Sand and Dust Storms Compendium

Summary for Decision Makers

United Nations
Convention to Combat Desertification

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The United Nations Convention to Combat Desertification (UNCCD) is an international agreement on good land stewardship. It helps people, communities and countries create wealth, grow economies and secure enough food, clean water and energy by ensuring land users an enabling environment for sustainable land management. Through partnerships, the Convention's 197 parties set up robust systems to manage drought promptly and effectively. Good land stewardship based on sound policy and science helps integrate and accelerate achievement of the Sustainable Development Goals, builds resilience to climate change and prevents biodiversity loss.

This Sand and Dust Storms (SDS) Compendium: Summary for Decision Makers, compiled and co-edited by Utchang Kang and Charles Kelly, is a subset of the full SDS Compendium: Information and Guidance on Assessing and Addressing the Risks.

The SDS Compendium is a collaborative effort led by the Secretariat of the United Nations Convention to Combat Desertification (UNCCD) in collaboration with the UNCCD Science-Policy Interface (SPI), the World Meteorological Organization (WMO), the World Health Organization (WHO), the United Nations Environment Programme (UNEP), UN Women, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Office for Disaster Risk Reduction (UNDRR) and external experts and partners.

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Contents

Key Messages

SDS Challenges

Sand and dust storms (SDS) are given many local names: examples include the sirocco, haboob, yellow dust, white storms, or the harmattan. They are a regionally common and seasonal natural phenomenon exacerbated by poor land and water management, droughts, and climate change. The combination of strong winds and airborne mineral dust particles can have significant impacts on human health and societies. Fluctuations in intensity, magnitude, or duration can make SDS unpredictable and dangerous.

In some regions, SDS have increased dramatically in frequency in recent years. Human-induced climate change, desertification, land degradation, and drought are all thought to play a role. While SDS can fertilize both land and marine ecosystems, they also present a range of hazards to human health, livelihoods, and the environment. Impacts are observed in both source regions, and distant areas affected directly and indirectly by surface dust deposits. The hazards associated with SDS present a formidable challenge to achieving sustainable development.

SDS events do not usually result in extensive or catastrophic physical damage. However, the accumulation of impacts can be significant. In source areas, they damage crops, kill livestock, and strip topsoil. In depositional areas atmospheric dust, especially in combination with local industrial pollution, can cause or worsen human health problems such as respiratory diseases. Communications, power generation, transport, and supply chains can also be disrupted by low visibility and dust-induced mechanical failures.

SDS are not new phenomena – some regions of the world have long been exposed to SDS hazards. SDS events typically originate in low-latitude drylands and subhumid areas where vegetation cover is sparse or absent. They can also occur in other environments, including agricultural and high-latitude areas in humid regions, when specific wind and atmospheric conditions coincide.

SDS events can have substantial transboundary impacts, over thousands of kilometers. Unified and coherent global and regional policy responses are needed, especially to address source mitigation, early warning systems, and monitoring.

SDS impacts are multi-faceted, cross-sectoral and transnational, directly affecting 11 of the 17 Sustainable Development Goals – yet global recognition of SDS as a hazard is generally low. The complexity and seasonally cumulative impact of SDS, coupled with limited data, are contributary factors. Insufficient information and assessments on these impacts hinder effective decision-making and planning to effectively address SDS sources and impacts.

SDS Responses

The goal of SDS policy and planning is to reduce societal vulnerability by mitigating the effects of wind erosion. A multi-sectoral process bolstered by information-sharing involves short- and long-term interventions, engages multiple stakeholders, and raises awareness of SDS.

Source and impact mitigation activities are part of a comprehensive approach to manage the risks posed by SDS, from local to regional and global scales. Local communities in source areas are directly affected and will need to take very different actions to those impacted thousands of kilometers away. Engagement and participation of all stakeholders is crucial to effective SDS decision-making and policy, underpinned by up-to-date scientific knowledge.

Source mitigation: Land restoration, using soil and water management practices to protect soils and increase vegetative cover, can significantly reduce the extent and vulnerability of source areas, and reduce the intensity of typical SDS events. Such techniques are also vital for land degradation neutrality and when integrated into sustainable development and land-use priorities, will contribute to food security, poverty alleviation, gender equality and community cohesion as well as SDS mitigation goals.

Early warning and monitoring: Any effective SDS early warning system demands a whole-of-community approach. Building on up-to-date risk knowledge, monitoring, and forecasting, all stakeholders (including at-risk populations) participate to ensure that warnings are provided in a timely and targeted manner, and that sector-appropriate actions are taken to reduce or avoid impacts.

Impact mitigation: Preparedness reduces vulnerability, increases resilience, and enables a timely and effective response to SDS events. It involves individuals, communities and organizations as well as industry and businesses. An effective preparedness strategy includes mitigation measures and protective actions informed by robust science, vulnerability analyses, and risk assessments.

Cooperation, collaboration and coordination: The United Nations Coalition on Combating Sand and Dust Storms was launched in September 2019 and has five working groups: adaptation and mitigation; forecasting and early warning; health and safety; policy and governance; and mediation and regional collaboration. The United Nations Coalition will help leverage a global response to SDS through collaboration and cooperation from local to global levels, making the issue more visible, enhancing knowledge-sharing, and mobilizing resources to upgrade existing efforts.

1 — Introduction

Sand and dust storms (SDS) are natural meteorological and hydrological hazards that can affect almost all sectors of society and the environment (United Nations Office for Disaster Risk Reduction and International Science Council 2020). An estimated 2,000 million tons of sand and dust enter the atmosphere annually. The majority is emitted due to natural conditions, although human activities contribute significantly to SDS through unsustainable land management and water use.

SDS impact local and global weather, nutrient cycles and biomass productivity, with some of these impacts understood to be positive. SDS can also negatively affect air and water quality, hygiene and sanitation, human and animal health, transport, education, agriculture, and business and industry.

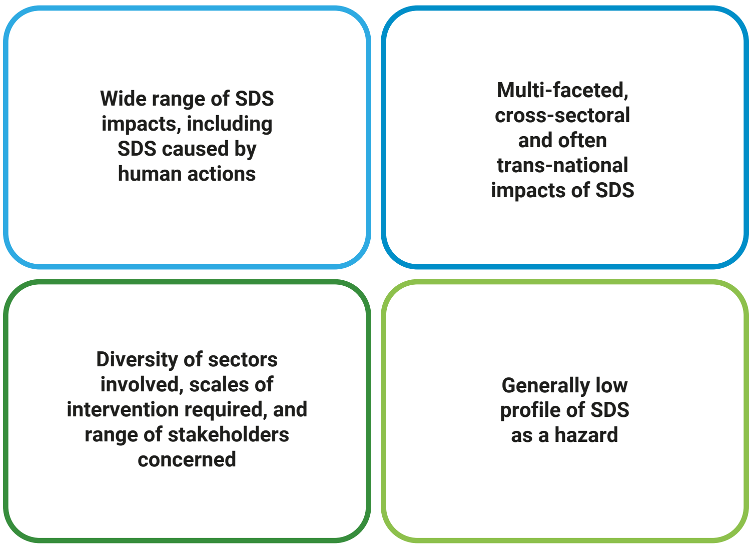
They often have significant economic impacts: for example, they cost the oil sector in Kuwait an estimated US$ 190 million annually, while a single SDS event in 2009 resulted in damage estimated at between US$ 229 and US$ 243 million in Australia.

SDS impact everyone – men, women, boys and girls – but not all in the same way. These differences stem from gender-based roles in the productive, economic, family and social spheres. Furthermore, SDS can be life-threatening for individuals with adverse health conditions.

There are several challenges when addressing the negative impacts of SDS (**Figure 1**):

- the wide range of SDS impacts, including SDS caused by human actions
- the multi-faceted, cross-sectoral and often trans-national impacts of SDS, requiring corresponding cross-sectoral, multidisciplinary and trans-national approaches and cooperation between stakeholders at all levels
- the diversity of sectors involved, the scales of intervention required, and the range of stakeholders concerned, with effective sharing of information about SDS critical to successful SDS management
- the generally low profile of SDS as a hazard, with weak data sets on impacts resulting in SDS often receiving limited attention in mainstream disaster risk management efforts

Figure 1. Challenges in addressing SDS impacts



By bringing together information and guidance from a wide range of sources, the Compendium enables its users to: (1) define the scope of SDS impacts, and (2) develop plans to address these impacts. Users are expected to include officials involved in local, subnational and national government, emergency management, health, natural resource management, agriculture, livestock, forestry and transport (including aviation), and community and civil society stakeholders. The Compendium will specifically benefit decision makers and other stakeholders by helping them define policies and approaches to mitigate the impacts and sources of SDS.

The Compendium aims to support the implementation of the **UNCCD Policy Advocacy Framework to combat Sand and Dust Storms** (United Nations Convention to Combat Desertification [UNCCD], 2017). The Policy Advocacy Framework seeks to reduce vulnerability to SDS by focusing on: (1) post-impact crisis management (emergency response procedures), (2) pre-impact governance to strengthen resilience, reduce vulnerability and minimize impacts (mitigation), and (3) preparedness plans and policies, including monitoring, forecasting and early warning (**Figure 2**).

Figure 2. UNCCD Policy Advocacy Framework to combat Sand and Dust Storms: goal and action areas

Using the Compendium to address SDS will contribute towards achieving eight Sustainable Development Goals (SDGs): SDG 1, 2, 3, 6, 11, 13, 15 and 17 (**Figure 3**). The Compendium supports the Sendai Framework for Disaster Risk Reduction by:

- improving the understanding of SDS risk (Sendai Priority 1)
- strengthening SDS risk governance (Sendai Priority 2) and
- increasing knowledge about preventive measures and impact mitigation options
- enhancing disaster preparedness for an effective response by strengthening SDS forecasting, early warning, preparedness and response capacities (Sendai Priority 4)

Figure 3. Links between SDS and SDGs

1 NO POVERTY	Reducing air pollution caused by SDS can help families become healthier, save on medical expenses and improve their productivity.
2 ZERO HUNGER	SDS can cause crop damage, negatively affecting food quality/quantity and food security. Reducing desertification/land degradation (including soil erosion) in source areas will help enhance agricultural productivity.
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 micro-organisms, salts and/or anthropogenic pollutants.
11 SUSTAINABLE CITIES AND COMMUNITIES	Mitigating SDS disasters will significantly lower the number of people affected and economic losses caused, contributing to safer, more sustainable and more disaster-resilient human settlements.
13 CLIMATE ACTION	Improving land/water use and management in SDS source areas contributes to creating climate-change-resilient landscapes and communities.
15 LIFE ON LAND	Reducing wind erosion in SDS source areas contributes to land degradation neutrality, thereby enhancing the sustainable use of terrestrial ecosystems.
17 PARTNERSHIPS FOR THE GOALS	SDS activities can be part of efforts to strengthen the means of implementation and revitalize the global partnership for sustainable development.

Source: Adapted from https://sustainabledevelopment.un.org/?menu=1300.

