near the station at time of observation	Usually <10 km
Blowing dust	Dust or sand raised at the time of observation	1–10 km
Dust storm	Strong, turbulent winds lift large quantities of dust particles	<1000 m
Severe dust storm	Very strong winds lift large quantities of dust particles	<200 m

Sources: Adapted from **McTainsh, G.H. & Pitblado, J.R.** 1987. Dust storms and related phenomena measured from meteorological records in Australia. *Earth Surface Processes and Landforms*, 12(4): 415–424; **Shao, Y. & Dong, C.H.** 2006. A review on East Asian dust storm climate, modelling and monitoring. *Global and Planetary Change*, 52(1–4): 1–22.

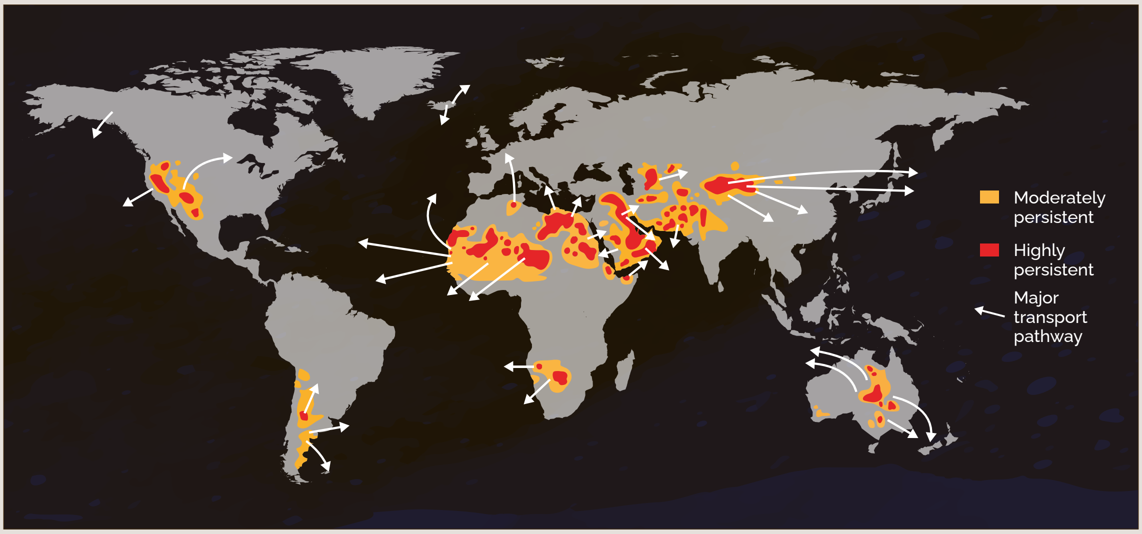
In terms of mineralogy, sand and dust particles from the low- to mid-latitudes are mainly composed of quartz, clay minerals (including illite, smectite, chlorite and kaolinite), feldspar, plagioclase, calcite and iron oxides (Nowak *et al.*, 2018). In chemical terms, sand and dust consist of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxides (Fe_2O_3 and FeO), calcium oxide (CaO), magnesium oxide (MgO) and potassium oxide (K_2O), with their relative abundance dependent on the sediment in the source area (Krueger *et al.*, 2004).

Depending on the nature of the source area, sand and dust particles may also contain a variety of salts, important quantities of organic matter, microorganisms (such as fungi, bacteria and viruses, some of which are pathogens) and pollutants derived from anthropogenic activities such as agriculture and industry (Goudie and Middleton, 2006). The airborne particles of biogenic origin, including fragments from living organisms (such as pollen and spores), also include elements derived from plant and animal matter, such as nitrogen (N) and phosphorus (P) (Gross *et al.*, 2016).

1.2 Global distribution and natural and anthropogenic drivers

The main sources of SDS are in the world's drylands and most of this wind erosion activity occurs in the northern hemisphere, in the so-called "Dust Belt" that extends from the Atlantic coast of the Sahara Desert, through the Near East and Central Asia to Northeast Asia. Sand and dust storms are much less frequent outside this region, although they have important local impacts in the drylands of southern Africa, the Americas and central Australia. Most of these sources are in low latitudes, but an estimated 5 percent of global desert dust is emitted from high-latitude sources, including Greenland, Iceland and the Patagonian Desert in Argentina (Bullard *et al.*, 2016). Figure 1.2 shows the global distribution of SDS sources and typical pathways of long-distance transport, many of which cross political boundaries.

Figure 1.2 | Global sources of desert dust and major pathways of long-distance, often transboundary, transport



Source: Adapted from **Muhs, D.R., Prospero, J.M., Baddock, M.C. & Gill, T.E.** 2014. Identifying sources of aeolian mineral dust: present and past. In: *Mineral dust*, pp. 51–74. Dordrecht, Germany, Springer.

Within these large dryland areas, SDS sources are frequently very localized and specific. Table 1.2 shows the principal factors that influence wind erosion in a particular location. Many sources produce SDS naturally, but SDS also occur in locations where human mismanagement leaves soil surfaces susceptible to wind erosion, which can happen in almost any environment given the right conditions. Agriculture is a prime driver of such environmental mismanagement (via changes to the physical factors shown in Table 1.2), but the magnitude of SDS sources that owe their origin to anthropogenic activity globally is a matter of debate. Yet agriculture is also part of the solutions to combat SDS, specifically in locations where human mismanagement is the cause of SDS, through the implementation of resilient and sustainable agricultural good practices.

Table 1.2 | Key physical factors influencing wind erosion

Climate	Soil/sediment	Vegetation	Landform/landscape
Wind speed (+)	Soil/sediment type	Vegetation type (–)	Surface roughness (±)
Wind direction	Particle composition	Coverage (–)	Slope (–)
Wind turbulence (+)	Soil/sediment structure	Density	Ridge
Precipitation (–)	Organic matter (–)	Distribution (±)	
Evaporation (+)	Carbonates (–)		
Air temperature (±)	Bulk density		
Air pressure (–)	Aggregation (–)		
Freeze–thaw action (±)	Moisture content (–)		

Note: (+) indicates the factor enhances wind erosion, (–) indicates the factor has a protective effect, reducing wind erosion, and (±) indicates the effect can be positive or negative, depending on the factor involved.

Sources: Adapted from **Shi, P., Yan, P., Yuan, Y. & Nearing, M.A.** 2004. Wind erosion research in China: past, present and future. *Progress in Physical Geography*, 28(3): 366–386; **Goudie, A.S. & Middleton, N.J. 2006.** *Desert dust in the global system*. Heidelberg, Germany, Springer Science & Business Media.

Estimates of the relative contribution of human activity to global dust emissions range from less than 10 percent (Tegen *et al.*, 2004) to greater than 50 percent (Mahowald and Luo, 2003). This uncertainty stems from a lack of detailed information on many SDS source areas and the challenges involved in distinguishing between anthropogenic effects and natural drivers of wind erosion (UNEP, WMO and UNCCD, 2016). A widely accepted estimate of the human impact, based on an agricultural land-use dataset, indicates that 25 percent of global dust emissions come from anthropogenic sources, with natural sources accounting for the other 75 percent (Ginoux *et al.*, 2012). The relative contributions in that assessment vary regionally: anthropogenic emissions make a higher contribution in the Middle East (30 percent) and in Australia (75 percent).

It is also important to note that these proportions are not fixed, because rates of wind erosion vary over time and through space for many reasons. The occurrence of SDS changes over time, from the seasonality that is characteristic in all SDS sources to variability over longer timescales. Many of the long-distance transport pathways shown in Figure 1.2 are highly seasonal. For instance, much dust from the Sahara Desert is transported southwestward across West Africa by the Harmattan wind that prevails between October and April and in the Near East, the northwesterly Shamal wind entrains and transports large quantities of dust across the Gulf region and the Arabian Peninsula from April to August.

Within the dusty season, frequency and intensity can vary considerably from year to year. They also vary over longer periods as conditions favourable to SDS respond to interannual and decadal variability in important factors such as rainfall, wind speed, vegetation cover and land use. Strong associations have been demonstrated between SDS activity and drivers such as drought (Middleton, 1985), the El Niño–Southern Oscillation (Banerjee and Kumar, 2016), the North Atlantic Oscillation (Moulin *et al.*, 1997) and the Pacific Decadal Oscillation (Notaro *et al.*, 2015). The variability of SDS activity also means that, through good management practices, agriculture can contribute to combating SDS in locations where human mismanagement contributes to their occurrence.

1.3 Impacts and international concern

The main sources of SDS are located in the world's drylands, but some impacts of desert dust are global in their extent. Sand and dust storms are important for ecosystem functioning and have many effects on the hydrosphere, lithosphere, biosphere, atmosphere and cryosphere. The material moved in SDS helps drive biogeochemical cycles such as the carbon, nitrogen, sulfur, phosphorus and silica cycles. These cycles are necessary for Earth system functions, making the dust cycle an integral component of Earth system science (Knippertz and Stuut, 2014).

Desert dust in the atmosphere has significant impacts on weather and climate (Schepanski, 2018) via scattering, absorption and re-emission of radiation in the atmosphere. Dust particles serve as nuclei for cloud formation and modify the optical properties of clouds, while the chemical composition of dust affects the acidity of rainfall. The deposition of dust particles is important in the formation of certain soils, such as terra rossa (Simonson, 1995), and provides significant nutrient input in various terrestrial ecosystems. Desert dust from the Sahara may contribute as much as 30 percent of total nutrient inputs to European forests (Lequy, Conil and Turpault, 2012), and constitutes a key source of phosphorous – an essential plant nutrient – to the rainforests of the Amazon Basin (Prospero *et al.*, 2020). When deposited in the oceans, dust has impacts – some positive, some negative – on marine biogeochemistry, primary productivity, carbon storage and deep-sea sedimentation (UNEP, 2020).

All these SDS impacts, both direct and indirect, are also important to human society. Many SDS represent a significant hazard to human society, not only in deserts and semi-deserts, but also to people living beyond these dryland regions, because dust haze is often transported over great distances (Kellogg and Griffin, 2006). There are numerous adverse consequences for human populations, including threats to agriculture, health, electricity generation and the transport industry (Middleton, 2017). Figure 1.3 illustrates some of these hazardous impacts. The impacts of SDS on agriculture can result in the loss of soil fertility, which directly affects crop yields, causing land degradation and undermining the sustainability of agriculture. Sand and dust storms can also cause the loss of livestock or significant decreases in their production (see Section 1.5).

Figure 1.3 | Global impacts of SDS

Sources: Information from **The Asian and Pacific Centre for the Development of Disaster Information Management.** 2021. *Sand and dust storms risk assessment in Asia and the Pacific*. Tehran; **Ahmadzai, H. 2021.** *The impact of sand and dust storms on agriculture in Iraq*. Unpublished report by International Center for Biosaline Agriculture to FAO under TCP/INT/3802; **Cordero, R.R., Damiani, A., Laroze, D., Macdonell, S., Jorquera, J., Sepúlveda, E., Feron, S., Llanillo, P., Labbe, F., Carrasco, J. & Ferrer, J.** 2018. Effects of soiling on photovoltaic (PV) modules in the Atacama Desert. *Scientific Reports*, 8(1): 1–14; **Cuevas, E., Milford, C. & Basart, S.**, eds. 2020. *Desert dust outbreak in the Canary Islands (February 2020): assessment and impacts*. Global Atmosphere Watch, Report No. 259, WWRP 2021-1. Geneva, World Meteorological Organization; **International Federation of Red Cross and Red Crescent Societies.** 2021. *Mongolia: sandstorm. Emergency Plan of Action, DREF Operation no. MDRMN014*; **Jusot, J.F., Neill, D.R., Waters, E.M., Bangert, M., Collins, M., Moreno, L.B., Lawan, K.G., Moussa, M.M., Dearing, E., Everett, D.B. & Collard, J.M. 2017.** Airborne dust and high temperatures are risk factors for invasive bacterial disease. *Journal of Allergy and Clinical Immunology*, 139(3): 977–986; **Lader, G., Raman, A., Davis, J.T. & Waters, K.** 2016. Blowing dust and dust storms: one of Arizona's most underrated weather hazards. National Oceanic and Atmospheric Administration Technical Memorandum NWS WR 290. Washington, DC, National Oceanic and Atmospheric Administration.

In recent years, these hazardous impacts of SDS have received attention from the United Nations General Assembly, which adopted resolutions entitled "Combating sand and dust storms" in 2015 (A/RES/70/195), 2016 (A/RES/71/219), 2017 (A/RES/72/225), 2018 (A/RES/73/237), 2019 (A/RES/74/226), 2020 (A/RES/75/222), 2021 (A/RES/76/211) and 2022 (A/RES/77/171). Other resolutions on SDS have been adopted by the United Nations Convention to Combat Desertification (UNCCD) (31/COP.13, 25/COP.14 and 26/COP.15), the United Nations Environment Assembly (Resolution 2/21) and the United Nations Economic and Social Commission for Asia and the Pacific (Resolution E/ESCAP/RES/72/7). Beginning in 2018, the United Nations has published annual reports by the Secretary General detailing developments within the United Nations system on SDS issues.

The United Nations General Assembly Resolution adopted in 2017 (A/RES/72/225) called for a global response to SDS, including a situation analysis, a strategy and an action plan, with the aim of developing a United Nations system-wide approach to addressing SDS. This call resulted in the creation of a United Nations Coalition on Combating Sand and Dust Storms, which was formally launched at the fourteenth session of the UNCCD Conference of the Parties in New Delhi, India in September 2019.

This United Nations SDS Coalition comprises more than 15 members, mainly United Nations entities, and has created five working groups[1] that have identified a set of priority themes (Box 1.1).

Box 1.1 | Priority themes of the United Nations Coalition on Combating Sand and Dust Storms

- Identifying and analysing sources of SDS;
- Identifying and implementing good practices for source and impact mitigation;
- Identifying vulnerable places and vulnerable populations;
- Advising policy and helping countries develop plans, as part of existing frameworks such as the Sendai Framework;
- Focusing on transboundary mechanisms because SDS represent a transboundary issue;
- Enhancing cooperation and coordination and sharing of data and information;
- Strengthening country capacities to tackle SDS.

Source: **United Nations General Assembly**. 2022. *Combating sand and dust storms, Report of the Secretary-General.* A/77/216. 22 July 2022. New York, USA, UN.

1.4 An emerging disaster risk management issue

The socioeconomic and environmental impacts of SDS outlined in Section 1.3 establish SDS as disasters according to the terminology adopted by the United Nations Office for Disaster Risk Reduction, which defines a disaster as "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts" (UNDRR, 2022). Moreover, SDS often occur in connection with other types of hazards and processes, particularly drought and climate change, with connections also to environmental risks such as land degradation and deforestation.

However, despite the widespread, severe and complex impacts associated with SDS, this type of extreme event does not feature prominently in disaster literature. Until now, SDS have had a low profile (if featured at all) in national DRR/DRM policies, plans, strategies and programmes (Middleton, Tozer and Tozer, 2019). Policymakers aiming to tackle this emerging DRM issue face a lack of information and poor understanding of SDS risks and the socioeconomic impacts of the phenomenon. Furthermore, the momentum and interest in combating extreme events such as SDS are high during the event, but often recede quickly thereafter. Combating SDS requires continuous efforts to tackle the root causes of the resultant problems, involving activities that focus on mitigation and adaptation.

Therefore, SDS should be addressed as part of national multihazard DRR and DRM strategies linked to the Sendai Framework and the land degradation neutrality (LDN) target (SDG

[1] The working groups are: (1) Adaptation and Mitigation, (2) Forecasting and Early Warning, (3) Health and Safety, (4) Policy and Governance and (5) Mediation and Regional Cooperation.

Target 15.3). They should also be addressed in development planning in and across various sectors, to further enhance national and regional resilience strategies and development programmes.

1.5 Agriculture and food systems

There are several strong linkages between SDS, agriculture and food systems. The agricultural sector is one of the main anthropogenic drivers of SDS, and also one of the most direct and immediately affected sectors. A farmer's field becomes susceptible to wind erosion when it is bare, dry and/or disturbed, such as after harvesting or ploughing. The results of agricultural mismanagement may also be revealed in longer-term enhancement of SDS activity, such as in areas of rangeland subject to intense grazing pressure. Abandoned fields are also frequently identified as SDS sources.

Excessive agricultural water offtakes from rivers in Central Asia over several decades have resulted in desiccation of the Aral Sea and creation of the Aralkum Desert, a dry lake bed that has become a significant new source of SDS (Figure 1.4). Conversely, SDS frequency may decline when fields are subject to successful wind erosion control practices (Middleton and Kang, 2017).

Figure 1.4 | A dust storm blown from the Aralkum Desert approaching the village of Qulandy, Kazakhstan. The Aralkum, the desiccated lake bed of the Aral Sea, produces very saline dust

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Overall, there is strong evidence to suggest that agricultural activities have enhanced SDS activity at large scales. Analysis of various proxy records indicates that human-induced dust emissions from the Sahel sharply increased with the advent of commercial agriculture in the region about 200 years ago (Mulitza *et al.*, 2010). A similar study, using sedimentary archives from numerous parts of the world, concluded that dust emissions had more than doubled globally over the past approximately 250 years, a period that saw the creation and widespread expansion of "industrial agriculture" (Hooper and Marx, 2018).

When SDS occur on agricultural land, that land loses fine soil particles and organic material, thus degrading soil structure. Nutrients, seeds, fertilizers, pesticides and beneficial microorganisms are removed from the soil. This reduces soil fertility, although the lost topsoil may benefit areas where the dust is deposited. Soil particles blown in the wind may also damage plant tissue by sandblasting, adversely affecting cropland and pastureland. Sand and dust storms therefore undermine the sustainability of agriculture, reducing its capacity to meet the needs of present and future generations. They also typically reduce key elements of sustainable food and agriculture: profitability, environmental health, and social and economic equity. Areas of cropland and rangeland that receive deposits blown from other sources may also be degraded in the long term, such as when saline material is eroded from ephemeral lake beds. In extreme cases, SDS can contribute to acute or even chronic food insecurity and malnutrition.

The linkages between SDS and land degradation also embrace LDN. The three global indicators used to monitor LDN – soil organic carbon, land productivity and land cover – are directly linked to food production and sustainable management of agricultural resources. The risk of SDS occurring is enhanced in areas where vegetative land cover is lost. Sand and dust storm events usually result in a decline in land productivity, and soil erosion by wind rapidly reduces soil organic carbon stocks. These linkages also create self-reinforcing or positive feedbacks: SDS causes land degradation, which results in further SDS, and land degradation causes SDS, which results in further land degradation. These are spirals of decline that must be interrupted by more sustainable use of agricultural resources.

1.6 Recent trends and future variability

Recent trends in SDS frequency and intensity have been identified in several parts of the world in response to changing climate conditions and/or to changing land-use and land-management practices. For instance, a trend (in 2000–2014) towards increased atmospheric mineral dust concentrations in the southwestern United States of America has been linked to increasing aridity (Hand *et al.*, 2017). In addition, changes in regional rainfall are thought to have been important in the occurrence of intense salt dust storms on the mudflats surrounding Mar Chiquita, Argentina, the largest saline lake in South America (Bucher and Stein, 2016). By contrast, a substantial reduction of dust in the Thar Desert in India and surrounding region has been linked to increases in rainfall, soil moisture and vegetation due to changes in the Indian summer monsoon since 2002 (Jin and Wang, 2018).

However, in many cases, distinguishing between the effects of changing climate conditions and changing land management is not straightforward, even in well-documented locations, as demonstrated by Middleton (2019) using examples across the Dust Belt in China, the Islamic Republic of Iran and Mauritania. For example, a decreasing trend in SDS in the northern hemisphere spring months of March, April and May (2007–2016) in East Asia was affected by higher precipitation and soil moisture during the period studied (An *et al.*, 2018), but large-scale state-sponsored ecological programmes in China have also played a role in restoring vegetation (Cai *et al.*, 2020).

In the latest report from Working Group II of the Intergovernmental Panel on Climate Change, the Sixth Assessment Report, the impacts of climate change on SDS activity are projected to be substantial, albeit with large regional variability (Mirzabaev *et al.*, 2022). Higher SDS emissions are consistent with climate change projections, indicating an expansion in the global area of drylands (Huang *et al.*, 2016) and increased drought risk (Xu, Chen and Zhang, 2019). New dust sources may also emerge with changing climate conditions, as Bhattachan *et al.* (2012) proposed for the Kalahari Desert in southern Africa, due to vegetation loss and dune remobilization.

1.7 Structure of this Guide

This Guide next gives a review of how agriculture can create SDS sources (Chapter 2) and highlights the impacts of SDS on agricultural production in source and deposition areas (Chapter 3). It includes results from research commissioned as part of the interregional project "Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture". The main body of the Guide focuses on SDS source and impact mitigation and adaptation interventions at local and policy levels. These include a range of high-impact, location- and context-specific practices to reduce SDS source and impacts on agriculture subsectors at local levels (Chapter 4), comprising technical and non-technical interventions identified as part of this interregional project. Hence the upscaling potential of interventions is also presented on a case study basis for wider uptake. Chapter 5 assesses how SDS risk is addressed at the policy level. It discusses options for integrating SDS at national and regional levels into multihazard DRR and DRM strategies or sectoral development programmes. Conclusions and recommendations are made in Chapter 6. Annexes offer further information, guidance and examples. More than 150 practices are presented in Annex 1, which is followed by details on their suitability mapping (Annex 2), potential effectiveness (Annex 3) and references in the literature (Annex 4). Examples from countries are given in Annex 5 (a policy brief on SDS and agriculture in Mongolia) and Annex 6 (describing how SDS risk and vulnerability assessments and contingency planning for SDS in agriculture were conducted in the Islamic Republic of Iran and Mongolia).

This Guide is published as a contribution to the work of the United Nations Coalition on Combating SDS, and will enhance the overall global knowledge base on SDS source and impact mitigation and adaptation in the agricultural sector.

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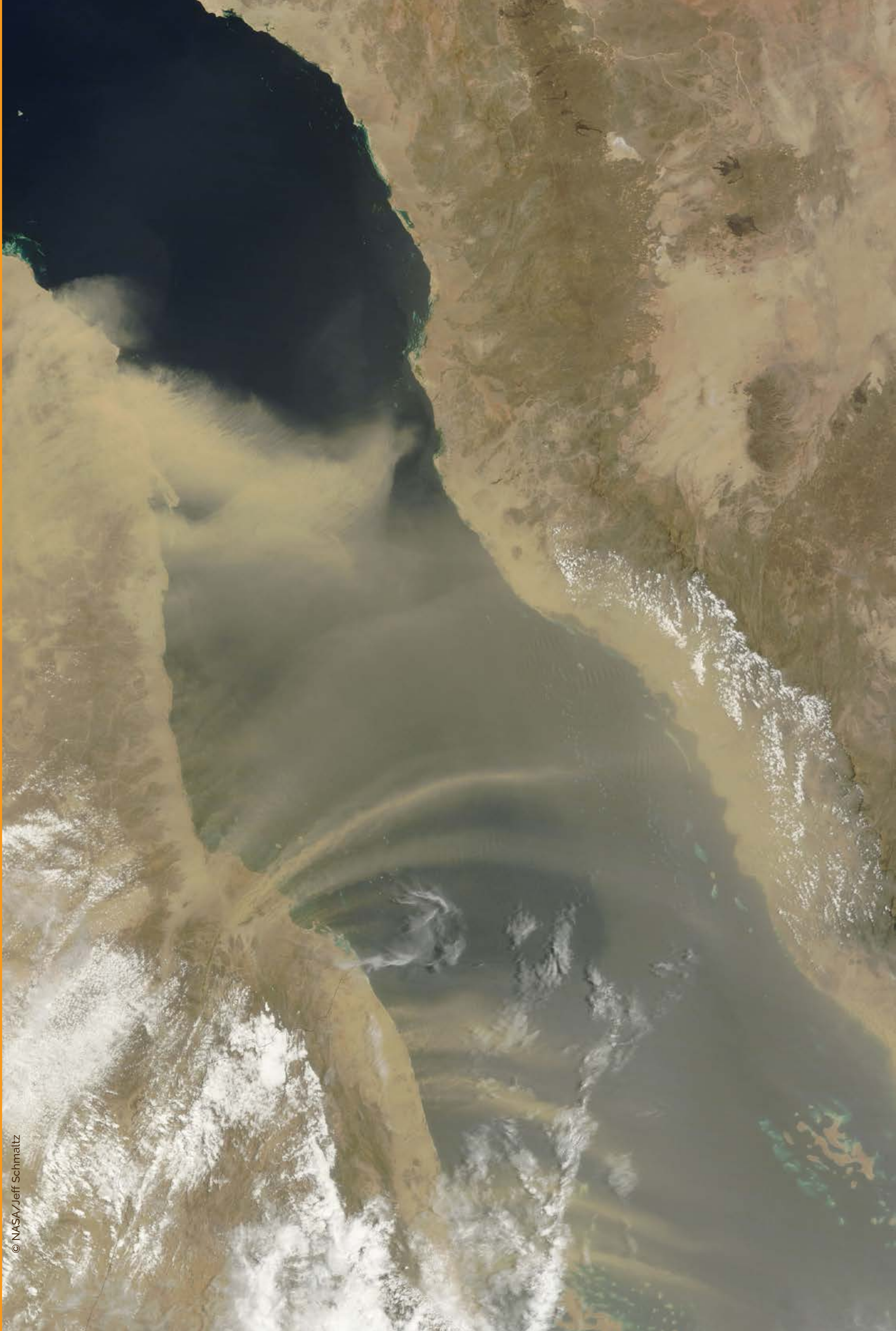


2 Agriculture as a source of sand and dust storms

Key messages

Many major agricultural activities take place in the world's drylands, environments that are naturally most susceptible to SDS. Some 40 percent of global cropland is located in the world's drylands.

If not carefully managed, agricultural practices that can contribute to the development of SDS either disturb soil surfaces and/or change the land cover that otherwise protects soil surfaces.

Farming operations on cropland with the potential to enhance wind erosion include activities associated with land preparation, cultivation and harvest. Abandoned cropland can readily become a source of SDS.

Any farmland or rangeland exposed to drought is more likely to produce greater dust emissions.

The shrinkage of water bodies due to excessive water use for agriculture can create new SDS sources. Such exposed lake beds commonly become hotspots of saline SDS.

In rangeland, trampling by livestock can destroy soil crusts and excessive grazing can deplete vegetation cover. These are impacts that typically increase SDS risk. Excessive use of rangeland is often the result of pastoralists being pushed into smaller and/or more marginal areas of rangeland, particularly by the encroachment of arable farming.

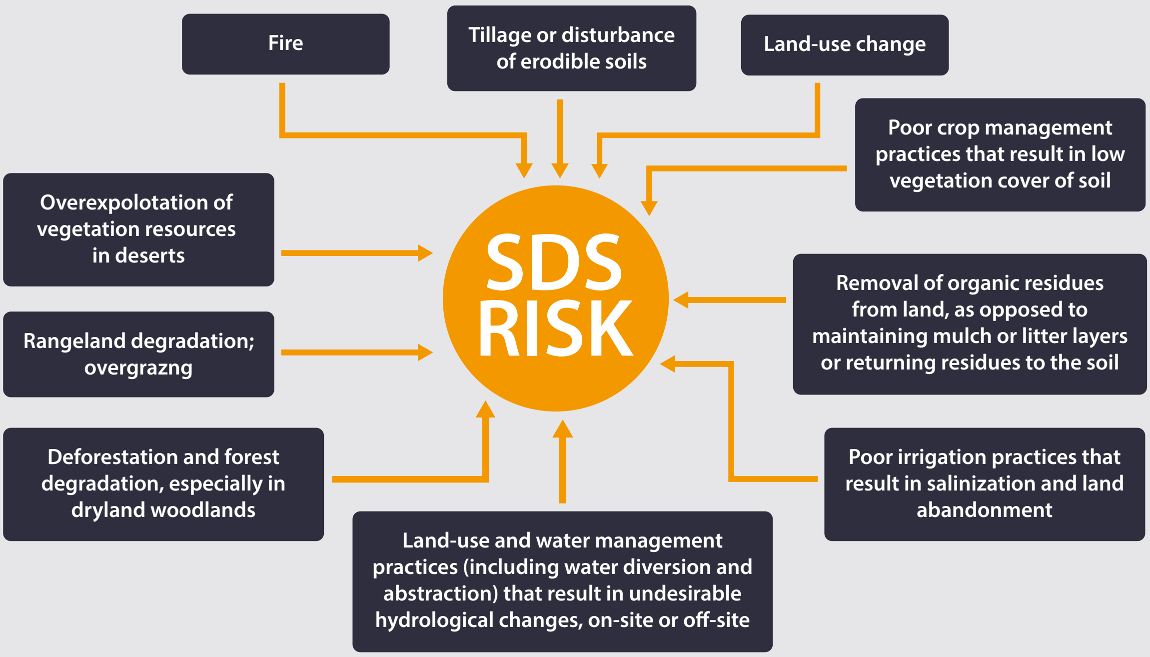
Land-use change can act as a major trigger of SDS occurrence. This occurs particularly when cropland is enlarged at the expense of grasslands without implementation of sustainable land and water management practices, and also when trees, woodland and forests are cleared to make way for cultivation. Burning, a common method of clearing land for agriculture or increasing nutrient availability for livestock, can dramatically enhance wind erosion rates.

Numerous factors affect the susceptibility of agricultural land to wind erosion and the occurrence of SDS. Principal among these are climate parameters (e.g. precipitation, wind), soil properties (e.g. particle size distribution, moisture content), surface characteristics (e.g. roughness caused by clods and ridges, field size), ground cover (e.g. crop type, crop residue) and management operations carried out by farmers or herders.

