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Contingency planning process for catalysing investments and actions to enhance resilience against sand and dust storms in agriculture in **the Islamic Republic of Iran**

Contingency planning process for catalysing investments and actions to enhance resilience against sand and dust storms in agriculture in **the Islamic Republic of Iran**

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Abbreviations

AERONET	Aerosol Robotic Network
AHP	analytical hierarchy process
AHPI	agriculture, health and property insurance
AOD	aerosol optical depth
AP	active population
APA	animal protective actions
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
CAI	cleaning agriculture infrastructures
CC	canopy coverage
CMT	crisis management team
CSD	cadaster system development
DEG	damage estimation group
DER	dust emission rate
DoE	Department of Environment
DRM	disaster risk management
DRR	disaster risk reduction
DSI	dust severity index
ERA5	Fifth-generation European Centre for Medium-Range Weather Forecasts atmospheric reanalysis of the global climate
EWS	early warning system
FAO	Food and Agriculture Organization of the United Nations
FFP	fruit and food protection
FVC	fractional vegetation cover
FWS	food and water supply
GIS	geographic information system
IRIMO	Iran Meteorological Organization
IRCS	Iranian Red Crescent Society
LDI	land degradability index
LGI	livestock grazing index
LR	literacy rate
MERRA	Modern-Era Retrospective analysis for Research and Applications

METAR	Meteorological Aerodrome Report
MODIS	moderate resolution imaging spectroradiometer
NDD	net dust deposition
NDMO	National Disaster Management Organization
NDVI	normalized difference vegetation index
NL	number of livestock
NPP	net primary production
NRWO	Natural Resources and Watershed Management Organization
PBO	Planning and Budgeting Organization
PD	population density
PDSI	Palmer drought severity index
PGP	promoting good practices
RHC	rural health centre
SDS	sand and dust storm(s)
SLM	sustainable land management
SOC	soil organic carbon
TNCM	transport network crisis management
TPK	technologies, good practices and local knowledge
UNCCD	United Nations Convention to Combat Desertification
Vis	visibility
WESI	wind erosivity severity index
WFPL	washing fruits and plant leaves
WMO	World Meteorological Organization

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Overview

Sand and dust storms (SDS) occur under a wide range of agricultural conditions. These global environmental phenomena arise from the interaction of natural drivers, such as climate change and drought, and anthropogenic factors, such as mismanagement of water, soil and plant resources.

The Food and Agriculture Organization of the United Nations (FAO) interregional technical cooperation programme (TCP) – Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture – has supported the Islamic Republic of Iran in conducting SDS disaster risk assessment in a selected district. This project served as the basis for development of timely, effective and appropriate preparedness and response measures in the frame of a contingency planning process, as an integral part of SDS disaster risk management in agriculture (cropland and rangeland). Following meetings with national organizations and other SDS stakeholders, Ahvaz County was selected to develop a contingency plan for mitigating SDS disaster risk in agriculture in the Islamic Republic of Iran.

Scope

This contingency planning process serves a guide for initiatives that aim to tackle SDS in agriculture. Its main purpose is to provide an applicable procedure for using web-based data to mitigate the risk of SDS in agriculture. This is a first attempt to develop a contingency plan for SDS risk reduction in agriculture using freely available remote sensing imagery and geographic information system (GIS) modelling. It presents a good starting point and guiding note for developing an SDS disaster risk reduction/management plan in agriculture.

Target audience

The main target groups are the agriculture, environment and natural resources management organizations responsible for combating SDS and mitigating their impacts. It is important to recognize that effective application of this contingency planning process requires basic knowledge of agriculture, the environment and natural resources management, and proficiency in remote sensing and GIS-based geoenvironmental modelling.

Structure

This contingency plan comprises an introduction, three chapters and four appendices, which are summarized as follows.

The **introduction** provides an overview of SDS and agriculture in the Islamic Republic of Iran. Emphasis is given to SDS impacts on agriculture.

Chapter 1 defines a GIS-based methodology for SDS disaster risk assessment in agriculture and explains the concepts and terminology of SDS disaster risk assessment. It provides a conceptual framework for developing SDS hazard and vulnerability mapping in agriculture, including a set of agriculture-specific indicators proposed to assess SDS disaster risk in agriculture. Appendix 1 further discusses the required processes for developing indicators and procedures.

