4. Assessing the risks posed by sand and dust storms

Chapter overview

This chapter discusses the nature of sand and dust storms (SDS) as a hazard and summarizes the differences between risks and impacts. Factors associated with SDS are identified, an SDS typology is proposed and the issue of vulnerability to SDS is explored.

4.1 Assessing SDS disaster risks and impacts

A definition of disaster risk can be found in the **Glossary of key disaster-related terms** (**Chapter 3**). Risk can be understood as the combination of:

- a hazard of a specific magnitude, intensity, spatial extent and frequency (a hazard event)
- 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 the specific hazard event

Where there is no exposure to a hazard, there is no risk, and therefore no need for a risk assessment.

Capacity is considered to be the practical opposite of vulnerability. Assessing vulnerability can incorporate any capacity to not experience damage (i.e. reduce vulnerability) from a hazard event. Further background on disaster risk assessment can be found in European Commission (2010) and Schneiderbauer and Herlich (2004).

Box 5 discusses the link between impact and risk assessment. Understanding the potential impact from, or risk posed by, SDS, requires answers to the following three questions:

- What is the physical and spatial nature of the SDS hazard, at different intensities and frequencies?
- How do SDS hazard events (such as Harmattan, haboob and dust storms) affect humans, society and nature, or what is the nature of vulnerability to SDS?
- How can risks from different combinations of SDS intensity and vulnerabilities be compared to identify the optimum points of intervention for reducing these risks?

In general, risk is seen as a negative factor – something that threatens lives and well-being. However, in the case of SDS (as with other hazards), not all of its impacts are negative. For instance, flooding can bring nutrients to flooded fields and SDS can have positive impacts on forestry and the ocean food chain (as cited in Goudie, 2009), or contribute to a dampening effect on hurricane development (University of Wisconsin-Madison, 2008).

At the same time, defining and quantifying trade-offs between positive and negative impacts is complicated; even more so in the case of SDS due to the lack of a full understanding of the links between possible positive impacts and related possible negative impacts. As a result, SDS risk assessment focuses on negative impacts of SDS events, examining how these events interact with human vulnerabilities to cause harm. Once identified, these risks can become the object of efforts to reduce negative impacts on lives and well-being.

Finally, it is critical to understand that risk assessments present a trade-off between accuracy, cost and timely results. Extremely accurate assessments are costly and time-consuming, while rapid inexpensive assessments can deliver contestable or unusable results. The two assessment procedures presented in this chapter can provide usable, and verifiable, results at reasonable costs.

Box 5. Impact and risk

Impact is how an event, real or conjectured, could affect something (for example a river) or someone (for example people living near a river). Post disaster impact assessments document what has happened during and after a disaster. For SDS, such assessments can be used to define future SDS impacts for the same or similar events.

However, information from post disaster impact assessments is not easily used to project the impacts of events that have not yet been experienced, or where there have been significant changes to the environment. Nonetheless, post disaster impact assessments can provide information that is useful in considering the impacts of SDS and they should be conducted whenever possible.

Environmental impact assessments (EIA) take a different approach to assessing impact. An EIA focuses on assessing the impact of a proposed action (for example a road project) and at least one alternative (for example no road) to generate a comparison of impacts and provide input into the best option for achieving a stated goal (such as improving access to a community) (International Association for Impact Assessment and Institute of Environmental Assessment, UK, 1999). The challenge with an EIA-type impact assessment is that its focus on a defined product (such as the construction of a road) and alternatives is difficult to reconcile with understanding the impact of a range of SDS hazard events with varying intensity, duration, recurrence and impacts.

The alternative to the post disaster and the environmental impact assessment approaches is to look at SDS from the perspective of the future risk of impacts on humans, society and the environment in general. These risks, or future impacts, are defined by different combinations of SDS hazard frequency, spatial extent and intensity and the levels of vulnerability of a population threatened by different combinations of these characteristics. This is usually done through disaster risk assessment, where a variety of methods can be used to develop an understanding of SDS impacts under a variety of conditions.


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4.2 SDS as hazards

4.2.1. SDS as composite hazards

SDS as a hazard is broadly defined as where blowing sand or dust causes visibility to drop below 1,000 metres (WMO, 2014). The US Air Force recognizes two classes of SDS: one where visibility is between 1,000 and 500 metres and the second where visibility is below 500 metres (Secretary of the Air Force, 2003). These two classes allow for a better differentiation of SDS intensity.

The World Health Organization (WHO) has indicated that, for particulate matter, "no threshold has been identified below which no damage to health is observed" (World Health Organization, 2016). While WHO sets guidelines for small particulate matter, the general finding means that any level of particulate matter found in SDS needs to be considered an active hazard, i.e. a potential source of harm.

To understand what makes an SDS event a hazard, the range of factors that must come together to create it must be defined. The term "sand and dust storms" highlights the composite nature of the hazard, involving sand, dust, storm and a range of other factors.

A single hazard event can be defined by the factors that contribute to (or mitigate against) an SDS event and its spatial coverage (size) or magnitude, intensity, duration and frequency. Also important are the impact and source areas of the event, given how these can affect the other four factors. Nevertheless, even when the factors that normally contribute to an SDS event are present, it is not guaranteed that an SDS event will occur (Middleton, 2017a).

Table 1 sets out the factors that can contribute to, or mitigate against, the development of an SDS event. Each factor is briefly described, together with parameters for measuring it (useful in SDS warning systems) and notes providing additional information on the factor.

The table supports the SDS risk assessment process by identifying what contributes to (and what can reduce) the likelihood of an SDS event. Considering these factors as part of the risk assessment process will improve the accuracy and focus of an assessment.