A variety of agricultural practices on cropland and rangeland can contribute to the development of SDS if not carefully managed (Figure 2.1). The focus of this chapter is on the ways in which these various forms of unsustainable land and water use can become SDS drivers. In brief, these are practices that either disturb soil surfaces and/or change the land cover that otherwise protects soil surfaces. Understanding the details of these practices is necessary to suggest measures to combat SDS, which are explained in the following chapters.

Chapter 1 highlighted the significance of agriculture as a cause of anthropogenic dust emissions. Its global importance can be emphasized further by recognizing the large proportion of major agricultural activities that occur in the world's drylands, environments naturally most susceptible to SDS. Rangelands – primarily natural grasslands, shrublands and savannas – typically occur mostly in semi-arid to arid climate zones and represent one of the planet's dominant ice-free land-cover types (Godde *et al.*, 2018). Some 40 percent of global cropland is located in the world's drylands (Prăvălie *et al.*, 2021).

Figure 2.1 | Land-use and agricultural management practices that increase the risk of wind erosion



Source: Adapted from **United Nations Environment Programme, World Meteorological Organization & United Nations Convention to Combat Desertification.** 2016. *Global assessment of sand and dust storms*. Nairobi, UNEP.

2.1 Farm operations as sources: rainfed cropland

An assessment of active farming operations on cropland in the United States of America (Nordstrom and Hotta, 2004) highlights numerous activities with the potential to enhance wind erosion, including ploughing, levelling beds, planting, weeding, seeding, fertilizing, mowing, cutting, baling, spreading compost, spreading herbicides and burning fields to control weeds and predators. Activities associated with cultivation and harvest accounted for a third of these operations, but only 18 percent of the dust emissions. Land preparation, which involves more contact with the soil, often when its moisture content is low, accounted for two-thirds of all operations but 82 percent of the dust (Clausnitzer and Singer, 1997).

Research indicates the importance of the technology used (Figure 2.2). Comparing the impacts of different ploughing tools (mouldboard, tiller and disc ploughs) on farmland in Tunisia showed that the resulting wind erosion fluxes were significantly higher over fields tilled by disc ploughs than those measured when mouldboard or tiller ploughs were used (Labiadh *et al.*, 2013). Nevertheless, as Colazo and Buschiazzo (2010) demonstrate in their work in a semi-arid area of Argentina, the impact of cultivation on wind erosivity is also determined in part by soil texture.

Figure 2.2 | Soil preparation in strong winds, Horqin Desert, China. The amount of soil lost to wind erosion depends on several factors, including the technology used, soil type and farmer timing

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However, land preparation is not always the farming operation that creates the most wind erosion in all parts of the world. In Free State Province, South Africa, SDS from farmland are most common after commercial, rainfed arable crops have been harvested, which is a time coinciding with the dry season and the strongest winds (Wiggs and Holmes, 2011). Leaving a field fallow in dryland environments can also result in significant soil losses by wind erosion, as demonstrated by research in northeastern Spain (López *et al.*, 1998). In integrated crop–livestock systems, the grazing of crop residues could similarly exacerbate SDS risk if too little crop residue is left to protect the soil surface adequately from wind erosion (Rakkar and Blanco-Canqui, 2018).

The type, cover and arrangement of vegetation exert a great influence on the capacity of the wind to reach the soil surface and move its small particles. Hence, some crops and tillage systems are more susceptible to SDS than others. Crops grown in rows under conventional tillage systems may be particularly affected by wind erosion. Crops, such as maize, which has a slim silhouette area, are especially vulnerable when the distance between rows is great (Funk and Engel, 2015). The orientation of rows relative to the wind direction is also critical: greater erosion occurs as the row orientation tends towards being parallel to the direction of the wind. Topography is another important factor. For example, Marzen, Porten and Ries (2022) show how strong thermal winds can be induced on steep-sloping vineyards, increasing the likelihood of wind erosion events during tillage operations.

Farmland exposed to drought is more likely to produce greater dust emissions, as Eckardt *et al.* (2020) noted during the 2015–2016 drought in Free State Province, South Africa. Indeed, drought conditions may help create SDS sources outside dryland environments. A disastrous example occurred in northern Germany in April 2011 when dust blown from potato fields, recently ploughed during a drought, led to an abrupt loss of visibility on the adjacent autobahn A19 and a multiple pile-up of vehicles. Eighty cars and three trucks were involved in the road traffic disaster, in which 8 people died and 41 others were injured (Deetz *et al.*, 2016).

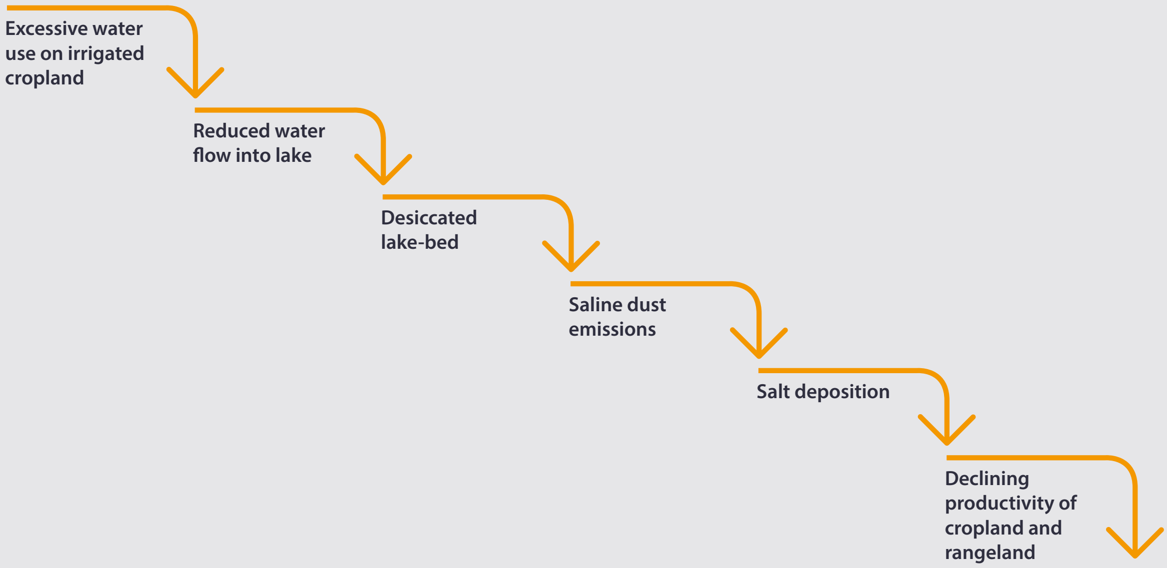
2.2 Unsustainable management of water resources: irrigated cropland

Unsustainable land management is undoubtably an important driver of anthropogenic SDS activity, but poor management of water can also have a similar result. For instance, soil salinization is a frequent outcome of unsustainable irrigation schemes which, in extreme cases, may result in fields being abandoned, to become SDS sources (see Section 2.3). Excessive offtakes of water for irrigated agriculture can also deprive downstream ecosystems of water, which can be transformed into SDS sources. A notorious large-scale example of this sequence of events is the transformation of the Aral Sea into the Aralkum Desert, a desiccated lake bed that has become a significant source of SDS since the late twentieth century (Semenov, 2012).

The demise of the Aral Sea is linked to the intensive development of irrigated agriculture since the 1950s in the then Central Asian republics of the Soviet Union. This resulted in a dramatic decline in the volume of water entering the sea from its two major tributaries: the Syr-Darya and Amu-Darya Rivers. The water level, surface area and volume of the Aral Sea have steadily declined since the 1960s. The average water level fell by more than 15 m over the period 1960–1990. The surface area and volume of the Aral Sea in 1990 were each reduced to about one-third of the 1960 values as salinity increased by a factor of 3 over the same period. In 1989–1990, the declining water levels meant that the Aral Sea was split into two to produce a "Big Aral" in the main lake basin and a "Little Aral" to the north (Breckle *et al.*, 2012). The Big Aral in particular has continued to shrink, and the desiccated former sea bed has become a large source of mineral aerosols (Indoitu *et al.*, 2015; Akramkhanov *et al.*, 2021).

The shrinkage of water bodies, due at least in part to excessive water use for agriculture, has created and/or enlarged SDS sources in other parts of the world, albeit none on as large a scale as the Aralkum. Examples include the perimeter of the Tarim Basin in China (Zhang, Tsunekawa and Tsubo, 2008) and Lake Urmia in the Islamic Republic of Iran (AghaKouchak *et al.*, 2015). The water in these dryland lakes is commonly saline, largely because of high evaporation rates, and when such water bodies shrink, the exposed lake bed becomes a hotspot of saline SDS (Zucca *et al.*, 2021). The salt deposited on surrounding cropland and rangeland can be toxic to plants, resulting in declining productivity (Figure 2.3).

Figure 2.3 | How off-site SDS generated by unsustainable water management can result in declining crop and pasture production



Source: Author's own elaboration

2.3 Abandoned cropland

Evidence from several parts of the world indicates that cropland abandoned after a period of cultivation can readily become a source of SDS. A study using remote sensing in Iraq (Moridnejad, Karimi and Ariya, 2015) showed that 39 percent of all detected SDS sources were in areas that had become newly desertified due to the removal of vegetation and salinization of soils. Analysis of a severe dust storm that struck the Iranian capital of Tehran in June 2014 concluded that abandoned agricultural areas south of the city were responsible for over 50 percent of the airborne dust in the storm (Vukovic Vimic *et al.*, 2021). Another example can be cited from southwestern Islamic Republic of Iran, where Heidarian *et al.* (2018) identified large numbers of rainfed agricultural lands that had been abandoned due to recent droughts and turned into dust production sources. The importance of abandoned cropland was also highlighted in an early study of land use and desert dust hazards in Arizona, United States of America, where Hyers and Marcus (1981) found a significant relationship between road accidents and abandoned fields.

An illustration of the often-complex reasons for land abandonment can be seen in the town of Minqin and its surrounding oasis farmland in northern China, where the study of Zhang *et al.* (2005) highlighted the importance of abandoned farmland as a significant local source of wind erosion after 1980. For many years, farmers had expanded the cultivated area to plant seed-melon, but then stopped cultivating these new fields as seed melon prices declined. Poor irrigation practices and rising soil salinity also contributed to the abandonment of farmland and a generally decreasing vegetation cover within Minqin Oasis (Xue *et al.*, 2015).

New vegetation cover may develop on abandoned farmland, protecting the soil from wind erosion. However, this can take many years, as demonstrated in the Manix Basin, a degraded shrubland in the Mojave Desert, United States of America (Okin, Murray and Schlesinger, 2001). Widespread wind erosion was observed in formerly irrigated fields that had been abandoned due to increasing costs of groundwater pumping. Okin, Murray and Schlesinger highlighted the dramatic differences in vegetation type and cover between abandoned fields and undisturbed desert several decades after abandonment, and suggested that full recovery of vegetation cover could take centuries, if it occurs at all.

2.4 Rangeland

Wind erosion may occur on rangeland due to impacts attributable to grazing livestock. Grazing can play a critical role in regulating grassland plant community composition and structure. In extreme cases, excessive grazing can result in depletion of vegetation cover so soil is exposed to wind action, thus generating SDS. The likelihood of wind erosion occurring can also be increased when trampling by animals causes soil compaction and the destruction of soil crusts, both of which can lower soil stability (Eldridge and Leys, 2003).

The effects of livestock trampling and excessive grazing may also combine to increase areas of bare soil, which can create greater wind flow over the soil surface and consequently higher wind speeds, increasing the chances of SDS events (Zheng *et al.*, 2020). These impacts, as Webb and Pierre (2018) point out, typically occur at the landscape scale. For example, in the western United States of America, Neff *et al.* (2008) suggest that the expansion of livestock grazing in the early twentieth century was largely responsible for a 500 percent increase in dust load levels. However, the effects of livestock can also be highly concentrated and very localized (Figure 2.4), such as around watering points where livestock regularly assemble and degrade piospheres,[2] which are particularly susceptible to dust emission (Dougill *et al.*, 2016). A similar situation can occur around feedlots (de Oro *et al.*, 2021). Off-road vehicle use, to transport livestock, water or

[2] A piosphere is a zone of ecological impact surrounding a watering point in dryland grazing systems.

feed, can also result in localized loss of vegetation cover and surface destabilization, thus creating new dust sources.

Figure 2.4 | Bare areas around watering points (piospheres) increase susceptibility to dust emission, Kenya

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The intensive use of rangeland by pastoralists resulting in overgrazing, loss of vegetation cover and accelerated soil erosion by wind is frequently cited as a cause of desertification in global drylands, although evidence supporting this linkage is not always unequivocal (Middleton, 2018). Soil erodibility responses to grazing are complex and influenced by numerous factors, including land sensitivity, different grazing strategies and local climate characteristics (Aubault *et al.*, 2015). Indeed, vegetation cover change and accelerated erosion by wind can also result from solely climatic drivers – drought in particular – without the influence of any rangeland mismanagement, and the issue of overgrazing is controversial (Rowntree *et al.*, 2004; Reid, Fernández-Giménez and Galvin, 2014). Distinguishing between vegetation cover adversely affected by climate and that altered by poor land management is not a straightforward matter (Miao *et al.*, 2021), and our understanding of grassland wind erosion processes is marred by many uncertainties (Shinoda *et al.*, 2011).

The excessive use of rangeland is often the result of pastoralists being pushed into smaller and/or more marginal areas of rangeland, particularly due to the encroachment of arable farming into pastoral ecosystems. The loss and fragmentation of grazing lands is a particular issue in African drylands (Reid, Thornton and Kruska, 2004; Ayantunde *et al.*, 2008). In many cases, this development has taken place alongside declining support for mobility as a response to environmental variability as government policies have promoted privatization, sedentary settlements and intensification of grazing (Niamir-Fuller and Turner, 1999). The consequent transition from nomadism to sedentary grazing has increased pressure on rangelands in many developing countries.

2.5 Woodland management

Forests and woodland make up an important portion of dryland ecosystems. Forests, other wooded lands and trees outside forests are present on 2 billion ha of drylands, or 32 percent of the total dryland area (FAO, 2019). Trees are generally considered to provide soils with protection against erosion, but open woodland may be susceptible to the risk of SDS. An example occurs in southern Morocco, where large areas of endemic argan woodlands form a landscape characterized by areas of sparsely vegetated and bare soil surfaces between single trees. For centuries, this unique ecosystem has been under extensive agrosilvopastoral management, but it has become progressively more susceptible to wind erosion because of the effects of intensive grazing and increasingly scarce and variable rainfall (Marzen *et al.*, 2020).

2.6 Burning practices

Burning is a common method of clearing land for agricultural use, and is employed seasonally on cultivated fields to fertilize the soil and prepare it for new planting. Prescribed burning is also part of some rangeland management strategies, used to increase nutrient availability for livestock and to control encroachment by woody plant species. However, the use of fire can dramatically enhance wind erosion rates (Shakesby and Doerr, 2006).

Burning vegetation reduces the cover it provides to the soil surface and can result in soil particles becoming water-repellent, which reduces the strength of interparticle wet-bonding forces, making them more susceptible to wind erosion (Ravi *et al.*, 2006). Such fires can also modulate the near-surface wind patterns and hence foster dust emission (Wagner, Schepanski and Klose, 2021). Nevertheless, although controlled burning by farmers and herders is widely practised in many drylands globally (e.g. Figure 2.5), and the linkages to enhanced SDS activity have been established, much more information is needed on many aspects of post-fire wind erosion events and how they are related to agriculture (Weltz *et al.*, 2020).

Figure 2.5 | Burning of fields increase susceptibility to wind erosion, Togo

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2.7 Land-use change

The risk of SDS may also occur due to long-term changes in land use. The history of agricultural expansion into grasslands is punctuated with dramatic examples of how such extensions can result in frequently catastrophic wind erosion. During the 1930s, the Great Plains of the United States of America were the focus of perhaps the most notorious example of large-scale SDS activity anywhere in the world. The drivers of this North American Dust Bowl have been comprehensively studied. Over a 50-year period, drought-resistant grasslands were widely converted to cropland and sown with drought-sensitive wheat using agricultural machinery developed in the more humid conditions of Western Europe (Worster, 1979). Waves of pioneer settlers were spurred on by high wheat prices and encouragement from the central government, such as the 1909 proclamation from the US Bureau of Soils that "The soil is the one indestructible, immutable asset that the nation possesses. It is the one resource that cannot be exhausted; that cannot be used up." (Hopkins, 1912, p. 621).

The occurrence of an unusually severe drought over the Great Plains during the 1930s exposed the unsustainable nature of this extension of cultivation, resulting in exceptionally large-scale SDS activity. By 1937, the US Soil Conservation Service estimated that 43 percent of a 6.5 million ha area in the heart of the Dust Bowl had been seriously damaged by wind erosion (Worster, 1979). The impact of the Dust Bowl, which also led to a mass outmigration of financially ruined farmers from the Great Plains, was further compounded by the severe economic problems that affected North America during the 1930s (Lee and Gill, 2015).

Comparable widespread and severe wind erosion of soils in other parts of the world resulted from similar encroachment of cultivation into grasslands: in the Argentine Pampas during the 1930s and 1940s (Viglizzo and Frank, 2006); after the 1950s Virgin Lands Scheme in the former Soviet Union (Indoitu, Orlovsky and Orlovsky, 2012); and in the Syrian steppe (Lahmar and Ruellan, 2007) and the Algerian steppe (Houyou *et al.*, 2016) in the latter half of the twentieth century. Certain elements have been common to all these examples: the use of unsuitable tillage technology in grasslands that were marginal for cultivation, in combination with dry and windy conditions, resulting in severe dust storms, and often followed by crop failure, farmer bankruptcy and rural outmigration.

The expansion of farming at the expense of trees, woodland and forest is another widely cited form of land-use and land-cover change. It has been reported from drylands in many parts of the world in recent times, including the Gran Chaco region in northern Argentina (Gasparri and Grau, 2009), the Mato Grosso forests in Brazil (Redo, Aide and Clark, 2013), northern Nigeria (Brandt *et al.*, 2016) and the central Rift Valley of Ethiopia (Garedew *et al.*, 2009).

Loss of natural woody vegetation cover frequently leads to an increase in soil erosion, although there are few case studies that link the removal or degradation of dryland forests directly to enhanced SDS activity. An exception is found in southwestern Australia, which has a lengthy history of forest clearance for dryland farming that has resulted in extensive land degradation problems, particularly from salinity and wind erosion. The widespread removal of deep-rooted natural vegetation and its replacement with shallow-rooted annual plants for farming have caused rising groundwater levels that mobilize natural salts previously stored deep in soils. These salts become concentrated by evapotranspiration in the root zone of vegetation, a problem known as "saline seep." Wind erosion is a recurrent feature of these salinized landscapes (Harper, Sochacki and McGrath, 2017).

2.8 Agricultural practices that exacerbate risk

Wind erosion rates and the risk of SDS can become accelerated above natural levels by cultivation and grazing practices that diminish vegetation cover and reduce soil surface stability, especially when they coincide with windy times of the year. Land-use change can also act as a major trigger of SDS occurrence, particularly when cropland is enlarged at the expense of grassland without the implementation of sustainable management practices, but also when trees, woodland and forests are cleared to make way for cultivation. The excessive use of water for agriculture can also have serious off-site impacts, depriving downstream ecosystems of water. The exposed beds of shrinking water bodies can readily become SDS sources.

The degree of greater SDS risk is dependent on local soil, vegetation and climate variability. However, all elements of human mismanagement are enhanced and exacerbated by drought conditions. Understanding the ways in which agricultural manipulation of soil, water and vegetation can lead to SDS has generated a wide range of SLM practices that can reduce wind erosion from land affected by agriculture. In brief, these measures seek to preserve or restore critical cover levels (of vegetation or water), preserve soil roughness and stability, and/or reduce wind erosivity by establishing ridges or windbreaks. Details of relevant SLM measures are the subject of Chapter 4. Chapter 3 next focuses on the numerous ways in which SDS affect agricultural production, including efforts made to quantify these impacts in economic terms.

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3 Impacts of sand and dust storms on agricultural production

Key messages

Sand and dust storms have many adverse effects on the yields and productivity of crops, trees, pastures and livestock. Many of these impacts have not yet been well quantified, but they have direct and indirect, on-site and off-site, and long-term and short-term effects.

Extreme SDS events are recognized as severe natural hazard-induced disasters. The cumulative effects of numerous short wind erosion events with moderate wind velocities can result in the loss of sizeable amounts of nutrients and fertilizer and can damage crop tissues by sandblasting. In addition, seedlings may be buried by sediments.

Poor air quality associated with SDS is hazardous to honeybees. Effects include a reduction in pollen and nectar, disruption of mating by the queen and a decline in honey production.

Soils that are lifted into the atmosphere during SDS events contain many micro-organisms such as bacteria, fungi and viruses. Some are pathogenic and can be transported considerable distances in a viable state. Plant and animal diseases have been dispersed in this way, some between continents.

Atmospheric dust emitted over large areas during periods of drought may create a land–atmosphere feedback that prolongs drought conditions.

However, soils in areas where the dust is deposited may benefit, and some plants have specially adapted to use nutrients in desert dust by direct foliar uptake.

A severe two-day cold wave SDS event in Mongolia in March 2021 resulted in 87 percent of herder households in one Gobi Desert district reporting deaths among their herds. Over 33 750 animals perished in the district, 16 percent of all livestock, which were valued at USD 1.2 million. The total value of livestock lost in the Mongolian SDS of March 2021 was estimated to be USD 69.3 million.

Econometric analysis in Iraq demonstrates a statistically significant negative impact of SDS on crop yields for cereals, dates and other fruits and vegetables. Losses due to an additional SDS day range from 0.7 percent to 2.8 percent, with the greatest impacts on vegetables and dates. Declines of cotton yields in Central Asia have been reported at 5–15 percent.

FAO has developed a damage and loss assessment methodology to monitor disaster impacts on agriculture. The tool is used as part of the Sendai Framework Monitor (SFM) to report on Indicator C-2 ("Direct agricultural loss attributed to disasters") and the corresponding SDG Indicator 1.5.2 ("Direct economic loss attributed to disasters in relation to global gross domestic product [GDP]"). The tool is also used to monitor SDS impacts on agriculture.

FAO proposes that an SDS event should be considered as disastrous when it has a visibility of 1000 m or less, following the widely agreed definition.

Efforts are growing to support SDS-affected countries in promoting sustainable land and water management, land-use planning, agroforestry, shelterbelts, afforestation/reforestation programmes, and the forest and landscape restoration mechanism, which all contribute to SDS source and impact mitigation in agriculture.

Sand and dust storms have numerous effects on agriculture, on the yields and productivity of crops, trees and livestock. These effects occur during all three phases of the wind erosion system: soil particle entrainment, transport and deposition. The impacts can be direct and indirect, with immediate short-term effects and chronic long-term consequences. Some of these consequences can be positive for farmers and herders, but many are negative and undermine the sustainability of agriculture, reducing its capacity to meet the needs of present and future generations.

3.1 Wind erosion

An SDS can cause a large-scale redistribution of topsoil, be it from a field or an area of rangeland. A wide range of impacts can ensue, on and off site, when this type of accelerated soil erosion occurs (Table 3.1). In a field, the moving soil particles often result in direct loss of plant tissue by sandblasting. This can cause serious damage to crops by abrasion, a problem that is particularly acute for young shoots at early stages of crop growth. Leaves are more sensitive to sandblasting damage than stems. Leaf loss results in reduced photosynthetic activity and therefore less energy (sugars) for the plant to use for growth, reproduction and development of grain, fibre or fruit. The overall result is usually lower yields (Stefanski and Sivakumar, 2009).

The intensity and nature of sandblasting impacts vary depending on when during the crop cycle they occur. Plant damage later in the season reduces yield during grain development. If the sandblasting takes place at maturity, but before harvest, it results directly in harvest loss. In areas with short growing seasons, the loss of energy for plant growth, which delays plant development, may increase the risk of end-of-season drought. This can occur when the delay in development moves the plant's moisture-sensitive period (reproduction to grain filling) past the time of favourable rains, again resulting in lower yields and production. Sandblasting can also damage farm machinery and infrastructure, and scouring by wind can undermine fence posts.

Table 3.1 | Some implications of SDS generated on agricultural fields

Location	Physical effects	Economic impacts
On site		
Crops	Sandblasting damage to crop tissue	Replacement costs
	Burial of crops	Replacement costs
	Seeds removed	Replacement costs
	Infection of crops by pathogens	Replacement costs
Soil	Fine soil particles and organic material removed, degrading soil structure	Decline in soil fertility and crop production, and costs of additional labour for tillage
	Nutrients removed	Replacement costs (e.g. agrochemicals)
	Fertilizers and pesticides removed	Replacement costs (e.g. agrochemicals)
Equipment	Sandblasting damage to farm machinery	Repair and maintenance costs
	Postponement of operations	Possible loss of production
Off site		
Adjacent	Sedimentation at field borders, in drainage ditches and on roads	Costs of labour for cleaning
	Dust in farm machinery	Repair and maintenance costs
At distance	Infection of crops and livestock by pathogens	Possible loss of production, and replacement costs

Source: Adapted from **Riksen, M.J.P.M. & De Graaff, J.** 2001. On-site and off-site effects of wind erosion on European light soils. *Land Degradation & Development*, 12(1): 1–11.

Some soil particles mobilized by wind are deposited on the same field or on fields nearby. Occasionally, this material can bury a growing crop, particularly in its early stages of development when the plants are small. In extreme cases, this results in plant deaths. In Sahelian Africa, where pearl millet is traditionally planted in small depressions, the depressions fill with sediment during storms. This frequently buries seedlings, sometimes requiring partial or complete resowing of the crop (Michels, Sivakumar and Allison, 1993).

In rangeland, pasture may also be covered by sand. In addition, thick dust clouds represent a hazard to livestock, which can be lost when visibility is reduced. A study conducted among pastoralists in southwestern Islamic Republic of Iran found that herders considered the greatest impact of dust to be on the palatability of forage: livestock avoided grazing the dusty plants (Zeidali, Barani and Hosseinaldi Zadeh, 2015).

Strong winds associated with SDS can damage livestock shelters and unsheltered animals become stressed, resulting in reduced productivity and growth. In extreme cases, livestock may perish due to burial and/or suffocation. The severe SDS in Mongolia in March 2021 killed nearly 34 000 livestock – most of them sheep and goats – in one of the hardest-hit districts, Saintsagaan in Dundgobi Province (see Section 3.4). Wind chill in the sub-zero temperatures added to the stress, and some animals froze to death (Enkh-Amgalan, 2023).

The poor air quality associated with SDS also poses hazards to honeybees. Monitoring a domesticated honeybee colony in Beijing before, during and after a dust event showed that the duration of foraging trips increased during the storm and for some time afterwards (Cho *et al.*, 2021). The finding was attributed to the high levels of particulate matter in the atmosphere altering the degree of polarization of sunlight, which is used by honeybees for navigation during their foraging trips. This reduction in foraging performance may explain some other SDS impacts on honeybees documented by Maleki *et al.* (2017) in the Islamic Republic of Iran. These effects include a reduction in pollen and nectar, disruption of mating by the queen and a decline in honey production.

In addition to these immediate impacts of SDS, longer-term effects are also apparent because of the loss of soil (Figure 3.1). The finest soil particles, which are easiest to move, are also some of the most important soil constituents: clay, silt and organic matter. Because the ratio of sand, silt and clay particles is of primary importance to a soil's stability, the preferential removal of fine particles is detrimental to soil structure (Chepil and Woodruff, 1963). These particles also have an important influence on the capacity of soil to retain water, so their removal reduces soil moisture storage. In addition, nutrients tend to be attached to the smallest and lightest particles, so the loss of fine particles reduces fertility.

A study of wind erosion in the Mallee region of Australia found that the soil dust blown from a cultivated paddock had 16 times more total nitrogen and 11 times more organic carbon than the soil it was derived from (Leys and McTainsh, 1994). Experimental work on semi-arid loess soils in the northern Negev, Israel, showed that even in a single five-minute wind erosion event of moderate velocity (7.0 m/s), the phosphorus flux in conventional agricultural fields can reach 1.83 kg/km^2, accumulating to produce an annual net loss of phosphorus up to hundreds of kilograms per square kilometre from soils used for field crops and for grazing (Katra *et al.*, 2016).

A notable finding of this research is the importance of short erosion events caused by comparatively low wind velocities. Such events, classified as blowing dust[3] as opposed to a storm (see Table 1.1), often remain mostly unnoticed compared to the more extreme SDS events that are rightly recognized as severe disasters. An erosive wind also carries away seeds, fertilizers and beneficial microorganisms.

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3 Such events may also include dust devils (Broersen, 2013).