Chapter 2 sketches out a methodology for SDS contingency planning in agriculture. It presents the legal and institutional frameworks in the Islamic Republic of Iran relevant for SDS implementation and flags the organizational responsibilities for implementing the contingency plan.

Chapter 3 provides an overview of the main action areas and challenges to be addressed in SDS contingency planning for agriculture in Ahvaz County. In doing so, it establishes an action framework in various technical domains to jointly mitigate SDS in agriculture in Ahvaz using the available capacities and undertaking specific priority activities. This action framework is a useful tool for local actors to identify and fine-tune (i.e. based on location-specific characteristics) the SDS priority actions, to be addressed and integrated into existing local disaster risk reduction and/or sectoral development plans.

Appendix 1 provides detailed explanations of the indicators for SDS disaster risk assessment.

Appendix 2 provides web-based data for implementing the contingency plan.

Appendix 3 presents an analytical hierarchy process questionnaire for allocating weights of SDS indicators.

Appendix 4 presents the implemented projects, local knowledge and new technologies to combat SDS in agriculture in the Islamic Republic of Iran.

Introduction

Sand and dust storms (SDS) are devastating environmental disasters that occur under a wide range of local and global environmental conditions. They arise from the interaction of natural drivers, such as drought, and anthropogenic factors such as mismanagement of water, soil and plant resources (Darvishi Boloorani *et al.*, 2021a). Sand and dust storms can have considerable effects on any environment (natural and human-made), even in places far away from the emission sources, due to the transportability of fine-grained dust particles over long distances (Goudie and Middleton, 2006; Middleton, 2017). They occur specifically along an extended "dust belt" in the northern hemisphere, from the western coast of North Africa, throughout the Middle East, Central and South Asia, and to East Asia and China. However, some SDS activities have also been identified outside this belt in the southern hemisphere, spanning the desert regions of southern Africa, South America and Australia (Prospero *et al.*, 2002; Ginoux *et al.*, 2004).

The Islamic Republic of Iran is centrally positioned in the global dust belt and is considered an arid/semi-arid country. Many parts of the country are desert and semi-desert areas, making SDS a natural and intrinsic feature of many plains across the centre of the country (Melville, 1984). However, successive droughts coupled with improper management of water and soil resources have led to the development of new, additional source areas for SDS in recent decades. These have occurred throughout different parts of the country, with adverse effects on human communities, the environment and agriculture (Rashki *et al.*, 2013; Najafi *et al.*, 2014; Sotoudeheian, Salim and Arhami, 2016).

The economy of the the Islamic Republic of Iran is highly dependent on agriculture, with an approximate share of 9 percent of the gross domestic product and 18 percent of the national employment. The agricultural land in the country is owned by about 3 359 000 agriculturalists (an average of 4.9 ha per person) and is mainly used for plant and orchard farming, which can satisfy nearly 90 percent of the domestic nutritional demands (Mesgaran *et al.*, 2016).

However, the country's agriculture is vulnerable to water shortages and change, climatic variability, climate change and droughts (Maghrebi *et al.*, 2020). The country's agricultural land spans an estimated 16 477 000 ha (Statistical Centre of Iran, 2014). The spatial pattern of the agricultural land is consistent with the spatial pattern of rainfall. Therefore, most of the country's agricultural activities are in the western, northwestern and northern regions, where the annual mean rainfall is over 250 mm.

Approximately 60 percent of cropland is rainfed and the rest is irrigated. Rainfed crops contribute to 32 percent of the total production of the country (Ghamghami and Beiranvand, 2022). The main agricultural products are cereals (e.g. wheat, rice and barley), legumes, industrial crops (e.g. oilseed, sugar beet and cotton), medicinal plants, potato, onion, tomato, cucurbits and forages (Maghrebi *et al.*, 2020).