It should be noted that while SDS events release dust, sand, spores, pollen and other small particulate matter (aerosols) into the atmosphere, not all of these elements in the atmosphere are linked to SDS. A range of aerosols exist in the atmosphere independent of SDS, including particles from fire and other forms of combustion, volcanic ash, pollen and spores (Boucher, 2015). Individually, these atmospheric aerosols can pose significant health and other risks but they are not covered in the assessment apart from their involvement in SDS. (See **chapter 2** for more on what an SDS event comprises.)

Table 1. Factors associated with sand and dust storms

Factor	Description	Parameters	Notes
Wind	Wind speed above a specific level can mobilize sand or dust.	• Speed • Direction • Duration of gusts • Turbulence	Wind speeds needed to create a storm differ under different land-use, land-cover and land-form conditions. Surface level effects, turbulence and fluid dynamics can affect the point or location at which sand or dust become mobile. See Kok et al. (2012) for a detailed discussion of the interactions between wind, sand and dust.
Precipitation (rain and snow)	Rainfall reduces the development of SDS, while periods of reduced precipitation (normal, seasonal or abnormal) can lead to increased likelihood of SDS. Snow-covered land is not expected to be a source of sand or dust, but patchworks of snow-covered and non-covered land may enable SDS generation.	• Cumulative precipitation compared to average • Period of days without precipitation (seasonal precipitation may be average but with extended dry periods) • Snow cover	Humidity levels may be an alternative indicator if high humidity is linked to a lack of SDS. Seasonal snow cover may define seasonality of SDS development. Precipitation can also enhance soil moisture and cohesion (Middleton, 2019).
Drought	The absence of normal levels of rainfall (drought) can lead to dry soils, which are more likely to contribute to SDS. Drought can also cause the reduction or loss of vegetation that provides soil cover or disrupts wind speeds to reduce the generation of SDS.	• Negative change in precipitation compared to short- to long-term averages	Long-term drought can change vegetation and land cover, increasing the likelihood of SDS.
Soil moisture	Soil moisture can affect the looseness of surface soil and its ability to be transported by wind.	• Level of soil moisture	Soil moisture can change with daily heating. Wind can have a drying effect. Soil moisture can be high in the morning following frost or condensed moisture and low in the afternoon/evening due to solar heating and wind.
Ground temperature	Whether the ground is above or below freezing. Freezing temperatures make sand and dust mobilization less likely. High ground temperatures can contribute to convention-related wind speed and dust whirlwinds and can reduce soil moisture and dry the soil.	• Ground temperature	Frozen sand or dust is unlikely to be mobilized by wind. Daily changes from a frozen to unfrozen state may define periods when sand or dust can be mobilized.

Factor	Description	Parameters	Notes
Sand	Sand-sized material can be mobilized by wind of a specific speed under specific ground conditions.	• Presence of sand and in what form: dunes, sheets, alluvial deposits? • Grain size more than 63 microns • Quantity of sand available to be mobilized • Type of land cover • Type of land use	Sand often moves relatively short distances when compared to dust. Wind-blown sand can do damage from pitting as well as filling, covering or piling against infrastructure, or burying vegetation.
Dust	Dust-sized material can be mobilized in an SDS event.	• Grain size less than 63 microns • Quantity of dust to be mobilized • Type of land cover • Type of land use	Dust can usually travel very long distances, particularly if lofted to higher altitudes. Dust clouds are often higher in altitude than blowing sand.
Land cover	Substances and natural and unnatural structures that cover land can protect sand or dust from wind action, either partially or totally.	• Standard land-cover characteristics likely to contribute to sand mobilization should be noted.	Land roughness should be considered as this may disrupt or augment wind movement. Changes in land cover (for instance seasonal ploughing and deterioration in vegetation) can significantly change the potential for sand or dust movement, if only for a short period.
Former or occasional lake beds and other areas usually covered by water[1]	Dry or former lake beds, glacial outwash planes, seasonally dried rivers or flood zones can all become sources of sand or dust when dry.	• Presence of sand or dust in formerly water-covered locations	These source areas can change seasonally or not be active for years, depending on water levels or glacial activity. Some locations can also be relatively inactive when covered by vegetation but activated following ploughing or other human activities.
Land use	How land is being used (impacted by humans)	• Standard land-cover characteristics likely to contribute to sand mobilization should be noted • Soil conservation measures	How land is used (for example ploughing, grazing) can create seasonal or long-term conditions that make sand and dust available for the wind to move. Soil conservation measures (such as no-till ploughing or windbreaks) can affect the availability of sand or dust for movement and wind speeds.

1 Added based on comments by Goudie, 2019.

Factor	Description	Parameters	Notes
Chemicals or minerals	The presence of potentially harmful natural or manufactured chemicals or minerals in source locations	• Antecedent land use • Areas known to contain harmful chemicals or minerals • Chemical analysis of source areas and presence in deposited sand or dust	Research suggests that some minerals and chemicals in sand or dust have positive impacts (Goudie, 2009). Some chemicals present in sand and dust may not be natural but the result of manufactured processes (for example pesticides and residues) or other human-generated processes (for example nuclear explosions).
Pollen and natural organic compounds	Carried by storms in the same way as sand and dust, but with different impacts	• Organic composition of airborne substances	A factor when carried in SDS but not when present due to other weather conditions. These compounds have a variety of impacts through a variety of pathways.
Disease agents	Communicable diseases transmitted together with or on sand or dust	• Presence of disease agents that can be transmitted by wind and sand or dust particles	Whether disease agents can be transported is separate from whether they have an impact.
Other non-pathological organisms	Micro-organisms, including fungi, transported by wind directly or on sand or dust	• Presence of micro-organisms	Organisms may not be pathological but may contribute to or establish a presence in the local ecology.

4.2.2. Spatial coverage, intensity and duration of SDS

The area covered by a specific type of SDS event is important in assessing the overall impact of the event, with intensity and duration also crucial factors. The general assumption is that an SDS event in a larger area will have a greater impact compared with an event of the same intensity and duration covering a smaller area. At the same time, the greater the duration or intensity of an SDS event, the greater the impact it will have when compared with less lengthy or less intense events with the same spatial coverage.