Figure 3.1 | Plumes of soil particles blown from farmland in Baja California, Mexico. Dust lost from a field adversely affects a soil's stability, structure, nutrient availability and ability to hold moisture

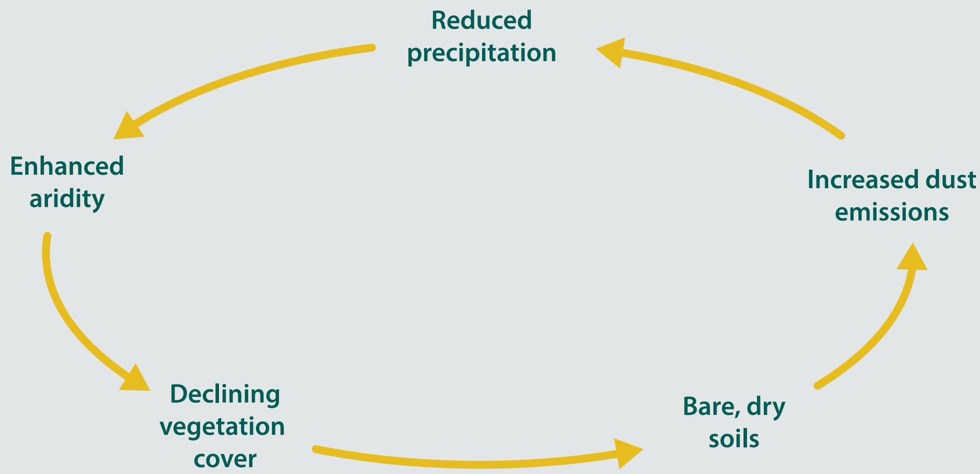
© NASA Earth Observatory

Overall, the loss of topsoil due to wind erosion commonly results in a measurable decline in field crop yields and loss of pasture quality in rangelands (Larney *et al.*, 1998). The decline in pasture quality may come about because of an altered plant community composition, such as an accelerated expansion of shrubs (Alvarez *et al.*, 2012), or an increasing dominance of plant species with high nutrient-use efficiency (Funk and Vitousek, 2007).

The effects of wind erosion are seldom felt in isolation. In a seven-year field manipulative experiment in a temperate steppe on the Mongolian Plateau, China, Zheng *et al.* (2021) examined the impacts of grazing and simulated aeolian processes (wind erosion and dust deposition) on plant community cover and species richness. They concluded that wind erosion and dust deposition had additive effects with grazing on vegetation cover and species richness. While grazing decreased plant community cover but increased species richness, wind erosion reduced plant community cover but did not affect species richness. In contrast, dust deposition enhanced plant community cover but decreased species richness.

The emission of large quantities of atmospheric dust over large areas during periods of drought may also create a land–atmosphere feedback that prolongs drought conditions. A decrease in vegetation cover during drought in marginal dryland areas, such as the Sahel, can result in enhanced dust emissions. More dust in the atmosphere may contribute to the persistence of drought by suppressing precipitation via effects on cloud microphysics and radiative transfer (Yu *et al.*, 2015). This suppression of precipitation further reduces vegetation cover (Figure 3.2). The effect may be intensified still further by related feedback caused by an increase in the albedo of the ground surface because it has lost vegetation. The increased surface albedo would result in a net loss of incoming radiation and an increase in radiative cooling of the air. In consequence, the air tends to sink, suppressing the likelihood of rainfall. A combination of these two feedbacks related to human-induced land degradation is likely to have suppressed precipitation and amplified the Dust Bowl drought in the US Great Plains in the 1930s (Cook, Miller and Seager, 2009).

Figure 3.2 | Positive feedback between SDS and drought



Source: Author's own elaboration

In addition to these geophysical effects related to SDS, the health hazards associated with atmospheric particulate matter may be particularly acute for those working in agriculture because of frequent exposure to SDS and blowing dust events. There is a general lack of research into the long-term health effects of SDS. However, dust suspended in the atmosphere has been associated with conjunctivitis and dermatological disorders, while inhalation may be a significant risk factor for cardiovascular and respiratory diseases, including asthma and chronic obstructive pulmonary disease (Tobias *et al.*, 2019). Silicosis (also known as desert lung syndrome) is a lung disease caused by the inhalation of silica, which is primarily composed of quartz dust, one of the most common components of SDS. In a review of agricultural dusts, Schenker (2000) concluded that it was plausible that exposure to inorganic components of soil dust in dryland farming areas is causally associated with chronic bronchitis, interstitial fibrosis and chronic obstructive pulmonary disease. Soil-borne pathogens can also cause disease when inhaled during an SDS event. An example is *Coccidioidomycosis* (sometimes called Valley fever), which is an infection caused by inhaling soil-dwelling fungi unique to the Americas (Hector and Laniado-Laborin, 2005).

3.2 Sand and dust deposition

Soil particles eroded from one place may affect vegetation directly, following deposition on plants, or indirectly, by changing soil composition and chemistry. Although the loss of topsoil negatively affects soil productivity on the land it was removed from, this topsoil can benefit areas where the dust is deposited. An indication of these benefits can be derived from soils in some regions that have developed with important inputs of dust from natural sources elsewhere. Saharan dust has provided such inputs to soils in West Africa (Vine, 1987), the Canary Islands (Menéndez *et al.*, 2007), southern Europe (Muhs *et al.*, 2010) and parts of the Caribbean (Muhs *et al.*, 1990). Similarly, inputs from desert dust have been discovered to make important contributions to the nutrient budgets of forest ecosystems in West Africa (Stoorvogel, Van Breemen and Jassen, 1997) and the Amazon Basin (Swap *et al.*, 1992).

Agricultural areas also receive deposits of mineral dust from natural SDS sources. These can have positive and negative impacts, depending on the dust's pH, trace metal content, nutrient content, surfactant properties or salinity (Grantz, Garner and Johnson, 2003). The nutrient inputs to soils and ecosystems mentioned above can also benefit agriculturalists. An example can be cited from the Loess Plateau in China, which is intensively used by farmers. Its soils are largely made up of desert dust from more northerly deserts laid down over many thousands of years (Sun *et al.*, 2008).

There is some evidence to indicate that certain crops can use nutrients in desert dust by direct foliar uptake. Experimental work by Gross *et al.* (2021) led them to conclude that plants that have evolved in dust-rich ecosystems, such as chickpea (*Cicer arietinum*) and wheat (*Triticum aestivum* cv Gedara), have adopted specialized strategies to utilize phosphorus delivered to their leaves with desert dust.

However, at higher levels of deposition, dust particles may block leaf stomata, adversely affecting rates of respiration, transpiration and photosynthesis. Stomata for a range of crops are typically 8–12 µm in diametre. Small dust particles may impair their function and act as a desiccant, reducing the drought tolerance of the plants (Burkhardt, 2010). Field experiments conducted in the Islamic Republic of Iran (Hatami *et al.*, 2017, 2018) have demonstrated the detrimental impacts of high rates of dust deposition on yields of wheat (*Triticum aestivum* L.) and cowpea (*Vigna unguiculata* L.). Similar findings were reported for grape (*Vitis vinifera*) yields by Behrouzi *et al.* (2019) and date palms (*Phoenix dactylifera* L.) by Torahi, Arzani and Moallemi (2021). Experiments involving high dust concentrations showed that a layer of dust on seedlings of wild barley (*Hordeum spontaneum*) and field mustard (*Sinapis arvensis*) can also exert a detrimental influence on the performance of certain commonly used herbicides (Asadi-Sabzi *et al.*, 2020).

As with other dust impacts, the timing of deposition can also be important. An experiment on cotton (*Gossypium hirsutum* L., Xinluzhong-21) in northwestern China found that the growth of cotton plants and their yield were adversely affected by dust deposits over a short interval of time during the flowering period (Zia-Khan *et al.*, 2015). It was concluded that the accumulation of dust on leaf surfaces induced conditions similar to those of water stress, such as a reduction of stomata conductance, photosynthesis and transpiration, and increased leaf temperature (Figure 3.3). Orlovsky and Orlovsky (2001) report losses of cotton yields at 5–15 percent close to the Aralkum Desert.

Figure 3.3 | Harvesting cotton in Kyrgyzstan. Dust deposited on cotton plants can adversely affect their growth and yield

The chemistry of the dust deposited is also relevant. Material blown from dry lake beds in drylands is often rich in salts, which can be toxic to plants and soils if concentrations are high. In northwestern China, the desiccation of Lake Ebinur – caused by increased water consumption for domestic, industrial and agricultural purposes – has revealed a dry lake bed larger than 500 km2 that has become a source of highly saline dust. Aeolian inputs from this lake bed are the main cause of increasingly saline soils downwind (Abuduwaili, Gabchenko and Junrong, 2008), adversely affecting oasis economies on the northern slopes of the Tian Shan mountains (Ge *et al.*, 2016).

Soils contain many microorganisms that can be lifted into the atmosphere during SDS. While most of them are probably transported only short distances, others may be transported further before being deposited. Bacteria, fungi and viruses have all been found in mineral dust, and some have proved to be pathogenic. A growing number of investigators have demonstrated that pathogens in SDS are transported considerable distances in a viable state (e.g. Maki *et al.*, 2019). In a review of pathogenic microorganisms in SDS and their relevance to agriculture, Gonzalez-Martin *et al.* (2014) highlight a number of plant and animal diseases that are likely to have been dispersed in this way, some between continents (Table 3.2).

Table 3.2 | Examples of microorganisms found in dust samples and related diseases

Origin of dust	Dust sampled	Pathogens isolated	Related disease	Reference
Sahara Desert	Crete, Greece	Sphingomonas spp.	Brown spots (e.g. in melons)	Polymenakou *et al.* (2008)
	Bamako, Mali	Aspergillus niger Aspergillus versicolor	Black mould in onions, aspergillosis (e.g. in ruminants, bees and poultry)	Kellogg *et al.* (2004)
		Alternaria spp.	Early blight, leaf spots (e.g. in beans, tomatoes and peas)	Kellogg *et al.* (2004)
		Staphylococcus gallinarum	Bumblefoot disease in poultry	Kellogg e*et al.* (2004)
	Northern Caribbean	Cladosporium spp.	Scab (e.g. in pecan, peach and cucumber) Inhibition of growth (e.g. in wheat and lettuce)	Griffin *et al.* (2003)
		Microsporium spp.	Dermatophytoses (e.g. in cattle and horses)	Griffin *et al.* (2003)
Australian Desert	Canberra and Melbourne, Australia	Bacillus spp.	Mastitis, and anthrax in mammals	Lim *et al.* (2011)
		Pseudomonas spp.	Skin and mucosal infections (e.g. in sheep), bacterial canker in cereal	Lim *et al.* (2011)
Asian deserts	Oregon, United States of America	Alternaria infectoria	Leaf black spot (e.g. in wheat)	Smith *et al.* (2012)
		Chaetomium globosum	Necrosis in roots (e.g. in barley)	Smith *et al.* (2012)
Arabian Desert	Riyadh, Saudi Arabia	Pythium spp.	Root rot (e.g. in rice)	Kwaasi *et al.* (1998)

Source: Adapted from **Gonzalez-Martin, C., Teigell-Perez, N., Valladares, B. & Griffin, D.W.** 2014. The global dispersion of pathogenic microorganisms by dust storms and its relevance to agriculture. *Advances in Agronomy*, 127: 1–41.

In addition to the impacts on plants, animals and soils documented in this section, deposition from SDS may result in other negative impacts on agriculture. Small particles easily become lodged in farm machinery, resulting in additional repair and maintenance costs. Sedimentation can cause damage or temporary malfunction of infrastructure. Examples include irrigation canals becoming filled with sediment and transport routes being covered in sand. Water quality may also be adversely affected by SDS deposits. The resulting disruption to the availability of goods and services increases the costs of agricultural production.

3.3 Land degradation

The relationship between SDS and land degradation is complex, multifaceted and synergistic. Sand and dust storm events that occur on productive agricultural land reduce soil productivity (see Section 3.1), and the deposition of material by SDS may result in land degradation through the negative impacts outlined in Section 3.2.

There are direct linkages between SDS and the three global interactive indicators used to monitor LDN (soil organic carbon, land productivity and land cover). In turn, these indicators are directly linked to food production and the sustainable management of agricultural resources. The risk of SDS occurring is enhanced in areas where vegetative land cover is lost. Sand and dust storm events almost invariably result in a decline in productivity in the source area; and soil erosion by wind rapidly reduces soil organic carbon stocks (Chappell *et al.*, 2019). These linkages also create positive feedbacks: SDS causes land degradation, which in turn results in further SDS and land degradation causing SDS, which in turn results in further land degradation. For these reasons, policies and programmes designed to mitigate SDS sources will also have the effect of avoiding, reducing and/or reversing land degradation, thus delivering multiple environmental, economic and social benefits.

3.4 Economic assessments of impacts on agriculture

There have been some attempts to estimate the on-site costs of soil erosion by wind on farmers' fields in economic terms. In Europe, a research project (Wind Erosion on European Light Soils, or WEELS) assessed the effects of cultivating a range of crop types (Riksen and De Graaff, 2001). The damage evaluated consisted mainly of crop losses and additional inputs in the case of resowing. The average annual on-site costs in high-risk areas amounted to about EUR 60 (USD 55) per hectare, but for sugar beet and oilseed rape, the costs could reach as high as EUR 500 (USD 450) per hectare once in five years.

A different approach was taken by Santra *et al.* (2017) in western Rajasthan, India, who calculated costs in terms of reduced soil fertility. They concluded that the losses were highest for groundnut (*Arachis hypogea*) and clusterbean (*Cyamopsis tetragonoloba*). Depending on the severity of wind erosion, economic losses for groundnut reached up to Rs 12241 per hectare (USD 184 ha-1) and for clusterbean up to Rs 12465 (USD 187) per hectare. It was pointed out that the economic loss due to wind erosion depends on the magnitude of yield loss and also on the minimum support price of the crop concerned. Groundnuts suffered the highest yield loss due to wind erosion and also had a high support price. The study went on to assess the average annual economic loss from agricultural fields in western Rajasthan. Taking a five year average acreage for six major crops and the average economic loss per hectare for each crop, the total economic loss per year was estimated to be INR 25.6 billion (USD 384 million).

That estimate compares to a much earlier assessment made for all crop types grown in New Mexico, United States of America, which took into account on-site crop and soil damage. The study, conducted in the 1980s, put the economic cost of wind erosion at USD 10 million per year on average (Davis and Condra, 1989). However, that figure is dwarfed by an estimate of the average annual off-site costs of wind erosion in New Mexico, including health and property damage, which Huszar and Piper (1986) put at USD 466 million. Assuming similar costs in western parts of the country, Pimental *et al.* (1995) suggested that the total off-site costs from wind erosion could be as great as USD 9.6 billion each year in the United States of America as a whole.

Other authors have used an econometric approach to assess SDS impacts on agriculture. A study in Iraq demonstrated a negative impact on crop yields for all crops assessed, with cereals, dates and other fruits and vegetables showing a statistically significant reduction in yields (Box 3.1). These findings are consistent with those of others who have used similar methods. In the Islamic Republic of Iran, Birjandi-Feriz and Yousefi (2017) calculated that one additional day with dust storms in a year decreases the yield by about 10 percent for industrial crops (including cotton, tobacco, soy, sunflower seed and sugarcane) and by 5 percent for vegetables. As part of a wider study on the effects of SDS on economic development in West Africa, Foreman (2020) found that yields of the most commonly grown crops (cassava, cowpeas, groundnuts, maize, millet and sorghum) decline by an average of 2 percent for a 1 standard deviation increase in dust in the year of exposure.

Box 3.1 | Impacts of SDS on agriculture in Iraq

The International Center for Biosaline Agriculture assessed the potential effects of SDS on agricultural subsectors in Iraq in a study using econometric modelling techniques. Combining data from terrestrial meteorological stations with household-level production and socioeconomic data taken from the World Bank's Living Standard Measurement Survey, a multiple regression analysis was used to test the multivariate association between SDS, other meteorological factors and agricultural production. The model estimates the statistical correlations between SDS and agricultural outcome variables conditional upon other relevant covariates, such as meteorological factors, that are likely to affect agriculture output. The mathematical model is specified by the following equation:

$$Y_{is} = \alpha + \beta SDS_{is} + g\ C_{is} + L_d + e_{is}$$

Where Y_{is} represents the outcome variable (e.g. value of crop or livestock production, physical yield or vegetation index such as the normalized difference vegetation index (NDVI) and land use): is a constant: represents the variable of interest, which is the number of SDS_{is} events (measured in days) for household i in state or governorate s, and β is the coefficient of interest to be estimated. This coefficient is expected to be negative: as discussed by Stefanski and Sivakumar (2009). The vector of control variables $g\ C_{is}$ represents meteorological factors, including temperature and precipitation, as well as household socioeconomic variables including the household size and agricultural holding. Location or spatially-fixed effects denoted by L_d are taken into account by including district dummy variables in the equation. Parameter e_{is} is an idiosyncrasy error term.

The results represent compelling evidence that exposure to SDS substantially reduces crop yields and has a significant bearing on agricultural productivity and household welfare. The impacts of SDS on crop yields were found to be negative for all crops assessed, with cereals, dates and other fruits and vegetables showing a statistically significant reduction in yields.

The losses due to an additional SDS day ranged from 0.7 percent to 2.8 percent, with the greatest impacts on vegetables and dates. The analysis also established a reduction in the value of crop production by 1.1 percent because of the additional SDS day, holding all other variables constant. This corresponds to a loss of about 0.045 percent in the GDP of Iraq, an amount equivalent to about USD 0.1 billion. These results are robust to the potential endogeneity in the SDS measure, having been cross-checked using a variant of the model involving only non-local SDS events.

The effects of SDS on household economic welfare were assessed by considering potential impacts on household consumption (using the Living Standard Measurement Survey poverty line as a proxy) and a consumer price index. Increased SDS days correspond to a higher poverty line, implying that SDS result in an increase in total per capita consumption expenditures for food and basic non-food items. This could be explained by the findings that SDS negatively affect agricultural yields and productivity, leading to higher spending on food items, especially for households that rely directly on agriculture for food security.

This study also found a small but statistically significant impact on vegetation cover, with one additional SDS day leading to a decline in NDVI of 0.1 percent. In addition, a negative correlation between SDS and the value of livestock production was established, although this relationship was not statistically significant.

Source: **Ahmadzai, H.** 2021. *The impact of sand and dust storms on agriculture in Iraq.* Unpublished report commissioned from the International Center for Biosaline Agriculture by FAO, Rome.

At the farm level, Gholizadeh *et al.* (2021) used the Ricardian approach, which borrows from econometrics and agricultural climate change studies, to examine the impact of SDS on the income of barley farmers in southwestern Islamic Republic of Iran. Their results indicated a significant negative effect on farmers' net revenues whereby a one-hour increase in SDS occurrence reduces barley farmers' income by USD 0.36 per hectare for irrigated barley and USD 0.08 per hectare for rainfed barley. However, although the dollar effect is smaller for rainfed than for irrigated barley, the relative (percentage) effects are larger because the average net returns of the former are much smaller than the latter. The impact on small-scale farmers, whose livelihood depends on the income from a few acres of land, is proportionally greater than that experienced by those farming irrigated fields that are typically larger in total acreage.

While there are few studies on the economic impacts of SDS on crops, there have been even fewer attempts to assess the impacts on herding. Nevertheless, a field survey conducted shortly after a major SDS that affected large parts of Mongolia in March 2021 found that the economic cost of livestock lost by just over half the herder households in one badly affected rural district totalled USD 1.2 million, equivalent to 13 percent of the total value of livestock owned by an average herder household in Saintsagaan (Box 3.2).

The impact of the March 2021 event was of a comparative magnitude to a severe SDS that occurred on 26 and 27 May 2008 in eastern Mongolia. The long-term effects of that storm were studied by Mu *et al.* (2013), who assessed the effects of livestock deaths on the health-related quality of life of herders. By comparing herders who had suffered livestock losses to others who had not, Mu *et al.* found a significant association between livestock loss and health-related quality of life.

Box 3.2 | Impacts of SDS on herders in Mongolia

A major SDS that lasted for two days in mid-March 2021 affected an estimated 8000 people in 2000 households across 14 of Mongolia's 21 provinces (*aimags*). Ten people lost their lives and 1.6 million livestock were reported missing (IFRC, 2021). Wind speeds up to 40 m/s were recorded. The event was officially classed as "catastrophic" by the Mongolian Government,[a] with visibility reduced to less than 5 m in some places.

A survey of herder households[b] in the rural district (or soum) of Saintsagaan in Dundgobi *aimag* was conducted in May, Two months after the storm. It found that 87 percent of households had suffered deaths among their herds and 90 percent reported that pastures had either been scoured by sand and blown away or buried beneath sand deposited in the storm. In total, over 33 783 animals in Saintsagaan perished in the storm, 16 percent of all livestock. Mortality rates were greatest for goats (17 percent), sheep (15 percent) and cattle (12 percent). The loss of livestock was valued at MNT 3537.7 million (USD 1.2 million) using local market prices. This loss accounted for 13 percent of the total value of livestock owned by an average herder household in Saintsagaan, a considerable impact from a two-day SDS event. Nationwide, the value of livestock lost in the SDS of March 2021 was estimated to be USD 69.3 million.

The impacts on pastures were also serious and with long-lasting consequences because of the considerable time required for pastures to recover. However, the economic impact was impossible to quantify. Some herder households also suffered additional economic losses, also not quantifiable. Five percent of households had their homes (traditional felt tents known as *gers*) damaged in the storm. Others reported damage to their livestock shelters and assets blown away in the strong wind.

The great severity of the SDS in March 2021 can be gauged by comparing the economic impact of livestock lost in Saintsagaan (USD 1.2 million) and the country as a whole (USD 69.3 million) to economic losses due to SDS over the 15-year period (2005–2019) in Mongolia. The damage value estimated by the National Emergency Management Authority in Mongolia over the 15 years was MNT 19 962.3 million or USD 7 million, a figure that includes the local market price of animals lost and also of *gers* damaged.

Notes: [a] According to Mongolian Government Resolution No. 286 of 2015, a storm is considered a "disaster" if the wind speed reaches 18 m/s, and "catastrophic" if the wind speed exceeds 24 m/s. [b] Some 503 herder households or 57 percent of the total number in Saintsagaan were affected.

Source: Adapted from **Enkh-Amgalan, A.** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia*. Rome. FAO.

3.5 FAO methodology for damage and loss assessment in agriculture

The general scarcity of studies that attempt to assess the economic impacts of SDS on agriculture is indicative of an overall lack of attempts to assess SDS impacts on any socioeconomic sector. Sand and dust storms do not feature prominently in the disaster literature (Middleton, Tozer and Tozer, 2019). While the climatic and physical conditions required for an SDS to occur are well researched, the economic and social effects of an individual SDS or a series of such events are neither well understood nor well quantified.

The few assessments of the economic consequences of SDS that have been conducted lack consistency in data collection methods and analysis, which makes comparisons difficult. In some cases, the location of impact assessed is unclear: erosion effects in SDS source areas are not the same as impacts in deposition areas. Furthermore, most of the studies that have been conducted make little or no distinction between wind erosion in general and SDS in particular (see Table 1.1 for how wind erosion events are classified). While evidence of impacts by severe SDS is generally clear cut, the cumulative effects of many smaller events may also be significant (Brennan and Danielak, 2022). The inadequacies of assessments of SDS impacts on agriculture inevitably hamper adequate agricultural DRR policy and planning, and lead to underinvestment in resilient agriculture.

Imprecise evaluations of impacts due to other disasters have prompted FAO to develop an agriculture-specific methodology, which provides a framework for identifying, analysing and evaluating the impact of disasters on the sector (Conforti, Markova and Tochkov, 2020). The impact consists of damage and loss, terms that are officially defined in the methodology, as shown in Box 3.3.

Box 3.3 | Definitions in the FAO damage and loss assessment methodology

Damage is the total or partial destruction of physical assets and infrastructure in disaster-affected areas, expressed as replacement and/or repair costs. In the agricultural sector, damage is considered in relation to standing crops, farm machinery, irrigation systems, livestock shelters, fishing vessels, pens and ponds.

Loss refers to the changes in economic flows occurring as a result of a disaster. In agriculture, loss may include decline in crop production, decline in income from livestock products, increased input prices, reduced overall agricultural revenues, higher operational costs and increased unexpected expenditures to meet immediate needs in the aftermath of a disaster.

Source: **Conforti, P., Markova, G. & Tochkov, D.** *2020. FAO's methodology for damage and loss assessment in agriculture.* FAO Statistics Working Paper 19-17. Rome, FAO.

Seeking to standardize disaster impact assessment in agriculture, the FAO damage and loss methodology corresponds to universal norms, commitments and collective action at the global level, while remaining flexible enough to be applied in various country/regional contexts. The tool serves national policy and planning needs as well as the post-2015 international resilience agendas, including the Sendai Framework and the SDGs. The FAO methodology is used to track progress of SFM Indicator C-2 on "Direct agricultural loss attributed to disasters" and the corresponding SDG Indicator 1.5.2 on "Direct economic loss attributed to disasters in relation to global gross domestic product (GDP)."

To standardize the process, FAO proposes that an SDS event should be considered as disastrous only when it has a visibility of 1000 m or less, following the definition presented in Chapter 1. A document produced by the Asian and Pacific Centre for the Development of Disaster Information

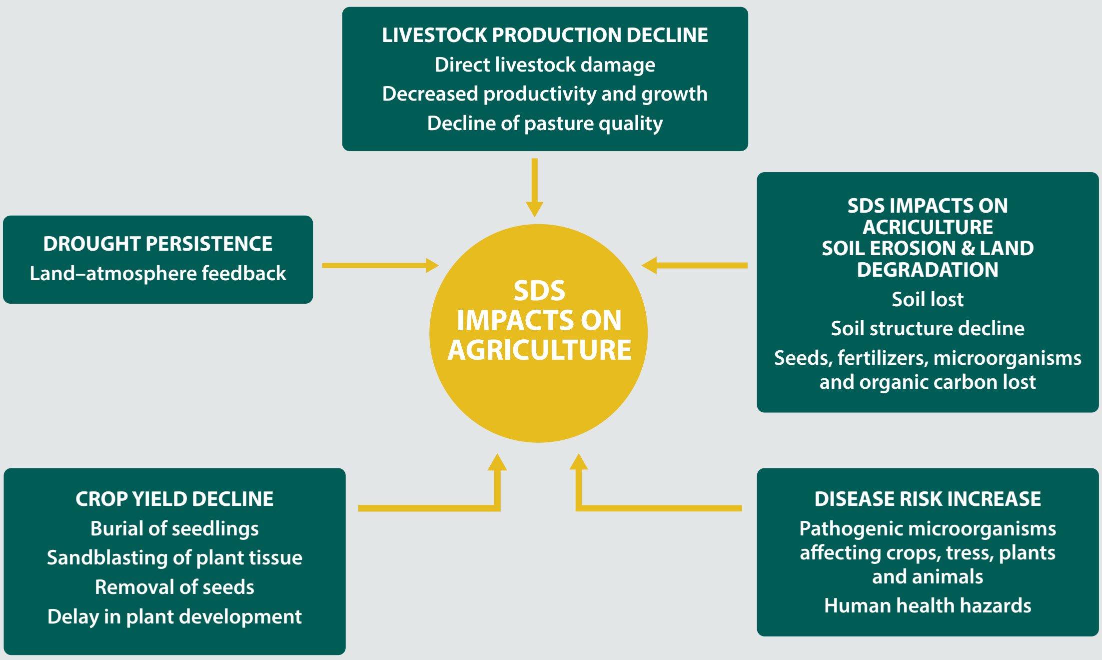
Management, a regional institute of the United Nations Economic and Social Commission for Asia and the Pacific, offers guidance on monitoring and reporting the impacts of SDS through SFM and facilitates use of the methodology (ESCAP and APDIM, 2020).

Countries began systematically collecting and reporting such data using this framework in 2020. Collection of data in this way will result in a growing archive of systematically-quantified information, enabling countries to progress more effectively with their agriculture DRR policy, planning and implementation.

3.6 The need for mitigation and adaptation measures

The evidence presented in this chapter documents the numerous ways in which SDS can affect agriculture, which are summarized in Figure 3.4. The effects are long- and short term, on- and off- site, direct and indirect. Although many of these impacts have not been well quantified, the evidence available indicates they can substantially reduce the yields of crops, trees, pastures and livestock. Sand and dust storms also have a significant bearing on agricultural productivity, household welfare and health-related quality of life, particularly for subsistence and small-scale food producers.

Figure 3.4 | Impacts of SDS on agriculture



Source: *Adapted from* **United Nations Convention to Combat Desertification.** 2022. *Sand and dust storms guide: information and guidance on assessing and addressing the risks.* Bonn.

Combining an understanding of these impacts with the knowledge of how agricultural activities can act as drivers of SDS (as outlined in Chapter 2) underlines the need to build agricultural resilience to these hazards. The next two chapters discuss the ways in which such resilience can be developed. Chapter 4 summarizes a range of source and impact mitigation and adaptation interventions, including technical and non-technical approaches, with a focus on the local level. Effective DRM also depends on sound governance frameworks for making decisions on how best to manage disaster risk to ensure resilience. Chapter 5 therefore assesses policy measures for managing SDS as an emerging risk, as part of wider DRR strategies.

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4 Mitigation and adaptation measures of sand and dust storms at the local level

Key messages

A systematic methodology has been developed to identify high-impact, context-specific practices to reduce SDS sources and impacts on the agricultural sector at the local level.

More than 150 SLM and non-SLM practices are identified and presented in Annex 1, which enables a user-defined filtering of most suitable practices per context according to multiple attributes.

The longlist of practices has been refined to produce a selection of 15 good practices to reduce SDS source and impacts on the agricultural sector. The choice of practices considers functionality, scaling, costs and cobenefits. These good practices have been chosen to cover a range of agroecological zones (AEZs).

The top four good practices are described in separate, detailed fact sheets followed by an evaluation of their economic cost and effectiveness. A more concise assessment of the remaining 11 good practices (5–15) is given in table format.

Agriculture is a major source of SDS, but is also a sector that is particularly vulnerable to SDS impacts. The huge areal extent of the various agricultural land uses also means that agriculture has a remarkable SDS mitigation and adaptation potential. Smallholder and subsistence farming systems, in particular, occupy a very large area of the most vulnerable dryland agroecosystems across the Dust Belt region, stretching from North Africa to East Asia.