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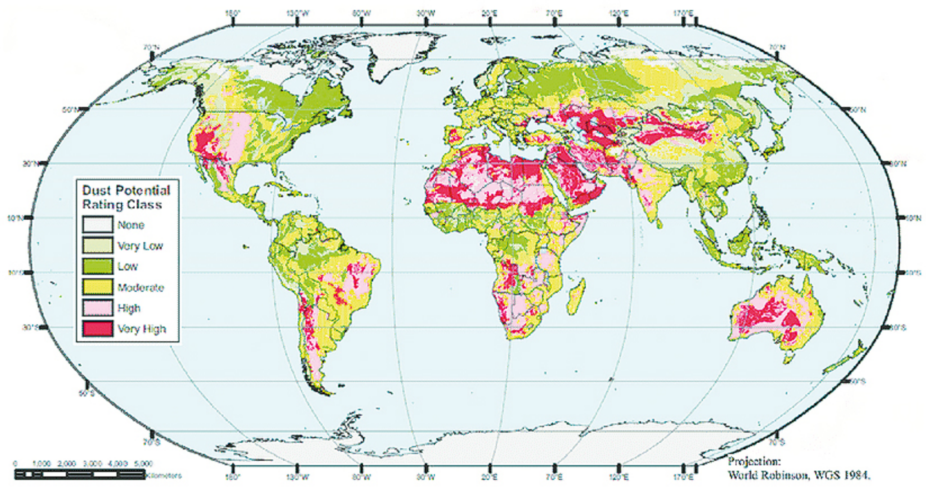
Based on inputs from a range of authors and contributors, it aims to provide up-to-date information across sectors and disciplines. It is acknowledged that as with any good research/scientific piece, there is room for further study and refinements as more evidence, information, case studies and best practices become available.

Figure 4. Global SDS sources areas



Source: United Nations Environment Programme, World Meteorological Organization and United Nations Convention to Combat Desertification, 2016.

2 — The nature of SDS

SDS are composed of mineral dust entrained from the Earth's surface into the atmosphere through a mechanical process involving wind. Mineral dust is considered, in most cases, as natural when produced in arid and semi-arid regions characterized by sparse vegetation, and as anthropogenic when human activities directly lead to dust emission.

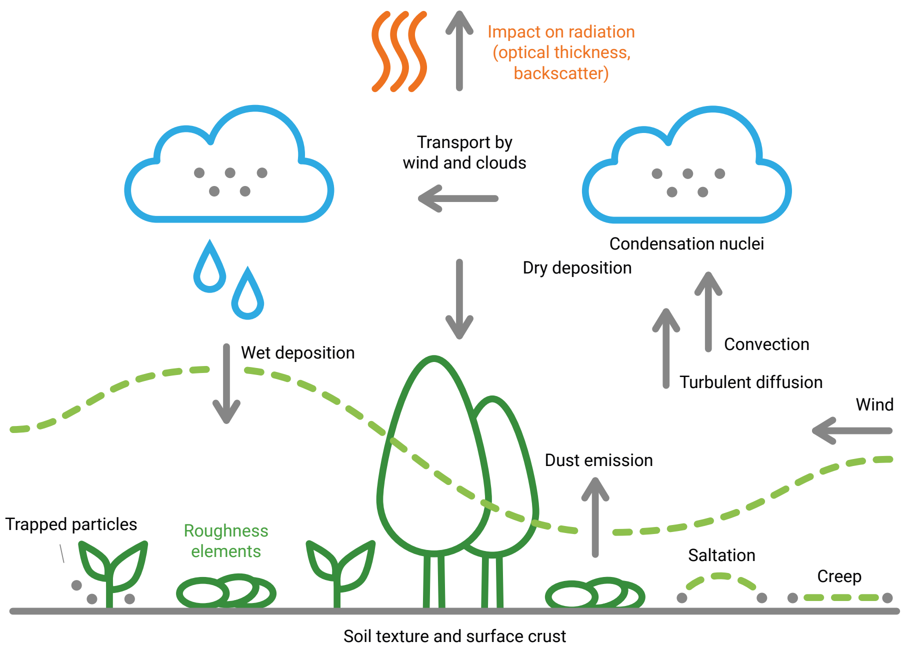
The major global sources of mineral dust are located in the northern hemisphere across an area including North Africa, the Middle East and East Asia. In the southern hemisphere, dust sources have a smaller spatial extension and are mainly located in Australia, South America and Southern Africa (**Figure 4**). Globally, the main large dust source regions are dried lakes, but local sources can be found in any location where soils can be lifted into the air by wind, including glacial outwash plains, volcanic ash zones and recently ploughed fields.

The potential for sand or dust to move into the atmosphere is affected by soil moisture, soil texture, surface crust, roughness elements, vegetation and wind speed. Conditions that are conducive to dust emission in one location can change from one part of a year to another and can vary significantly between years.

SDS involve dust emission, transport and deposition over a wide range of spatial and temporal scales (**Figure 5**). The release of sand and dust into the atmosphere occurs through:

- saltation bombardment for particles between 60 μm and 2 mm
- aerodynamic entrainment or suspension of particles finer than 60 μm
- aggregate disintegration for rolling (or creeping) particles larger than 2 mm

Figure 5. Summary of SDS processes



Source: Lu and Shao, 2001.

Fine dust particles are carried by turbulent diffusion and convection to higher tropospheric levels (up to a few kilometres in height) and then winds can transport them over long distances. The lifetime of dust particles in the troposphere depends on the particle size. Generally, it takes longer for smaller particles to deposit back on the surface than larger particles.

Six conditions can trigger SDS where mineral dust is available to be picked up by winds:

1. large-scale air flows (for example, the Harmattan linked to a high pressure zone of the Sahara)
2. synoptic-scale weather systems such as cyclones, anticyclones and their cold frontal passage, leading to episodic, large, intense dust events
3. moist convection, leading to convective mesoscale dust storms, often referred to as haboobs
4. microscale dry convection in the daytime planetary boundary layer over deserts, creating turbulent circulation that leads to dust whirlwinds and dust plumes
5. topographic effects, such as gaps in mountain ranges, that can channel wind and lead to local SDS and
6. diurnal cycles that can mobilize dust through the development and subsequent breakdown of nocturnal low-level jets

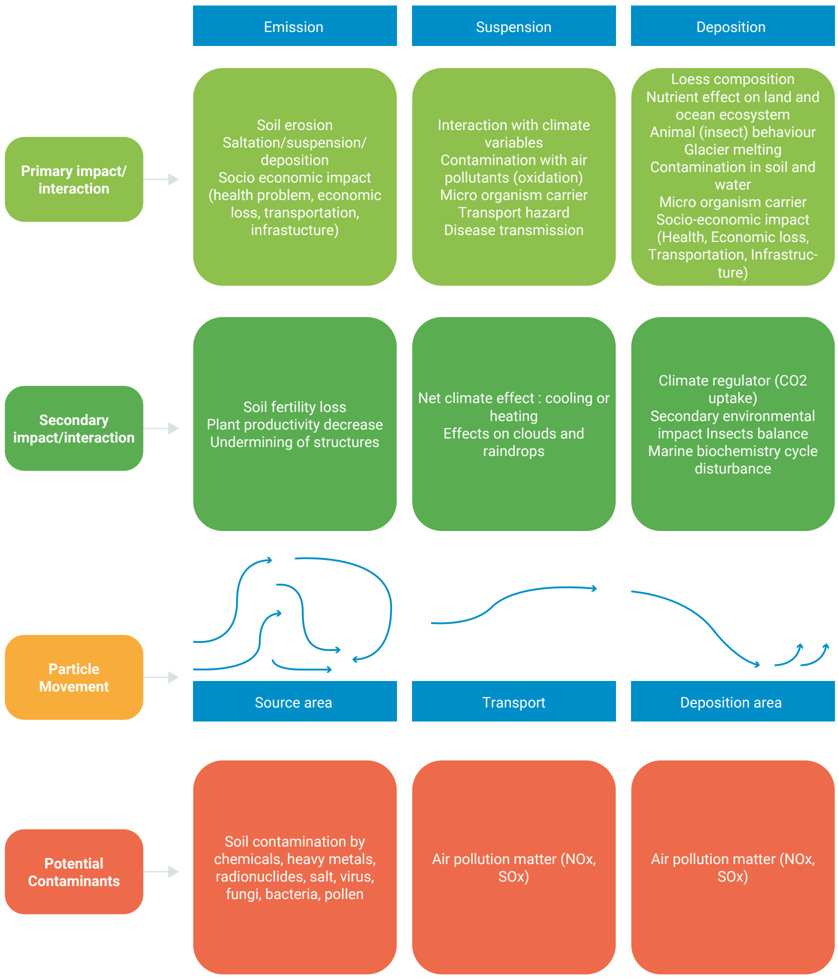


Figure 6. Summary of the interaction of dust with environment factors

3 — Understanding SDS as a disaster risk

Recognition of SDS as a disaster risk appears to be high in North-East Asia, parts of West Asia and North America but less prominent elsewhere. Low recognition of SDS as a disaster risk is likely due to the lack (in many cases) of significant immediate direct human fatalities or injuries from individual SDS events, and limited consolidated documentation on their long-term health, economic or other impacts.

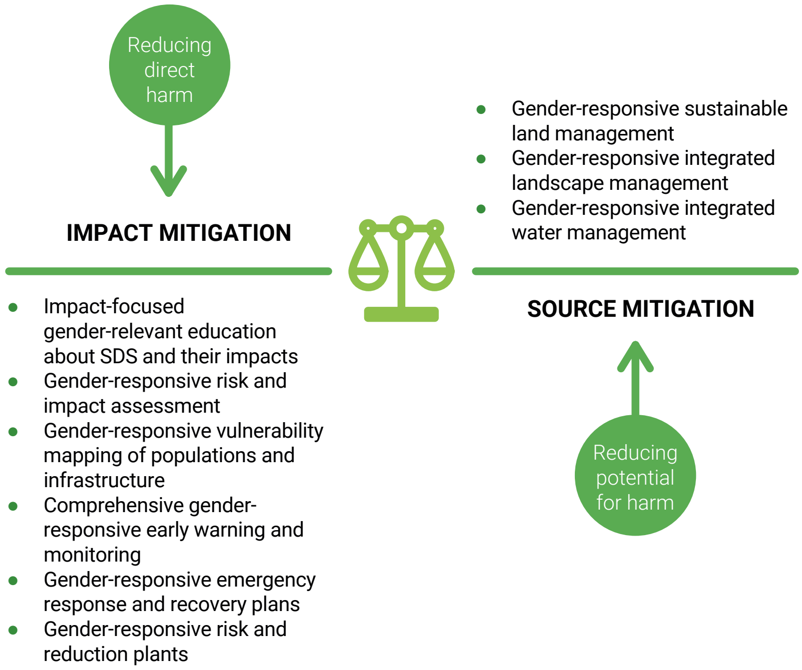
Managing the disaster risk posed by SDS involves: (1) defining the physical nature of the hazard, and how its physical factors can vary over time and space, (2) assessing social vulnerability and risk levels associated with the hazard, and (3) designing and implementing measures to prepare for, respond to, recover from and, most importantly, proactively reduce the risk of SDS, and (4) monitoring SDS impacts and SDS mitigation interventions.