These general assumptions need to be conditioned by possible variations within an SDS event. For instance, wind speed in one part of an SDS event may drop due to local conditions, leading to a reduction in the quantity of dust or sand being moved – or the opposite may occur. Meanwhile, sand or dust size, or the inclusion of chemical contamination or disease agents, in an SDS event may affect the severity of SDS impacts on the environment.

Therefore, within an SDS event, actual intensity and duration need to be assessed at the locations where impact is being assessed. This reflects the weather observation process, whereby observers report on the conditions they observe and not on conditions reported from other sources. While remote sensing may provide improvements in understanding the areal coverage, intensity and duration of SDS, the results would need to be calibrated to the level of individual on-the-ground observers in order to be useful in assessing local impacts.

4.2.3. SDS frequency

Hazard frequency is computed based on the expected return period for an event of a specific intensity and duration at a specific location. It would be useful if return periods were defined on locally based frequency curves, but this may make comparing results across locations difficult if these periods were different.

For the purposes of the assessment, the recommended return periods are 1:1, 1:10, 1:25 and 1:50.[2] As more than one SDS can occur in any one year, and the intensity of SDS conditions can vary within a season, an additional, more frequent, return period can be set at 5:1, or an event once every two months. A risk assessment matrix based on the frequency and intensity of SDS has been suggested and applied to assess SDS events in Kuwait (Al-Hemoud et al., 2019).

Since intensity can vary within an SDS event, and may be less intense at the start and end than during the midpoint, or more intense at the start than the end, the return period should be based on the most intense point of the storm, based on the 1,000 metre visibility threshold. Also note that these return periods are for SDS that can be grouped into specific event typologies (see **Table 2**).

4.2.4. SDS hazard source and impact areas

Global SDS mapping efforts (see UNEP et al., 2016; Huimin et al., 2015) provide a good overview of where SDS originate and where they impact. The global and regional mapping of SDS source and impact areas is important in understanding the global extent of the hazard and how source and impact areas are linked even when a considerable distance apart (for example Sahelian dust in Barbados or Brazil).

However, mapping from a global perspective likely understates the local generation and impact of SDS at the national and subnational scales. This local generation and impact can occur through, for instance, the ploughing of multiple fields over a short period of time during a windy week in the spring, or can arise from winds that move sand on a daily basis but over relatively short distances each day for several months a year, for instance, leading to local sand storms and the movement of dunes across roads or fields, but over a fairly small area.

SDS can actively collect sand and dust during movement, as is the case with SDS associated with convective frontal weather systems (for example a haboob). Observations suggest that this ongoing collection of sand and dust can be a significant contributor to the overall sand and dust load of an SDS event.

Nonetheless, all SDS impacts are local. The assessment of the risks associated with these impacts needs to focus on where the impacts occur. Information on the origin of the sand or dust and factors such as disease or chemical contamination are helpful in understanding impact and risks, and should constitute part of the information collected and reviewed in an assessment, if possible.[3]

It is likely that many SDS source areas are also impact areas. Exceptions, such as Sahelian dust in Barbados, or dust in Korea or Japan, are relatively well documented and can be identified as part of the assessment process. As a result, the SDS assessment process does not need to differentiate between source and impact zones except by noting that both sourcing and impacts are occurring in the same location, if this is the case.

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2 While a 1:100 return period is commonly used in risk assessment, it is unclear whether sufficient data are available globally for an assessment at this return period to be possible in most cases.

3 A challenge with assessing chemical or disease components of SDS is that this information often needs to be collected during an SDS event.

The source-impact overlap could pose a challenge in locations where the physical process of sourcing sand or dust leads to significant negative impacts on the environment, for instance erosion damaging vegetation or crop production. Where local source area impacts are considered significant, they can be integrated into the overall SDS risk assessment process by expanding the survey process to consider the impacts of concern (see **chapter 5** on collecting information on SDS impacts).

If specific hazards such as wind erosion or chemical contamination are of significant concern, these hazards should be subject to their own risk assessment. A separate assessment of risks from hazards in a source area can be useful in designing location-specific mitigation measures, for instance to control wind erosion.

4.2.5. SDS hazard typology

A significant range of combinations of winds, sand, dust, land cover and other factors can lead to SDS. The fact that they can move across thousands of kilometres or affect a single small valley adds to the challenge of classifying each SDS event reported.

In reality, SDS risk assessments cannot undertake long-term extensive scientific research to create a detailed classification of SDS events for each location to be assessed. In addition, weather station data, which can be very scarce in a number of the SDS regions, may miss SDS events (for example, a haboob may pass between observations) or a reporting station may be located where localized SDS events occur, such as downwind from a gap in mountains causing localized blowing sand, leading to limited reliability of records of SDS events. (See O'Loingsigh, 2014, for a discussion on using weather station observations to understand SDS events.)

This challenge can be addressed by using a typology of SDS that captures their main characteristics in a uniform and clearly understandable manner. An SDS hazard typology is provided in **Table 2**.

The typology is not intended to present a new scientific definition of SDS, but rather to provide a practical framing of SDS that enables an assessment of relative SDS impacts and risks. Similar typologies are used for earthquakes (Modified Mercalli Intensity Scale, USGS, n.d.) and wind (Beaufort Wind Scale, NOAA, n.d.).

The typology is based on two broad factors:

1. Intensity, defined by the distance of objects visible at eye-level to an observer during an SDS event. This definition of intensity draws on the visibility-less-than-1,000 metres definition (Secretary of the Air Force, 2003), but recognizes the WHO reference to no acceptable minimum level of dust (World Health Organization, 2016). Visibility is used because it is (1) employed as part of the official reporting on weather conditions, (2) easily measured through reference to known objects (for example, is the smoke stack visible?), (3) can easily be included in an assessment questionnaire, and (4) results are relatively less likely to be disputed.