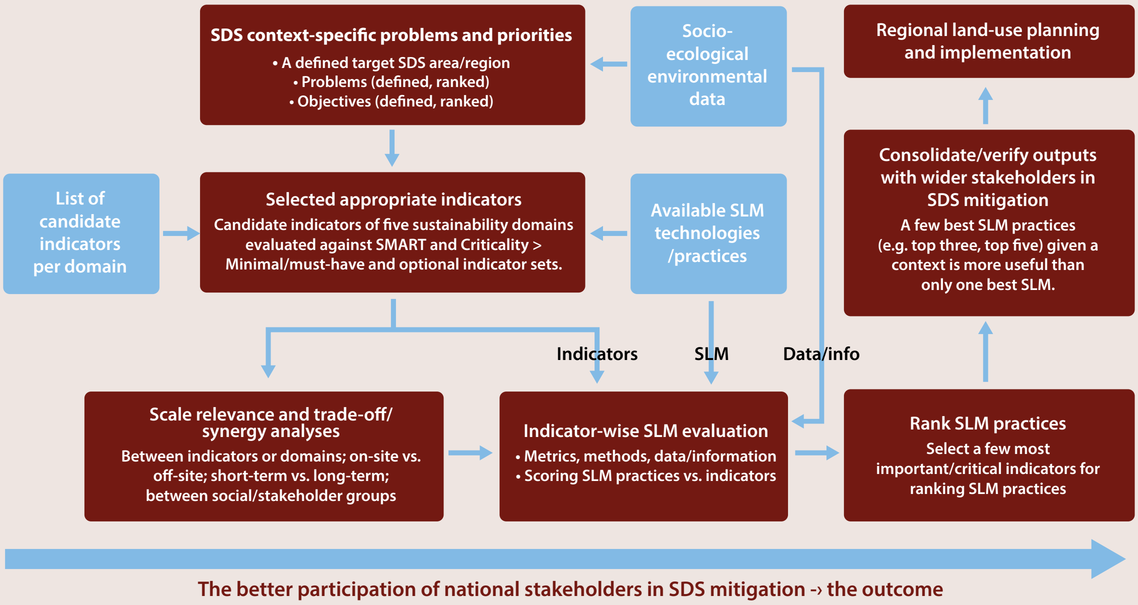
Land tenure and management systems are complex across the Dust Belt. Smallholder field crop cultivation is predominantly pursued on private arable lands, while livestock management in the marginal drylands, such as rangeland and steppe, is often pursued on governmental or public lands. Effective SDS mitigation and adaptation measures must acknowledge the structure of local farming systems, their diverse environments and livelihood bases, and particularly local farmers' potential to adopt beneficial SLM practices. The scaling potential of various SLM practices strongly differs across the agroecologies and their biophysical and socioeconomic settings. Beyond SLM, some non-SLM practices exist, or are under development (e.g. early warning and insurance systems), which can serve as means of adaptation to SDS in numerous sectors, including agriculture.

4.1 Evaluation and selection of effective sand and dust storm mitigation and adaptation measures in agriculture

4.1.1 Evaluation of sustainable land management and non-sustainable land management practices

A critical aspect of the interregional project Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture was the identification of a range of high-impact, context-specific practices to reduce SDS sources and impacts on the agricultural sector. This task was conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA) using a multistakeholder approach to collect, describe, assess and rank various existing and new/experimental SLM and non-SLM practices as shown in Figure 4.1. Sand and dust storm context-specific problems and priorities were jointly defined during all-partner project meetings. Selection of appropriate indicators for SLM and non-SLM performance assessment was pursued by technical expert groups, which defined various indicators clustered into six overall domains of attributes (further described below). Good practices were selected following a systematic methodology, as shown in Figure 4.1.

Figure 4.1 | Framework schematic for selecting SLM and non-SLM good practices by SDS context



Note: SMART = specific, measurable, achievable, relevant and timebound.

Source: Author's own elaboration

A longlist of practices was drawn up, based on extensive literature review, project scientific partners' in-house SLM repositories, interrogation of online SLM databases (e.g. the World Overview of Conservation Approaches and Technologies) and the project country partners' unique knowledge of their locally-applied strategies and practices. This longlist of measures contains over 150 individual practices that mitigate the generation of SDS (source areas) and/or the impacts of SDS on agriculture (impact areas). Several of the identified practices have the potential for source and impact mitigation and adaptation, albeit with different effectiveness and applicability levels per context. Socioeconomic factors were considered through the practices' adoption and scaling potential as well as a qualitative evaluation of costs and (co) benefits. The longlist of identified SDS source and impact mitigation practices considers multiple attributes and indicators that allow user-defined filtering of most suitable practices per context (see Annex 1).[4] The main attributes of the longlist are:

- Type of practice
- Target particle size
- Target AEZ
- Functionality (source and/or impact)
- Target scale of implementation
- Benefits (versus costs) of implementation

[4] Further details on many of the practices are available at www.wocat.net/en/global-slm-database.

Type of practice: Describes the intervention, whether SLM (S), non-SLM (N) or a combination/both (B).

Target particle size: Describes the primary SDS particle size that the practice aims to mitigate, either at source and/or impact. The target particle size is either sand (S*)[5] or dust (D). This closely relates to the functionality of the practice (e.g. reducing larger particles' near-surface creep and saltation processes [S*] or the impact of fine particles transported some distance through the atmosphere [D]), as well as the target environment's characteristics (e.g. whether a practice requires a sandy or clay soil environment).

Agroecological zone (AEZ): Describes the target environment/farming system for practice implementation: cropland (C), pasture (P) or forest (F). In cases where more than one AEZ is relevant, the technology description distinguishes between primary and secondary AEZ.

Functionality: Differentiates between "source" and "impact" aspects and describes the main functions of the practice. Source mitigation functionalities differentiate between obstacle (O), cover (C*), resistance (R) and landscape effects (L), largely relating to wind erosion processes as described by Tibke (1988). Impact functionalities are categorized as either hard (H) involving physical structures, Agronomic (A) or Soft (S**) measures that do not involve physical structures.

Scale of implementation: Differentiates between individual (I) local level and community/compound (C**) scale. "C" indicates practices that would not be applied by an individual farmer but would take place through, , for example, governmental or international initiatives and projects.

Benefits: Differentiate between environmental (E), agricultural production (A*), risk reduction/improved resilience (R*) or energy (En), covering the types of (co)benefits associated with the listed practices.

The longlist is available in Excel format (see Annex 1, including macros) and can be searched with user-defined filtering to identify the most suitable practices per context according to multiple attributes.

4.1.2 Selection of good practices: sustainable land management and non-sustainable land management

A limited performance assessment was also conducted. The longlist of SLM and non-SLM practices (> 150 practices) was further refined to produce a selection of 15 good practices, particularly applicable within the Dust Belt target area, for further description in this Guide. This shortlist of 15 was selected to give a balanced agroecological coverage, and takes into account the level of available knowledge of well-ranked practices. The shortlisted measures include examples of source and impact mitigation good practices, as well as practices with a good cost to (co)benefits ratio across the three AEZs.[6]

[5] The * is used here to distinguish between more than one (S) in the list of six main attributes, as with (C), (A) and (R).
[6] Note that the shortlist reflects the selection process and the available regional information and context, hence the 15 good practices do not necessarily represent all-purpose, universally top-ranked performance technologies.

The 15 good practices are further described in this chapter at two levels of detail: (i) detailed assessment, including advanced qualitative and semi-quantitative analyses (four practices) and (ii) limited assessment (11 practices), providing brief description and ranking performance information on a table. The detailed assessment section contains a practice description and a case study reference, an SDS mitigation and adaptation function description, suitability and scaling methods and literature references. The "sand and dust storm mitigation and adaptation functions" description provides information about the practices' functionality and the relative performance of a certain technology compared to all other (> 150 entries) technologies expressed as a percentile of the specific practices' source and impact ranking (0 percent is the lowest and 100 percent the highest score, with 100 percent indicating the best practice in a particular category). The longlist is designed to be dynamic, and the addition of new practices will alter rankings and the associated relative scoring/performance.

The "suitability and scaling methods" section provides qualitative and ranking information on the practices' potential scale/scaling of implementation, technology readiness and usability. In addition, the detailed assessment provides a certain level of quantitative scaling information. For the four good practices described in detail, a spatial suitability analysis was conducted using a Google Earth Engine (GEE) code developed by ICARDA. The GEE code and suitability analyses use several online datasets on regional climate, topography, soil and land cover/management, and introduce thresholds (e.g. minimum and/or maximum ranges) based on practice guidelines and extensive expert knowledge.[7] Areal scaling information is shown in the potential suitability map covering the Dust Belt region, although the GEE code can be applied to any defined target area.

4.2 Selected good practices

The following 15 good practices were selected for assessment (type of practice and target AEZs are indicated in brackets [type; AEZs]):

1. Conservation agriculture in dryland mixed systems (S; C, P).
2. Drought-tolerant forage species (sulla) (S; P, C).
3. Mechanized micro water harvesting (MWH) using the Vallerani tractor plough (S; P, F).
4. Aerial seeding of saxaul trees (S; F).
5. Mulching with leguminous species (S; C, P).
6. Agroforest wind barriers and alley cropping (S; F, C).
7. Agrosilvopastoral systems (S; F, P).
8. Wind erosion control by polymer cover (B; P, C).

7 See Annex 2 for details.

9. Climate advisory services (N; C, P).

10. Livestock shelter (N; P).

11. Bahiagrass (*Papsalum notatum*) intercropping in orchards (S; F, C).

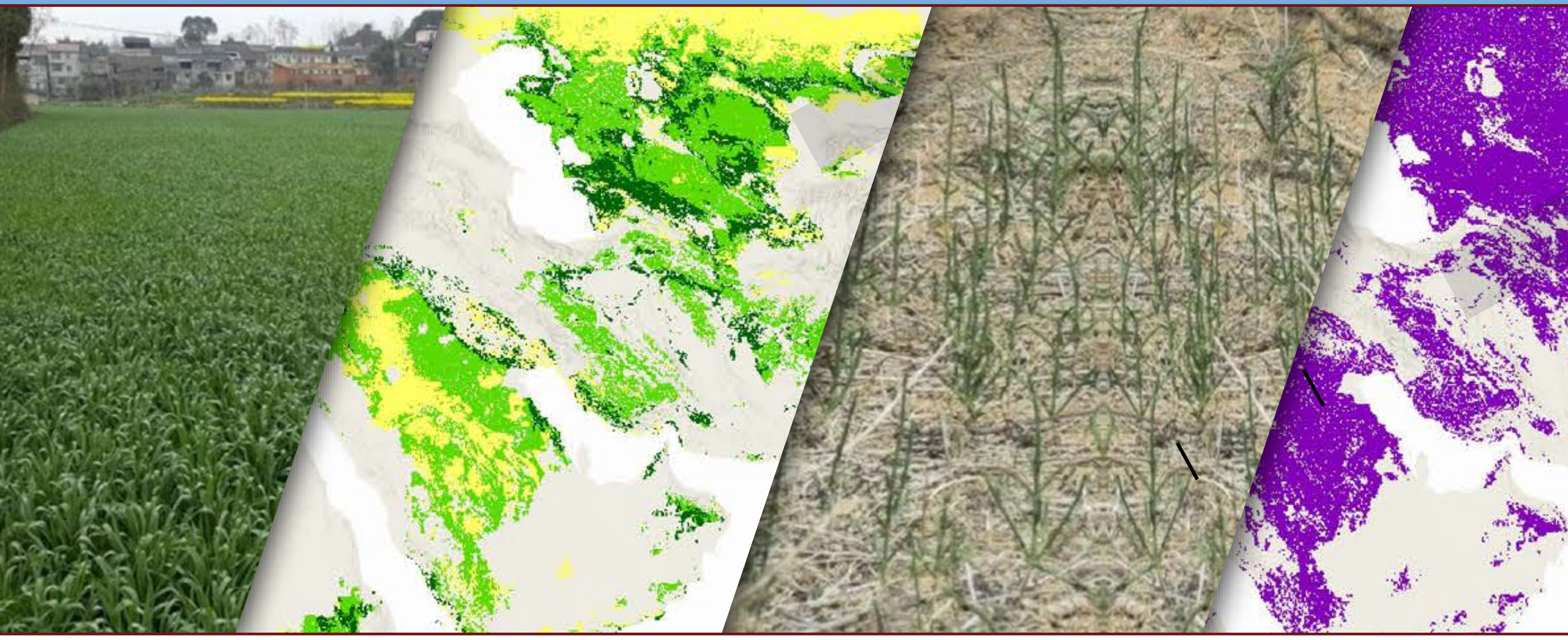
12. Index-based livestock insurance (N; P).

13. Temperature- and disease-tolerant chickpea varieties (S; C, P).

14. Marab floodwater harvesting in landscape depressions (S; P, C).

15. Large-scale solar panel installation (N; P, C).

The four selected good practices are described in separate, detailed fact sheets below, followed by an evaluation of their economic cost and effectiveness. Then, a concise assessment of the remaining good practices 5–15 is given in table format below (Table 4.1).



4.2.1 Detailed assessment of good practices 1–4

Good practice 1: conservation agriculture in dryland mixed systems

Description

Type of practice: SLM (S)

Agroecological zone: cropland (C); pasture (P)

Global

Conservation agriculture (CA) is a proven and scalable concept aimed at sustainable agricultural production based on three major principles: (i) minimizing soil disturbance, (ii) enhancing soil cover and (iii) introducing crop rotations. These principles are evolving over time towards a system-based approach to CA and also include (iv) integrated nutrient management. Conservation agriculture covers a wide range of potential applications in diverse environments and climatic zones. This practice targets the mixed dryland system with cereals and legume biennial rotation and integrated livestock management. Conservation agriculture in dryland mixed systems benefits soil health and significantly reduces agricultural inputs.

Case study

Conservation agriculture in dryland mixed systems practice is applied in arid and semi-arid areas of China with an average annual precipitation ranging from < 50 mm to around 1000 mm. Agricultural areas are not tilled and are directly seeded (using a zero-tillage seeder machine), which reduces the demand for fuel and reduces labour costs. Cereals and legumes are planted in rotation; cereals are mostly traditional winter wheat (*Triticum aestivum*) or maize (*Zea mays*), while legumes (e.g. peanut [*Arachis hypogaea*]) diversify nutrition and income and generate environmental benefits through natural nitrogen fixation. The integrated crop–livestock practice allows sustainable (controlled) livestock grazing on the freshly harvested fields (assuring some stubble remains), which also adds manure (Figure 4.2).

Figure 4.2 | Zero-tillage wheat field in China

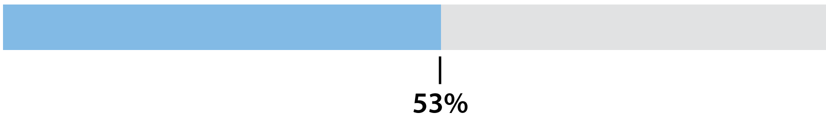
Sand and dust storm mitigation and adaptation functions

Sand and dust storm source: Conservation agriculture in dryland mixed systems primarily enhances surface cover (C*) through crop rotation and residue management (stubble and/or mulch), which protect the soil from (wind) erosion. Secondarily, non-disturbance (zero tillage) and nitrogen fixation through legume rotation form resistant (R) soils with stable aggregates and structure.

Relative performance (percent relative effectiveness; percentile rank in longlist):

Sand and dust storm impact: The agronomic (A) measure of crop diversification and rotation enhances resilience to SDS impacts through introducing secondary stress-resilient crops and/or variable/multiple harvesting options that mitigate the impacts of SDS.

Relative performance (percent relative effectiveness; percentile rank in longlist):



Suitability and scaling methods

Scale of implementation: Individual (I) local level

Technology readiness:

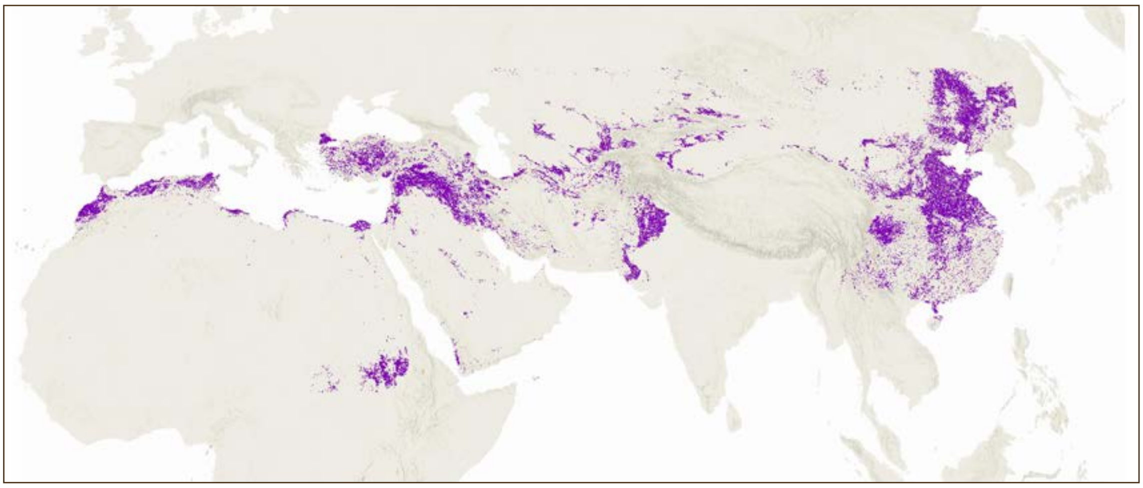
4/5 (high)

Technology use level:

4/5 (high)

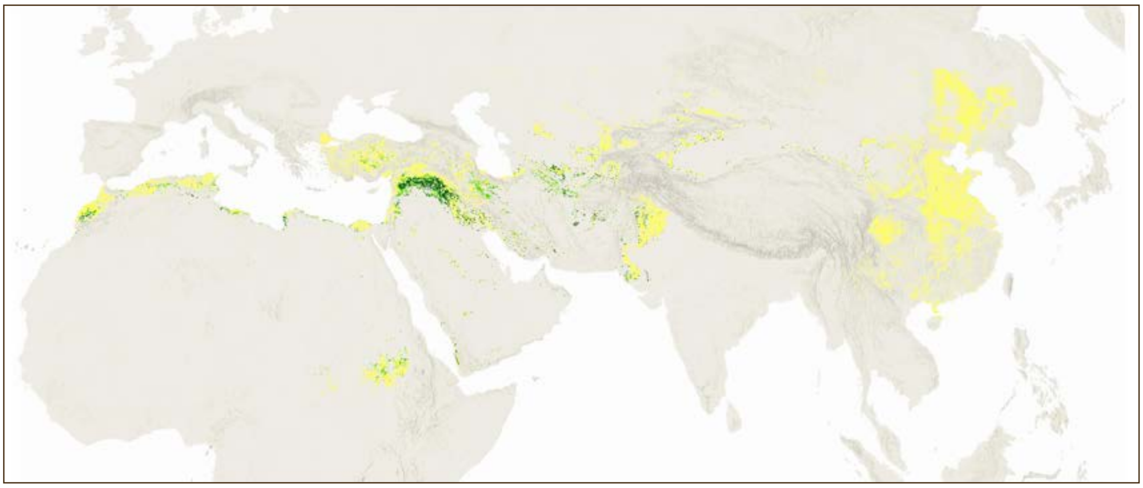
Conservation agriculture in dryland mixed systems practice targets integrated cropland (C) and pasture (P) systems. The practice is particularly tailored for the 350–600 mm rainfall zone, low to medium steep slopes (< 15 percent), minimum 0.4 m deep soils with < 50 percent sand and clay content and < 20 percent rock fraction. Suitability criteria are expert estimates and may vary locally. Temperature and altitude regimes must be appropriate for the locally out-planted field crops. The scaling potential and potential effectiveness of CA across the Dust Belt are shown in Figures 4.3 and 4.4.

Figure 4.3 | Scaling potential (suitability) of CA in dryland mixed systems practice across the Dust Belt



Source: Author's own elaboration

Figure 4.4 | Potential effectiveness of CA in dryland mixed systems practice across the Dust Belt



Note: See Annex 3 for details of potential effectiveness.

Source: Author's own elaboration

Benefits: Conservation agriculture in dryland mixed systems generates evident long-term benefits for individual (I) farmers such as potentially increased yields (evident in the China case study) and enhanced environmental services and resilience (e.g. soil health). The impacts of CA on yield vary locally, and strongly relate to/depend on the environmental and management context.

Cobenefits:
Agricultural production (A*) – high;
Environmental (E) – medium.

Implementation costs: Costs strongly depend on the scale of implementation due to specific machinery requirements (zero-tillage seeder). Related to the CA rotational system, the machinery can be shared among several farmers (rotational renting system). Workload and fuel demand are commonly reduced (e.g. reduced seedbed preparation through direct seeding), resulting in decreased input costs and labour compared with conventional cultivation practices.

Policy recommendations: Incentives to individual farmers for enhancing biodiversity and achieving LDN on farmlands, as well as promoting high-value sustainably-produced products (e.g. biolabelling).

Literature references

Lal (2018); WOCAT (2010).

Good practice 2: drought-tolerant forage species (sulla)

Description

Type of practice: SLM (S).

Agroecological zone: pasture (P); cropland (C)

Global

The practice is based on the manual seeding of drought-tolerant legume species in dry agropastures. The practice rehabilitates bare erosion-prone and degraded soils by (re)developing a dense surface cover, enhancing soil fertility by adding organic matter and nitrogen fixation (legumes), as well as enhancing rainwater infiltration characteristics through forage root system development. The legume forage serves as nutrient-rich fodder plants for livestock grazing.

Case study

The practice is applied in the overgrazed and degraded semi-arid areas of central northern Tunisia, where average annual rainfall in target areas ranges between 350 and 600 mm. Target implementation areas receive (shallow) ploughing before manual seeding of the native forage species *Hedysarium coronarium* (sulla) seeds. The sulla cultivated areas approximately double land productivity (dry matter) compared with the control degraded rangeland in Tunisia (Figure 4.5). The successfully rehabilitated areas require subsequent sustainable grazing management; reseeding sulla after three years is recommended.

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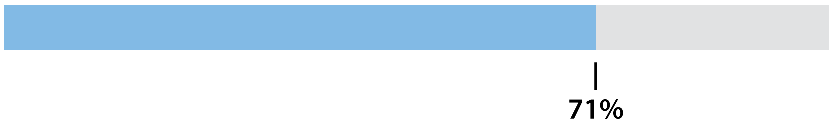
Sand and dust storm mitigation and adaptation functions

Sand and dust storm source: (Re)vegetated areas protect the vulnerable dryland soils through increased surface cover (C*). Secondarily, through the dense root system development, nitrogen fixation and the subsequent formation of stable soil aggregates, soil resistance (R) is enhanced.

Relative performance (percent relative effectiveness; percentile rank in longlist):

Sand and dust storm impact: The agronomic (A) measure supports the (re)development and intensification of a drought-tolerant vegetation cover adapted to the local conditions. The species' resilience and stable biomass production mitigates a potential production loss through SDS impacts.

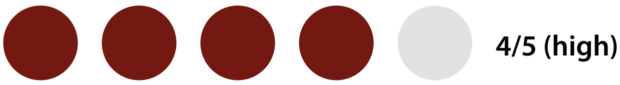
Relative performance (percent relative effectiveness; percentile rank in longlist):



Suitability and scaling

Scale of implementation: individual (I) local level; community/compound (C**).

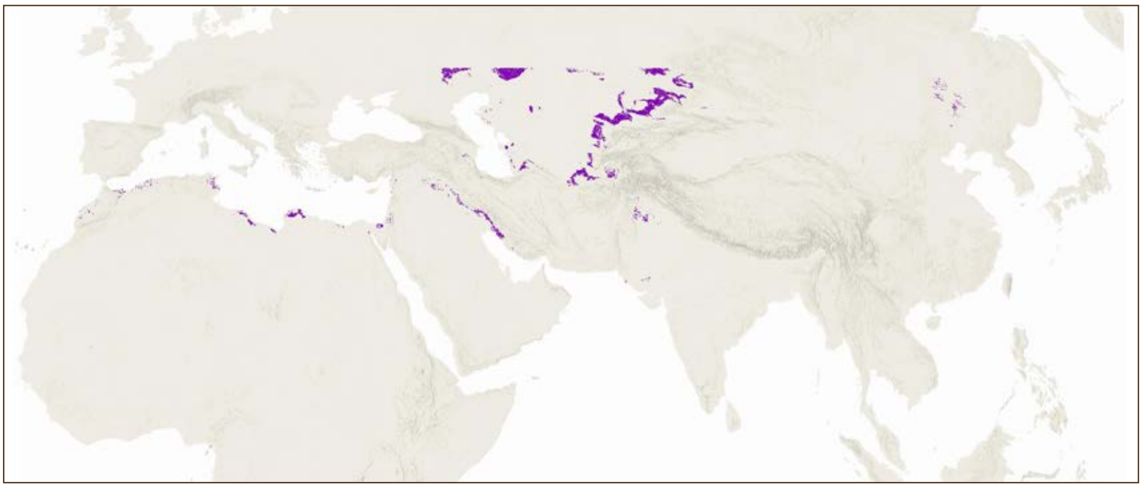
Technology readiness:



Technology use level:

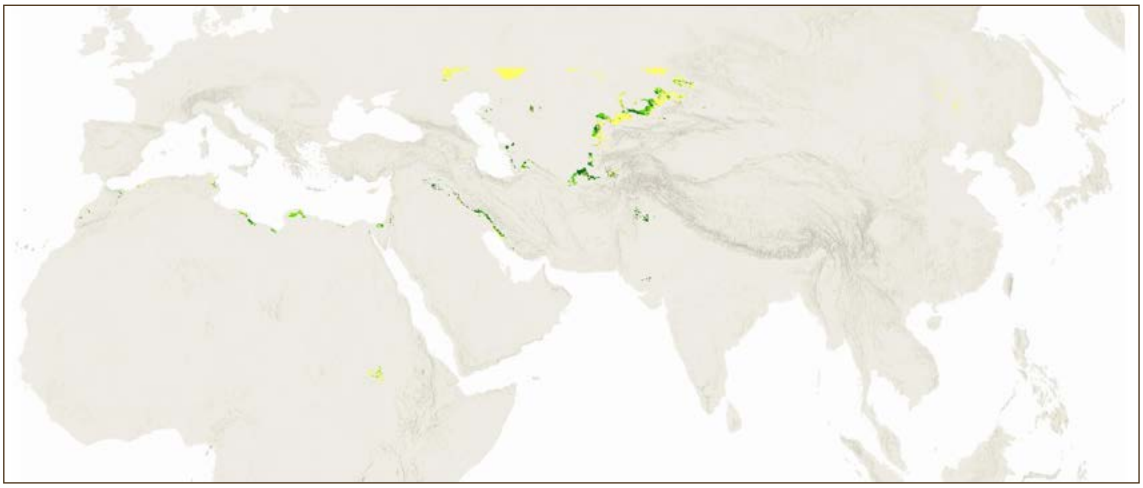
The sulla forage seeding practice targets pastoral (P) and cropland (C) AEZs with an average annual rainfall between around 350 and 600 mm, at low to medium steep slopes (< 15 percent), minimum 0.2 m deep soils with < 40 percent sand and clay content and < 20 percent rock fraction. Suitability criteria reflect expert estimates and may vary substantially according to environmental conditions; temperature and altitude regimes must be appropriate for sulla (or other appropriate species). The scaling potential and potential effectiveness of sulla across the Dust Belt are shown in Figures 4.6 and 4.7.

Figure 4.6 | Scaling potential (suitability) of the forage legume species sulla practice across the Dust Belt



Source: Author's own elaboration

Figure 4.7 | Potential effectiveness of the forage legume species sulla practice across the Dust Belt



Note: See Annex 3 for details of potential effectiveness.

Source: Author's own elaboration

Benefits: The sulla native forage seeding practice can be applied at the individual (I) local level and the community/compound (C**) level for mitigate and reverse land degradation. The practice leads to fast-response direct benefits for farmers through increased biomass production and nutrition for livestock grazing.

Cobenefits: environmental (E) – high; agricultural production (A*) – medium.

Implementation costs: The field preparation (shallow ploughing) requires conventional agricultural machinery (tractor and plough). Short- and long-term return on the technology are considered high/positive compared to the cost of establishment and maintenance. The technology reduces the cost of feed imports and improves the economic situation of local farmers.

Policy recommendations: Incentives and benefits for livestock farmers related to achieving LDN (i.e. increased surface cover, production and carbon stocks).

Literature references

Slim *et al.* (2021); WOCAT (2021a).

Good practice 3: mechanized micro water harvesting using the Vallerani tractor plough

Description

Type of practice: SLM (S)

Agroecological zone: pasture (P); forest (F)

Global

Mechanized MWH forms straight to semi-circular bunds and pits, and encourages the retention and deep infiltration of surface runoff from surrounding soil surfaces during sporadic rainstorms. Regularly spaced MWH ditches are mechanically created along the contour through upward and downward movement of a Vallerani tractor plough. The MWH pits store harvested excess rainwater and provide moisture to planted (shrub and tree) seedlings and emerging annual vegetation. Eventually, resilient vegetation patches form and revitalize the degraded drylands, predominately for extensive livestock grazing.

Case study

The practice is successfully applied in rangeland watershed restoration initiatives in Jordan's Badia region. The climate in the case study's watershed is arid and warm; average annual rainfall is approximately 100–150 mm. The MWH pits constructed by the Vallerani tractor plough (Delfino 50 MI/CM) have approximately 5–10 m contour spacing (Figure 4.8). The adjusted MWH pit length along the contour is around 4.5 m. Two native shrub seedlings are planted in each pit.