This is a cross-sectoral process that involves both short- and long-term interventions, engages multiple stakeholders and raises awareness among at-risk populations of SDS as a hazard and disaster risk.

As a natural hazard, SDS occur through a combination of weather conditions, the geophysical presence of mineral dust and sand, and specific land forms. Understanding how the right wind speeds and right-sized sand and dust particles come together on the right land forms – often with other factors – to form SDS is essential to defining and addressing the risk posed by SDS.

Drawing on the **UNCCD Policy Advocacy Framework to combat Sand and Dust Storms**, actions to reduce damage from SDS fall into two categories: source mitigation and impact mitigation. Together, source and impact mitigation activities provide a comprehensive approach to managing the potential disaster risks posed by SDS on local to global scales, as shown in **Figure 7**.

Figure 7. A twofold approach to mitigating SDS hazards for disaster risk reduction



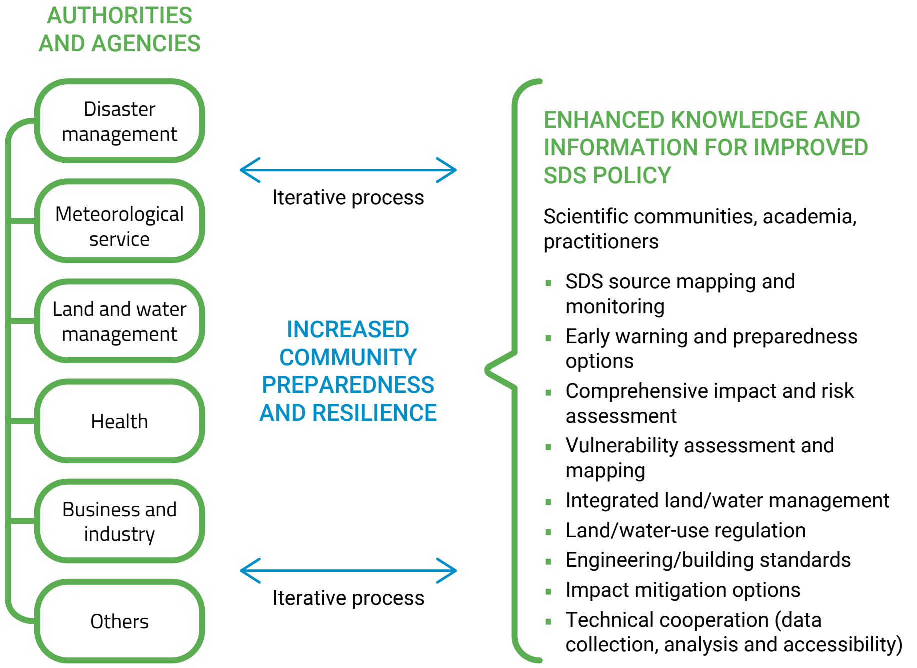
Source: Adapted from Middleton and Kang, 2017.

Given the diverse spatial and temporal nature of SDS, impact and source management require a unified, coordinated cross-sectoral approach. As summarized in **Figure 8,** this approach involves three main groups:

- the agencies, institutions and authorities responsible for setting SDS risk management policies and implementing plans covering risk reduction, preparedness, warning and response
- the scientific research and academic communities
- the at-risk communities impacted by SDS and who should be directly empowered to reduce SDS risk. This group includes the private sector, which can engage in a range of approaches, technologies and actions to reduce SDS impacts.

The process, as indicated in **Figure 8**, is iterative, with a constant exchange between the three groups in an attempt to find better policies and activities to reduce SDS impacts. This process is also gender-responsive, recognizing that women, men, girls and boys are affected differently by SDS and are presented with different ways of reducing SDS impacts based on their social or cultural roles and expectations. Similar attention is given to young children and older persons as well as individuals with health conditions, all of whom who may be impacted more severely by an SDS event than the general population.

Figure 8. Framework for SDS risk management coordination and cooperation



4 — Gender and disaster risk reduction

According to the Sendai Framework for Disaster Risk Reduction 2015–2030, "Women and their participation are critical to effectively managing disaster risk and designing, resourcing and implementing gender-sensitive disaster risk reduction policies, plans and programmes; and adequate capacity building measures need to be taken to empower women for preparedness as well as to build their capacity to secure alternate means of livelihood in post-disaster situations" (United Nations, 2015a, Paragraph 36 (a)(i))

Disaster-related impacts affect women, girls, boys and men differently. Gender inequalities can limit the influence and control that women and girls have over decisions governing their lives, as well as their access to resources such as finance, food, agricultural inputs, land and property, technologies, education, health, secure housing and employment. In addition, social expectations of gender roles and economic factors that lead to the restricted participation of women and girls in decision-making and education, their limited access to funds and constrained access to information, can make women and girls more vulnerable to SDS events than men and boys.

Despite progress in developing gender-responsive disaster risk reduction measures, disaster preparedness plans and strategies, vulnerability and risk assessments, and early warning systems rarely incorporate gender perspectives (United Nations, 2015b). As a result, many institutions and organizations — both national and local — working on disaster risk reduction do not engage women, girls, boys and men equally.

The result is that:

- the impact of hazards on, and corresponding disaster risks faced by, women and girls are not recognized
- women's and girls' needs and capacities are not taken into account in planning, risk reduction, emergency response and recovery activities

These results perpetuate gendered stereotypes and lead to an increase in women's and girls' vulnerability. Considering that women and girls make up roughly half the population, risk reduction and response plans that do not consider gender are only partially effective, at best.

International laws and agreements are placing gender equality at the centre of disaster risk reduction and resilience-building. At the normative level, the international community has committed to focusing on gender equality and women's rights in disaster risk reduction. These commitments are grounded in the **Convention on the Elimination of All Forms of Discrimination against Women** (CEDAW),[1] the **Beijing Declaration and Platform for Action,[2]** resolutions on gender equality and the empowerment of women in natural disasters by the Commission on the Status of Women, and other international agreements.[3]

1 *The Convention on the Elimination of All Forms of Discrimination against Women (CEDAW),* http://www.un.org/womenwatch/daw/cedaw/cedaw.htm.

2 *Beijing Declaration and Platform for Action,* http://www.un.org/womenwatch/daw/beijing/pdf/BDPfA%20E.pdf.

3 For example: *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*, https://www.unisdr.org/we/inform/publications/1037; Commission on the Status of Women resolution 56/2 and resolution 58/2 on gender equality and the empowerment of women in disasters, http://www.un.org/ga/search/view_doc.asp?symbol=E/2012/27&Lang=E, http://www.un.org/ga/search/view_doc.asp?symbol=E/2014/27&Lang=E

The **Sendai Framework for Disaster Risk Reduction 2015-2030** emphasizes the importance of engaging women in building disaster resilience (United Nations, 2015a). Furthermore, engaging women and girls in boosting community resilience is essential to achieving the SDGs, particularly **SDG 5 – Gender Equality and Women's Empowerment**. Gender equality and women's empowerment are crosscutting issues and prerequisites for achieving many other SDGs, including **SDG 1 – No Poverty**, **SDG 11 – Sustainable Cities and Communities** and **SDG 13 – Climate Action** (**Figure 3**).

The following actions (adapted from United Nations Development Programme, 2013) are key to ensuring a gender-responsive approach throughout the integrated SDS risk management planning process:

1. Incorporate gender perspectives into SDS risk management efforts at the national, local and community levels, including in policies, strategies, action plans and programmes.
2. Increase the participation and representation of women at all levels of the decision-making process.
3. Analyse SDS and climate data from a gender perspective and collect sex-disaggregated data.
4. Carry out gender analysis as part of the risk profile by documenting the different roles that women and men play in sectors relevant to SDS. For example:

    a. How are women and men's livelihoods affected by SDS?
    b. How could gender-based differences in decision-making power and ownership of/access to assets lead to different abilities to respond the hazard?
    c. What kinds of information do women have and need to better prepare for SDS?
    d. What does this imply in terms of differences in vulnerability and coping capacity between women and men?

5. Ensure that women are being prominently engaged as agents of change at all levels of SDS preparedness, including early warning systems, education, communication, information, and networking opportunities.
6. Consider reallocating resources from the actions planned, in order to achieve gender equality outcomes.
7. Take steps to reduce the negative impacts of SDS on women, particularly in relation to their critical roles in rural areas in the provision of water, food and energy by offering support, health services, information and technology.
8. Build the capacity of national and local women's groups and provide an adequate platform that presents their needs and views.
9. Include gender-specific indicators and data disaggregated by sex and age to monitor and track progress on gender equality targets.

Box 1. Concepts and definitions

Gender refers to the roles, behaviours, activities and attributes that a given society at a given time considers appropriate for men and women. In addition to the social attributes and opportunities associated with being male or female and the relationships between women and men and girls and boys, gender also refers to the relations between women and those between men. These attributes, opportunities and relationships are socially constructed and are learned through socialization processes. They are context- and time-specific and changeable. Gender determines what is expected, allowed and valued in a woman or a man in a given context. In most societies, there are differences and inequalities between women and men in terms of responsibilities assigned, activities undertaken, access to and control over resources, as well as decision-making opportunities. Gender is part of the broader sociocultural context, as are other important criteria for sociocultural analysis including class, race, poverty level, ethnic group, sexual orientation and age.

Source: UN Women, no date, OSAGI Gender Mainstreaming - Concepts and definitions

A gender-responsive approach means that the needs, priorities, power structures, status and relationships between men and women are recognized and adequately addressed when designing, implementing and evaluating activities. This approach seeks to ensure that women and men are given equal opportunities to participate in and benefit from an intervention, and promotes targeted measures to address inequalities and promote the empowerment of women.

Source: The Global Environment Facility (GEF), 2017, GEF Policy on Gender Equality

5 — SDS risk assessment framework

Understanding the risk posed by SDS is critical to managing their disaster potential. SDS risk assessment results based on a systematic and gender analysis can shape SDS prevention and risk reduction, preparation and warning, response and recovery.

Risk is the combination of:

- a hazard of a specific magnitude, intensity, spatial extent and frequency (a hazard event)
- the exposure of society directly or indirectly to this hazard event
- the level of social and physical vulnerability to this hazard event and
- the capacity to deal with the impact of this specific hazard event. Capacity is considered to be the practical opposite of vulnerability

A variety of approaches can be used to assess risk. Risk assessments present a trade-off between accuracy, cost and timely results. The Compendium presents two approaches to risk assessment: one based on a survey of at-risk populations and the other based on structured expert evaluation of factors defining SDS risk. A survey-based assessment (**Figure 9A**) can require from weeks to over a month, depending on the sample size and number of survey teams. While this type of assessment does not need to be completed by SDS experts, their involvement can be useful to understanding the results and defining risk management measures.