2. Scale, defined by the area covered by an SDS event. Three areal classes are used:

- Small (local) – sand and dust transported over tens of kilometres, generally occurring within part of one country
- Large – sand and dust transported over hundreds of kilometres, generally affecting several countries, or occurring at a regional[4] scale
- Very large – sand and dust transported over thousands of kilometres, generally crossing several countries and often several regions

4 "Region" and "regional" are used here to refer to regions of the globe, not political divisions.

Note that the scale of the event and the scale of the assessment are different. An assessment within a country may consider one or more small-scale events, such as SDS triggered by ploughing, or a very large event, such as dust transported over a great distance, for instance from the Sahel to Brazil. The typology is impact-location-based, in the sense that it is applied where an SDS event is occurring. A small, high-intensity SDS event in one location may be part of a very large, low-intensity SDS event in another location.

Not every SDS event will fit exactly into a grouping in the typology, but any SDS event is expected to fit primarily into one of the six groupings. Outliers can be assigned to groups to which they have the greatest number of common major characteristics.

The typology incorporates:

- the most relevant World Meteorological Organization (WMO) description of SDS characteristics taken from the **Manual on the Observation of Clouds and Other Meteors** (Secretariat, 1975),[5] noted in the table as "WMO" and
- the WMO system for standardized coding of observed weather conditions at the time of observation (see https://www.nodc.noaa.gov/archive/arc0021/0002199/1.1/data/0-data/HTML/WMO-CODE/WMO4677.HTM), noted in the table as "Obs.".

Individual countries also have their own SDS classification systems. For instance, China is reported to use a five-level classification system based on a combination of visibility and wind speed, while the Republic of Korea uses the duration of the presence of sand and dust particle size in the atmosphere (Kang, 2018). These national classification systems can be integrated into the narratives for each type of SDS shown in the table, as part of the background preparation for the assessment procedures detailed in
chapter 5.

It should be kept in mind that the typology is for use among individuals who are not weather experts. The objective is to establish a common understanding of the hazard being assessed by those being interviewed about it.

In the case of the survey-based assessment (**chapter 5.5**), the typology is used to classify perception-based information about SDS affecting those being surveyed. For the expert-based assessment (**chapter 5.6**), the typology aids assessment team members in understanding the hazard being assessed and helps with framing the different types of impacts from different types of events.

Rod Longko ©Unsplash, January 2, 2018

5 The WMO definitions are also available at https://cloudatlas.wmo.int/lithometeors-other-than-clouds.html, with pictures, for reference.

Table 2. Sand and dust storm hazard typology

High intensity, large area (Type One) Frontal generation of dust wall through convection; source and impact areas overlap; can include local movement of sand; high dust density (visibility can drop below tens of metres); hundreds of kilometres long but not very deep; national or subregional; high wind speed (tens of kilometres per hour); often short duration and not persistent; at times with precipitation following; very seasonal (specific months). Example: haboob. WMO: "Dust storm or sandstorm" and Obs.: "Thunderstorm combined with duststorm or sandstorm at the time of observation".	**Low or moderate intensity, large area (Type Two)** Frontal generation of dust; limited source generation in impact area; variable density (visibility rarely down to 1 km, and infrequently lower); hundreds of kilometres long and deep, extending over large areas; long-distance transport possible (thousands of kilometres), national to regional in scale; moderate to no frontal speed, diurnal movement and persistent over days to months; without precipitation; seasonal (range of specific months). Example: Harmattan. WMO: "dust haze" to "dust storm or sandstorm" depending on intensity.
High intensity, small area (Type Three) Windblown sand or dust carried over short distances (tens of kilometres) with prevailing winds (not haboob or Harmattan); source and impact areas can overlap; high speed (tens of kilometres per hour); generally local; often locally significant reduction of visibility; often limited spatial scale but can be frequent and persistent (for example diurnal winds). Example: afternoon sand storms in areas with numerous sand dunes. WMO: "Blowing dust or blowing sand".	**Low to moderate intensity, small area (Type Four)** Windblown sand or dust carried over short distances (tens of kilometres) with prevailing winds (not haboob or Harmattan); source and impact areas can overlap; limited reduction of visibility; limited source or impact areas but can be persistent (for example diurnal winds) over weeks to months; seasonal; without precipitation. Example: blowing dust or sand due to land forms (for example passing between two mountains) that channel and increase wind speed over source areas such as river beds, dryland or dry lake beds. WMO: ""Blowing dust or blowing sand" to "Drifting dust or drifting sand".
High intensity, very small area (Type Five) Windblown sand or dust carried over very short distances (tens of kilometres) due to high speed (tens of kilometres per hour); source and impact areas overlap, very local; often locally significant reduction of visibility; frequent and persistent (for example diurnal winds) or triggered by changes in local conditions. Example: dust from ploughed fields obscuring highways. WMO: "Blowing dust or blowing sand".	**Low intensity, very large area (Type Six)** Regional movement of dust at low density (dust visible but not disruptive to normal activities); source and impact areas different; often at mid-to-high altitude, over large areas; persistent over days or months, but with variable density; seasonal. Example: Dust from the Sahel in Barbados. WMO: "haze" or "dust haze" and Obs.: "Widespread dust in suspension in the air, not raised by wind at or near the station at the time of observation".

4.3 Vulnerability to SDS

4.3.1. Defining vulnerability

For this report, vulnerability is understood to be "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" (United Nations Office for Disaster Risk Reduction, 2017).