Figure 4.8 | Implementing Vallerani MWH in central Jordan's Badia region

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Sand dust storm mitigation and adaptation functions

Sand and dust storm source: The intermittent MWH pits foster the development of shrub (and tree) wind barriers that primarily act as obstacles (O). Secondarily, the enhanced (annual) vegetation and litter around the MWH pits increase surface cover (C*), protecting highly erodible bare soils.

Relative performance (percent relative effectiveness; percentile rank in longlist):

Sand and dust storm impact: The agronomic (A) measure fosters the (re-)establishment of native shrub and tree species resistant and tolerant to SDS impacts (e.g. saltbush species in Jordan). Furthermore, MWH practices prolong the growing and potential vegetation facilitation period, which increases the (temporal) flexibility of grazing management (soft [S**] measure).

Relative performance (percent relative effectiveness; percentile rank in longlist):

Suitability and scaling

Scale of implementation: community/compound (C**)

Technology readiness:

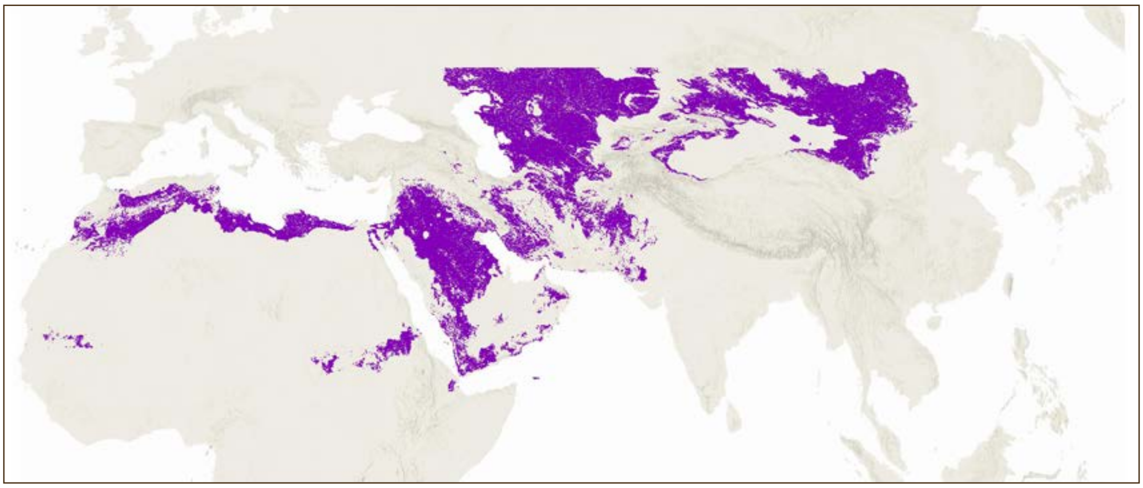
4/5 (high)

Technology use level:

3/5 (medium)

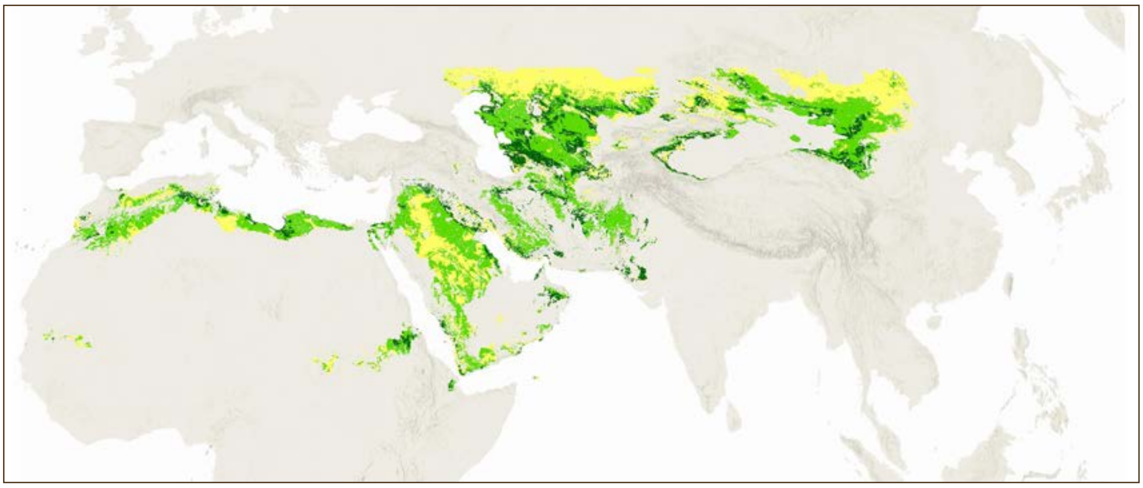
The Vallerani MWH practice, adapted for dry rangeland rehabilitation, is tailored for pastoral (P) AEZs (secondary forest [F]) with an average annual rainfall between 80 and 300 mm, at low to medium steep slopes (< 20 percent), minimum 0.4 m deep soils with < 50 percent sand and clay content and < 20 percent rock fraction. The indicated thresholds are expert estimates and may vary locally; temperature and altitude regimes must be appropriate for the target out-planted vegetation. The scaling potential and potential effectiveness of the Vallerani MWH practice across the Dust Belt are shown in Figures 4.9 and 4.10.

Figure 4.9 | Scaling potential (suitability) of the Vallerani MWH practice across the Dust Belt



Source: Author's own elaboration

Figure 4.10 | Potential effectiveness of the Vallerani MWH practice across the Dust Belt



Note: See Annex 3 for details of potential effectiveness.

Source: Author's own elaboration

Benefits: The practice's benefits are increased biomass production (potential livestock fodder) in marginal drylands and restoring degraded ecosystems. Over time, the practice creates environmental and ecological benefits, including increased surface cover, carbon stocks and genetic diversity, and regulating water cycles, decreasing soil erosion and preventing floods. The practice unfolds its potential at the integrated landscape/watershed level and requires sustainable grazing management, particularly during early vegetation development stages. The benefits address rangeland communities (C) as a whole rather than individual farmers.

Cobenefits: agricultural production (A*) – high; environmental (E) – high.

Implementation costs: Costs strongly depend on the scale of implementation. The mechanized MWH practice requires technical know-how and advanced machinery (Vallerani tractor plough), but application over a large area brings economies of scale. Under ideal conditions and sustainable grazing management to protect the seedlings while young, the Vallerani MWH technique is a "one-time" application practice with long-lasting benefits.

Policy recommendations: Local community empowerment (community-based watershed management) and sustainable management incentives coupled with monitoring and law enforcement. Watershed restoration through MWH can be combined with local high-yield cereal agriculture in downstream watershed depressions (e.g. Marab technology; see good practice 14).

Literature references

Strohmeier *et al.* (2021); WOCAT (2021b).

Good practice 4: aerial seeding of saxaul trees

Description

Type of practice: SLM (S)

Agroecological zone: forest (F)

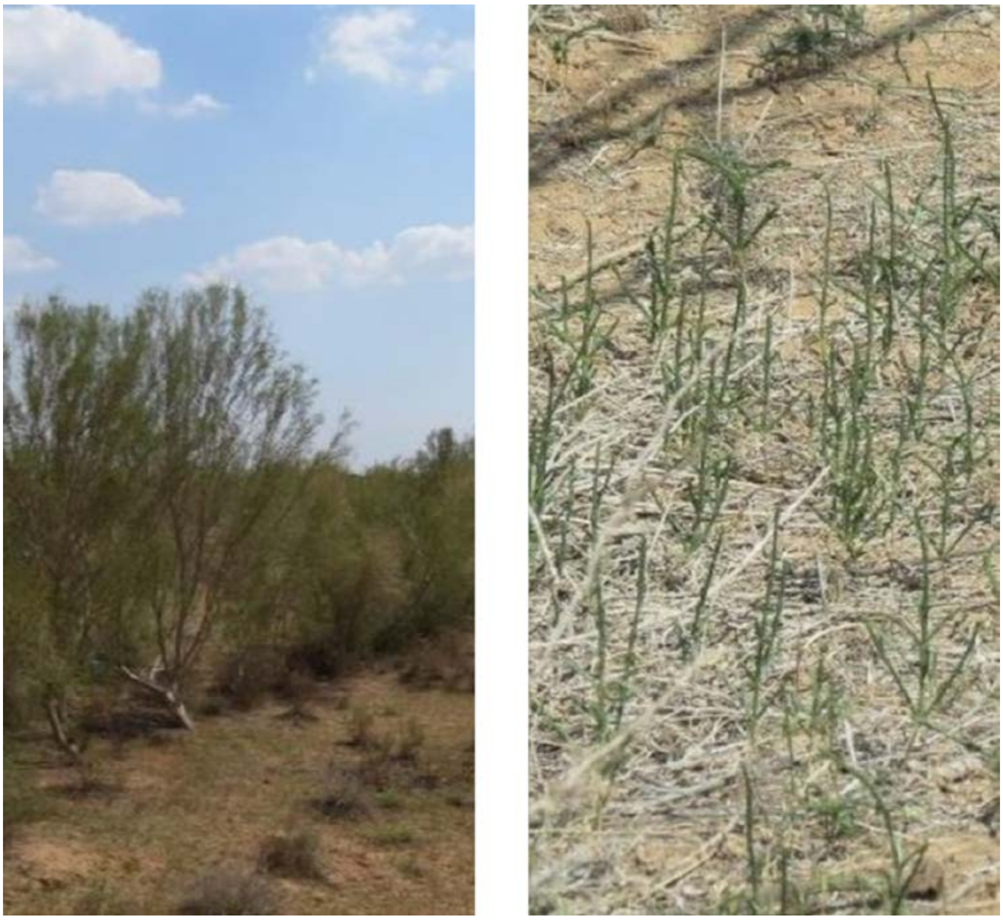
Global

Haloxylon spp. (saxaul) is a small tree (around 1.5–12 m height) with forked branches and jointed shoots. Saxaul trees are highly tolerant of drought, heat and salinity, and develop a deep root system. They can be planted in a variety of ways, using seeds and/or seedlings. The practice described here involves aerial seeding from low-flying aircraft.

Case study

The practice is particularly tailored and applied to mitigate the generation of SDS at source on the dry lake bed of the Aral Sea near Muynak, Uzbekistan (Figure 4.11). The climate is continental (winter cold and summer hot), and average annual rainfall is around 100 mm. The saxaul tree is native to the region. Planting is executed through aerial seeding in spring (between January and March).

Figure 4.11 | Reclamation of dry Aral Sea lake bed areas with saxaul tree seedings



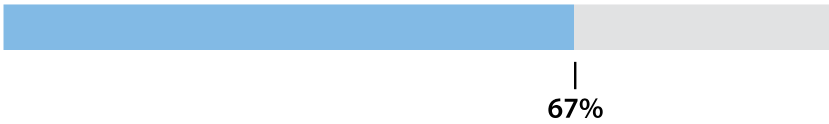
Sand and dust storm mitigation and adaptation functions

Sand and dust storm source: Saxaul trees create medium- to large-sized obstacles (O). Secondarily, the annual and recruited vegetation (including litter) around the vegetation patches increase surface cover (C*), protecting bare areas.

Relative performance (percent relative effectiveness; percentile rank in longlist):

Sand and dust storm impact: Saxaul trees are drought, heat and salt tolerant, and particularly able to withstand SDS impacts (agronomic [A] measure). The trees provide benefits (e.g. grazing, timber wood) throughout the year, which allows temporally optimized facilitation (soft [S**] measure).

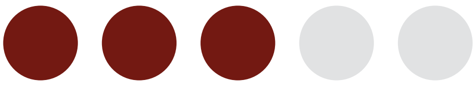
Relative performance (percent relative effectiveness; percentile rank in longlist):



Suitability and scaling

Scale of implementation: community/compound (C**).

Technology readiness:



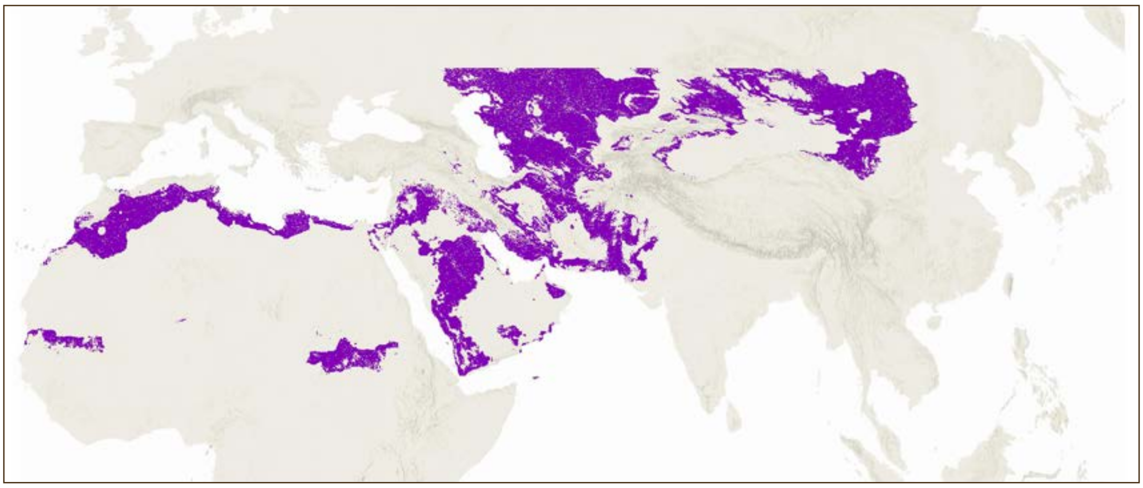
3/5 (medium)

Technology use level:

2/5 (low)

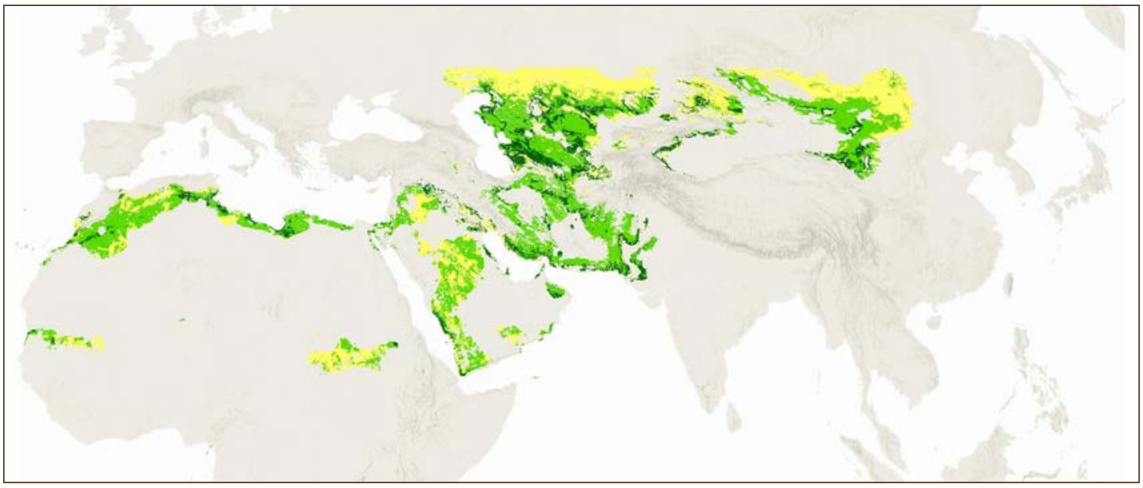
The aircraft-based saxaul tree seeding practice targets the forest (F) AEZ with an average annual rainfall between 80 and 300 mm, at low to steep slopes (< 100 percent), minimum 0.4 m deep soils with < 60 percent sand and clay content and < 40 percent rock fraction. The indicated thresholds are expert estimates and may vary locally; temperature and altitude regimes must be appropriate for saxaul plantation. The scaling potential and potential effectiveness of saxaul tree plantations across the Dust Belt are shown in Figures 4.12 and 4.13.

Figure 4.12 | Scaling potential (suitability) of the saxaul tree seeding practice across the Dust Belt



Source: Author's own elaboration

Figure 4.13 | Potential effectiveness of the saxaul tree seeding practice across the Dust Belt



Note: See Annex 3 for details of potential effectiveness.

Source: Author's own elaboration

Benefits: High initial investment costs produce potentially high long-term gains through large-scale implementation (landscape-level benefits). Primary benefits are environmental (E); however, the increased vegetation cover provides biomass and nutrition for grazing and firewood, and can serve agrotouristic purposes.

Cobenefits: environmental (E) – high; agricultural production (A*) – low.

Implementation costs: Freight airplane(s) and a nearby airfield are required. Through fast and efficient implementation, the cost of the practice per unit area can be considerably decreased. For the Uzbekistan (Aral Sea) case study, temporary airfields were constructed near to the target sites. Environmental suitability (sowing should not take place on completely bare soils to avoid wind erosion of seeds) and timing need to be carefully considered.

Policy recommendations: This practice can contribute to achieving LDN, particularly for large-scale impact generation.

Literature reference

Akramkhanov *et al.* (2021).

4.2.2 Evaluation of cost and effectiveness of combined good practices through linear programming

Performance on mitigating SDS sources in agriculture by the four top-ranked practices was further assessed using a linear programming (LP) study. The LP study uses an iterative process model that seeks optimum locations and coverage of user-selected practices within their suitable implementation area, either optimized per areal coverage (extent) or as a set ceiling of investment costs (implementation and maintenance costs). The LP model also considers the temporal development of the practice (e.g. tree growth and developing mitigation efficiency) and the estimated investment costs over a certain time horizon of interest (for this study, ten years) such as implementation costs and maintenance. The LP study is based on

i. the UNCCD Sand and Dust Storms Source Base-map (https://maps.unccd.int/sds/), which provides information on the relative intensity of potential dust sources;

ii. the suitability of spatial practices (GEE code); and

iii. estimated SDS reduction potential per practice and suitability zone (low, medium and highly suitable) based on quantitative scientific studies and/or regional expert knowledge.

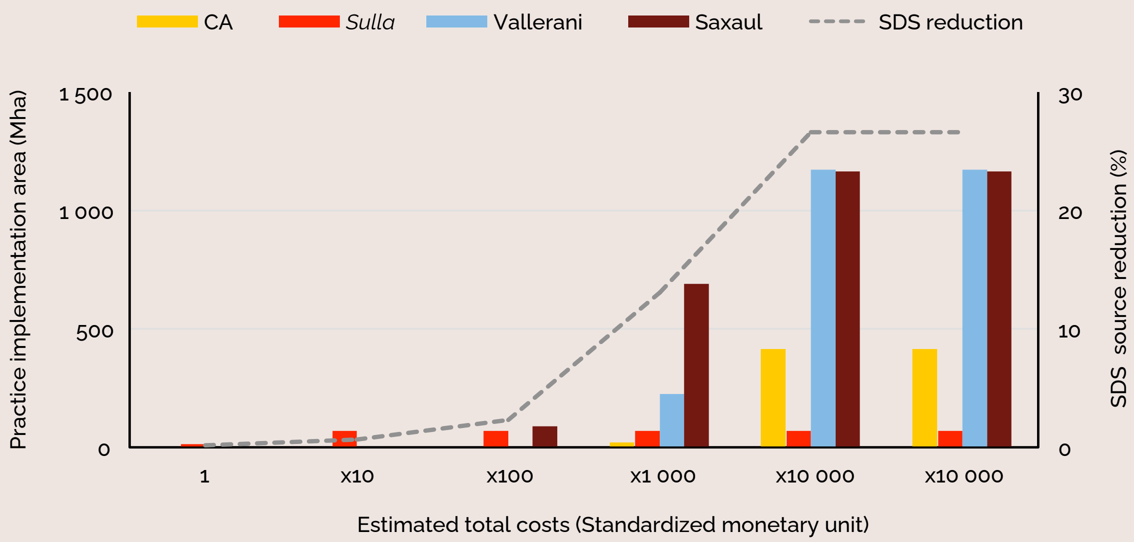
The output of the LP model delivers the areal implementation extent and performances of selected practices across their specific AEZs. Based on the targets and suitable areas for the different practices and varying performances per implementation costs, the LP model yields the best combination of practices per investment budget or user-defined SDS reduction level. Aligned with the GEE code methodology, the LP tool also allows further adjustment and updates (e.g. costs or performance).

Cost and SDS source mitigation effectiveness was assessed with the LP model for the four top-ranked practices. The LP model (Figure 4.14) was conducted over a ten-year time period showing: (i) areal extent in million hectares (*y*-axis, left side), (ii) SDS source reduction in percent (*y*-axis, right side) and (iii) required estimated total costs (*x*-axis) as a generalized monetary unit.[8] The LP model must be considered a user-defined tool for effectiveness trend assessment; real costs and effectiveness might vary considerably due to the highly variable local context in space and time. Further updates may be available through, for example, harmonized economic estimates provided through the World Overview of Conservation Approaches and Technologies.

[8] The monetary unit was initially based on estimated United States dollar implementation and maintenance costs per practice. However, due to the large cost variance across multiple countries and fluctuation of, for example, fuel prices, the monetary unit provided in Figure 4.14 is generalized (no specific currency) and indicates the relative development (i.e. cost increase) as an order of magnitude approach.

Figure 4.14 indicates the merged potential of the four good practices[9] for SDS source mitigation across the Dust Belt region. The stepwise LP approach intercompares implementation of the four selected practices, and yields a suggestion for implementing the best-performing combination per defined context (costs; areal coverage; SDS source reduction). The LP model (Figure 4.14) reveals that initially the largest SDS reduction performance per investment costs is through the sulla (2) practice, as the technology cost-effectively covers most vulnerable SDS source areas. However, the areal extent for implementing (2) is limited. Related to an increasing implementation budget and/or SDS source reduction target, saxaul (4) is the second most efficient practice. With increasing budget and/or set SDS reduction target, a large increase in performance can be further achieved through the Vallerani (3) technology, as it potentially tackles pasture (P) and forest (F) AEZs. While the large SDS source reduction potential of combined saxaul (4) and Vallerani (3) flattens out, additional increase in performance can be achieved through implementing CA (1) in the SDS source vulnerable cropland (C) AEZ – albeit at relatively large additional costs. Constrained by the overlay of the suitable amplementation areas for good practices with SDS souce locations and the reductionn potential of the practices, the maximum total SDS reduction is limited (around 25 percent) and independent of further upscaling of the good practices. Also, the implementation areas for different practices can develop simultaneously through the non-linear performance response of practices in different SDS source zones (e.g. Vallerani [3] and saxaul [4] implementation areas increase simultaneously in similar AEZs through additional budget availability). Figure 4.14 can be interpreted as an overall practice implementation recommendation for the Dust Belt region, not for a particular country. However, the LP approach can be adapted at country scale and for a targeted selection of practices for decision support.

Figure 4.14 | Linear programming indication of the combined performance of four selected good practices: (1) conservation agriculture in dryland mixed systems (CA), (2) drought-tolerant forage species (sulla), (3) mechanized MWH using the Vallerani tractor plough (Vallerani) and (4) aerial seeding of saxaul trees (saxaul) on SDS source mitigation



Source: Author's own elaboration

9 (1) Conservation agriculture in dryland mixed systems, (2) drought-tolerant forage species (sulla), (3) mechanized MWH using the Vallerani tractor plough and (4) aerial seeding of saxaul trees.

4.2.3 Limited assessment of good practices 5–15

Table 4.1 illustrates the assessment of good practices 5–15, and contains information extracted and compiled from the longlist of practices in Annex 1. Good practices 5–15, like good practices 1–4, are evaluated according to the major attributes (type of practice; target particle size; target AEZ; functionality (source and/or impact); target scale of implementation; costs and benefits of implementation). The description and performance assessment are reduced and indicate either type (practice; target particle size; AEZ; scaling; costs and benefits) and/or the relative ranking performance (functionality; scaling; costs and benefits) per practice. The relative ranking performance was pursued for selected and well-represented aspects of each attribute. Moreover, Table 4.1 shows good practices 5–15 clustered into practices that are particularly effective according to the three categories: (i) SDS source mitigation, (ii) SDS impact mitigation and (iii) costs and benefits. The relative ranking performance is illustrated as a coloured bar (larger extent bars express larger values) in Table 4.1.

Use of Table 4.1 can be illustrated for Practice 5: mulching with leguminous species, listed among the high-performing SDS source mitigating practices. This is an SLM (S) technique. The major target particle size addressed by the practice is primarily sand (S*) and secondarily dust (D) that can be transported after the movement of the coarser (S*) fragments. The practice is mainly applied in cropland (C), but can also be applied in mixed cropland (C) and pasture (P) AEZs. The functionality concerning SDS source mitigation predominately relates to increased cover (C*) effects; however, the practice also enhances soil structural health (e.g. formation of stable soil aggregates through organics and nitrogen release in the root zones), which leads to increased (soil-inherent) resistance (R). The SDS source mitigation performance is high, indicated by the large orange bar, because the practice exceeds around 88 percent of all other practices. The practice's SDS impact mitigation mechanism is agronomic (A) through farm management (i.e. mulching of residues). The SDS impact mitigation performance is below average (around 42 percent, the green bar) comparing the various practices. Impact mitigation of SDS basically functions through the stress tolerance of leguminous species compared with conventional cropping (e.g. cereal monoculture), as well as the increased surface cover (mulch) and consequential stable macropores that can potentially reduce surface pore clogging through accumulating fine SDS sediments. Scaling of the mulching technique is through individual (I) farm management with an overall low-medium scaling potential (light blue bar). Implementation costs (red bars) are low to medium and the recurrent maintenance costs are medium high (through seasonal maintenance). However, primary cobenefits (agricultural [A]) yield stability and increase, and secondary benefits (environmental (E) (e.g. soil health)) are medium to high (black bars). A similar assessment approach applies to all other listed technologies.

Further details on good practices 5–15 can be found in the list of references in Annex 4.

Table 4.1 | Overview of type, functionality and performance of selected good practices 5–15 clustered for good source mitigation, impact mitigation and cost–benefit ratio

Practice				Target particle size	AEZ	Functionality				Scaling		Costs		Cobenefits			
No.	Theme	Name	Type			Source		Impact		Type	Scalability	Implementation	Maintenance	Primary		Secondary	
						Type	Performance	Type	Performance					Type	Performance	Type	Performance
5	Source mitigation	Mulching with leguminous species	S	S, D	C, P	C, R		A		I				A		E	
6	Source mitigation	Agroforest wind barriers and alley cropping	S	S, D	F, C	O, C		H, A		C, I				E		R	
7	Source mitigation	Agrosilvopastoral systems	S	S, D	F, P	O, C		A		C, I				A		E	
8	Source mitigation	Wind erosion control by polymer cover	N	S, D	P, C	C		-		C, I							
9	Impact mitigation	Climate advisory services	N	D	C, P	-		S, A		I, C				R			
10	Impact mitigation	Livestock shelter	N	D, S	P	-		H		I				R			
11	Impact mitigation	Bahiagrass (Papsalum notatum) intercropping in orchards	S	S, D	F	C, R		A		C, I				E		A	
12	Impact mitigation	Index-based livestock insurance	N	D	P	-		S		I				R			
13	Cost–benefit	Temperature- and disease-tolerant chickpea varieties	S	D, S	C, P	C		A		I, C				A		R	
14	Cost–benefit	Marab floodwater harvesting in landscape depressions	S	S, D	P, C	O, C		A, S		I, C				A		R	
15	Cost–benefit	Large-scale solar panel installation	N	S, D	P, C	O, C		H		C, I				En			

Source: Author's own elaboration

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5 Mitigation and adaptation measures of sand and dust storms at the policy level

Key messages

The linkages between SDS and other risks, such as drought, desertification and land degradation, call for a multihazard, multisectoral and multiactor risk management approach.

Sand and dust storms must be mainstreamed into national and local DRR, as well as sectoral laws, policies, plans and strategies, which should be informed by multihazard risk and vulnerability assessments and actionable risk information.

Relevant national policies that can help to mitigate anthropogenic SDS source areas are those related to sustainable land and water management, integrated landscape management and climate change mitigation and adaptation.

Relevant institutions require specific mandates and clearly defined roles and responsibilities to address SDS as outlined in DRR and sector-specific legislation and policy frameworks, so that their mandates are enforced and clear synergies are established.

Risk-informed planning and implementation of well-coordinated actions at national, regional and interregional levels are needed, given the frequent transboundary impacts of SDS.

Effective SDS risk management requires preventative and anticipatory risk management approaches. Integrated legislation and policy actions, adequate budget and an enabling environment are needed to facilitate the large-scale application of SDS source and impact mitigation actions. Short-term responses need to be linked to long-term development actions when combating SDS.

Investment in strengthening SDS risk information systems (e.g. development of damage and loss information system for SDS, SDS early warning systems and SDS risk assessments) are key to strengthening the evidence base for urgent policy action to reduce SDS risks and impacts.

Sand and dust storm source and impact mitigation actions include the adoption and upscaling of SLM and DRR good practices at local and landscape levels, as well as the upscaling of well-coordinated risk monitoring and early warning systems to enable anticipatory actions to minimize impacts of SDS events.

There is a need to foster knowledge exchange among countries on good SDS policies and practices.

Building agricultural resilience to SDS hazards requires a range of source and impact mitigation and adaptation interventions, as summarized in Chapter 4. However, effective DRM also depends on sound governance frameworks to catalyse the technical measures at field level. Policy frameworks related to SDS vary considerably among countries and regions. This chapter highlights selected country and regional case studies and good practice examples of various SDS source and mitigation policy guidelines that reduce SDS risks, sources and impacts.