Figure 9A

Nine steps of the survey-based assessment process

- Step one – Define why the assessment is needed
- Step two – Define the assessment area
- Step three – Collect background data
- Step four – Design the survey
- Step five – Develop a questionnaire and plan the field survey
- Step six – Secure authorization to conduct the survey
- Step seven – Conduct the survey
- Step eight – Analyse and report on the data
- Step nine – Disseminate and validate results

Figure 9B

Seven steps of the expert-based assessment process

- Step one – Define why the assessment is needed
- Step two – Define the assessment area
- Step three – Design the assessment workshop
- Step four – Collect background data
- Step five – Share information before the workshop
- Step six – Conduct the workshop
- Step seven – Document, disseminate and validate results

Figure 9A, 9B. Survey-based assessment process steps

The expert-based assessment process (**Figure 9B**) involves using experts in SDS and related fields (for example, meteorologists, geographers, sociologists, agriculturalists, community development experts, gender, age and disability experts, health officials (doctors as well as public health specialists) and engineers responsible for infrastructure at risk from SDS) to develop a structured understanding of SDS risk. An expert-based assessment can be completed in as little as a single day-long meeting, with several additional days required to prepare for the meeting and complete a post-meeting report.

The two approaches take into account that detailed data on the nature of the SDS hazard and vulnerability may not be available where risk assessments are needed to evaluate risk and define risk reduction measures. The Compendium includes a draft questionnaire and other guidance.

Both assessment methods provide results that identify risk salience and can guide risk management interventions, including in terms of:

- SDS risk management policy: using evidence-based identification of risk to frame SDS risk reduction policy.
- SDS warning: identifying which triggers are most relevant to at-risk populations.
- SDS response: identifying and raising the profile of SDS response options by identifying where specific responses can be most effective in reducing SDS impact, as well as defining coping and adaptation strategies used by at-risk populations.
- Risk reduction: identifying where risk reduction efforts should be targeted and providing evidence justifying the cost and nature of these interventions. SDS risk assessment results can also feed into larger assessments and strategies related to other hazards such as flooding or drought.

Box 2. Key risk assessment terms

- Disaster: "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."
- Hazard: an event "…that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation".
- Mitigation: "… lessening or minimizing of the adverse impacts of a hazardous event".
- Resilience: The "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management."
- (Disaster) risk: "The potential loss of life, injury, or destroyed or damaged assets which 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 assessment: "A qualitative or quantitative approach to determine the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend."
- Risk management: The "plans [which] set out the goals and specific objectives for reducing disaster risks together with related actions to accomplish these objectives."
- Risk reduction: "… preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development."
- Vulnerability: "The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards."

Source: Report of the Open-ended Inter-Governmental Expert Working Group on indicators and terminology relating to disaster risk reduction https://www.preventionweb.net/files/50683_oiewgreportenglish.pdf

6 — Geographic information system-based SDS vulnerability assessments and mapping

Maps of social vulnerability can provide a detailed understanding of: (1) who is vulnerable to SDS (including sex, age and disability), (2) their degree of vulnerability, and (3) the reasons for this vulnerability. This vulnerability mapping informs decision makers and policymakers about the severity and extent of SDS risks and who is most vulnerable, and provides information to local government, emergency, health and social welfare officials, civil society and other stakeholders on where to direct SDS risk management efforts.

Social vulnerability exhibits such large spatial-temporal variability that an interactive geographic information system (GIS)-based platform can help to handle it efficiently. Vulnerability is not an intrinsic property of a system to be directly observed or measured. Instead, it has to be deduced through a set of variables (indicators) estimating exposure, sensitivity and adaptive capacity.

Box 3. Key terminology used in a GIS-based vulnerability assessment process

- **Vulnerability:** a function of three interactive components: (1) exposure to change, (2) associated sensitivities, and (3) related adaptive capacities. The more the exposure or sensitivity, the greater the vulnerability.
- **Exposure:** the nature and degree to which elements of a system are at risk of a natural or human-induced hazard.
- **Sensitivity:** the degree to which a system is modified or affected by hazard stimuli.
- **Adaptive capacity:** the ability to cope with, manage, recover from, and adapt to the potential adverse impacts. Gender, age and health status need to be considered in defining adaptive capacity.

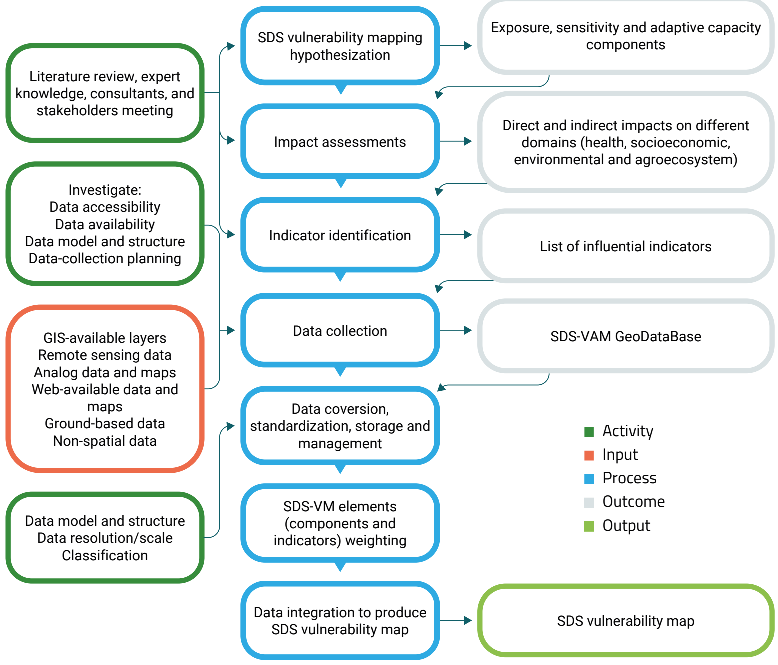
A common practice to estimate vulnerability is to use surrogate measures of vulnerability components and then aggregate them to yield the overall vulnerability "score". Indicators related to human health, socioeconomics, the environment and the agroecosystem are considered key to the vulnerability assessment process.

When selecting specific indicators, three questions must be considered:

- Question 1: How do the given indicators (GIS data layer) contribute to vulnerability to SDS?
- Question 2: To which vulnerability component(s) (exposure, sensitivity or adaptive capacity) does the given indicator belong?
- Question 3: To which level of analysis (local, sectoral, national or international) does the given indicator belong?

A number of technical issues need to be considered in the assessment and mapping process. These include data conformity in the same geometric data model and structure; conversion of a non-geometric data source to spatial representation; unification of different measurement scales used for the indicators (including scaling and standardization) and the data-weighting process (**Figure 10**).

Figure 10. A summarized process of a GIS-based vulnerability mapping



Note: VM: vulnerability mapping; VAM: vulnerability assessment and mapping.

7 — SDS economic impact assessment framework

Measuring the impact of SDS is critical as it allows the government of a country to determine whether the costs of SDS can be moderated by investing in mitigation projects. Governments should also include the costs of SDS in their reporting as part of the Sendai Monitoring process.[4]

It is important to recognize that most benefits of mitigation will accrue to individuals, but most of the costs are incurred by government or government agencies. Thus, even though there may be a net benefit, the funding agency may not have sufficient funds to finance the mitigation programme.

Dust mitigation projects may also be undertaken in source regions outside the national boundaries of a country, as airborne dust particles have been shown to travel long distances, meaning there can be a significant distance between the source region and the impact region. As a result, the benefits and costs of a mitigation programme may fall on, or be incurred by, countries that do not experience some of the major impacts. However, the major decision criterion is that the net benefits of the programme (the sum of benefits in both the impact and source regions) exceed the costs.

A range of costs need to be considered when assessing economic impact. These include: (1) direct costs – those associated with the immediate impact of a disaster, and (2) indirect costs – those imposed on an economy due to business disruptions or other similar impacts caused by a disaster. SDS costs are also calculated based on whether they are incurred on-site or off-site.

On-site costs are usually in the form of loss of soil and sand and, in turn, the loss of soil nutrients and organic matter, including soil carbon. This can have significant long-term effects on agricultural production in SDS source areas. Further on-site costs are incurred in the source region due to damage to infrastructure such as irrigation or water systems,

4 See https://sendaimonitor.undrr.org/.

destruction of fences, loss of livestock and forage for livestock, sandblasting of crops and road cleaning. Dust can also contain soil carbon, which could have a value to the landowner, particularly if in the future carbon sequestration and carbon markets become more functional.

Off-site costs (**Box 4**) depend on many factors, the principal being the level of economic activity in the impact region. Specific areas of off-site cost include transport, health, household cleaning, commerce and manufacturing, and agriculture (including crop and animal loss and/or a deterioration in their quality).

Box 4. Specific areas of off-site cost

- **Transport** – Any event that limits transport capacity or vehicular movement can cause substantial economic losses. However, the impact of SDS on travel speed and transport costs may be difficult to estimate.
- **Health** – The health impacts of SDS are difficult to measure and to assign a cost to, due to the differences in reporting across countries or regions and differences in data analyses. One issue that arises in much research related to the health impacts of dust is the attribution of effect. For example, an at-risk portion of the population, especially those with pre-existing cardiopulmonary issues, may have a higher mortality or morbidity rate during a dust storm due to the atmospheric dust exacerbating their pre-existing condition. The question is whether the dust has direct effects on health or whether it should be considered as an indirect modifier of health effects.
- **Household cleaning** – Research has shown that households face the highest direct costs of SDS due to interior and exterior cleaning, as well as repairs and maintenance of structures and vehicles.
- **Commerce and manufacturing** – Measuring the effect of SDS on the commercial sector is fraught with challenges. Some expenditure that is not made during an SDS event may be made after, meaning that there is no loss in income for some commercial operators. Time-sensitive purchases, such as fresh foods, may not occur during the SDS event, meaning retailers will lose revenue and the product(s) must be discarded. Similarly, discretionary purchases such as takeaway coffee may not be made, again reducing retailer income. Other indirect costs may be incurred in the commercial sector due to delays in the delivery of goods required for production or in the movement of goods out of production facilities.
- **The manufacturing sector** may be affected by SDS if the particulate matter enters the manufacturing facility, or through delays in material required for production being held up in transit. Another cost is that of absenteeism: employees may be absent to care for children (if schools are closed during an SDS event) or others who need care. Absenteeism has been shown to reduce productivity and, as a consequence of the SDS event, must therefore be added to the cost.
- **Agriculture** – SDS can impose costs on the agricultural sector through:
  1. crop destruction or reduced yield,
  2. reduced animal production due to animal death or lower yields of milk or meat, and
  3. damage to infrastructure.

  For annual crops, losses are due to burial of seedlings or crops under sand deposits, loss of plant tissue and reduced photosynthetic activity as a result of sandblasting. This can lead to complete loss of crops in a particular region or a reduction in yield due to partial losses or reduced/delayed growth rates. The impact on perennial crops may be similar to annual crops, leading to current-year crop losses or reduced yield. However, there may also be a longer-term effect on some perennial crops due to tree or crop damage (such as lucerne/alfalfa crowns being damaged), leading to reduced production in future years.