Attention to vulnerability, or the potential impact of SDS, broadly focuses on:

- human health impacts, including illness and fatalities associated with SDS
- economy and industry, including economic and financial impacts and livelihoods
- social impacts, generally related to how SDS affect a person, a family or society, for instance changes in social and gender-based roles as a result of SDS impacts
- political system impacts, including the governance of SDS vulnerabilities and the allocation of power within a society, and
- environmental impacts, including impacts on the ecology and nature resources

Capacity is often used as a counterweight to vulnerabilities, such as in the **Vulnerability and Capacity Assessment** process (International Federation of Red Cross and Red Crescent Societies, 2006). For practical reasons, the focus of assessing vulnerability is on what can be considered "net vulnerability", that is, taking into account any capacities that may reduce vulnerability.

The concept of resilience is also being increasingly used in association with vulnerability. While the concept has attracted considerable attention, definitions are still in a state of flux, making it hard to apply consistently when assessing vulnerability.[6]

Resilience is considered to be something that occurs after a hazard event has had an impact and has revealed vulnerability. As resilience does not relate directly to the level of impact, but rather the ability to rebound from this impact, it is not incorporated into assessing vulnerability.

This report uses a disaster risk assessment concept for assessing vulnerability to SDS. An alternate approach to defining vulnerability draws on the process of assessing the impact of climate change. In this approach, vulnerability is "… the propensity of human and ecological systems to suffer harm and their ability to respond to stresses imposed as a result of climate change effects" (Parry et al., 2007).

Table 3 provides a more detailed explanation of how the climate change assessment of vulnerability and the disaster risk assessment terminology compare. Per the comparisons in the table, the climate change definition of vulnerability is close to the one used in disaster risk assessment. As a result, the climate change-based assessments of vulnerability (see **chapter 7**) can be integrated into the vulnerability analysis process described in the table.

6 The situation described in Manyena (2006) continues today.

Table 3. Comparison of climate change and disaster risk assessment terminology (Modified from CAMP Alatoo, 2013a)

Term	As applied to climate change assessment	As applied to disaster risk assessment
Exposure	"...background climate conditions against which a system operates, and any changes in those conditions..."	Whether someone or something is in a location that can be affected by a hazard.
Sensitivity	"...the responsiveness of a system to climatic influences, and the degree to which changes in climate might affect it in its current form..."	Incorporated as part of vulnerability.
Potential outcome	Exposure and sensitivity	Incorporated as part of vulnerability.
Adaptive capacity	"Adaptation reflects the ability of a system to change in a way that makes it better equipped to deal with external influences."	Incorporated as part of vulnerability, but only to potential damage and not to risk reduction.
Vulnerability	Exposure, sensitivity, potential outcome and adaptive capacity, as defined in climate change assessment.	The damage that can be done by a hazard event of a specific magnitude, frequency and timing.
Hazard	The change between the current and future climate (e.g. increase in average temperature).	An event that can lead to negative consequences on humans.
Hazard event	Incorporated in Exposure – "...any changes in those conditions".	An occurrence of a hazard of a specific magnitude, timing and frequency.
Frequency	Incorporated in Exposure – "...any changes in those conditions".	How often a hazard of a specific magnitude will occur.
Magnitude	Incorporated in Exposure – "...any changes in those conditions".	The physical scale of a hazard event, measured in a standard metric (e.g. mm of precipitation).
Resilience	Similar to Adaptive capacity but only in relation of a hazard event, not reducing the likelihood of future hazard events.	The means that reduce the initial outcome of a hazard event on six capitals; the means to reduce vulnerability.

The "**As applied to climate change assessment**" column contains quotes from the Australian Greenhouse Office (Allen Consulting Group, 2005). The use of "vulnerability" in climate change assessments is broader than the use of the word in disaster risk assessment. For more on this difference, see Jones et al. (n.d.).

4.3.2. Vulnerability to SDS

Since SDS can vary in size, duration, intensity and so forth, as indicated in **Table 2. Sand and dust storm hazard typology**, assessing vulnerability to SDS must consider the full range of possible impacts (i.e. vulnerabilities) from these events. Middleton and Kang (2017) developed a list of impacts, arranged by sand and dust entrainment, transport and deposition. This list is expanded on below to provide a broad base for considering vulnerabilities as part of the risk assessment process.

Conflict – SDS may take place in ongoing or post-conflict zones. The conflict may induce conditions that increase the likelihood of SDS events (see Tharoor, 2015), or post-conflict recovery may lead to measures to reduce SDS vulnerability, such as re-filling marshes in the Khuzestan Province of south-western Iran.[7]

Economic – These impacts can be associated with disrupted transportation, but also reduced agriculture and animal production (Stefanski and Sivakumar, 2009), and can cause significant loses (as cited in Judger et al., 2011), as well as contamination of production facilities (for example semiconductor manufacture) and increased operating costs (Kang, 2018). SDS can also cause damage to electrical transmission and communications systems and increase operating costs in the form of higher cleaning and maintenance costs (for example air conditioner filters), and household and business cleaning following the passage of an SDS event (Middleton, 2017b).

SDS events can also affect major national economies, such as the oil and gas operations and oil transport in Kuwait (Al-Hemoud et al., 2019), or flight operations (Al-Hemoud et al., 2017). They can also impact tourism (Tulinius, 2013), with these impacts also shared across transport (for example diverted aircraft) and livelihoods (for example reduced income due to dusty weather reducing tourist excursions).[8] See **chapter 6** for more on the economic impacts of SDS.

Environmental – Apart from location-specific environmental impacts, SDS can also have broad environmental impacts by affecting weather patterns (University of Wisconsin-Madison, 2008), albedo and atmospheric clarity (for example affecting photosynthesis).[9] These impacts are often so broad as to be difficult to assess on an SDS-event-specific basis.

The movement and removal of sand and dust over short or long distances is due to a combination of winds and ground conditions. This movement can reduce soil depth and fertility, cover vegetation and create hard-pan surfaces that do not support vegetation normally found in the local environment. These impacts are to the source area environment, but source areas can also experience the other impacts summarized below, as sand and dust may move over very short distances, making the source-destination distinction less relevant when SDS occur.