At present, overarching policy frameworks to address SDS issues are not in place. This implies that SDS risks and impacts currently have to be addressed through other existing frameworks. The Sendai Framework is a key instrument to guide the policy context for SDS from a multihazard risk management perspective. The overarching goal of the Sendai Framework is to substantially reduce "disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and economic assets of persons, businesses, communities and countries" (United Nations, 2015). It is thus critical for guiding the policy context to prevent and mitigate impacts of extreme SDS events, and to ensure timely early warning, preparedness and response actions as and when needed.

As previous chapters have demonstrated, there are important linkages among SDS, land degradation, desertification and drought, especially in the context of SDS source mitigation. In this regard, the other highly relevant international policy framework is UNCCD, one of the three Rio Conventions, adopted in 1994 with the aim to protect, restore and manage the world's land, and ensure the sustainability of the Earth and the prosperity of future generations. It is the only legally binding framework to address desertification and the effects of drought. The SDS issue is included in UNCCD Decision 25/COP.14, which notes that "the global frequency and intensity of sand and dust storms have increased in the last decade and that sand and dust storms have natural and human causes that can be exacerbated by desertification/land degradation and drought" (UNCCD, 2019).

Since 2016, SDS issues have become increasingly prominent on the United Nations agenda. The United Nations Environment Programme, WMO, the United Nations Office for Outer Space and the United Nations General Assembly, as well as the United Nations regional commissions, such as the United Nations Economic and Social Commission for Asia and the Pacific, have adopted several resolutions that respond to requests by Members for United Nations system support to help address and mitigate this emerging challenge. The United Nations General Assembly has adopted several resolutions entitled "Combating sand and dust storms" (see Section 1.3).

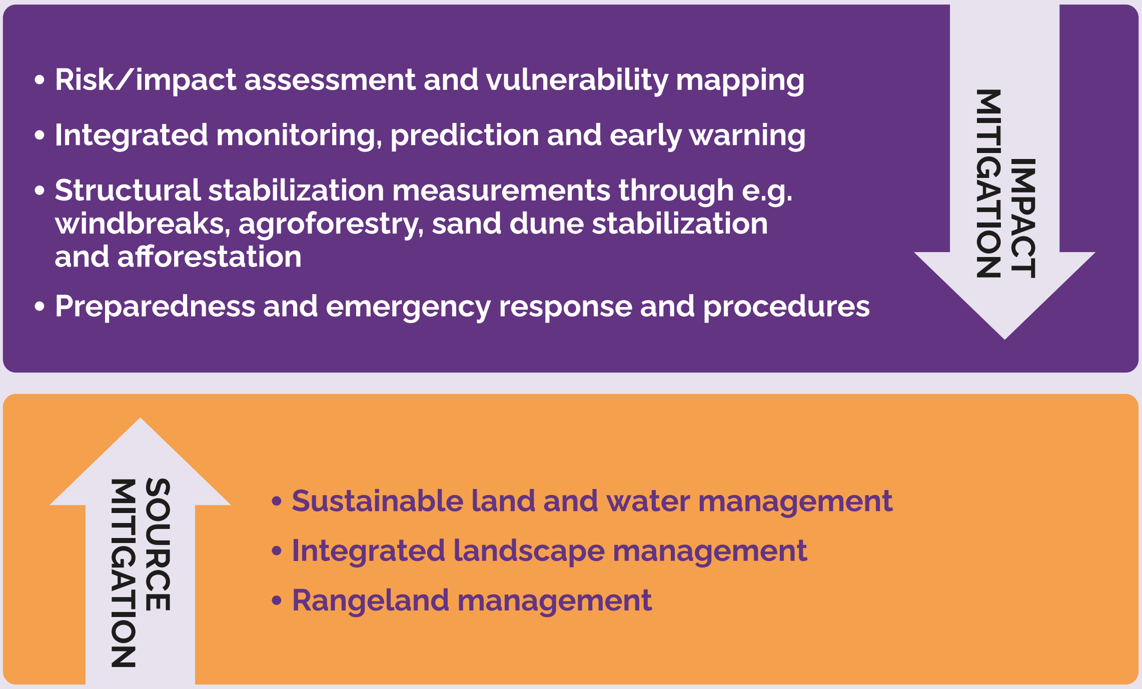
Decision 26/COP.15 of the UNCCD emphasized the need to continue collaboration with other United Nations agencies and members of the United Nations Coalition on Combating SDS in the development of a global implementation initiative on SDS and to support Parties in the development and implementation of national and regional policies on SDS, including early warning, risk assessment and anthropogenic source mitigation.

Efforts at local, national, regional and global levels must be designed to further promote resilient and sustainable agricultural development, including through sustainable land and water management. In addition, SDS risks must be integrated into national and local DRR legislation, policies, plans and strategies, which should be informed by multihazard risk and vulnerability assessment and actionable risk information. Furthermore, sectoral and development policy instruments must include SDS as an emerging risk. It is equally important that the relevant institutions are given specific mandates and clearly defined roles and responsibilities to address SDS as outlined in their DRR, SDS, agriculture, land and water management legislation and policy frameworks, including the identification and prioritization of specific SDS source and mitigation actions, with timelines and adequate budgets.

Figure 5.1 provides an overview of SDS source and impact mitigation actions, and some specific local-level practices identified and analysed in Chapter 4. These measures are key to mitigating the sources and impacts of SDS. Without these actions, SDS sources and impacts are likely to become even more severe in the future, as many regions are expected to experience increased aridity, drought frequency and drought intensity due to climate change. Their large-scale application calls for enhanced and integrated legislation and enabling policies that facilitate implementation of these actions on the ground.

The following sections provide selected good practice examples of how SDS-related policies are addressed in existing national/local DRR policies and to what extent SDS issues are main-streamed into agricultural sectoral development policies, strategies and plans. They also provide country examples of various impact and source mitigation measures designed to reduce SDS sources, risks and impacts on agriculture.

Figure 5.1 | Overview of impact and source mitigation actions to address SDS in the agricultural sector



Source: Adapted from **Middleton, N. & Kang, U.** 2017. Sand and dust storms: impact mitigation. *Sustainability*, 9(6): 1053.

5.1 Main policy issues from a disaster risk reduction perspective

The Sendai Framework consists of four priorities for action: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster risk reduction for resilience; and (iv) Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction. These priorities provide the structure for the good practice examples for SDS-related legislation, policy and institutional frameworks in certain countries and regions outlined below.

5.1.1 Understanding disaster risk

Understanding SDS risk to the agricultural sector requires that SDS hazards are systematically included when countries conduct multihazard, vulnerability and risk assessments. These assessments allow determination of the nature and extent of various risks – their location, intensity, frequency and probability – as well as the consideration of existing conditions of exposure and vulnerability, including the physical, socioeconomic and environmental dimensions, and evaluation of the effectiveness of coping capacities within potential risk scenarios (UNDRR, 2022).

In order to identify and monitor these hazards and risks, data and information systems for DRM need to be in place, available and accessible. This includes multirisk and vulnerability profiles and sector-specific maps where the risks, vulnerabilities and exposure of smallholders and farming communities are identified and prioritized so that decision-making and planning capacities for the agricultural sector can be risk-informed (FAO, 2008).

At the regional level, the Asian and Pacific Centre for the Development of Disaster Information Management, an institution of the United Nations Economic and Social Commission for Asia and the Pacific, has conducted a comprehensive SDS risk assessment study in Asia and the Pacific for different sectors, including agriculture (Box 5.1). One of the key challenges noted was the lack of SDS hazard data. This finding highlights the need for in-depth risk assessments across multiple sectors at national and local levels.

Box 5.1 | Assessment of SDS risk for the agricultural sector in Asia and the Pacific

The SDS risk assessment study undertaken by the Asian and Pacific Centre for the Development of Disaster Information Management used a quantitative method with a transboundary approach at the regional level. The findings for the agricultural sector indicated that substantial agricultural areas are affected by dust deposition in Turkmenistan (71 percent of the cropland area), Pakistan (49 percent) and Uzbekistan (44 percent).

A characteristic of dust in these parts of the region is its high salt content, which can be toxic to crops. Irrigated cotton, an important cash crop in these countries, is particularly affected (see Section 3.2). High dust deposition rates were also noted in the Himalaya Hindu Kush Mountain Range and the Tibetan Plateau, which are areas that provide freshwater to over 1.3 billion people in Asia. The deposition of dust induces a warming effect on mountain glaciers, enhancing the melting of ice, which has direct and indirect impacts on agriculture, including floods and water stress.

Source: **The Asian and Pacific Centre for the Development of Disaster Management.** 2021. *Sand and dust storms risk assessment in Asia and the Pacific*. Tehran.

At the global level, there is also a need for coordinated multicountry transboundary studies so that the multiple socioeconomic and environmental impacts can be fully understood. Risk-informed planning and the implementation of well-coordinated actions at national, regional and interregional levels are needed, given the frequent transboundary impacts of SDS. A coordinated monitoring and early warning system is also required.

At the country level, SDS risk assessment is variable. In China, the Center for Combating Desertification of National Grassland and Forestry Administration monitors SDS risks. This organization has developed a system for SDS risk assessment (Zeng *et al.*, 2007; Li, 2011), and a series of SDS risk maps are included in a collection of China's natural hazard-induced disaster risk maps (Government of China, 2011). Part of the FAO interregional project, "Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture", involved developing SDS risk assessment models for particular countries. Box 5.2 presents an example for the livestock subsector established for Mongolia, and Annex 6 summarizes a model for agriculture in the Islamic Republic of Iran.

Box 5.2 | Mongolian SDS risk assessment model for livestock

The Mongolian SDS risk assessment model for livestock was developed by selecting a variety of indicators considered to provide an adequate representation of SDS risks affecting livestock in the country. These were classified into indicators for the SDS hazard itself, the exposure of livestock and their vulnerability/coping capacity (Table 5.1). A scoring system was also developed to assess each variable and a weighted average overall score used to define five risk classes, ranging from "very low risk" to "extremely high risk." The model was tested in two selected districts (soums) that are particularly affected by SDS: Saintsagaan soum in Dundgobi aimag (province) and Zamyn-Uud soum in Dornogobi aimag (see Annex 6 for more information).

Table 5.1 | Sand and dust storm disaster risk assessment indicators for the livestock subsector in Mongolia

Risk assessment components and key variables		Description	Indicators	Assessment timing: when; which period	Scores	Weight (%)	Component weight (%)
Hazard	1. SDS frequency	Short-term condition	Number of days with SDS in March–May	Daily; March–May, CY	1–5	5	40
	2. SDS severity	Triggers SDS and determines its severity	Product of wind velocity (m/s) and duration (hours) of days with SDS in March–May	Daily; March–May, CY	1–5	15	
	3. Dust concentration level	Immediate condition	PM_{10} level (data from local monitoring or SDS-WAS)	Daily; March–May, CY	1–5	5	
	4. Temperature (accounts for wind-chill effect on animals)	Immediate condition	Daily temperature	Daily; March–May, CY	1–5	5	
	5. Drought condition	Short-term condition	Standardized precipitation evapotranspiration index	Monthly; March–May, CY	1–5	10	

Box 5.2 (continued)

Risk assessment components and key variables		Description	Indicators	Assessment timing: when; which period	Scores	Weight (%)	Component weight (%)
Exposure	6. Soil characteristics critical for SDS susceptibility and severity	Mid-term trend	Integrated soil erodibility map	Once; for previous 3–5 years	1–5	6	23
	7. Vegetation characteristics critical for SDS susceptibility and severity	Mid-term trend	NDVI monitoring/ desertification map	Once; for previous 3–5 years	1–5	6	
	8. *Dzud* condition in previous months	Short-term condition	Dzud risk classes	Once; December, PY	1–5	3	
	9. Seasonal stocking density	Short-term condition	Number of sheep units per 100 ha	Once; December, PY	1–5	8	
Vulnerability/ coping capacity	10. Level of overgrazing	Medium-to long-term condition	Annual average animal numbers compared to optimum (%); percentage area of high desertification class/rate	Once; December, PY	1–5	15	37
	11. Animal shelter supply	Short-term condition	Supply (%)	Once; December, PY	1–5	10	
	12. Communication capacity	Short-term condition	Share of households with mobile phones (%) and georeferencing application	Once; December, PY	1–5	8	
	13. Supplementary fodder supply	Short-term condition	Feed unit (kg) per sheep unit	Once; December, PY	1–5	4	

Notes: Mid-term trend refers to timing for three to five years; short-term condition refers to timing for less than a year, usually three to five months; immediate condition refers to timing for less than a day. For risk assessment of any particular year, values in mid-term and short-term variables will not change, while values in immediate and trigger variables will change according to dates when SDS events happen. The model can be used for SDS risk forecasting using forecast data for immediate and trigger variables. CY = current year; PM_{10} = particulate matter with diameter less than 10 μm; PY = previous year. Dzud is a very harsh winter condition, during which the ground is frozen solid, sometimes under firm snow, to a degree that animals cannot graze.

Source: **Enkh-Amgalan,** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia.* Rome.

The risk assessment conducted for Mongolia found there was a need to further strengthen continuous risk monitoring and to develop SDS risk maps to inform anticipatory action. Proactive risk management legislation and policies are also required to ensure countries conduct systematic SDS damage and loss assessments (see Section 3.5). This will strengthen the evidence base for urgent policy action in response to SDS disasters.

Countries are advised to make better use of the SFM online tool. For agriculture-related damage and loss, SFM Indicator C-2 allows close monitoring of damage and loss in and across all agricultural subsectors by hazard and commodity types at subnational administrative levels. The application of this tool requires well-oriented capacity development, including training and awareness-raising, backed up by strong policy guidance.

Policies and practices for DRM should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. This knowledge can be leveraged for predisaster risk assessment, for prevention and anticipatory action measures, as well as for the establishment and implementation of appropriate impact mitigation and preparedness actions for effective response to disasters.

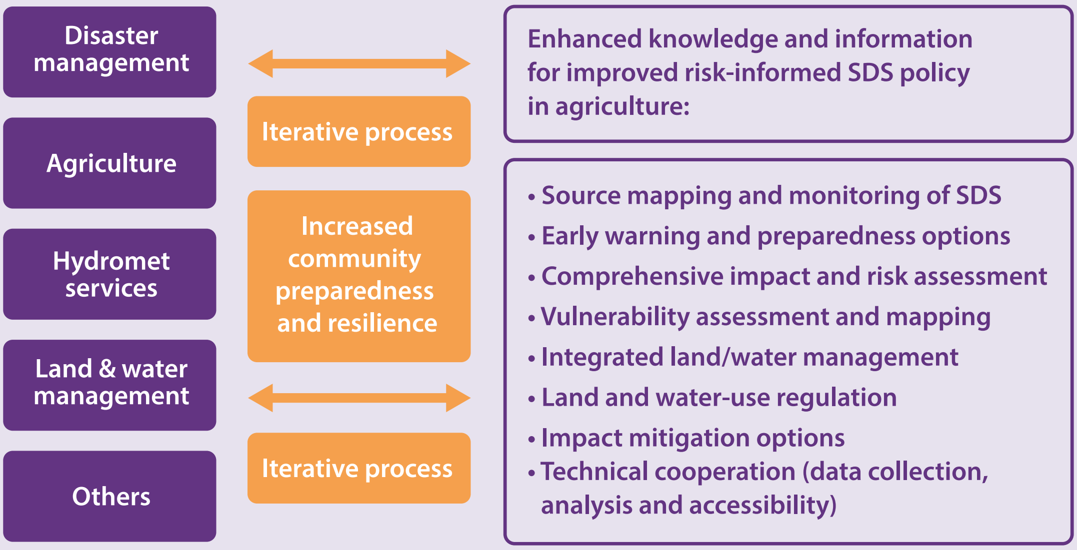
However, in many countries, policies to proactively support the better understanding of risk are still lacking, especially for SDS. As an example, a recent report by the World Bank (2019) discussed disasters induced by natural hazards in the Middle East and North Africa region, and noted that there were no risk assessment reports available for Kuwait, even though SDS are a frequent occurrence in the country (Al-Dousari, 2021). Policies supporting the institutionalization of this type of risk assessment are a first step towards better understanding the existing SDS risk situation. Thereafter, the policies can inform relevant national DRR and sectoral policies, plans and strategies.

5.1.2 Strengthening governance for disaster risk reduction and management

Mitigating the impacts of SDS requires SDS to be mainstreamed into national and local DRR and DRM laws, policies, plans and strategies, as well as their sectoral equivalents. The linkages between SDS and climate change should be integrated into these legal and policy frameworks. In addition, the specific DRR roles and responsibilities of relevant institutions should be outlined in DRR and DRM and sectoral laws and policies so their mandates are enforced, and clear synergies are drawn among the various agriculture-relevant stakeholders.

Another important element is the establishment of horizontal and vertical coordination mechanisms (among the various governance levels – national to local and vice versa), as well as institutional interlinkages within and across sectoral agencies. These coordination mechanisms and interinstitutional linkages are also key to ensuring appropriate channelling of resources and information (FAO, 2008). Figure 5.2 provides an overview of a coordination and cooperation framework for enhanced knowledge and information for risk-informed SDS policy in agriculture.

Figure 5.2 | Coordination and cooperation needs for enhanced knowledge and information for risk-informed SDS policy in agriculture



Source: Adapted from **United Nations Convention to Combat Desertification.** 2022. *Sand and dust storms guide: summary for decision makers*. Bonn.

Mainstreaming SDS into national/local DRR and sectoral plans, policies and strategies is essential. In addition, SDS hazards should be integrated into regional-level planning and policies due to the transboundary nature of SDS. A good example of such strengthened regional governance is from a recently developed regional plan of action on SDS in the Asia-Pacific region (Box 5.3). Similar plans should be developed for other SDS-prone regions.

Box 5.3 | Regional plan of action on sand and dust storms in asia and the pacific

A regional plan of action on SDS in the Asia-Pacific region has been developed, based on a comprehensive risk assessment study (Box 5.1). This regional plan of action is a first of its kind and was endorsed at the seventy-eighth session of the United Nations Economic and Social Commission for Asia and the Pacific on 27 May 2022. It serves as a strategic framework for countries in Asia and the Pacific to undertake actions at the national and regional levels, in the context of multihazard DRR, to reduce the negative impacts of SDS and identify anthropogenic measures that could contribute to mitigating their formation and intensity.

The five-year action plan includes three operational objectives:

Operational Objective 1: "Improve the understanding of the socioeconomic impact of sand and dust storms with a view to accurately inform policies and investments to mitigate their impact and enhance source mitigation."

Operational Objective 2: "Extend the monitoring system and improve the early warning system to include an impact-based focus, to provide timely forecasts of sand and dust storms and enable targeted measures to minimize exposure and reduce risks."

Operational Objective 3: "Put in place coordinated regional actions in the most at-risk and exposed geographical areas to mitigate the risk of and exposure to sand and dust storms."

Source: **United Nations Economic and Social Council.** 2022. *Regional plan of action on sand and dust storms in Asia and the Pacific*. ESCAP/78/12/Add.1. 4 April 2022.

5.1.3 Investing in disaster risk reduction for resilience

Building resilience to SDS requires investment in DRR measures, such as those detailed in Chapter 4. The right policy framework is a critical precursor to such investment. There is also a need for increased risk financing to support and scale up the application of these SLM and DRR measures to combat SDS and to mainstream SDS into LDN activities. Combating land degradation will help combat SDS and vice versa. There are currently no specific international funds that focus on SDS-related risk financing.

The strong linkages noted in earlier chapters among SDS and land degradation and drought/climate change should be harnessed to better link SDS risk financing to climate finance and green investments, thus addressing multiple environmental challenges in an integrated way. Countries should consider international funds, including the Green Climate Fund and the Global Environment Facility, as sources of finance to support the application of existing SDS good practice options at local and landscape levels, which can be linked to national LDN targets, for example. It therefore becomes even more important to include the implementation (adoption and upscaling) of good practices in the sectoral policies, strategies and plans of countries to reduce the adverse impacts of SDS.

Policies should also encourage and facilitate the implementation of risk transfer mechanisms, including risk-informed and shock-responsive social protection systems and risk insurance. This can help to reduce people's vulnerabilities and exposure to financial impacts, as well as underlying risks to food and nutrition insecurity (Glauber *et al.*, 2021). Risk-informed and shock-responsive social protection schemes can provide cash or in-kind support (food or agricultural assets), conditionally or unconditionally, which can improve farmer/smallholder welfare and livelihoods through reducing cash, savings and liquidity constraints. These schemes can thus protect assets and livelihoods to better manage risks. They can also assist producer organizations or farmer cooperatives to manage contingency funds, savings, loan schemes and risk-sharing schemes (e.g. grain reserves, warehouse receipt systems and revolving funds).

By contrast, risk insurance, such as crop insurance and weather index-based insurance, can spread the risk of income loss to farmers. Such insurance can also help farmers to avoid having to sell their assets (crops and livestock) as a coping strategy after the negative impacts of a disaster (FAO, 2013). For instance, in Jordan, even farmers who are not subscribed to the Agricultural Risk Fund (ARF) can be compensated against the impact of certain natural hazard risks (Box 5.4) (FAO, 2013).

Box 5.4 | Agricultural Risk Fund to compensate disaster damage and loss incurred by farmers

In Jordan, due to the revision and approval of the by-law for the ARF by the Lower House of Parliament in January 2021 (Article 2), the compensation coverage was expanded for farmers who are not subscribed to the fund and also to include other natural hazard risks, such as drought, snow, flash floods, heavy rains and storms as well as epidemiological diseases that might affect plants and animals (Government of Jordan, 2021).

The ARF was established in 2009 and became fully functional in 2015 with the adoption of a by-law issued in the same year, which makes provisions for a national budget allocation of JOD 15 million over a three-year period (CADRI, 2017). The Agriculture Risk Fund Unit of the Ministry of Agriculture, which was established in the same year of the creation as the ARF, supports the roll out of the Fund.

The ARF (FAOLEX Database, 2015) aims to: (i) manage the risks to the agricultural sector and reduce the effects; (ii) compensate farmers affected by natural hazard risks according to standards, mechanisms and limits set by a by-law issued for this purpose; (iii) compensate beneficiaries in case of agricultural risks according to standards, mechanisms and limits set by a by-law issued for this purpose; (iv) encourage farmers and beneficiaries (subscribers) to adopt modern means to minimize agricultural risks and develop control techniques to reduce losses; (v) build institutional capacity in agricultural risk management; and (vi) contribute to sustainable agricultural development.

5.2.4 Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction

Strengthening capacities in proactive disaster preparedness for effective response and recovery at all levels is needed due to the future expected increase in SDS risk in many parts of the Dust Belt. Preparedness for response and recovery from SDS requires the knowledge and capacities to effectively anticipate, monitor and be prepared to respond to and recover from the impacts of SDS events. It also helps to ensure orderly transitions from disaster response to a resilient and green recovery. Enhancing disaster preparedness involves a sound understanding of disaster risks, and strong linkages with hazard-specific or multihazard early warning systems to enhance the capacity to predict, monitor and act quickly when necessary.

The implementation of adequate risk-informed preparedness measures before a disaster occurs can make response actions more effective, efficient and timely, and can save lives and livelihoods (UNISDR, 2008). Such measures include national and local preparedness planning, specific contingency planning, simulation drills and exercises, stockpiling equipment and supplies, and establishment of coordination mechanisms for evacuation, rapid risk assessment and dissemination of public information.

Preparedness actions for SDS should be included in relevant national-level policies, strategies and plans. One example for systemic, anticipatory SDS preparedness measures is China’s 2005 national emergency plan for severe SDS, which was revised in 2020 (Government of China, 2020). The updated 2020 plan is based on lessons learned from over ten years of experience in emergency management of major SDS storm disasters. It outlines the working principles, incident and response classification standards, emergency response processes and information reporting as part of an enhanced organization and command system, optimized monitoring and early warning of SDS, and proposed systematic safeguard measures.

In addition to regular contingency planning, SDS require continuous risk monitoring and early warnings to allow people downwind to take preparedness and anticipatory action measures to minimize impacts. These systems should provide localized, timely, relevant, reliable and accurate multihazard alerts so that the adverse effects on the agricultural sector can be reduced/mitigated, or better prepared for (UNISDR, 2010; FAO, 2013). As SDS are national as well as transboundary events, it is important to link national SDS early warning to regional and global systems.

The WMO SDS Warning Advisory and Assessment System (SDS-WAS) was established in 2007 to establish such linkages, providing timely, quality SDS forecasts, observations, information and knowledge to users through international partnerships of research and operational communities. It operates through five regional nodes:[10]

- **Northern Africa, Middle East and Europe**, hosted by the Barcelona Supercomputing Center;
- **Asia,** hosted by the China Meteorological Administration;
- **The Americas,** hosted by the Caribbean Institute for Meteorology and Hydrology in Barbados;
- **Gulf Cooperation Council countries,** hosted by the National Center for Meteorology in Saudi Arabia; and
- **West Asia,** cohosted by the Iran Meteorological Organization and the Turkish State Meteorological Service.

The ways in which the information provided by the SDS-WAS is used is used within countries is an issue for national governments. Box 5.5 gives an example of how a warning advisory system for SDS can be developed at the subnational level for Burkina Faso. It also includes an effort to make SDS warnings applicable to agriculture. Warnings need to be developed to provide impact-based forecasts for SDS that are specific and relevant to agriculture and its subsectors.

10 Note the geographical coverage of some regional nodes overlaps with others.

Box 5.5 | Warning advisory system for SDS in Burkina Faso

Burkina Faso, a landlocked country in Sahelian Africa, is frequently affected by SDS during the dry season. Such storms adversely affect human health and various sectors of the economy, including agriculture. A warning advisory system for SDS has been established for the country's 13 administrative regions.

The core of the system features a colour-coded map indicating the risk of high dust concentrations during the next 48 hours. The State Meteorological Agency of Spain and the Barcelona Supercomputing Center, in collaboration with the Burkina Faso National Meteorological Agency, design and operate the system, using data from the WMO SAS-WAS. The warning thresholds, which are specific for each region, have been established based on the climatology of the forecast product itself, using a percentile-based approach.

This SDS warning system issues generic warnings of atmospheric dustiness. Critical next steps include adapting the warnings to specific sectors, including agriculture. This requires assessment of the needs of user groups in agriculture (e.g. farmers and herders). At the end of 2017, assessments of user requirements were undertaken with regard to agrometeorological services in general in the pilot municipalities of Niangoloko, Tenado and Titao. Seminars were also conducted with agrometeorologists, radio operators, extension services, local authorities and farmers to enhance the adaptive capacity of farmers to the dynamics of the rainy season, anticipate crop yields and strengthen the service over time, as well as evaluate the benefits of enhanced agrometeorology services at the pilot sites during the 2019–2020 seasons.

Studies showed that, on average, 86 percent of the pilot farmers received regular and understandable weather and climate information from May to October and approximately 80 percent of the end users used them to make risk-informed decisions regarding their agrosilvopastoral operations.

Source: **Climate Risk and Early Warning Systems.** 2020. *CREWS Burkina Faso status report – July to Dec 2020.* ***Washington, DC.*** https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocrews/s3fs-public/ckeditor/files/421433_Burkina_Faso_CREWS_Project_Status_Report_July_Dec_2020.pdf?tozqGKsHLPs9rsvrd5L4rjYUykxebh_p

5.2 Policies for source mitigation

The strong linkages between SDS on the one hand, and desertification, land degradation and drought on the other, have put SDS issues firmly on the agenda at the UNCCD Secretariat. In 2017, it produced a policy advocacy framework for combating sand and dust storms (UNCCD, 2017) in which countries were invited to consider developing and adopting SDS policies, where appropriate, in each of three interrelated principal action areas: (i) monitoring, prediction and early warning; (ii) impact mitigation, vulnerability and resilience; and (iii) source mitigation. The policy advocacy framework focuses on DRR, in line with the Sendai Framework. The first two of the interrelated principal action areas have been discussed above, but the third – source mitigation – is worthy of further discussion in this section.

Areas where human actions play a part in SDS events should be the focus of SDS policies designed to facilitate actions to reduce the occurrence of SDS through methods for controlling soil erosion by wind. These SDS source mitigation strategies will be most effective when opportunities are maximized for synergies with the other Rio Conventions and related initiatives.

Sustainable land and water management and integrated landscape management practices, ecosystem restoration interventions and climate change mitigation and adaptation options can all contribute towards the mitigation of anthropogenic SDS source areas. An especially important opportunity lies in the strong synergy between SDS source area mitigation practices and national efforts to achieve SDG Target 15.3 on LDN. Linking SDS source mitigation to national LDN targets can generate multiple cobenefits.

Relevant national policies that can mitigate anthropogenic SDS source areas are those related to SLM, integrated landscape management, integrated water management and climate change mitigation and adaptation (Middleton and Kang, 2017). They include policies for land governance, land-use planning and natural resource conservation and management. Such policies should aim to address the physical and sociocultural aspects of the local context.

To provide a foundation for SDS source mitigation, UNCCD has developed voluntary policy guidelines for SDS source management that present practical, proven, gender-responsive, scientifically based and generally accepted principles along with clear guidance on how to translate these principles into practice.

5.3 Risk-informed policy frameworks and actions in agriculture

Societies in many regions – in the Dust Belt and beyond – have long been exposed to SDS hazards. Numerous techniques for reducing wind erosion have therefore been developed in areas of dryland agriculture, as have methods for protecting agricultural activities from the worst impacts of SDS. However, many approaches to SDS impacts tend to be reactive, with a general focus on crisis management.

The risks and impacts of SDS can be reduced and managed. To do so, all stakeholders, including policymakers, practitioners (development and humanitarian actors) and local communities, must work together to change the way SDS risks and impacts are managed. This can be done by employing preventive and anticipatory measures to multihazard DRR and climate change adaptation and mitigation actions, including through the application of sustainable land and water management, biodiversity conservation for sustainable agricultural production and development, and ecosystem restoration, supported by risk-informed preparedness and anticipatory actions. These complementary actions are key to enhancing the resilience capacities of societies (particularly those that are strongly dependent on agriculture) to prevent, anticipate, absorb, adapt and transform ahead, and in the face of, SDS events threatening and affecting their livelihoods and food systems.