Animal production can also be affected in several ways. There may be a reduction in milk produced during the SDS event, thus costing the producer income with no compensatory reduction in costs. Livestock not sheltered from SDS could be injured and any stress from the physical environment could reduce their productivity and growth.

The SDS may lead to the loss of animals, either through death (particularly through suffocation in severe events) or through producers being unable to locate them after they fled the SDS event. An animal producer may also face destroyed or damaged feed stocks (either pasture or forage crops), requiring them to purchase feed that they would otherwise not have done.

Other negative impacts include damage to agricultural infrastructure (such as the burial of irrigation canals with sediment and covered transportation routes), reduced quality of water in rivers and streams and reduced air quality.

Other costs of SDS in the impact region include: (1) reduction in construction and mining activity, due to health and safety issues at the construction or mine site, (2) increased emergency service activity, due to road or traffic accidents or ambulance traffic transporting patients with dust-related health problems to hospital, and (3) damage to utility infrastructure such as electricity transmission lines or pylons. SDS can also impact cultural, leisure and sporting activities and the cost to the economy will depend on the type of event affected.

Typically, SDS events offer few immediate benefits, and these are usually relatively small when compared with off-site costs. Benefits of SDS arise from two main sources – nutrient deposition on land, and mineral and nutrient deposition on water, particularly ocean bodies. SDS dust can contain soil nutrients such as nitrogen, phosphorus and potassium, as well as organic carbon. When deposited, these can provide nutrients to crops or pasture downwind of the source area.

There are numerous approaches to measuring the economic impact of SDS and the costs and benefits of mitigation programmes (**Table 1**). However, given the diversity of resources to collect and analyse SDS economic impact data across countries, a relatively simple approach is recommended. The preferred method is a combination of cost accounting and surveys, where the latter are used to identify costs that may not be readily available, such as household cleaning costs. This method will allow intercountry comparisons as all countries or regions will be using the same framework.

Table 1. Summary of methodologies, data requirements and skills required

Impact methodology	Data requirements	Analyst skills	Strengths of method	Weaknesses of method	Applications to SDS impact analysis
Computable general equilibrium (CGE)	Very high – need data set including the entire economy.	Very high – need to be able to construct a social accounting matrix.	Good for single event analysis.	Need a control year.	No applications to SDS. Has been applied in single event disasters: Rose and Lim (2002), California earthquake; Horridge, Madden and Wittwer (2005), Australia drought.
Input-Output (I-O)	Very high – need data set including the entire economy.	Very high – need to be able to construct a social accounting matrix.	Good for single event analysis.	Need a control year.	Ai and Polenske (2008), impact of SDS on Beijing.
Surveys	Medium – need a good response rate to surveys.	Medium, but high with respect to survey design and sample selection.	Simple; easy for low-skilled analysts. Can extrapolate single events to multiple events.	May be costly to gather sufficient quality and quantity of data for complete analysis.	Huszar and Piper (1986), impact on New Mexico of multiple SDS events.
Hybrid	Medium–high.	Medium–high – need skill to identify data and data gaps.	Relatively simple; can capture whole impact, providing there are no data gaps. Can extrapolate single events to multiple events.	If there are data gaps or poor data-collection, results will be very poor.	Tozer and Leys (2013), single event SDS in Australia; Miri et al. (2009), multi-ple events in Sistan region of Iran.

A major challenge in cost-benefit analysis is estimating costs and/or benefits for attributes that may be impacted by SDS but that have no identifiable market value or method to value them using market-based techniques, such as environmental benefits, ecosystem services, or societal benefits including health and gender equality.

There are two classes of non-market valuation techniques: revealed preferences and stated preferences. Several methods are available for revealed preferences, including hedonic pricing, the travel cost method, the contingent valuation method, choice modelling, and experimental analysis (**Box 5**).

Box 5. Methods for revealed preferences in cost-benefit analysis of SDS economic impact assessment

- **Hedonic pricing.** Hedonic price analysis treats a "product" not as a single product but as a collection of attributes, qualities and characteristics that consumers desire and for which they are willing to pay. The price a consumer pays for a product reflects how they "value" each attribute of that product (Costanigro and McCluskey, 2011).
- **Travel cost method.** The travel cost method uses consumer behaviour to measure the value that consumers place on "goods" such as environmentally or culturally significant sites (Hanley and Spash, 1993). The method measures how much consumers will pay to "travel" to a site, where paying includes travel costs (such as flying or driving), entry fees, accommodation costs, capital equipment (for example, camping gear), and on-site expenses such as food and drink. By summing the travel costs across the expected number of visitors to a site, the "value" of the site can be estimated.
- **Contingent valuation method (CVM).** This method uses surveys of consumers, usually in some form of controlled experiment, who are asked how much they would be willing to pay for a particular product or service with specific attributes. In ecosystem or environmental analysis, "consumers" are asked how much they would be willing to pay for the services provided by the ecosystem or environmentally sensitive area or, alternatively, they are asked how much they would be willing to accept for the loss of the services provided (Ninan, 2014).
- **Choice modelling.** Choice modelling is similar to CVM, except that instead of valuing the service provided by the ecosystem or environmentally sensitive area, "consumers" are asked to value the specific environmental attributes of the area, then to choose between the alternatives that provide varying levels of the attributes (Ninan, 2014).
- **Experimental analysis.** This method is used to address some of the shortcomings of the stated preference methods, such as differences between what people say in the surveys (their reported willingness to pay) and what they do in reality (their actual behaviour), referred to as "hypothetical bias". In some experimental analyses, consumers use real money to determine a more accurate willingness to pay. This can remove some of the hypothetical bias that may be apparent in survey responses in which there are no consequences for the decisions made.

8 — SDS and health

Since the late 1900s, the health implications of SDS have been under increased investigation. In particular, the modification of air pollution in areas affected by SDS has been studied to understand its effect on health.

To understand the health impacts of SDS, the first issue to consider is that the characterization of exposure of individuals and populations can be approached in different ways. Secondly, the availability of health data is a challenge in many areas affected by SDS. Most of the studies to date have been conducted in East Asia, Europe and the Middle East, and there is lack of studies in West Africa.

Many health outcomes, in terms of both mortality and morbidity, have been examined in epidemiological studies that have mainly focused on the short-term effects of SDS, while the results of systematic reviews indicate different conclusions. Effects in terms of increased risk are seen for cardiovascular mortality and for morbidity due to respiratory causes and childhood asthma.

The cause-and-effect between sand and dust in the atmosphere and health outcomes remains unclear and requires more extensive research. For this reason, together with gaps in data about SDS-associated morbidity and mortality, specific estimates of the health impact and burden of SDS are yet to be fully developed.

9 — SDS source mapping

An SDS source can be defined as a relatively dry, unprotected topsoil surface that is free from vegetation, snow/ice or water, is not frozen and has soil particles available for emission under windy conditions. Source erodibility or dynamics are affected by climate, weather conditions (for example, wind speed or drought), soil surface conditions and characteristics, and human activity.

The dynamics of SDS sources are related to seasonal changes in vegetation cover and snow cover, the existence of or changes in the extent of water bodies, and whether the soil is frozen. These variations cause notable change in SDS source geographic distribution. A soil surface that contains smaller soil particles, generally clay- and silt-size particles up to about 50–60μm in diameter, is more susceptible to wind erosion. Dust emission increases if the soil structure is disturbed and loose.

Knowledge of SDS sources is required for SDS risk and impact assessment, SDS mitigation planning, SDS forecasting and the establishment of SDS early warning systems. Mapping of spatial and temporal distribution of SDS sources requires an understanding of the causes, formation and activation of SDS sources.

SDS source mapping can be divided into two approaches. One approach is based on data on past SDS occurrence: the longer the time frame covered by the data sets used, the better the maps produced. This approach provides a good overview of major and frequently active SDS sources, including global and regional sources dominating SDS generation. Weakness of this approach include: (1) spatial and temporal coverage of observations is not continuous, (2) mapping resolution is relatively lower than when using soil-related parameters, and (3) local and short-term SDS events and sources can be neglected or underestimated.

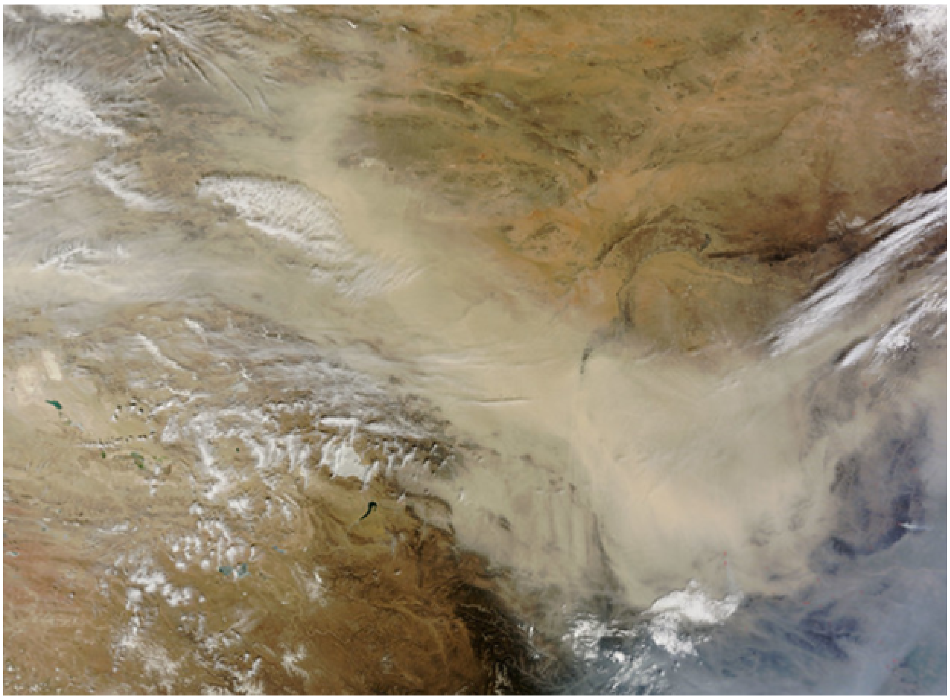
The other approach to source mapping is based on data about surface conditions, focusing on assessing the potential for winds to cause soil surface erosion. The important soil-related parameters required for SDS source mapping include soil characteristics such as soil texture, soil structure, soil particle size distribution, soil moisture, soil temperature, soil texture, land cover and frozen soil.

Advantages of this approach include: (1) its incorporation of information on soil surface status such as soil characteristics and land use, (2) its detection and delineation of localized sources, and (3) its identification of dormant or non-significant seasonal sources. However, this approach requires a complex combination of information from different data sources and can be presented with a lack of information on soil characteristics and soil analysis.

10 — SDS observation, monitoring and modelling

Dust measurements can be divided into two groups: remotely sensed and in situ. Operational meteorologists typically use multi-spectral product measurements generated by instruments on board geostationary satellites for dust monitoring and nowcasting. Imagery from the latest generation of geostationary satellites (**Figure 11**) are a vital tool for atmospheric monitoring, since they combine the advantages of geosynchronous orbits (frequent image capture over a vast area) with the capabilities of high-resolution radiometers and can be available in near real-time. However, satellite products used to monitor dust events encounter challenges including: (1) difficulties in ascertaining the elevation of dust particles, (2) low aerosol detectability over bright surfaces, such as deserts, and (3) the absence of information about dust layers under clouds.