In addition, livestock plays a key role, especially in the lives of the rural poor, creating employment and often providing about 80 percent of their cash income. Common farm animals are sheep, goats, cattle, buffalo and camels. The production of milk, red meat, poultry meat and eggs increased during the 1988–2008 period by 7.2, 3.1, 7.9 and 5.4 percent respectively. This was driven by essential policy tools such as guaranteed and remunerative producer prices for major commodities. Milk production has grown because of improved yields and expanding herd size (Kamalzadeh *et al.*, 2008). Small ruminants are mainly managed under two different systems: rural and migratory (nomadic). In both systems, the animals are mostly kept on rangeland and farmland with a little supplementary feeding. Although the nomadic population is decreasing due to settlement in different parts of the country, this production system is still a major contributor to the livestock production sector of the country.

In the rural system, flocks and herds are allowed on the natural communal grazing pastures, irrigated farmlands or even mountain ranges. The vegetation ranges provide part of the annual fodder requirements throughout the year. In the villages, supplementary feeding is necessary as well, especially in winter. The rural system has promising planning programmes for improving the productivity of animals. In this system, suitable breeding, feeding and management programmes, new technologies and rangeland management are practised through cooperatives and individual producers (Kamalzadeh, Rajabbaigy and Kiasat, 2008).

The country's total area of rangeland is about 84.8 million ha. The available forage in the grazing rangeland is sufficient for feeding 37 million animal units for seven months, while 83 million animal units (more than double the capacity) are now grazing over the rangeland (NRWO, 2022). Thus, overgrazing of livestock is one of the main problems that has caused a reduction in the quantity and/or nutritional quality of the vegetation available for grazing, termed "rangeland degradation." The rangelands are classified into three canopy cover classes: dense (area: 7 181 250 ha, 8.5 percent), semi-dense (area: 21 419 151 ha, 25.3 percent) and sparse (area: 56 214 590 ha, 66.2 percent).

Agriculture accounts for over 92 percent of freshwater consumption in the country (Mesgaran *et al.*, 2016). Water productivity in agriculture is very low, despite the high agricultural water consumption (Alizadeh and Keshavarz, 2005). Support provided to agricultural production has been translated mainly into massive expansion of irrigated cropland across different parts of the country, with little attention to their natural and ecological capacities. Meanwhile, irrigated cultivation is practised in areas with less than 200 mm or even less than 100 mm of mean rainfall. The natural climatic limitations on agricultural production in major parts of the country and crop reliance on irrigation have made water resources the primary natural restrictive factor on agriculture.

Some of the anthropogenic limitations that agriculture in the country is facing are outcomes of several mutually reinforcing factors including: the traditional system of small-scale land ownership; macroscale restrictive policies; the financial problems of many farmers and their need for support and financing; insufficient investment in agricultural infrastructure and insufficient technical skills. These lead to widespread unsustainable land-use practices. In addition, more than 50 percent of agricultural producers are over 50 years old and have low literacy rates. This is also decreasing agricultural productivity, since enhancing productivity in agriculture is highly dependent on employing the latest science and technology, including through the application of disaster risk reduction (DRR) good practices at farm and landscape levels. Farm-level DRR good practices perform, on average, 2.2 times better than traditional agricultural practices (FAO, 2019). A review of the composition of the workforce in the agriculture sector shows that – as in many other countries – the young workforce has lost interest in this line of work in recent decades and prefers to work in other economic sectors.

On top of those structural constraints, the droughts of the past two decades and the resulting water scarcity have increased the plight of the country's agricultural sector, neutralizing a great part of its potential and actual efficiency. Increasing population growth, successive droughts, climate change, global warming, poor management of water, soil and vegetation resources, land degradation and desertification have therefore increased the country's susceptibility to the formation and impacts of SDS events.

As a phenomenon that greatly affects and is affected by the critical climate situation, SDS have become an increasingly significant challenge for agriculture over the last decade. The agricultural sector, as a source of SDS, contributes indirectly to damage in other domains of society when SDS events occur. In addition, the damage caused by SDS events to agriculture and related occupations is significant. The main SDS-affected areas in the Islamic Republic of Iran are in the southwest, south and southeast. Significant numbers of the SDS events affecting the country have a cross-border origin, specifically from Afghanistan, Iraq, the Sahara and North Africa, Saudi Arabia, the Syrian Arab Republic and Turkmenistan. The main national SDS sources include Dasht-e Kavir, Dasht-e Lut, the Jazmurian Depression, the Khuzestan Plain, the Makran Coast and the Sistan Plain (Rashki, Middleton and Goudie, 2021).