Financial – All the aforementioned impacts have direct or indirect impacts on finances, whether from loss of employment due to damage irrigation systems, loss of production for the same reason, increased operating costs due to a need to clean up after an SDS event, or increased operating and maintenance costs for infrastructure. Under ideal conditions, all the financial impacts of SDS would be translated into clearly defined cost data, leading to a clear costing of these impacts. Middleton (2017b) and Tozer and Leys (2013) provide overviews of SDS cost issues.

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7 As viewed during a field trip organized as part off the International Conference on Combating Sand and Dust Storms, Tehran, Iran. 3–5 July 2017.

8 Tourists can also intentionally visit SDS-impacted areas, such as the Dust Bowl in the United States.

9 SDS are often associated with low humidity. While entrained dust and sand does affect air density, the lack of heat-retaining moisture in the air can lead to a pattern of warm days due to direct heating from the sun and cool nights since the dry air retains little heat.

However, this is likely possible in only a few cases where good quality reporting on the range of impacts is available (Tozer and Leys, 2013). See **chapter 6** for more on the financial aspects of SDS.

Governance – These impacts are generally associated with the extent to which a governance system (including political systems and politics) respond to SDS, as single events or as a type of hazard. Disaster risk governance systems that have strong capacity to address SDS will reduce the impacts noted above, with weak governance having the opposite impact. For SDS as a transboundary hazard, governance impacts include consideration of national as well as transnational capacities, generally in the form of cooperation and collaboration, as well as the role that regional and international organizations are engaged in to assist governments with managing SDS. More on risk governance can be found in Gall et al. (2014), while Hemachandraa et al. (2017) discuss the role of women in disaster risk governance.

Health – Entrained dust, in particular where particles are smaller than 10 microns, can enter lungs and smaller 2.5 microns can reach deep into lung tissue (UNEP et al., 2016). The result can be severe breathing problems for at-risk populations (for example people with chronic lung problems), as well as the potential for disease transmission (Goodyear, 2014) or the transportation of toxic chemicals or radiation, for instance reported for the Aral Sea region (Columbia University, 2008). Other direct health impacts include eye and circulation problems, as well as illnesses from contaminated water supplies. Vulnerability to health impacts appears to first impact those with pre-existing health conditions (for example asthma) and then, as SDS conditions become more severe, the larger population in an SDS-impacted location. (See Goudie, 2014; Khaniabadi et al., 2017; Al-Hemoud et al., 2018; and Middleton, 2017b.) See **chapter 11** for more details on health and SDS.

Infrastructure – SDS events can close roads with blowing sand or, under the right conditions, shift the ballast of roads. Blowing sand and moving sand dunes (often associated in space and time) can cover buildings and other infrastructure and incur recurrent costs for regular sand clearance.

The movement of sand and large quantities of dust can fill irrigation and water supply channels, reducing effectiveness and requiring increased maintenance costs and also affecting water quality (which can lead to health issues, as well). Dust can impact solar panel efficiency (Al-Dousari et al., 2019) and microwave and radio transmission effectiveness. Blowing sand can pit glass on solar panels and other surfaces, leading to reduced effectiveness and higher operating costs. (See Middleton, 2017b and Baddock et al., 2013.)

Livelihoods – Livelihoods impacts are a broad category that can encompass economic, health, infrastructure and financial impacts but generally focus predominantly on SDS impacts at the individual and household levels. These impacts include lost or reduced income due to SDS damage to crops or reduced work opportunities, reduced food security due to these and other impacts, SDS-related health cost burdens on individuals and families and other impacts that may be noted at the individual or household levels, but not well captured elsewhere.

Social – Health and other impacts can have a knock-on effect on individuals, extended families and society in general. These impacts can range from the stress of dusty conditions or blowing sand to caring for family members who experience health problems during an SDS event. Social systems are important in reducing or mitigating impacts and the severity of impacts often reflects how well social systems deal with potential disasters.

Transportation – SDS can lead to reduced visibility, leading to transport accidents (Tobar and Wilkinson, 1991; Associated Press, 1991). Even relatively low densities of atmospheric dust have contributed to aircraft accidents. Note that transport impacts can be very local (blowing dust due to the ploughing of fields) or regional (dusty conditions leading to airport closures). (See Baddock et al., 2013, for a more detailed discussion of SDS and the transport sector.)

4.4 Assessing vulnerability to SDS

Defining a process for assessing vulnerability to SDS needs to firstly consider the availability and reliability of data on weather conditions (including air quality), health status, economic impacts and environmental conditions, and whether the data are consistent spatially and over time. Where SDS-affected locations have good data, in the sense of reliability and consistency, a range of statistical methods can be used to assess impacts and differentiate impacts by levels of exposure to a single SDS event, or the cumulative impact of several events. **Chapter 7** provides an SDS-focused process to assess vulnerability where data availability or quality is not a critical issue.

It is also possible, and preferred as a decision-making tool, to define SDS impacts in terms of value lost. Such economic impact assessments are often used after a disaster to define the cost of the disaster. As part of a risk assessment, projecting economic loss from future events can be very useful in identifying where investments in risk reduction will be most effective. Economic-loss-based risk assessment and updates can be extremely useful in measuring progress in reducing losses and the changing nature of risk over time.

Chapter 6 provides a process for assessing the economic impact of SDS. Where data are available, economic damage and loss assessment procedures can be used, with such assessments often being carried out, in one form or another, post disaster (see Global Facility for Disaster Reduction and Recovery, n.d.).

However, a challenge arises when the assessment of SDS vulnerability includes locations where data are not considered fully reliable or consistent for all the impacted areas and populations. This situation, in addition to missing data sets for some locations covered in an assessment, will yield results that over- or understate vulnerabilities, or miss them altogether. Such results limit the utility of an assessment in defining and prioritizing actions to reduce individual and societal vulnerability to SDS.
Clearly, some SDS-affected locations have access to reliable and consistent data. However, to compare SDS impacts at a regional scale, between nations or between adjoining parts of neighbouring nations, the least reliable or consistent sources of data need to be considered the norm upon which the assessment process is based. Issues with data reliability and consistency and the availability of sex- and age-disaggregated data are noted for several large parts of the SDS-affected areas globally.