Figure 11. Dust storm in the Gobi Desert



Note: On 8 March 2013, dust plumes rose from the Gobi Desert and blew along the China-Mongolia border. Strong winds kept the dust aloft for several days. By 13 March, dust appeared as far eastward as Henan Province and as far south as the Sichuan Basin. The Moderate Resolution Imaging Spectroradiometer (MODIS) on the National Aeronautics and Space Administration (NASA) Terra satellite captured this true-colour image.
Source: NASA/GSFC/Jeff Schmaltz/MODIS Land Rapid Response Team, 2013.

In situ information collection on SDS is also required for effective monitoring and forecasting. This includes ground measurement stations, air quality networks, weather records, and visibility observations. These measures have pros and cons depending on locations and measurement methodology. For instance, visibility observations recorded in weather records can be used as a way of identifying past dust events, while weather station reporting based on the WMO synoptic codes of present weather can be used to identify airborne sand and dust.

Detailed information on the methods used for dust monitoring and characterization (including size distribution, bulk composition and optical properties) can be found in the review paper by Rodríguez et al. (2012) and references therein. The WMO Global Atmosphere Watch (GAW) Programme envisions the comprehensive, integrated and sustained observation of aerosols on a global scale through a consortium of existing research aerosol networks that complement aircraft, satellite and environmental agency networks (World Meteorological Organization, 2009).

Since 2004, and at the request of more than 40 countries, WMO has taken the lead in this area. It established the Sand and Dust Storm Warning Advisory and Assessment System (WMO SDS-WAS) to develop, refine and provide a basis for distributing to the global community products that can be used to reduce the adverse impacts of SDS and to assess the effects of SDS on societies and on the environment.

Box 6. Copernicus Atmosphere Monitoring Service: a European initiative

Since 2008, the European Centre for Medium-Range Weather Forecast (ECMWF) has been providing daily aerosol forecasts (including dust forecasts) as part of successive European Union-funded projects. A detailed description of the forecast and analysis model, including aerosol processes, is provided in Morcrette et al. (2009) and Benedetti et al. (2009).

These efforts have made it possible to incorporate dust forecasts into the operational Copernicus Atmosphere Monitoring Service (CAMS), which provides daily global dust forecasts up to five days in advance and contributes to the World Meteorological Organization Sand and Dust Storm Warning Advisory and Assessment System (WMO SDS-WAS). All data are publicly available online at http://www.copernicus-atmosphere.eu and on the WMO SDS-WAS centres' websites. An example is shown below. Currently, in addition to the CAMS/ECMWF, a further six global dust forecast models from different national centres contribute to the WMO SDS-WAS (WMO, 2020).

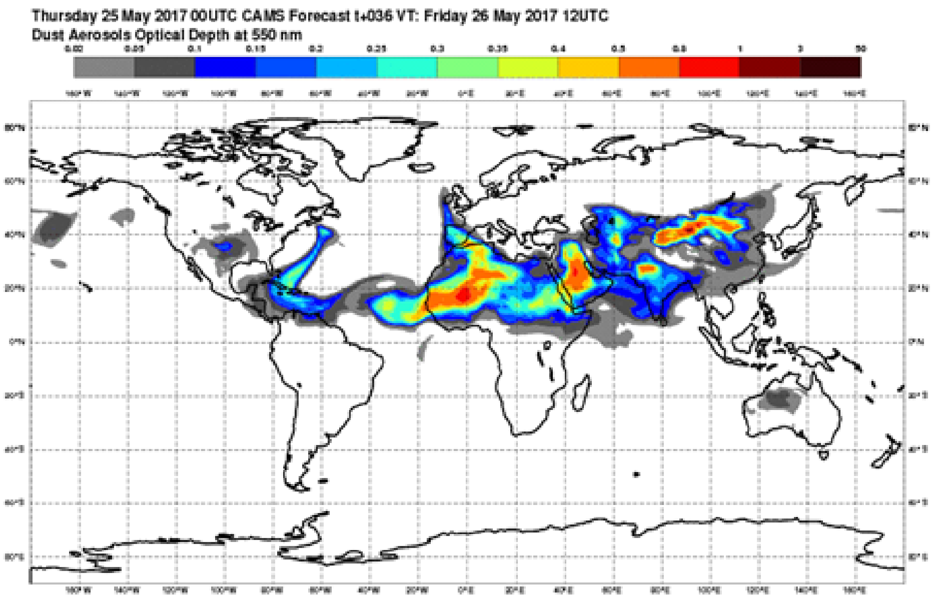


Figure 12. Dust aerosol optical depth 36-hour forecast for 26 May 2017 at 12 UTC provided by CAMS

Source: CAMS, 2017: https://atmosphere.copernicus.eu/

The capabilities of numerical weather prediction models have been developed further by including atmospheric composition (including dust) transport and transformation models, so they are able to predict concentrations of atmospheric constituents such as mineral dust and address the limitations of in situ observation.

These numerical models are closely linked to SDS forecasting. At the global scale, the WMO SDS-WAS has been operating since 2007. Annual dynamics of SDS and descriptions of severe dust events are published in the WMO Airborne Dust Bulletins (World Meteorological Organization, 2017–2020).

This system enhances the ability of countries to deliver timely and quality SDS forecasts, observations, information and knowledge to users through an international partnership of research and operational communities (Nickovic et al., 2015; Terradellas et al., 2015; Basart et al., 2019; World Meteorological Organization, 2020). Working as an international hub of research, operational centres and end users, the WMO SDS-WAS (https://public.wmo.int/en/our-mandate/focus-areas/environment/SDS) is currently organized through three regional nodes:

- a regional node for Northern Africa, the Middle East and Europe (NAMEE), coordinated by a regional centre in Barcelona, Spain, hosted by the State Meteorological Agency of Spain (AEMET) and the Barcelona Supercomputing Center (BSC) (**Box 7)**
- a regional node for Asia, coordinated by a regional centre in Beijing, China, hosted by the China Meteorological Administration (**Box 8**)
- a regional node for Pan America, coordinated by a regional centre in Bridgetown, Barbados, hosted by the Caribbean Institute for Meteorology and Hydrology (**Box 9**)

Box 7. WMO SDS-WAS regional centre for Northern Africa, the Middle East and Europe

The WMO SDS-WAS regional centre for Northern Africa, the Middle East and Europe (NAMEE) based in Barcelona collects and distributes forecast products based on different numerical models on a daily basis through its web page (https://dust.aemet.es/). This initiative has grown significantly with the incorporation of more and more partners.

Currently, 12 modelling groups provide forecasts every three hours of DSC and DOD at 550 nm for a reference area extending from 25°W to 60°E in longitude and from 0° to 65°N in latitude. The reference area is intended to cover the main source areas in Northern Africa and the Middle East, as well as the main transport routes and deposition zones from the equator to the Scandinavian Peninsula. Forecasts of up to 72 hours are updated every three hours.

Ensemble multi-model products are daily generated by the Barcelona regional centre after bilinearly interpolating all forecasts to a common grid mesh of 0.5˚ x 0.5˚.

Since October 2015, the WMO SDS-WAS regional centre for Northern Africa, the Middle East and Europe releases six-hourly maps indicating the weather stations in its geographical domain that report visibility reduced to less than 5 km associated with the presence of airborne sand and dust (**Figure 13**).

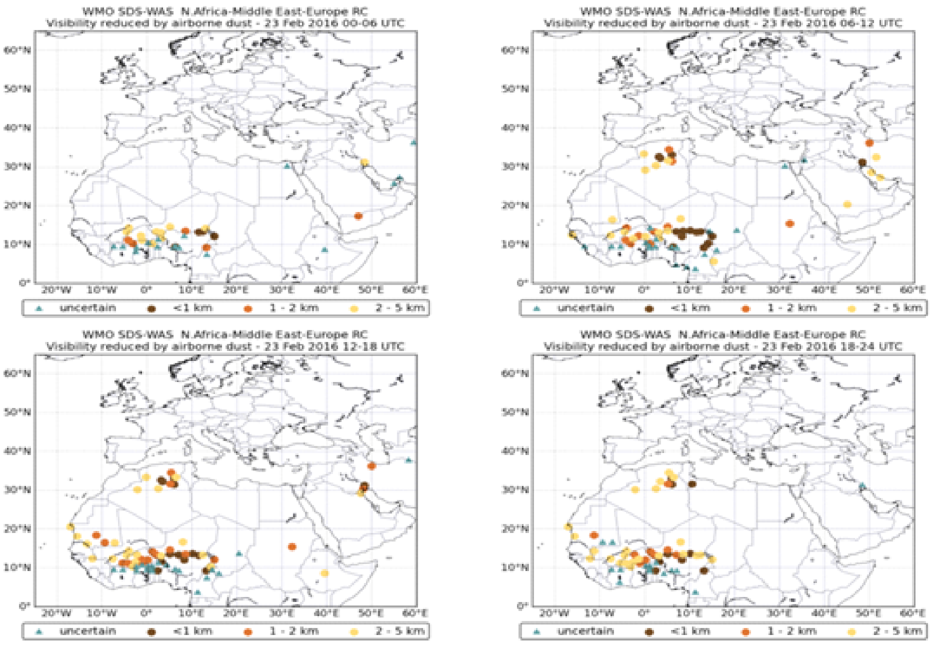


Figure 13. Six-hourly maps of visibility reduced to less than 5 km associated with airborne sand and dust for 23 February 2016

Source: SDS-WAS regional centre for Northern Africa, the Middle East and Europe, 2016: https://sds-was.aemet.es/forecast-products/dust-observations/visibility

Box 8. WMO SDS-WAS regional centre for Asia

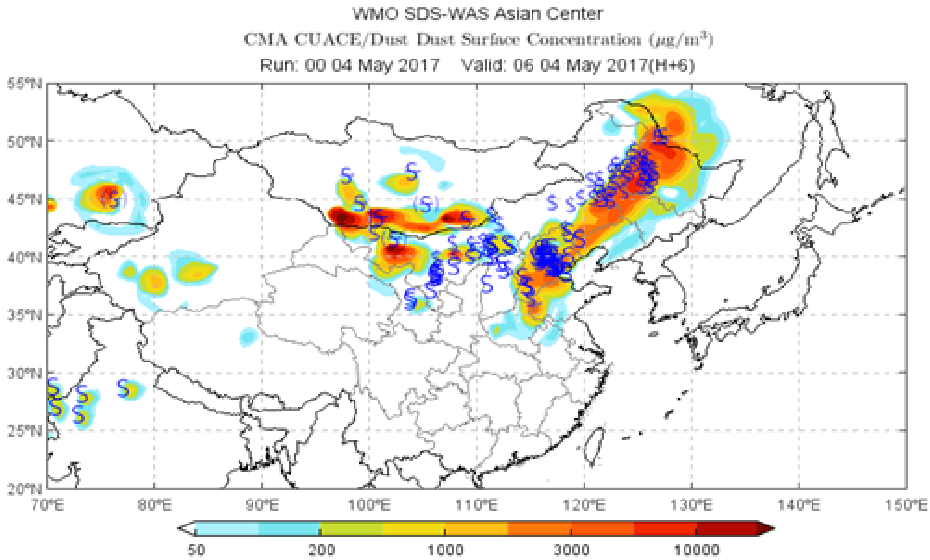
Based in Beijing, the WMO SDS-WAS regional centre for Asia (http://eng.nmc.cn/sds_was.asian_rc/) operates in a similar way to the Barcelona regional centre. Information on sand and dust is collected on a daily basis and used in five numerical models to produce daily reports. The Beijing centre covers the primary dust sources in Central and Eastern Asia, and transport routes and deposition zones up to the Central Pacific. Like the Barcelona regional centre, its forecasts cover dust surface concentration (DSC) and dust optical depth (DOD) every three hours and up to 72 hours in advance. The initiative aims to facilitate the development of forecasting techniques and improving forecast accuracy within the region.