Building resilience to SDS hazards in agricultural societies, which will also build longer-term sustainability, needs sound governance frameworks to catalyse technical and non-technical measures at field and landscape levels. Policy frameworks related to SDS vary considerably among countries and regions, as well as among sectors, and this chapter has highlighted some examples of how they can be developed further from an agricultural perspective.

Policies for SDS should be driven by prevention rather than by crisis, and should be based on synergies with other complementary policies. Reducing the impacts of SDS requires policy frameworks and action on the ground for all countries that suffer from SDS. Furthermore, because of the transboundary nature of many SDS events, national SDS policies must be coordinated, supported by and aligned to international and regional contexts and policy frameworks. Finally, SDS risk funds need to be put in place to support implementation of risk-informed SDS policies and actions on the ground.

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6 Conclusions and recommendations

6.1 Conclusions

Sand and dust storms commonly occur in drylands, where their impacts on society are severe. The impacts of SDS are also felt outside the drylands because desert dust is frequently transported over great distances, often across boundaries. Many aspects of this emerging disaster risk management issue are understudied and poorly understood, a situation that weakens the risk reduction and mitigation response of policymakers and society's efforts to tackle the issue. In addition, societies often seek actions during SDS events but pay less attention to long-term risk reduction strategies. However, long-term actions, such as integrated SDS risk management measures, are indispensable if the actions to combat SDS are to be strengthened.

Agriculture is one of the major anthropogenic drivers of SDS, via poor land and water management, desertification and land degradation as described in Chapter 2. In turn, SDS have direct adverse impacts on agriculture, resulting in the loss of crops, trees and livestock or significant decreases in their production, which also causes land degradation. These effects occur during all three phases of the wind erosion system: on entrainment of soil particles in source areas, during their transport and on deposition, as described in Chapter 3. The impacts can be direct and indirect, having both immediate short-term effects and chronic long-term consequences. Some of these consequences can be positive for farmers and herders, but many are negative and undermine the sustainability of agriculture and food systems, reducing their capacity to meet the needs of present and future generations.

Drought conditions typically result in more frequent and intense SDS. Climate change projections also indicate worsening SDS due to the expansion of global drylands, increased aridity and enhanced drought conditions (frequency, severity and duration), and, consequently, less vegetation cover. Unless appropriate interventions are made therefore, the adverse impacts of SDS are likely to become even more severe in the future.

A large proportion of major agricultural activities take place in the world's drylands. Most rangelands are in semi-arid to arid climate zones and some 40 percent of global cropland is located in the drylands. Agriculture is therefore key to mitigating SDS globally when sustainable practices are implemented. However, in areas where SDS are generated naturally, there is much less potential to reduce them, so the SDS hazard will not disappear entirely. Consequently, a combination of good mitigation measures, together with proper planning for emergencies and adaptation to SDS, is necessary to combat the sources and impacts of SDS.

This Guide identifies more than 150 high-impact, context-specific practices (both SLM and non-SLM) to reduce SDS sources and impacts on the agricultural sector at the local level. These practices are presented in Annex 1, which serves as a guide to choose the most suitable practices per context according to multiple user-selected attributes. This longlist of practices has also been refined to produce a selection of 15 good practices to reduce SDS source and impacts on agriculture as described in Chapter 4. The choice of practices considers functionality, scaling, costs and cobenefits. These good practices have been chosen to cover a range of AEZs. The four top-ranked practices are: (1) conservation agriculture in dryland mixed systems; (2) drought-tolerant forage species (sulla); (3) mechanized MWH using the Vallerani tractor plough and; (4) aerial seeding of saxaul trees.

Building resilience to SDS hazards in agricultural societies requires sound governance frameworks to help catalyse technical and non-technical measures at local levels. Sand and dust storms should be addressed as part of national multihazard DRR and DRM strategies linked to the Sendai Framework and the SDG Target 15.3 on LDN. Tackling SDS should also be incorporated into development planning in and across various sectors to further enhance national and regional resilience strategies and development programmes as described in Chapter 5.

There are direct links between SDS and the three indicators used to monitor LDN – soil organic carbon, land productivity and land cover. These indicators are in turn directly linked to food production and sustainable management of agricultural resources. The risk of SDS occurring is enhanced in areas where vegetative land cover is lost; SDS events themselves almost invariably result in a decline in productivity in the source area; and soil erosion by wind rapidly reduces soil organic carbon stocks. Policies and programmes designed to mitigate SDS sources will also have the effect of avoiding, reducing and/or reversing land degradation, thus delivering multiple environmental, economic and social benefits. Benefits will also be realized in downwind impact areas (deposition areas) in various sectors including health, electricity generation and transport.

6.2 Recommendations

Up-to-date scientific information is needed to identify and monitor specific high-risk SDS source areas and their agricultural systems (in particular, crops, trees, pastures and livestock) before selecting the appropriate good practices to reduce SDS sources and adverse impacts. Further research is also needed to assess the economic and social impacts of SDS on the agricultural sector, both on site and off site, using standardized methods. The FAO damage and loss methodology is available to help in this regard. The tool is used as part of the SFM to report on Indicator C-2 ("Direct agricultural loss attributed to disasters") and the corresponding SDG Indicator 1.5.2 ("Direct economic loss attributed to disasters in relation to global GDP"); it considers an SDS event as disastrous when it has a visibility of 1000 m or less. Including SDS in the national SFM system will ensure regular impact assessment and monitoring of SDS events that will inform long-term risk reduction policies.

Selection of appropriate context-specific good practices (both SLM and non-SLM) to reduce SDS sources and impacts can be achieved using the database presented in Annex 1. Navigating through the longlist of more than 150 practices can be pursued with filters for multiple attributes (e.g. agroecological target zone, scaling readiness). For each practice in the longlist, a practice description is complemented by ranking mechanisms indicating how well a certain practice performs (e.g. on SDS source or impact mitigation, scaling and costs or [co]benefits).

Large-scale application of SDS source and impact mitigation practices requires enhanced and integrated legislation and enabling policies, institutional capacities and adequate financial resources that facilitate implementation of these actions on the ground. For guidance, this Guide includes various country examples of how this has been approached. It will be important to strengthen the enabling environment for programme implementation and upscaling, including policies, knowledge-sharing and awareness-raising, innovative finance (e.g. harnessing carbon markets via sequestration gains achieved by greening of at-risk landscapes), incentive systems (e.g. with links to social protection schemes) and public-private partnerships (e.g. development of affordable disaster and climate risk insurance products for farmers/herders).

Strengthening SDS information and analysis should include the development of SDS risk monitoring and early warning systems that allow timely alerts and early warnings to be issued through various communication channels. This will enable early/anticipatory actions to be undertaken in high-risk areas, aiming to especially protect the most vulnerable people's lives and livelihoods. Such early warning for agriculture should be impact-based and tailored to specific vulnerable agricultural sub-sectors.

Mitigating the impacts of SDS requires SDS to be mainstreamed into existing national and local DRR and DRM laws, policies, plans and strategies, as well as their sectoral equivalents. The linkages between SDS and climate change and sustainable land/natural resources management should be integrated into these legal and policy frameworks. In addition, specific DRR roles and responsibilities of relevant institutions should be clearly defined and outlined in DRR and DRM and the sectoral laws and policies, so that their mandates are enforced. Coordination mechanisms among the various governance levels (national to local) should be established, as well as institutional interlinkages within and among sectoral agencies, so that synergies and complementarities can be strengthened.

The transboundary nature of many SDS events means risk-informed planning and implementation of well-coordinated actions are required at national, regional and interregional levels. National capacity and awareness-raising of SDS should be developed (e.g. through trainings, workshops, educational materials, preparedness planning, specific contingency planning). Transboundary coordination will be mutually beneficial, for instance in the exchange of knowledge and experience among countries on risk-informed policies, plans, strategies and good practices, as examples to guide successful implementation in other countries. The recently developed regional plan of action on SDS in the Asia-Pacific region is a good example of strengthened regional governance. Similar plans should be developed for other SDS-prone regions. At the national level, this Guide highlights how three countries (Iraq, Islamic Republic of Iran and Mongolia) were supported in developing SDS risk contingency planning and SDS risk management action plans in selected pilot districts affected by SDS. This effort needs to be scaled up to other parts of these countries subject to SDS risk, and similar actions should be developed for SDS-prone regions in other countries.

Urgent action must be taken now. Short-term responses need to be linked to long-term development actions to enhance efforts to combat SDS. The adverse impacts of SDS are likely to become even more severe in the future, particularly due to climate change, unless appropriate interventions are made.

Annex 1

High-impact, context-specific practices to reduce SDS sources and impacts on the agricultural sector at the local level

The Excel database (including macros) consists of three worksheets:

Sheet 01. "Read me first"

Sheet 02. "SDS - Full list"

Sheet 03. "Filter"

Sheet 01 "Read me first" provides explanations of all headers of the list of SDS practices on Sheet 02 ("SDS - Full list"). It describes each column of the SDS practices list (Sheet 02) and provides information on the abbreviations and ranking mechanisms applied. The "SDS - Full list" (Sheet 02) contains all SDS source and impact mitigation practices collated and described. Navigating through the longlist of good practices can be pursued through a "Filter" (Sheet 03). Various filters are defined in Sheet 03, which provides connections to all practices and enables convenient user navigation and filtering for multiple attributes. The user can control the various themes (e.g. SLM type, agroecological target zone or scaling readiness) that eventually allow the selection of good practices matching the individually set application context.

For each practice in the longlist (Sheet 02), a description is complemented by ranking mechanisms, depending on the attribute, indicating how well a certain practice performs (e.g. on SDS source or impact mitigation, scaling and costs or [co]benefits). The ranking was developed in several iterations through an international SLM expert group and in close collaboration with the project partner countries. Site suitability (scaling), technology readiness (ranging from experimental status to market available technology) and technology use level (limited use/widely used) are also reflected through ranking, which subsequently feeds into an overall scoring system that allows the comparison of practices. Ultimately, the longlist provides total scores for source and impact mitigation as well as for a combination of source and impact mitigation performances. In addition to the benefit type classification, the SLM and non-SLM (co)benefits and costs are ranked (low, medium and high values), which enables selection of highly effective SLM and non-SLM practices within a certain cost–benefit ratio.

The database can be found here:
https://www.fao.org/fileadmin/user_upload/faowater/docs/SDS/Annex_1_SDS_good_practices.xlsx

Annex 2
Data used for suitability mapping for selected good practices

Criteria		Good practice				Data source		
Criterion	**Range**	**Vallerani**	**Saxaul tree**	**Sulla**	**Conservation agriculture**	**Name**	**Citation**	**Link**
Rainfall (mm)	Min	80	100	250	0	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	**Funk, C., Peterson, P., Landsfeld, M., Pedreros, D. Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A. & Michaelsen, J.** 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data, 2*: 150066.	https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_PENTAD
	Max	300	300	500	2500			
Slope (%)	Min	0	0	0	0	Shuttle Radar Topography Mission (SRTM)	**Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D. & Alsdorf, D.E.** 2007. The shuttle radar topography mission. *Reviews of Geophysics*, 45(2): RG2004.	https://developers.google.com/earth-engine/datasets/catalog/USGS_SRTMGL1_003
	Max	20	100	15	15			
Soil texture (%)	Rock (max content)	20	40	20	20	World Soil Information International Soil Reference and Information Centre (ISRIC)	**Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E. & Rossiter, D.** 2021. SoilGrids 2.0: Producing soil information for the globe with quantified spatial uncertainty. *Soil*, 7: 217–240.	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/713396f8-1687-11ea-a7c0-a0481ca9e724
	Clay (max content)	50	40	40	50			https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/713396f7-1687-11ea-a7c0-a0481ca9e724
	Sand (max content)	50	60	40	50			https://doi.org/10.17027/isric-soilgrids.713396fa-1687-11ea-a7c0-a0481ca9e726

Criteria		Good practice				Data source		
Criterion	**Range**	**Vallerani**	**Saxaul tree**	**Sulla**	**Conservation agriculture**	**Name**	**Citation**	**Link**
Soil depth (m)	Min	0.4	0.4	1	0.4		**Poggio, L., de Sousa, L. M., Batjes, N. H., Heuvelink, G. B. M., Kempen, B., Ribeiro, E. & Rossiter, D.** 2021. SoilGrids 2.0: Producing soil information for the globe with quantified spatial uncertainty. *Soil*, 7: 217–240.	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/f36117ea-9be5-4afd-bb7d-7a3e77bf392a
Altitude (m)	Min	-400	-400	100	-400	Shuttle Radar Topography Mission (SRTM)	**Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M., Rodriguez, E., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Oskin, M., Burbank, D. & Alsdorf, D.E.** 2007. The shuttle radar topography mission. *Reviews of Geophysics*, 45(2): RG2004.	https://developers.google.com/earth-engine/datasets/catalog/USGS_SRTMGL1_003
	Max	2500	2000	500	2000			
Temperature (°C)	Min (monthly)	> -10	> -20	> -5	> -10	TerraClimate	**Abatzoglou, J.T., Dobrowski, S.Z, Parks, S.A. & Hegewisch, K.C.** 2018. Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958-2015. *Scientific Data*, 5: 170191.	https://developers.google.com/earth-engine/datasets/catalog/IDAHO_EPSCOR_TERRACLIMATE
	Annual average	5	5	5	5			
Ecosystem	AEZ	Pasture	Forest	Pasture	Crop	Copernicus Global Land Service (CGLS) Land Cover 100 m resolution version 3	**Buchhorn, M., Lesiv, M., Tsendbazar, N.- E., Herold, M., Bertels, L. & Smets, B.** 2020. Copernicus Global Land Cover Layers - Collection 2. *Remote Sensing*, 12: 1044.	https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_Landcover_100m_Proba-V-C3_Global
			Pasture					

Source: Author's own elaboration

Annex 3
Potential effectiveness of good practices 1–4

Maps of the potential effectiveness of the good practices for combating SDS risk were created in the following way.

The suitability map, considered as one masked layer for each good practice, was overlain on a reclassified version of the UNCCD's Sand and Dust Storms Source Base-map (https://maps.unccd.int/sds/), which provides information on the relative intensity of potential dust sources.

The original UNCCD SDS map index ranges between 0 and 1, but was reclassified into the following ranges and given values of 1, 2 and 3:

0–0.4 → 1 (low risk)

0.4–0.7 → 2 (medium risk)

0.7–1 → 3 (high risk)

Using a simple multiplication between the two maps, the resulting layer is classified as follows:

1 → low effectiveness

2 → medium effectiveness

3 → high effectiveness

0 → not applicable

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Annex 5
Policy brief: tackling sand and dust storms in Mongolia – An agricultural perspective

Key messages

The growing frequency, intensity and geographical coverage of sand and dust storms (SDS) in Mongolia are of grave concern. Evidence of SDS impacts on the environment and socioeconomic sectors is increasing. Issues related to SDS must be mainstreamed and addressed in national disaster risk reduction (DRR) and climate change adaptation strategies and policies, as well as in sectoral development plans.

Sand and dust storms are closely linked to desertification, drought, *dzud* and climate change. In the absence of mitigating actions, the impacts of such storms will become even more severe, with increasing aridity as well as a growing frequency and severity of *dzud* and drought due to climate change.

The economic damage and loss due to SDS must be systematically assessed and included in the national Sendai Framework Monitor (SFM) and translated into long-term DRR policy actions. This will guide and direct investment where it is needed to strengthen the resilience of affected communities and sectors.

Combating SDS requires integrated approaches to multihazard DRR, climate change adaptation and sustainable land/natural resources management within and across sectors and ecosystems, including cropland, wetland, rangeland, desert and semi-desert. To do so, effective governance and financing mechanisms for interministerial collaboration, capacity development, information exchange, implementation and targeted upscaling of sustainable land and water management and grazing management practices, knowledge-sharing, knowledge transfer and resource mobilization must be in place.

Key preventive and anticipatory measures to address SDS include: (i) promoting sustainable land and water management and good DRR practices, through an integrated approach and coupled with a conducive enabling environment, to address the root causes of SDS at field and landscape levels; (ii) strengthening SDS risk assessment and analysis, monitoring and early warning systems (single and multiple hazards) to enable early action; and (iii) promoting SDS risk transfer mechanisms such as through risk-informed social protection and risk insurance.

Sand and dust storm risks

Mongolia is recognized as a high dust emission zone (> 500 tonnes/km2 annually), with the total deposition amount in 2010 estimated at 371.8 million tonnes (UNECE, 2018). The impacts of SDS are extremely high when they occur in combination with, or after, other hazards, such as *dzud* and drought, which are also common phenomena in the country. Such cascading impacts significantly increase the exposure and vulnerability of natural habitats and herders to SDS.

Furthermore, most of the country's natural resources are increasingly vulnerable to degradation or scarcity, due to the overuse of certain land and water resources to the point where they cannot be sufficiently replenished in a certain place and time period. Changes in climate conditions, human behaviour, economic growth and development decisions contribute to further increasing risk and exposure to SDS and other types of disasters (Jeggle, 2013).

The worst impacts of SDS are felt during the spring months of March to May, when livestock are weakened and not well fed after the long winter period, with subzero temperatures often adding a significant wind-chill factor to SDS events. Hence, the term "snow and dust storm" is widely used in Mongolia. The low temperatures, especially at night, are a key factor leading to high livestock mortalities. During 2004–2013, snow and dust storms caused a total economic loss in Mongolia of approximately MNT 845.2 billion (USD 127.8 million[11]) (NEMA and JICA, 2018; UNDRR, 2019).

The SDS event of 14 March 2021 hit several *aimags* (provinces) in the country with wind velocities of up to 40 m/s and visibility of less than 5 m, continuing for 6–10 hours. The storm caused the loss of 35 506 livestock (some 18.1 percent were goats, 16.1 percent were sheep and 12.6 percent were cattle) among 454 herder households in just one district (Saintsagaan, Dundgobi Province) in the Gobi Desert region (FAO, forthcoming).

The regular occurrence of various and interconnected natural hazards creates a significant threat to the food security, nutrition and livelihoods of herding households in Mongolia. Hence, urgent actions are needed to implement and scale up multihazard DRR, climate change adaptation and sustainable natural resources management interventions. These should be aimed at reducing vulnerabilities and strengthening the coping and adaptive capacities of affected and at-risk communities.

Drivers and nature of sand and dust storms

The drivers of SDS encompass land degradation, desertification and climate change, exacerbated by unsustainable land and water use, extreme wind events, great aridity in some areas, and frequent and severe drought of extended duration. Temperature and precipitation level also have an indirect effect on SDS activity due to their influence on vegetation growth. Global warming is

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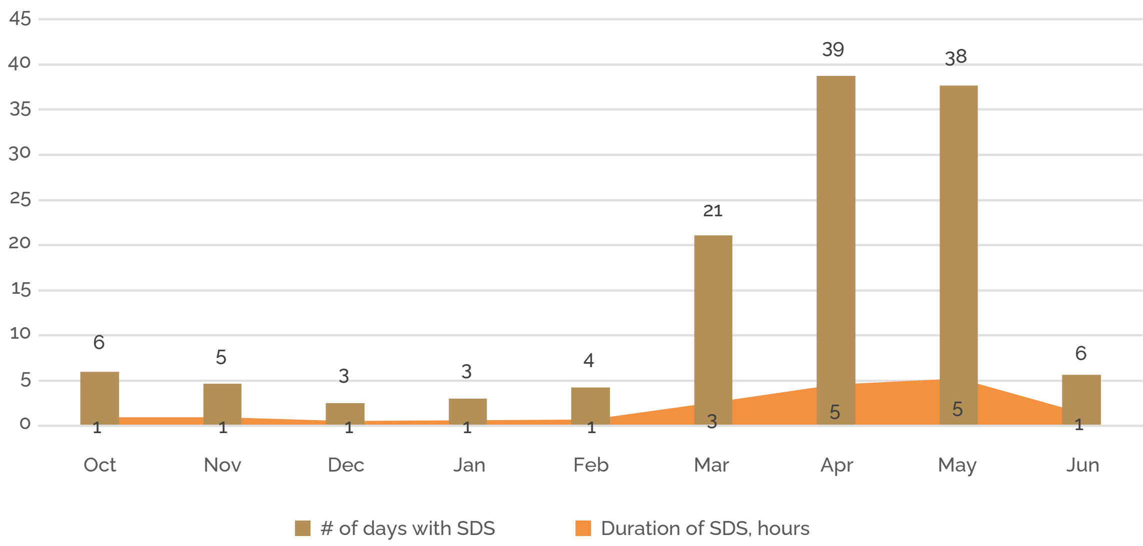
11 At the 2013 average exchange rate.

leading to a further increase in dry areas and widespread droughts. Mongolia is particularly at risk of increased drought due to climate change, which will result in greater SDS activity.

Pasturelands in Mongolia showed severe signs of overgrazing and degradation in 2019. With 70.9 million livestock (National Statistics Office of Mongolia, 2020), a historic record in animal numbers, exceeding the optimum carrying capacity by a factor of 2.3. This excessive resource use led to further decreasing vegetation cover, land degradation and inadequate animal feed availability, particularly during the winter. About a quarter of the country's territory has been categorized as being severely affected by desertification. This degradation is jeopardizing the resilience of herders, communities and the nation as a whole to cope with increasing hazard risks.

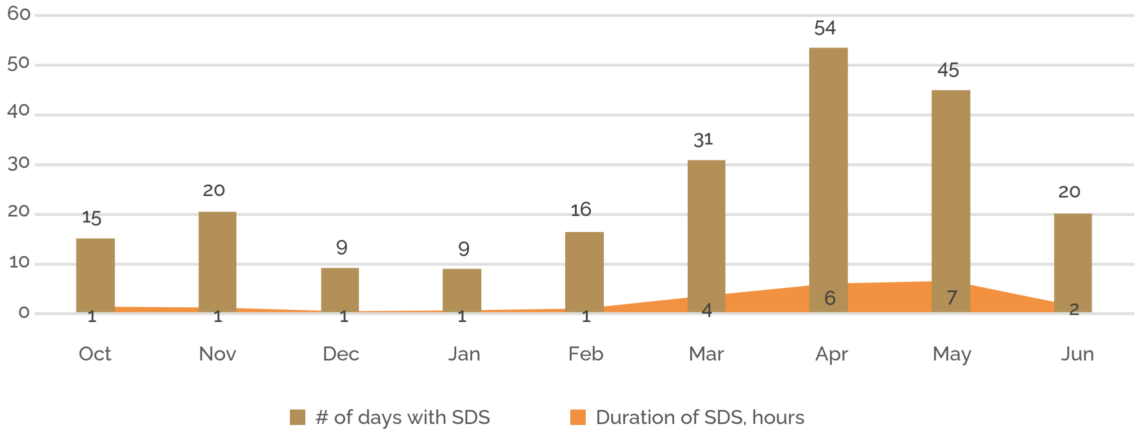
The widespread areas with soil high erodibility in Mongolia are in southern dry steppe and Gobi Desert regions in the south of the country (Jugder *et al.*, 2018). The areas coincide with the regions most exposed to SDS, as SDS sources as well as impact areas in Mongolia. The severity of SDS is generally estimated as a product of wind speed (in metres per second) and duration (in hours) of days with SDS. Figures A5.1 and A5.2 show the nature of SDS events in Saintsagaan *soum* (district) and Zamyn-Uud *soum* in the Gobi Desert region of the country. In these two *soums*, the exposure to SDS is, on average, 31–60 and 61–90 days per year, respectively (Natsagdorj, Jugder and Chung, 2003).

Figure A5.1 | Number of days with SDS and SDS duration (in hours), monthly averages for 2000–2020, Saintsagaan *soum*



Source: **Enkh-Amgalan,** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia*. Rome.

Figure A5.2 | Number of days with SDS and SDS duration (in hours), monthly averages for 2000–2020, Zamyn-Uud *soum*



Source: **Enkh-Amgalan,** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia*. Rome.

Measures for tackling sand and dust storms

Tackling SDS risks and impacts requires integrated approaches to multihazard DRR, climate change adaptation and sustainable land/natural resources management. These should be undertaken within and across sectors and ecosystems, including cropland, wetland, rangeland, desert and semi-desert. Effective governance and financing mechanisms for interministerial and multistakeholder collaboration/coordination, capacity development, information exchange, knowledge-sharing, knowledge transfer and resource mobilization must therefore be in place. The following measures for tackling SDS have been identified.

1. Strengthen risk analysis, monitoring and early warning systems of sand and dust storms

It is crucial to analyse the cause and effect relationships between the SDS components to develop appropriate, science-based policy actions (ESCAP, 2018). Such analysis should identify drought, wind erosion, land degradation and desertification, as well as changes in vegetation cover and conditions, land-use and land-cover status and agricultural productivity as drivers for SDS. The Earth observation satellite-based normalized difference vegetation index and aerosol index can be used to understand the geography and interconnectivity of four slow-onset phenomena (drought, desertification, land degradation and SDS) and to identify potential risk hotspots as well as allowing real-time risk assessment and monitoring (ESCAP, 2018). In addition, the Earth observation satellites (SRTM, ASTER and CartoDEM) provide mapping and monitoring data for vegetation cover, snow cover, soil moisture, and surface topography.

Sand and dust storms require continuous risk monitoring and early warnings to allow people downwind to take preventive measures to minimize their impact. Given the frequency and severity of SDS events, and building on the existing country capacity for the development of a *dzud* early warning system, it is necessary for Mongolia to develop SDS risk monitoring and early warning systems to enable early actions. Through these systems, SDS risk and vulnerability maps can be produced so the most at-risk and affected groups and areas are identified. Once early warning signs emerge or surpass the thresholds, early action interventions will be activated to mitigate the impacts of the SDS. Features and warnings specific to agriculture and SDS can be elaborated and embedded within existing multihazard risk early warning systems. Box A5.1 demonstrates the views of herders on the value of early warnings, weather forecasting and monitoring to reduce the impacts of SDS on livestock.

Box A5.1 | Herder views on the value of early warnings, weather forecasting and monitoring to reduce the impacts of SDS on livestock

The high importance of early warnings, weather forecasting and monitoring was confirmed by herders interviewed during the FAO field survey after the SDS event on 14–15 March 2021.

Interviews in Zamyn-Uud *soum* and Saintsagaan *soum*, in the southern part of the country, revealed that 79.5 percent of herders were not prepared and did not expect such severe conditions; 64.4 percent were unable to oriente themselves and find their herds in the low visibility caused by the SDS; 56.1 percent could not bring livestock back to their camp before the loss of visibility and 14.7 percent ignored weather forecasts.

Nearly 85 percent of herders thereafter highlighted the importance of regularly listening to weather forecasts and better heeding them.

Source: **Enkh-Amgalan, A.** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia.* Rome, FAO.

Damage and loss from SDS events must be systematically assessed, monitored and reported. This can be activated as part of the national SFM process using the online global SFM tool and reporting formats provided by the United Nations Office for Disaster Risk Reduction for all countries, sectors and hazards. The SFM Indicator C-2 ("Direct agricultural loss attributed to disasters") is specifically designed for reporting on the economic impacts of disasters on agriculture, allowing disaggregation by crops, livestock, forestry, and fisheries and aquaculture subsectors, as well as by hazards and subnational administrative units, including associated facilities and infrastructure. Such reporting on SDS will help generate evidence on the return of investments in SDS source mitigation measures and impact mitigation.

2. Promote investment and financing in sustainable land management and disaster risk reduction to address the root causes of sand and dust storms at field and landscape levels

Combating desertification and land degradation, and restoring and protecting ecosystems (cropland, rangeland, dryland and wetland) through sustainable land management (SLM) practices offer cost-effective solutions for SDS risk reduction. Sustainable land management plays an important role in preventing SDS occurring at source and in enhancing mitigation and adaptation, while simultaneously optimizing natural resource use and restoring productivity. It promotes vegetation cover to protect soils, reduce local wind speeds and increase soil stability. In the livestock sector, this is provided through sustainable methods of rangeland management, including encouraging mobility to spread grazing pressures and the use of enclosures to protect certain pastures and young trees. Box A5.2 gives two examples of SLM good practices to help mitigate the impacts of SDS on agriculture in Mongolia.

Box A5.2 | Sustainable land management good practices to mitigate the impacts of SDS on agriculture in Mongolia

A good practice that could help rehabilitate Mongolia's degraded and bare erosion-prone soils is to plant drought-tolerant legume forage species. As a denser surface cover is (re)developed, soil fertility is also enhanced by adding organic matter and nitrogen fixation, and rainwater infiltration is enhanced through the development of the forage root system. The legume species also serves as a nutrient-rich fodder plant for livestock grazing (Slim *et al.*, 2021).

Another good practice that could mitigate SDS impacts in Mongolia is aeroplane-based planting of saxaul trees. These trees can provide vegetation cover for biomass, nutrition for grazing, fire-wood for fuel and so on. Although there are high initial investment costs, there are good long-term gains through large-scale implementation (landscape-level benefits) (Akramkhanov *et al.*, 2021).

Disaster risk reduction good practices that can reduce the impact of SDS on the livestock sector in Mongolia include improving animal shelters with good insulation, improving storage for hay and animal feed, ensuring proximity of animals to their shelters, and using durable enclosure and insulation materials.

Financing models, such as risk transfer mechanisms, are key to reducing communities' vulnerabilities to SDS, to strengthening their coping or absorptive capacities to manage SDS and other risks, and to responding to shocks and stresses. They can be delivered through risk-informed and shock-responsive social protection schemes and agricultural/risk insurance programmes, into which SDS should be embedded.