A common approach to the need for reliable and consistent data is to create proxy indicators of vulnerability using the best available data. One example is associating the level of poverty with increased vulnerability under the assumption that poorer people will have fewer means to manage a hazard.

While such logical justifications for selecting indicators from limited data sets may appear sound, the process faces three problems:

- The underlying data, for instance on poverty, may have the same reliability-consistency issues as for data more directly related to SDS vulnerability.
- There may be no clear evidence to back the logical justification, in part because of the lack of reliable or consistent data.
- The process of combining different indicators may not address the issue that the indicators themselves may not be comparable. For instance, does it make sense to combine poverty levels and urban environmental conditions and poverty levels and rural environmental conditions, given that urban and rural environments are very different?

Working through these problems, for an assessment process that needs to consider local to aggregate global SDS vulnerability, presents significant challenges that are unlikely to be resolved in the near future. (See **chapter 7** on data used for a GIS-based system to assess vulnerability.)

The alternative is to turn to research on the sociology of hazards and use the perception of vulnerability to measure and compare vulnerability.
The use of perceptions in understanding vulnerability and risk is well established (see Slovic,1987, and Pidgeon et al., 2003).

In practice, using perceptions to assess vulnerability is reasonable because:

- data can be collected in ways that are reliable and consistent spatially and over time
- these data can be analysed using normal quantitative methods, and
- the process can incorporate general perceptions of SDS vulnerability from those at risk and potentially more informed perceptions from topical experts

Evidence indicates that individuals act to address hazards based on their perceptions of the significance (threat) of a hazard. Knowing how individuals, and groups of individuals in a location, perceive a hazard, and how these perceptions differ due to gender, age, social status and so on, is important to understanding how individuals will act to address the hazard. This, in turn, helps define the needs for education about the hazard before people will be being willing to act to reduce vulnerability.

Data on respective perceptions of SDS vulnerability are most easily collected through a questionnaire administered to individuals or groups. Recent advances in data collection have significantly reduced the difficulty and time needed to collect and analyse questionnaire-generated data.[10]

As noted, individuals use their perceptions as a way of defining their vulnerability to hazards. Meanwhile, an expert's understanding of vulnerability is based on research and data, but also on their professional experience – their perceptions – gained over time. Thus, a doctor treating breathing problems will base their assessment of vulnerability not only on research results and recorded health data from patients, but also on their experience in treating patients with similar conditions. This combination of data-based analysis and experience significantly expands an expert's ability to understand and define vulnerability.

Using expert understanding of vulnerability presents two challenges:

- No single expert will have a full understanding of all aspects of vulnerability.
- Individual experts may frame their understanding in ways that are different from other experts in the same field.

The first challenge is addressed by involving a range of experts from different fields (for example health, weather, agriculture, social services, economics, emergency management, transport, gender) in the assessment process. Within reason, the more – and the more diverse – the experts involved, the broader and deeper the common understanding of vulnerability to SDS that will develop.

The selection of experts should reflect the scale of the assessment. For example, experts with a knowledge of vulnerability due to changes in environmental conditions within one part of a country may not be appropriate for an assessment with a transnational focus on vulnerabilities.

10 The KoBoToolbox is a commonly used software package for the collection and analysis of data collected through questionnaires. See https://www.kobotoolbox.org/.

The second challenge is addressed by providing those involved in the assessment with a structured set of definitions of levels of vulnerability. This serves to frame discussions and decisions by experts so that, to a significant degree, expert understanding of vulnerability generates similar assessment results across different locations and scales of assessment. This allows assessment results to be compared across space and scale – a significant advantage given the global nature of SDS events.

The use of expert understanding in a structured assessment framework is an adaptation of the Delphi method, with a focus on gaining a consensus of experts on levels of vulnerability.

Background on the Delphi method, and its more complex applications, can be found in Cuhls (n.d.). A similar method for climate hazards is described in the CAMP Alatoo and UNDP Central Asia Climate Risk Management Program (2013a, and 2013b).

Framing vulnerability

The analytical framework to be used by experts in assessing vulnerability is drawn from the Sustainable Livelihoods Framework (SLF) (United Kingdom of Great Britain and Northern Ireland, 1999) and the identification of types of capital that can be affected by a hazard. An advantage of using the SLF is that it covers a broad range of factors which can define vulnerability and so provides

a broad base for understanding the nature of vulnerability and where actions to reduce vulnerability can be targeted. The Sustainable Livelihoods Framework encompasses the categories of impacts already set out in **chapter 4.3.2**.

The six types of capital used to assess vulnerability are:

1. **human**, principally human health in recognition of the health impacts of SDS, including fatalities due to SDS-related transport or other accidents
2. **natural**, broadly, the natural environment (for example ecology, natural resources) which can be affected by, but also contribute to, SDS in the case of locations that are both sources of SDS and impacted by SDS
3. **physical**, including infrastructure (such as roads and irrigation, power, communications and other lifeline systems) and assets needed for work or employment, including seeds, tools and equipment that can be affected by SDS
4. **financial**, covering the income, credit and savings available to places vulnerable to SDS to pursue normal activities and cover extraordinary costs, where these assets can be lost or reduced by an SDS event. Note that the cost of addressing SDS impacts can reduce savings even as income remains unaffected.
5. **social**, covering the personal connections (for example extended family, associations, and other support mechanisms) that play a significant role in reducing or exacerbating vulnerability to SDS
6. **political**, the governance systems that can reduce or increase vulnerability to SDS

The first five types of capital are adapted from the Department for International Development (United Kingdom of Great Britain and Northern Ireland, 1999) and Twigg (2001). Political capital is not included in the standard SLF but it is included in the SDS assessment process to capture government engagement in addressing vulnerability. These six capitals largely cover the focus of the SDS risk assessment on the environment, economy and industry, human health and socio-politics.