Dust forecasts are evaluated using an approach that differs from that used by the Barcelona centre. A thread scoring system based on different observational sources has been integrated into a geographic information system. The observational data set consists of regular surface weather reports, PM mass concentration data, aerosol optical depth (AOD) retrievals from the China Aerosol Remote Sensing Network (CARSNET), retrievals from the Fēngyún (FY) satellites and lidar data.

Four categories of dust event have been defined:

- suspended dust (horizontal visibility less than 10 km and very low wind speed)
- blowing dust (visibility between 1 and 10 km)
- sand and dust storm (visibility less than 1 km) and
- severe sand and dust storm (visibility less than 500 m) (Wang et al., 2008).

Figure 14. Verification of a dust forecast released by the CUACE[34]/dust model with surface SDS observational data from meteorological stations



Note: CUACE stands for the Chinese Unified Atmospheric Chemistry Environment (CUACE) for Dust
Source: Wang et al., 2008.

Box 9. WMO SDS-WAS Pan-American regional centre

The WMO SDS-WAS Pan-American regional centre (http://sds-was.cimh.edu.bb/) based in Barbados conducts an exercise that is similar to the other two regional centres. However, in addition to the regional focus, the Barbados centre provides global SDS-WAS forecasts based on three US global models run by the National Oceanic and Atmospheric Administration (NOAA), NASA and the US Navy, as well as the ensemble of global research models of the International Cooperative for Aerosol Prediction (ICAP).

In accordance with the aims of the WMO SDS-WAS, the Barbados centre is a node for collaboration across the Americas, working with other WMO SDS-WAS centres to:

- develop, refine and distribute to the global community products that are useful in reducing the adverse impacts of SDS, and
- assess the impacts of SDS on society and nature

The centre's highest priority is addressing the adverse health implications of airborne dust in the region, which experiences both local-source dusts, such as from the Mojave, Sonoran and Atacama deserts, and imported dusts from arid lands of other continents, such as from the deserts of Africa and Asia.

11 — SDS forecasting

Impact-based, people-centred forecasting incorporates information on the impact of the forecasted weather on individuals who may experience it into information provided to the public. Whereas a traditional forecast would state that there would be a dust storm in the next few days, an impact-based, people-centred forecast would specify the time at which the dust storm would begin, and the impact that dust may have on individuals, for example advising those with breathing problems to take steps to protect themselves against the forecast SDS.

Impact-based forecasts are based on:

- a very good, near real-time understanding of evolving weather conditions, based on weather models incorporating accurate and timely weather data from ground and remote sensing sources
- a clear classification of weather conditions and their corresponding levels of impact and
- a risk assessment, to be used to identify impacts on specific locations or groups in these locations (such as children)

Forecast information is usually generated through numerical weather prediction models. A number of models are available covering the national, regional and global levels. One of the methods being worked on to improve the forecast results is ensemble prediction, which aims to describe the future state of the atmosphere from a probabilistic point of view. Multiple simulations are run to account for the uncertainty of the initial state and/or for the inaccuracy of the models and the mathematical methods used in the simulation process (Palmer et al., 1993).

National meteorological and hydrometeorological services (NMHS) are responsible for formulating SDS forecasts at the national level. Depending on the size of a country and its NMHS capacities, forecasts may be developed at the subnational (provincial or state) level. These forecasts and the associated warning information need to be linked to subnational (provincial or state) disaster management authorities, as well as other organizations and actors involved in dealing with SDS.

The capacity of NMHS to manage the SDS data analysis and forecasting process can vary considerably. Where NMHS modelling and forecasting capacities may be limited, the WMO SAS-WAS centres and the WMO website (https://public.wmo.int/en/our-mandate/focus-areas/environment/SDS) can provide global or regional SDS-WAS products to support NMHS with local forecasting. These outputs, together with any modelling done by NMHS, can be used in daily and near-term (three-day) forecasting for SDS.

To ensure that SDS forecasts are consistent and SDS warnings are timely, accurate and coordinated, NMHS and commercial forecasters working in a country should collaborate to develop a coordinated forecast and warning dissemination plan. This plan may also need to include forecasting coming from outside a country when warnings are commonly provided from these sources, for example through global media.

12 — SDS early warning

The effectiveness of SDS warning systems and plans is judged by how well those affected by an SDS event take action to avoid or reduce the impact of the SDS, rather than only by the accuracy and sophistication of the SDS forecast and modelling. A critical part of a successful warning system is ensuring that those intended to receive a warning receive and understand the information provided as well as the corresponding actions to reduce impacts.

The people-centred, gender-responsive and impact-based approach recognizes that at-risk individuals turn warnings into practical actions to reduce the impact of SDS on individuals and on society as a whole.

The impact focus of the warning system identifies how an SDS event can affect someone threatened by the event and what can be done to reduce this threat.

Figure 15 shows the four components of an effective people-centred, gender-responsive and impact-based warning system: (1) disaster risk knowledge, (2) detection, monitoring, analysis and forecasting of the hazards and possible consequences, (3) warning dissemination and communication, and (4) preparedness and response capabilities.

An effective SDS warning system uses a whole-community approach, where all stakeholders – including the at-risk populations (**Box 10**) – are incorporated into a single approach to ensuring that warnings are provided in a timely and targeted manner, and that appropriate actions are taken to reduce or avoid impact.

Figure 15. People-centred, impact-based forecasting concept

DISASTER RISK KNOWLEDGE

- Are key hazards and related threats identified?
- Are exposure, vulnerabilities, capacities and risks assessed?
- Are roles and responsibilities of stakeholders identified?
- Is risk information consolidated?

DETECTION, MONITORING, ANALYSIS AND FORECASTING OF THE HAZARDS AND POSSIBLE CONSEQUENCES

- Are there monitoring systems in place?
- Are there forecasting and warming systems in place?
- Are there institutional mechanisms in place?

WARNING DISSEMINATION AND COMMUNICATION

- Are organizational and decision-making processes in place and operational?
- Are communication systems and equipment in place and operational?
- Are impact-based early warnings communicated effectively to promt action by target groups?

PREPAREDNESS AND RESPONSE CAPABILITIES

- Are disaster preparedness measures, including response plans, developed and operational?
- Are public awareness and education campaigns conducted?
- Are public awareness and response tested and evaluated?

Source: Based on International Strategy for Disaster Reduction (ISDR) and Federal Foreign Office, 2006.

An SDS warning system is based on an overall warning plan, which includes sources of information and analysis, dissemination methods and standard operating procedures to ensure warnings are received in a timely manner. This overall plan is complemented by subplans for specific sectors (for example, health) and specific facilities (such as clinics) or specific purposes (such as road travel warnings or aviation warnings). The planning and overall coordination of the warning process is usually led by the national disaster management authority.

As the SDS warning process can vary considerably between countries, the following questions need clear answers that are acknowledged by all stakeholders involved:

- Who has the legal authority to issue warnings?
- Who ensures that a warning is acted upon? (The party responsible for issuing a warning (for example, the local weather office) may be different from the party responsible for ensuring warnings are followed (for example, the head of local government, disaster office staff, police)).
- How and to whom do the NMHS or subnational offices provide forecast and warning information to ensure warnings are issued in a timely manner?

Box 10. Early warning stakeholders

A range of stakeholders in the forecast process have important roles in developing, transmitting and using the SDS warning information. These include:

- specific at-risk groups that could experience significant negative health or other impacts from SDS
- regional forecast centres, including SDS forecasters, modellers and researchers
- NMHS, including forecasters, modellers and weather education specialists
- national disaster management authorities (NDMA) and subnational counterparts, including planners, early warning system managers, response managers and trainers
- telecommunications officials, including technicians focused on system reliability and message management (including targeting messages to specific locations or audiences)
- health care providers, including health specialists, facility managers, patient managers and emergency health care providers
- transport system management authorities (air, land, sea), including planners, maintenance crews and police to ensure safety during SDS events
- the media, including radio, TV and the Internet and those working through these systems (for example, news readers, presenters and bloggers)
- people working in agriculture and livestock production, including agronomists, livestock specialists, extension agents and infrastructure managers, to minimize SDS-related damage and losses
- industry, including facilities that can be affected by high sand or dust loads in the ambient air, such as those involved in high-precision or low-contamination production
- education providers, including training centres, teachers providing education on SDS and school directors taking action to ensure student safety during SDS
- community welfare or care groups, which focus on assisting those more likely to be affected by SDS

How forecast or warning information is provided to the public can vary between countries.

In some cases, written-text watches and warnings are the norm, while in other countries, colours or numbers may be used to indicate the significance of warnings. Common mechanisms for warning dissemination include print media, radio, TV, the Internet (including emails, social media and warning websites), and mobile phone messaging.