3. Mainstream sand and dust storms into the national disaster risk reduction strategy, sectoral policies and development plans

At the planning level, SDS risk management must be embedded as an integral part of national policies and strategies. Source and impact mitigation strategies and measures of SDS must be integrated explicitly within the national and subnational DRR and climate change adaptation strategies/plans. They should also be addressed proactively in sectoral policies and development strategies to support Mongolia's efforts towards achieving land degradation neutrality (LDN).

The direct links between SDS and the three global indicators used to monitor LDN (soil organic carbon, land productivity and land cover) mean that many policies and programmes designed to avoid, reduce and/or reverse land degradation will also have the effect of mitigating SDS sources, as well as increasing soil health and enhancing carbon sequestration. In this regard, enhanced intersectoral coordination, in particular between the Ministry of Food, Agriculture and Light Industry and the Ministry of Environment and Tourism, is crucial to ensure adequate mainstreaming in national policy instruments and synergistic implementation of various mitigation measures that will reduce the impact of SDS.

FAO has been assisting the Ministry of Food, Agriculture and Light Industry since 2016 to take account of SDS by assessing them as part of the strong snow and dust storm risk. A separate SDS risk assessment was carried out in 2021. This considered the SDS hazard and the vulnerability and coping capacity indicators. Moreover, sample SDS risk management plans were developed in two rural districts. FAO assistance is providing a sound basis for treating SDS as a serious risk, especially in the southern dry steppe and desert areas of Mongolia, where SDS are severe and frequent. Based on FAO support and recommendations, local governments and the Ministry of Food, Agriculture and Light Industry have started mainstreaming SDS into local and national DRR strategies. Box A5.3 provides an example of how disaster risks are integrated into the country's Vision-2050 policy document (Government of Mongolia, 2020).

Box A5.3 | Mainstreaming disaster risks into Mongolia's Vision-2050 policy document

The latest policy document on Mongolia's Vision-2050 addresses disaster risk in general, but does not mention SDS explicitly. However, this policy aims to reduce disaster risk and includes the following objectives:

- Enhance local disaster protection capacity, strengthen its structure and fully determine the national disaster risk level.
- Develop natural disaster warning systems, border and area monitoring, and remote education and health services with the help of space technologies. Create benefits for the country's economy, security and business competitiveness.
- Strengthen the capacity for early detection of disasters, and mitigate and be resilient to the adverse effects of climate change.

Such provisions provide good guidance and an entry point to advocate for multihazard DRR and climate change adaptation, which need to be further elaborated, detailed and tailored to the SDS context.

Source: **Government of Mongolia.** 2020. *Vision-2050: introduction to Mongolia's long-term development policy document***.** *Ulaanbaatar*

Policy recommendations

1. Strengthen risk information, analysis, monitoring and early warning systems on sand and dust storms

- Proactively include SDS in the national SFM system, to ensure regular impact assessment and monitoring of SDS events to inform long term risk reduction policies.
- Establish SDS risk monitoring and early warning systems that allow timely issuing of alerts and early warnings through various communication channels to enable early/anticipatory actions.

2. Strengthen risk governance of sand and dust storms

- Mainstream SDS into national and/or subnational planning processes for multihazard DRR and climate change adaptation, as well as into sectoral development and risk reduction strategies. In addition, integrate aspects of national land-resource and land-use planning and the principles and objectives of SLM and LDN into these multi-hazard and sectoral risk reduction planning instruments, including implementing SLM and DRR measures at field and landscape levels to enhance long-term prevention and reduce risk of future SDS.

- Establish interministerial/multistakeholder governance and financing mechanisms to foster collaboration, information exchange, knowledge-sharing, knowledge transfer and resource mobilization. Such mechanisms will strengthen coordination and interaction among various existing national and regional early warning early action systems. These should include SDS-specific issues and warnings to enhance timely outreach into remote areas of Mongolia, especially among herding communities.

- Strengthen preparedness capacities of agricultural stakeholders. Develop and regularly update SDS contingency plans for affected areas and ensure that preparedness gaps are addressed and resources are mobilized to implement the plans, including timely anticipatory actions ahead of imminently forecast hazards/shocks.

3. Promote investment and financing in sand and dust storm risk reduction and impact mitigation measures in agriculture

- Scale up implementation of SDS prevention and impact mitigation measures at field and landscape levels, including through SLM and DRR good practices tailored to the specific situation of Mongolian herders, to reduce the risks of SDS and exposure to damaging SDS impacts.

- Include SDS in the social protection programme to reduce vulnerabilities and provide income protection for affected communities.

- Through public–private partnership, develop and scale up financing instruments to enhance delivery of SDS preventive and impact mitigation measures, including through the development of affordable disaster and climate risk insurance products for farmers/herders.

4. Develop national capacity and raise awareness of sand and dust storms

- Strengthen capacities of the National Emergency Management Agency, sectoral ministries/agencies and other stakeholders in SDS risk management through tailored trainings, workshops and awareness-raising events.

- Develop information/educational materials and increase public awareness on exposure, vulnerabilities and possible coping/adaptive measures to SDS impacts, including through national awareness-raising campaigns and outreach programmes.

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Annex 6

Sand and dust storm contingency planning for agriculture – Summary of project results

The FAO interregional project, "Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture", supported three countries (Iraq, Islamic Republic of Iran and Mongolia) in conducting sand and dust storm (SDS) risk and vulnerability assessments and contingency planning for SDS in agriculture. The overall aim was to support these countries and local stakeholders in their efforts to better prepare the agricultural sector to reduce the impacts of SDS events and to improve future coping capacity.

The project supported national consultants, liaising with national and district experts and government personnel, in three key tasks:

- development of a systematic, replicable methodology for SDS contingency planning that helps to mitigate the risks and impacts of SDS on agriculture in the future;
- fieldwork in selected districts of the three countries to test and fine-tune the methodology;
- initiation of planning processes at a decentralized level aimed towards establishing anticipatory SDS contingency planning as a tool for development of timely, effective and location-specific preparedness and response measures for SDS.

The project intended that the three case study examples would demonstrate that SDS contingency planning can become an integral part of wider, national disaster risk reduction (DRR) planning and sectoral development in agriculture and related sectors.

The main target groups for the contingency planning process were: DRR/disaster risk management (DRM) planners and actors; sectoral planners and actors in agricultural, environmental and natural resources management organizations; and other development actors interested in contributing to a reduction in SDS sources and impacts and helping vulnerable populations to be better prepared to cope with SDS and other risks.

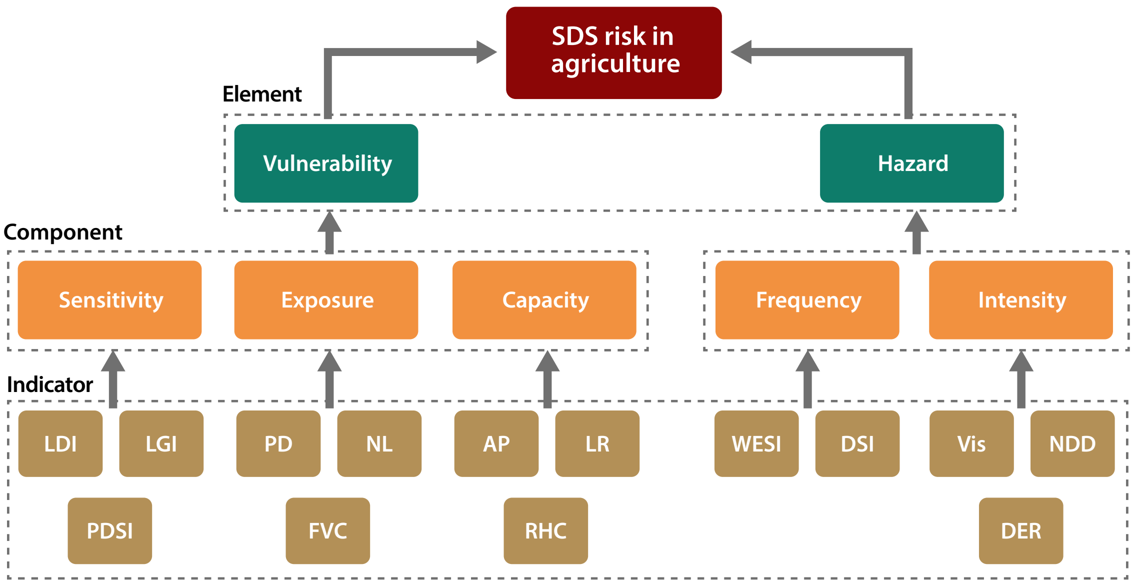
This summary outlines the conceptual framework applied for developing the SDS hazard risk and vulnerability assessment and mapping in agriculture, and provides illustrative examples of the main steps and elements addressed as part of SDS contingency planning in agriculture. In doing so, it illustrates – using results from the Islamic Republic of Iran case study as an example – the type of indicators chosen for the assessment, together with a geographic information system (GIS)-based map that plots the spatial dimension of results derived from the risk and vulnerability assessment based on the chosen indicators.

Thereafter, the summary showcases consolidated results from the institutional framework analysis done as a basis for contingency development planning – using the Mongolia case study as an example – together with a locally-elaborated and prioritized action framework of measures and interventions that help reduce SDS risk at the district level in two districts of southern Mongolia used by mobile pastoralists and their herds. This action framework is a useful tool for wider replication by local actors to identify and fine-tune, on a highly location-specific basis, the SDS priority actions to be addressed and integrated into existing local DRR and/or sectoral development plans.

Conceptual background

The proposed methodological framework for the SDS risk assessment in agriculture was designed in line with the conceptualization of disaster risk established by the United Nations Office for Disaster Risk Reduction. It is thus based on the assumption that SDS disaster risk is a function of vulnerability and hazard. As shown in Figure A6.1, risk is taken as the result of the interaction between the hazard and the vulnerability of the area affected by SDS. The assessment of vulnerability is conceptualized through integration of three components: sensitivity, exposure and coping capacity (UNCCD, 2022). The hazard risk is characterized by two components: frequency and intensity. Each component is described and analysed by a set of specific, measurable indicators that establish criteria that are particularly important from an agricultural perspective. The element and components shown in Figure A6.1 were applied equally across all the country case studies, although the specific indicators varied among countries according to country specificities and data availability.

Figure A6.1 | Conceptual model for SDS risk assessment in agriculture



Note: AP = active population; DER = dust emission rate; DSI = dust severity index; FVC = fractional vegetation cover; LDI = land degradability index; LGI = livestock grazing index; LR = literacy rate; NDD = net dust deposition; NL = number of livestock; PD = population density; PDSI = Palmer drought severity index; RHC = rural health centre; Vis = visibility; WESI = wind erosivity severity index.

Source: **Darvishi Boloorani, A.** 2023. *Contingency planning process for catalysing investments and actions to enhance resilience against sand and dust storms in agriculture in the Islamic Republic of Iran*. Rome, FAO.

Indicator development example: Ahvaz County, Islamic Republic of Iran

National expert panels were established to consolidate a country-specific set of a maximum of 15 indicators to conceptualize SDS risk as a function of vulnerability (comprising three components: sensitivity, exposure and coping capacity) and hazard (comprising two components: frequency and intensity). The indicators were based on the criteria of: (a) relevance for SDS in agriculture, (b) focus on pre-existing indicators or indices, (c) data availability, and (d) data accessibility. In the Islamic Republic of Iran case study, data availability for GIS-based processing was an additional criterion. A ranking and scoring system was developed in each country by expert panels to give different weights to different indicators and components of the risk and vulnerability assessment based on the context- and situation-specific importance allocated to them. Table A6.1 shows the indicators used in the Islamic Republic of Iran case study.

Table A6.16 | Indicators for SDS disaster risk assessment in agriculture (Islamic Republic of Iran case study)

Element	Component	Indicator	Description	Source	Alternative source
Hazard	Frequency	1. Dust severity index (DSI)	Dusty days in a year Direct impact on the exposed community/ecosystem	Moderate resolution imaging spectroradiometer (MODIS) products	Aerosol Robotic Network (AERONET)
		2. Wind erosivity severity index (WESI)	Wind speed (m/s) per dusty day Triggers dust emission and determines dust severity	Fifth generation European Centre for Medium-Range Weather Forecasts atmospheric reanalysis of the global climate (ERA5)	National meteorological stations and Automated Surface Observing System (ASOS)/Automated Weather Observing System (AWOS) Meteorological Aerodrome Report (METAR) data
	Intensity	3. Visibility (Vis)	Average monthly visibility Measure of the concentration of the dust event with direct impact on exposed community/ecosystem	Meteorological station	ASOS/AWOS METAR data
		4. Net dust deposition (NDD)	Net deposition (wet deposition + dry deposition) Direct impact on ecosystem/agriculture	Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) reanalysis products	
		5. Dust emission rate (DER)	Direct impact on agriculture	MERRA-2 reanalysis products	

Element	Component	Indicator	Description	Source	Alternative source
Vulnerability	Sensitivity[a]	6. Palmer drought severity index (PDSI)	Drought results in vegetation loss and topsoil erosion that reduces agricultural productivity. Hence, predominance of drought intensifies dust emission in a region.	National Oceanic and Atmospheric Administration National Climatic Data Center	
		7. Livestock grazing index (LGI)	Net primary production (NPP)-based grazing index Direct impact on land degradation	FAO NPP	Ground-based NPP and livestock statistics
		8. Land degradability index (LDI)	Land degradation is one of the main drivers of dust formation.		
	Exposure[b]	9. Population density (PD)	Number of people per unit area The higher the PD, the more people will be exposed to dust events.		
		10. Number of livestock (NL)	NL per unit area The higher NL, the more livestock will be exposed to SDS.	National agriculture census	
		11. Fractional vegetation cover (FVC)	Calculated using the normalized difference vegetation index (NDVI) Direct impact on dust mitigation impacts.	MODIS NDVI	Landsat and Sentinel-2
	Coping capacity[c]	12. Active population (AP) (15<age<65)	Ratio of active people to population The AP provide the labour force of the agriculture domain of a community.		National population and housing census
		13. Literacy rate (LR)	Ratio of literate people to population Literate people are generally better able to benefit from health protocols and dust alarm systems, so they are less exposed to this phenomenon.		
		14. Rural health centre (RHC)	Ratio of number of health centres to population (1:8000) These centres provide health services related to dust storms to vulnerable rural communities.		

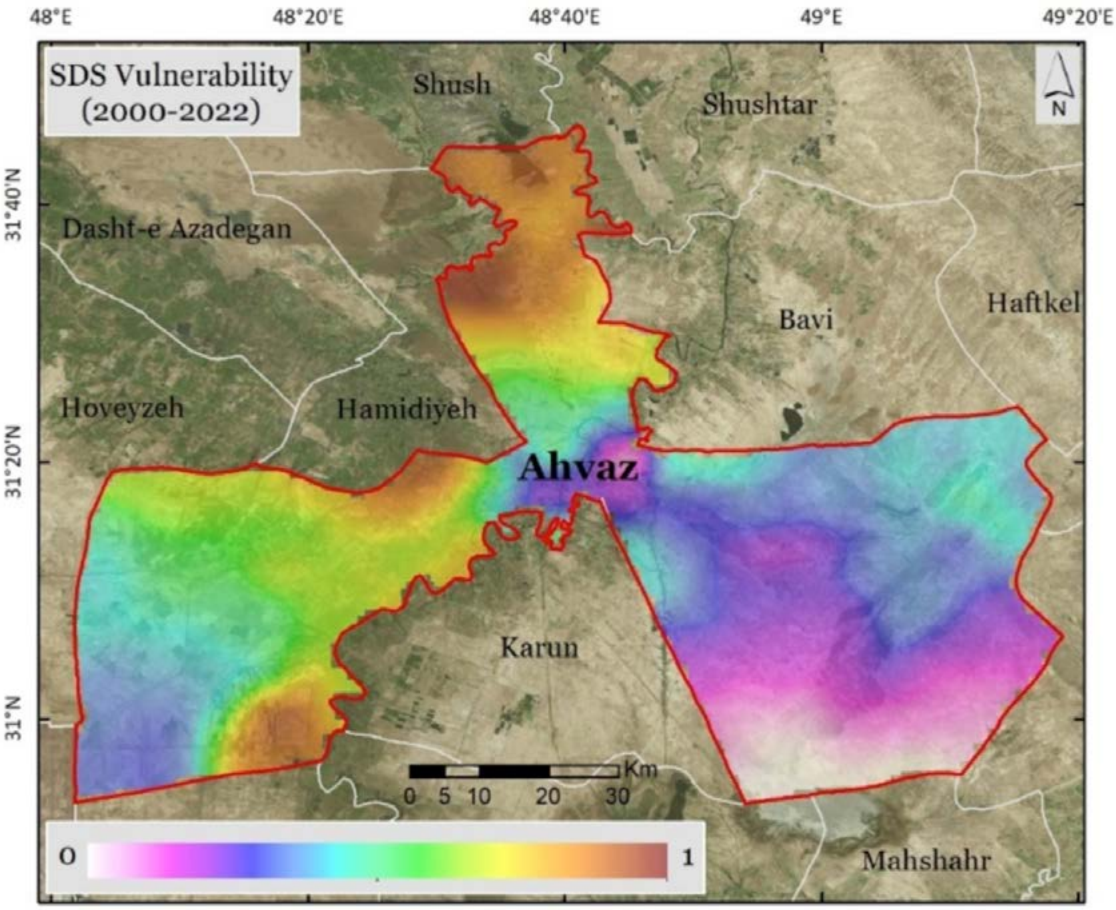
Notes: [a] For sensitivity, some other indicators could also be considered, for example, agriculture development level, sustainability of water resources, and age and gender composition of the population. It was not possible to use these data due to data constraints. [b] For exposure, some other indicators could also be considered, for example, rainfall, air humidity and wind speed affect the SDS deposition mechanism, and the ratio of outdoor/indoor jobs, which all lead to different levels of SDS exposure. It was not possible to use these data due to data constraints. [c] For coping capacity, some other indicators could also be considered, for example, human development index, agriculture protection system, fruit warehousing facilities and dredging irrigation channels system. It was not possible to use these data due to data constraints.

Source: **Darvishi Boloorani, A.** 2023. *Contingency planning process for catalysing investments and actions to enhance resilience against sand and dust storms in agriculture in the Islamic Republic of Iran.* Rome, FAO.

Risk and vulnerability assessment

In the Islamic Republic of Iran case study, the risk and vulnerability assessment was based on GIS methodologies and data. Thus, as an interim step, GIS-based maps were created for each indicator and consolidated thereafter in line with the conceptual framework for each component and element presented in the conceptual framework (Figure A6.1). The integrated SDS vulnerability map generated at the "element level" for Ahvaz County in the Islamic Republic of Iran is presented here as one mapping example (Figure A6.2). The other maps from this analysis are available in the Islamic Republic of Iran country case study report (Darvishi Boloorani, 2023).

Figure A6.2 | Vulnerability map of SDS (example of Ahvaz County, Islamic Republic of Iran)



Source: **Darvishi Boloorani, A.** 2023. *Contingency planning process for catalysing investments and actions to enhance resilience against sand and dust storms in agriculture in the Islamic Republic of Iran*. Rome, FAO.

The SDS expert panels in Iraq and Mongolia also developed context- and situation-specific indicators. Instead of using GIS methodology, qualitative ranking and scoring approaches were used to define risk and vulnerability categories at the decentralized level, which are suitable for contingency planning and comparison among different areas and institutional levels. The more specialized SDS disaster risk assessment model developed for the livestock subsector in Mongolia is shown in Chapter 5.

Institutional planning framework for sand and dust storms: Mongolia case study

The design and implementation of SDS contingency planning is essential for understanding the overall institutional environment in which which SDS contingency planning must be implanted. This includes identifying the best possible institutional home, as well as the actors that will take operational responsibilities for the implementation of a contingency plan and its components. In the case of SDS, which can affect large areas and several sectors, this requires looking at and across all institutional layers from national to local, and applying a cross-sectoral perspective.

In the Mongolia case study, the following existing legal reasons provide the rationale for developing and implementing SDS risk management plans at the local (*soum*) level:

- Law on Administrative and Territorial Units of Mongolia and their Governance, Clauses 59.1.12, 59.1.13 and 59.1.31;
- Law on Disaster Protection, Clauses 32.1.1, 32.1.6, 32.1.7 and 32.1.12;
- Law on Hydro-Meteorology and Environmental Monitoring, Clauses 7.1.3 and 7.1.4;
- Budget Law, Clause 60.2.8;
- National Programme for Participatory Disaster Risk Reduction, approved by Government Resolution 303 of 2015; and
- State Emergency Commission approved by Government Resolution 11 of 2008, and *aimag* and *soum* governor's action plan for 2020–2024 and relevant provisions of the working procedure of the *soum* emergency commission.

In addition, the study highlighted that all measures towards reduction and mitigation of SDS risks should be accomplished in accordance with the general principles and methodology of *soum* risk management planning and implementation. The proposed SDS contingency plan implementation responsibilities were as follows:

- *soum* emergency commission: ensures the plan is prepared with due consideration of herders' proposals;
- *soum* governor: earmarks financial resources required for plan implementation in the annual *soum* budget; and
- *soum* governor: organizes monitoring and evaluation of the plan implementation.

Contingency planning for agriculture: Mongolia case study

The objective of the contingency plan for herders in rangeland areas in Mongolia is to minimize the adverse impacts of SDS events on pastures, livestock and herder livelihoods by mobilizing technical and financial resources to better prepare for risks, and undertaking timely and effective mitigation activities during and after SDS events. Table A6.2 highlights the measures and actions proposed to counteract SDS development and impacts at district (*soum*) and subdistrict (*bagh*) levels. However, it is important to ensure that these plans are linked to or complemented by higher level plans (district and provincial development plans and other policies/strategies in relation to sustainable land/rangeland and water management, national agricultural development strategy/plan, national DRR/DRM strategy, national economic development plan, etc.).

Table A6.2 | District (*soum*) and subdistrict (*bagh*) level measures and actions proposed to counteract SDS development and impacts in Mongolia

SDS mitigation activity	Timing	Responsibility
Create emergency reserve grazing plots near winter and spring camps with fencing and water supply.	Annually, April–August	Herder groups, khot ails, herder households and absentee herd owners
Plan and implement measures to expand contractual use of pastureland by herder groups, and stop and prevent overgrazing of pastureland.	In 2–3 years	Soum governor, land officer, *bagh* governor and leaders of herder groups
Organize awareness-building among herders of the need to invest a part of livestock income on risk preparedness activities.	Annually	Agriculture unit, veterinary unit, herder groups and cooperatives
Organize evaluation of the leeward winter and spring shelters by experienced herders and take measures for owners to build barriers.	In 1–2 years	State Emergency Commission (SEC), herders and land officer
Provide herders and citizens with official information on drought, *dzud* and natural disasters, assess potential risks and ensure herders take preparedness measures.	When needed	SEC
Insure livestock and valuable property.	When available	Herder households and absentee herd owners
Ensure repair and maintenance of shelters, sheds and other infrastructure (e.g. sand removal and well draining).	August	Herder groups, herder households and absentee herd owners
Arrange placing of wind barriers and windbreaks to protect winter and spring shelters, sheds and other facilities using naturally available materials (e.g. rocks and stones).	Annually, April–June	Herder groups, *khot ails*, herder households and absentee herd owners
Take and enforce decisions on receiving SDS early warning information.	When needed	SEC, governor's office and agriculture unit
Develop rules for circulating SDS warning information in accordance with the SEC decisions and update with lessons learned.	When needed	SEC and agriculture unit
Promote use of mobile phones equipped with global positioning systems to herders and provide simple handouts on their use.		Governor's office, SEC and *bagh* governor

SDS mitigation activity	Timing	Responsibility
Establish soum and herder emergency fodder reserves.	Annually, August–November	SEC, governor's office and herder households
Organize, repair and fix *ger* framework and lattices, and roofs of livestock shelters, sheds and houses.	Annually, March–June	*Khot ails*, herder households and absentee herd owners
Ensure horses, camels and off-road vehicles are ready and available to search for lost livestock.	When needed	*Khot ails*, herder households and absentee herd owners
Store petrol/fuel reserves.	When needed	Herder households
Ensure warm clothes, boots and other facilities and food are ready and available.	Annually	*Khot ails*, herder households and absentee herd owners
Identify and map leeward places where live-stock that have gone downwind can be kept, and inform herders about how these places can be reached.	When needed	SEC, bagh governor, *khot ails*, herder house-holds and absentee herd owners
Keep sheep and goats nearby on pastures or in shelters as soon as an SDS warning is received.	When needed	*Khot ails*, herder households and absentee herd owners
Keep camel, cattle and horses in low-wind pastures or sheds.	When needed	*Khot ails*, herder households and absentee herd owners
Make feed and water available for livestock that are fenced in (e.g. soaking bran and granu-lated feed).	When needed	*Khot ails*, herder households and absentee herd owners
Promptly access information about unexpected changes in wind speed and direction and visibility, and deliver it to appropriate persons.	When needed	SEC and *bagh* governor
Protect young and small animals kept in shel-ters from being killed by mounting each other.	When needed	Herders
Promptly notify SEC and related personnel if any person is lost.	When needed	Herders and absentee herd owners
Report to SEC if livestock has been driven downwind by an SDS.	When needed	Herder households and absentee herd owners
Promptly organize searches for lost humans and livestock.	When needed	SEC, herder households and absentee herd owners
Take immediate measures to bury and destroy carcasses of dead animals.	When needed	Veterinary unit, herder groups, herder households and absentee herd owners
Estimate SDS damage and loss at the *soum* and *bagh* administrative unit within the *soum* level.	Annually	Herder households, absentee herd owners, agriculture unit, SEC and insurers' agents
Make requests to the provincial governor's office, non-governmental organizations, humanitarian organizations and international bodies for necessary assistance for affected households.	When needed	Governor's office and SEC

Note: *Dzud* is a very harsh winter condition, during which the ground is frozen solid, sometimes under firm snow, to a degree that animals cannot graze, a *khot ail* is a herding camp; a *ger is a traditional felt tent.*

Source: **Enkh-Amgalan,** 2023. *Preparing for sand and dust storm contingency planning with herding communities: a case study on Mongolia*. Rome.

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Glossary

Conservation agriculture: A farming system that can prevent losses of arable land while regenerating degraded lands. It promotes maintenance of a permanent soil cover, minimum soil disturbance and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency, and to improved and sustained crop production.

Contingency planning: A management process that analyses disaster risks and establishes arrangements in advance to enable timely, effective and appropriate responses.

Cropland (or cultivated land): The land that is under agricultural crops.

Desertification: The degradation of land in arid, semi-arid and dry subhumid areas due to various factors, including climatic variations and human activities.

Disaster: A serious disruption to the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.

Disaster risk: The potential loss of life, injury, or destroyed or damaged assets that could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

Disaster risk management: The systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) the adverse effects of hazards.

Disaster risk reduction: The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

Dryland: Tropical and temperate areas with an aridity index (mean annual precipitation/mean annual potential evaporation) of less than 0.65. This includes hyperarid, arid, semi-arid and dry subhumid climatic zones.

Dust Belt: Area of dryland extending from West Africa through the Near East and Central Asia to Northeast Asia, where most of the world's sand and dust storms occur.

Erosion: The wearing away of the land by running water, rainfall, wind, ice or other geological agents, including such processes as detachment, entrainment, suspension, transportation and mass movement.

Forest: Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use.

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

Land degradation: The reduction in the capacity of the land to provide ecosystem goods and services over a period of time for its beneficiaries.

Land degradation neutrality: A state whereby the amount and quality of land resources necessary to support ecosystem functions and services to enhance food security remain stable, or increase, within specified temporal and spatial scales and ecosystems.

Pasture: Land covered with grass and other low plants suitable for grazing animals, especially cattle or sheep.

Rangeland: Land on which the indigenous vegetation (climax or subclimax) is predominantly grasses, grass-like plants, forbs or shrubs that are grazed or have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife.

Salinization: The process by which salt accumulates in or on the soil. Human-induced salinization is mostly associated with poor irrigation practices.

Sustainable land management: The use of land resources, including soils, water, animals and plants for the production of goods to meet changing human needs while ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.

Tillage: Changing of soil conditions for crop production; the mechanical manipulation of soil for any purpose.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Sand and dust storms

A guide to mitigation, adaptation, policy and risk management measures in agriculture

Sand and dust storms (SDS) are common in drylands with dust often transported over great distances, frequently across international boundaries. Such storms are important for ecosystem functioning, but they also create numerous hazards to society, in agriculture and other socioeconomic sectors.

The yields and productivity of crops, trees, pastures and livestock are adversely affected by SDS. With climate change it is expected that droughts and land use changes will increase the frequency and risk of SDS.

While agriculture is a major driver of SDS, agriculture is impacted by SDS and it is also part of the solution to combat SDS risks and mitigate their impacts. This guide aims to provide an overview of sand and dust storms and the impacts on agriculture and food systems. It gives a review of how agriculture can create SDS sources and highlights the impacts of SDS on agricultural production in source and deposition areas. It includes a range of high-impact, location- and context-specific practices to reduce SDS source and impacts on agriculture subsectors at local level, comprising technical and non-technical interventions. Moreover, it assesses how SDS risk is addressed at the policy level and discusses options for integrating SDS at national and regional levels into multi-hazard DRR and DRM strategies or sectoral development programmes, which is followed by the conclusions and recommendations.

Urgent action must be taken now. Short-term responses need to be linked to long-term development actions to enhance combating SDS. The adverse impacts of SDS are likely to become even more severe in the future, particularly due to climate change, unless appropriate interventions are made.

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