Table 4. Scaling vulnerability to sand and dust storms provides descriptive indicators for various levels of SDS vulnerability for each of the six capitals, ranging from insignificant to extreme.

While the expert-based assessment draws primarily on the participating experts' understanding of the impacts of SDS, reference should be made, where possible, to existing reliable and consistent data sets. This reference to available data supports a deeper understanding of the nature of vulnerability and can make the selection of one descriptor of vulnerability over another easier and clearer.

Elaborating on what is covered under each capital in terms of vulnerability to SDS based on local conditions, for instance including solar panels under the physical capital group, can help with developing the expert consensus on levels of vulnerability. In other words, the more information to inform expert decision-making, the better.

SDS impacts are not consistent across all age groups and physical conditions. As a result, the expert-based assessment process should first cover the general population vulnerable to SDS within an area to be assessed. Moreover, on the surface, the SLF framework does not differentiate between women, men, boys or girls, age or disability. As a result, gender, age and disability analysis should be used as part of the scaling of vulnerability to better understand the vulnerabilities and capacities.

Consequently, the assessment process should then be redone for specific groups considered to have specific or heightened vulnerabilities to SDS, such as girls, women, children, older persons or those with lung or circulation-related health conditions, for example. This leads to results that help understand the depth and breadth of vulnerability to SDS across the at-risk population.

Table 4. Scaling vulnerability to sand and dust storms

Type of capital	Level of vulnerability				
	Insignificant	Low	Medium	High	Extreme
Human, focused on human health	No negative short- or long-term outcomes for health indicated.	Temporary negative short-term health outcomes for part of general population; no deaths.	Limited, short-term negative health conditions for majority of the target population; one or more deaths attributed directly to dust or sand.	Large numbers of target population experiencing negative short- to long-term health impacts, with several deaths directly attributed to sand or dust.	Widespread health impacts and fatalities above 1:10,000/day in affected population.*
Physical, focused on infrastructure and physical assets needed for work or other purposes	No vulnerability of physical capital noted.	Limited, local, short-term damage to limited segments of physical capital.	Broad but short-term (less than a week) damage to physical capital.	General, lasting (more than a month) damage to physical capital.	Destruction of physical capital, limiting the use of infrastructure and buildings and the operations of irrigation systems and affecting resources for crop production or animal husbandry.
Financial, focused on income, savings or access to credit	No loss of income or financial resources.	Temporary loss of income due to unemployment or other reasons (for example no rental income), reduction in savings, increased reliance on credit, or a combination of all three.	Loss of income due to unemployment or other reasons (for example no rental income) beyond a month, reduction of savings for more than a month, reliance on credit or a combination of all three.	Loss of work for more than six months and reliance on savings or credit to meet needs.	Near-total loss of income and savings and no access to credit.
Social, focused on support available from family, friends and other social networks	Support from social network not needed.	Limited support from social network required.	Significant support from social network required, but for only a limited period (months).	Significant support from social network required for an extended period (beyond several months).	Total reliance on social network to meet needs.
Natural, focused on the state of the natural environment and natural resources	No damage beyond levels normally experienced.	Short-term reduced use of natural resources to meet basic needs.	Reduced use of (access to) natural resources needed to meet normal needs for 3–4 months.	Extended reduced access to natural resources needed to meet normal needs.	No access to natural resources due to damage to natural systems.
Political, focused on capacity of governance systems to address threats from SDS	Government response addresses threat.	Government response effective but with limited gaps.	Government engagement with SDS, but significant gaps.	Very limited government engagement with SDS.	No government engagement with SDS.

Note: The 1:10,000 fatalities to population threshold is generally used as the marker for a transition from a normal level of fatalities to those indicating a disaster. For more details on disaster-related fatality rates, see Checchi and Roberts, 2005.

4.5 Conclusions

This chapter has reviewed the nature of SDS as a hazard and defined SDS characteristics that should be considered when defining the scale and impact of these events. A typology of SDS events has been provided based on the characteristics of different SDS events. The typology is intended to make SDS classification clearer for SDS risk assessment, considering that those performing the assessments will not be SDS experts.

The chapter has reviewed the nature of vulnerability and how it is affected by SDS. A table for **Scaling vulnerability to sand and dust storms** has been developed based on a modification of the Sustainable Livelihoods Framework (SLF) (United Kingdom of Great Britain and Northern Ireland, 1999). This vulnerability scaling provides those conducting SDS risk assessments with a way of assessing vulnerability in data-poor conditions, or where data are inconsistent between locations. The vulnerability assessment process is also linked to the GIS Vulnerability Mapping process found in **chapter 7**.

The materials covered in the chapter, and the typology and vulnerability scaling information, provide a straightforward foundation for assessing the risks posed by SDS. Specific approaches to risk assessment are covered in **chapter 5**.

4.6 Web-based resources

- Environment and Disaster Management – http://envirodm.org/
- Environmental Emergencies Centre – http://www.eecentre.org/
- Environmental Peacebuilding – https://postconflict.unep.ch/publications/UNEP_ECP_PBR01_highvalue.pdf
- The Health and Environment Linkages Initiative (HELI) – http://www.who.int/heli/impacts/hiabrief/en/
- ReliefWeb – https://reliefweb.int/
- WMO, Environment web page – https://public.wmo.int/en/our-mandate/focus-areas/environment/sand-and-dust-storm/sand-and-dust-storm-warnings
- WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) – https://www.wmo.int/pages/prog/arep/wwrp/new/SDS_WAS_background.html
- Convention on Biological Diversity, What is impact assessment? – https://www.cbd.int/impact/whatis.shtml

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