SDS forecasts and warnings contribute to improving SDS preparedness in three ways:

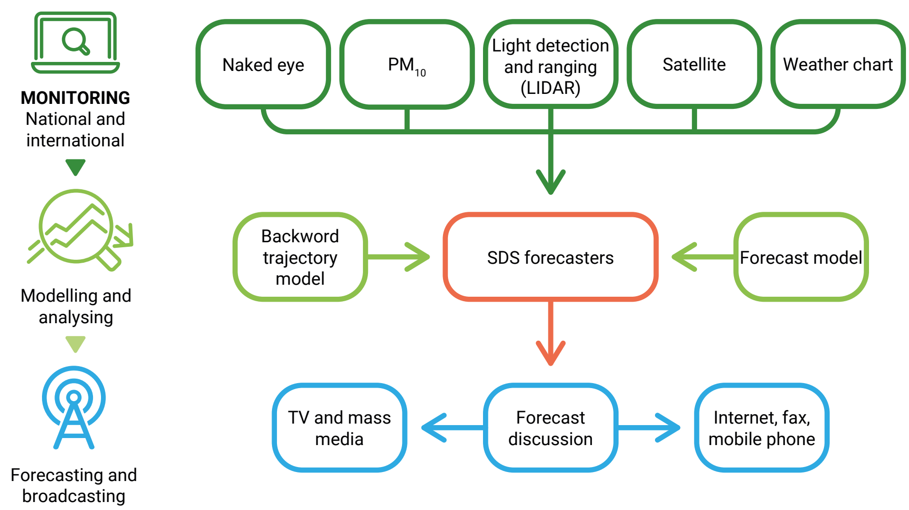
- understanding the nature of SDS creates the basis for understanding SDS as a hazard for which preparedness is needed
- forecasts can trigger warnings, which in turn trigger other actions needed to reduce the impact of an SDS event and
- educating those at risk about SDS so that warnings can be effective not only improves capacities to respond once the warning has been received, but also improves the level of individual and societal preparedness for SDS

Box 11. Dust monitoring and forecasting system of the Korea Meteorological Administration

The Korea Meteorological Administration (KMA) monitors and forecasts Asian dust in four stages:

- First, the KMA uses Asian dust observations made by the naked eye as well as PM_{10} concentrations from the China-KMA Joint SDS Monitoring Network located in the SDS source regions and along the pathways to Korea.
- Second, the KMA also uses international meteorological information from the Global Telecommunication System (GTS) at three-hour intervals and satellite images from the Communication, Ocean and Meteorological Satellite (COMS), NOAA, Himawari-8 and Aqua & Terra/MODIS, to identify the location and intensity of Asian dust.
- Third, the supercomputer-simulated Asian Dust Aerosol Model (ADAM) results are fed to the KMA intranet to be utilized for Asian dust forecasting and the WMO SDS-WAS Asian center to be included in the regional ensemble.
- Finally, PM_{10} concentrations from 29 sites and particle counter data from seven sites are utilized to identify the path and intensity of Asian dust.

The KMA's Asian Dust Warning System uses the results of the monitoring and forecasting system to issue warnings when the hourly average dust (PM_{10}) concentration is expected to exceed 800 μg/m^3 for over two hours. When the KMA issues a warning, the information is shared with the public and broadcasting companies online, including through social networking services.



13 — Source management and impact mitigation

Measures for mitigating the impacts of SDS fall into two groups, designed to reduce: (1) emissions from the sources of sand and dust (preventive measures/ source management), and (2) the impacts of mobilized sand and dust in deposition areas (protective measures/impact mitigation).

Preventive control measures can be further divided into three groups: those for natural ecosystems, forests and rangelands; those for croplands; and those for industrial settings, including mining. Protective measures cover physical protection of valuable assets, such as towns, infrastructure and irrigation schemes; forecasting and early warning systems; and preparedness and emergency response procedures.

Control measures in natural ecosystems, rangelands and croplands are focused on reducing wind speed and soil erodibility. Control of windblown sand and moving sand dunes is also considered, even though these phenomena can occur at wind speeds below those required to generate SDS.

Sustainable land management (SLM, **Box 12**) and integrated landscape management (ILM, **Box 13**) are important concepts for ensuring the integrated application of these control measures. Greatest attention needs to be paid to ILM in potential source areas, as this approach combines sustainable management of all landscape elements, including a water-use strategy and reduction of dust from industrial sites such as tailings dams or open storage areas.

Given the various factors that aggravate wind erosion and the occurrence of SDS, the most effective control strategies would be SLM systems that:

- reduce the elimination of vegetation cover over large areas
- reduce the length of un-vegetated areas to decrease the momentum of wind
- increase soil cohesiveness or stability of soil aggregates and resistance of the soil surface to prevent the lifting of soil particles by wind
- reduce the velocity of wind near the ground and deflect its direction
- control the source of dune-building material (Ben Salem, no date)

Depending on the biophysical conditions of a given area, a combination of SLM practices could be implemented to reduce soil erosion by wind and enhance source management, in order to control SDS.

Sustainable rangeland management also plays a key role in reducing SDS source areas. Methods for controlling wind erosion and soil degradation in rangelands generally take the form of preventative measures such as rangeland resting and rotational or controlled grazing, reduced stocking rates or maintenance of, and support for, the ecologically sound transhumant pastoral system.

However, this type of rangeland management requires rangeland users to be provided with secure use rights, offered adequate incentives and supported in their organizational capacities and collective actions, particularly under open-access grazing systems. There is increasingly recognition that for sustainable rangeland management in drylands, location-specific, bio-physical, social, cultural and economic factors at a multitude of temporal and spatial scales need to be taken into consideration.

Box 12. Sustainable land management principles

The TerraAfrica Partnership (http://terrafrica.org/) presents three principles of SLM as well as principles for upscaling SLM (https://www.wocat.net/library/media/26/):

SLM principle 1: increased land productivity

- Increase water-use efficiency and water productivity (reduce losses, increase storage, upgrade irrigation)
- Increase soil fertility and improve nutrient and organic matter cycles
- Improve plant material and plant management, including integrated pest management
- Improve microclimatic conditions
- Key principle: improved soil cover

SLM principle 2: improved livelihoods and human well-being

- Support small-scale land users with initial investments, where there are often high initial costs and no immediate benefits
- Ensure maintenance through land users' self-initiative
- Consider cultural values and norms

SLM principle 3: improved ecosystems

- Prevent, mitigate and rehabilitate land degradation
- Conserve and improve biodiversity
- Mitigate and adapt to climate change (increase carbon stock above and below ground, for example through improved plant cover and soil organic matter)

Principles for upscaling SLM

1. Create an enabling environment: institutional, policy and legal framework
2. Ensure local participation combined with regional planning
3. Build capacities and train people
4. Monitor and assess SLM practices and their impacts
5. Provide decision-making support at the local and regional levels to:
    - identify, document and assess SLM practices
    - select and adapt SLM practices
    - select priority areas for interventions

Box 13. Integrated landscape management

Five key elements characterize ILM, all of which facilitate participatory development processes. These are:

1. Shared or agreed-upon management objectives that encompass multiple benefits from the landscape.
2. Field practices that are designed to contribute to multiple objectives.
3. Management of ecological, social and economic interactions for the realization of positive synergies and the mitigation of negative trade-offs.
4. Collaborative, community-engaged planning, management and monitoring processes.
5. The reconfiguration of markets and public policies to achieve diverse landscape objectives (Scherr et al., 2012).

Sayer et al. (2013) proposed 10 principles for ILM. A landscape approach seeks to provide tools and concepts for allocating and managing land to achieve social, economic and environmental objectives in areas where agriculture, mining and other productive land uses compete with environmental and biodiversity goals. These principles emphasize adaptive management, stakeholder involvement and multiple objectives:

1. Continual learning and adaptive management
2. Common concern entry point
3. Multiple scales of intervention
4. Multifunctionality
5. Multiple stakeholders
6. Negotiated and transparent change logic
7. Clarification of rights and responsibilities
8. Participatory and user-friendly monitoring
9. Resilience
10. Strengthened stakeholder capacity

Policies for SLM and ILM can be best deployed in the context of the land degradation neutrality (LDN) process to address SDS sources in affected areas at the national level. The LDN target-setting process provides an opportunity to collectively consider options to mitigate anthropogenic SDS sources in particular, including by assessing land degradation trends and identifying land degradation drivers, with the participation of relevant stakeholders linked to land and water resources. An integrated and holistic approach of SLM and ILM can be an integral part of – and maximize synergies among – various actions to reduce anthropogenic dust emissions at larger scales in the long term.

Dune stabilization and afforestation are key practices for protecting soils from wind erosion in drylands and deserts and are an important initial step towards landscape restoration (**Figure 16**).

Regional cooperation is crucial for the management of anthropogenic dust emission at the landscape level, including through sustainable water use. Regional mechanisms based on strong political commitment are therefore needed to coordinate policy between source and deposit areas.

Figure 16. Stabilization of sand dunes in the Kubuqi Desert in northern China

Note: The images show the use of fences made from straw and shrub stems laid out on a grid pattern, followed by the planting of drought-resistant indigenous shrubs which are established using a water-jetting technique. The result 25 years later is a protection belt along the highway. The normal sand dunes in the area can be seen in the background. Source: United Nations Environment Programme, 2015.

14 — Preparedness and impact mitigation

Preparedness and emergency response play critical roles in disaster risk management by helping mitigate disaster risk and lessen the impacts. Preparedness for, and emergency response to, SDS events can take place at the individual, community and organizational levels. Identification and mapping of the hazard in question, vulnerability analysis and risk assessments that take into account gender considerations are used to develop preparedness strategies, identify impact mitigation measures and develop protective actions. The effectiveness and cost-to-benefit justification of each of these measures needs to be assessed based on local conditions.

Effective preparedness reduces vulnerability, increases mitigation levels and enables timely and effective response to a disaster event. These actions shorten the recovery period from a disaster, while simultaneously increasing community resilience. Effective preparedness also requires an understanding of the specificities of communities, including gender inequalities that are relevant in terms of disaster management.

An SDS disaster management plan for a specific location or activity (such as a city, school or factory) should follow the outline of other disaster risk management plans for the same location or activity. Current general good practice is for disaster or emergency plans to be developed at the family, village, town, city, county, province or state, and national levels, as well as for industry and businesses.

These plans generally follow a similar model, with family plans focusing on immediate survival after a disaster (for example, stocking food, water and medicines), and each higher level of plan focusing on providing support to the next level down, for example county plans defining support to cities, towns and villages; state or provincial plans defining support to counties within the state or province.

Based on current good practice, an SDS disaster plan above the family level could be expected to include the following elements:

- Authorities for the plan (may be included in the overall plan for all disasters).
- An overview of SDS as a hazard in the area covered by the plan.
- A risk assessment.
- A gender analysis.
- Specific source and impact mitigation measures based on the risk assessment. This section may include references to subsidiary plans specific to individual sectors, for instance for a hospital or for road transport.
- Warning, information dissemination and public awareness procedures. Warning procedures may include standard operating procedures to effectively disseminate warnings based on the impact-based forecasting approach.
- Thresholds that trigger the activation of the preparedness plan.
- Examples of mitigation measures, where appropriate.
- Links to other programmes (such as soil conservation) that could play a role in SDS mitigation.
- Sources of information and contacts.

Annexes to the plan can include specific procedures for source and impact mitigation and indicate who has primary and supporting responsibility for implementing these procedures. Sector-specific plans tend to cover major economic or social sectors, such as agriculture, construction, education, electricity, health, hygiene, livestock, manufacturing, public awareness, sport and leisure, transport, or water and sanitation. As a general rule of thumb, SDS disaster plans should include sufficient information to allow necessary actions to be taken, while ensuring that no excessive details are added that may hinder the use of the plan.

A range of measures can be taken to mitigate the impact of SDS. The selection of specific measures needs to consider the type of SDS that may occur, the extent to which a warning is possible, and the nature of the activities being undertaken when an SDS event may occur. In all cases, education about SDS and impact measures should be provided to anyone at risk, even if for a short time, and supported by warning and preparedness plans.

An example of state (province) level SDS disaster planning is contained within the Oregon Natural Hazards Mitigation Plan 2015 (State of Oregon, 2015). The plan includes an assessment of SDS and historical examples of impacts, references to warnings and impacts, and source mitigation measures.

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