Sand and dust storms can have many different impacts on the agricultural sector, including the quantitative and qualitative reduction of crop production and orchard yields, reduction of livestock products (Shi *et al.*, 2005) and the spread of plant pests and diseases (Sivakumar, 2005; Khaledi, 2017; Maleki *et al.*, 2017). The agricultural lands in the Islamic Republic of Iran that are exposed to transboundary and national SDS are experiencing a reduction in crop production of 5–40 percent (Saarabian and Nikpour, 2011). This reduction rate is 20–40 percent for the western and southwestern provinces, including Bushehr, Fars, Ilam, Kermanshah, Khuzestan, Kurdistan and Lorestan. This rate is about 5–20 percent for other provinces (Khaledi, 2013, 2017). The effect of SDS on vegetation cover can be direct (effects on plants) and indirect (pollution of water and soil resources).

Indirect effects are the predominant case in Islamic Republic of Iran. This is because fine SDS particles deposited on leaf surfaces are partially washed away by rain during the wet seasons, thus lessening their direct negative effects such as reduced photosynthesis and plant yield. In wet seasons, SDS may reduce plant yield because the plants are feeding on water and soil contaminated with SDS particles, mainly from transboundary sources.

In contrast, in dry areas and during dry seasons, dry SDS deposition is more prevalent, through which coarse-grained SDS particles directly affect the vegetation. Although the deposition rate and the extent of the severely affected areas are much lower in dry deposition, they cause more economic damage and losses to the agricultural sector and related occupations due to the direct impacts of SDS on the plants. Some of the agricultural lands located along the central and eastern coasts of the Caspian Sea are in a very high dry SDS deposition class.

Sand and dust storms in spring and summer coincide with bee activity. Such events therefore cause significant damage to the economy of rural beekeepers and biodiversity in the country. The storms generally reduce the detection power and visibility of bees, decreasing nectar volume, disrupting queen bee mating and creating pollination-related problems, all of which can lead to reduced honey production. In addition, air pollution can hinder the formation of bee colonies (Maleki *et al.*, 2017).

From 2017 to 2021, the Government of the Islamic Republic of Iran spent about IRR 25 000 billion (equivalent to about USD 30 million[1]) to combat SDS by implementing activities such as mulching, tree and bush planting, soil and water resources management, and capacity building in areas such as dried wetlands and lakes, dried rivers, floodplains and agricultural lands. These areas are the main SDS emission sources in the country, especially in Khuzestan Province (Rahmani, 2021).

Analysing single SDS events shows that one major event alone can have disastrous impacts. For instance, the occurrence of a dust storm in 2009 reduced agricultural production by 726 000 tonnes (equivalent to IRR 3415 billion, USD 90 million) in Kermanshah Province (Khaledi, 2013, 2017). Furthermore, nearly 300 rare plant species with medicinal applications are on the brink of destruction in Ilam Province. Many of the farmers in these areas have also lost their jobs due to the growing frequency and intensity of SDS. The total economic damage of SDS on the agricultural sector of Ilam, Kermanshah and Khuzestan Provinces was estimated to be at least USD 2 227 million and at most USD 13 361 million in the period 2006–2011 (Khaledi, 2017).

Sand and dust storms can also be accompanied by different types of pests, plaguing the palm groves of southern provinces such as Bushehr. The situation shows how crucial it is to counteract the impacts of SDS and reduce SDS sources within the country and across the global dust belt.

Within the above overall context, the Food and Agriculture Organization of the United Nations (FAO) interregional technical cooperation project – Catalysing Investments and Actions to Enhance Resilience Against Sand and Dust Storms in Agriculture – has supported the Islamic Republic of Iran in conducting an SDS risk assessment and preparing a contingency plan for agriculture using Ahvaz County of Khuzestan Province as a case study and demonstration example. The aim is that the systematic planning approach developed for Ahvaz County will also serve as a basis for the development of wider, timely, effective and appropriate SDS preparedness and response measures elsewhere in the country. It will also help to address and integrate agriculture-specific requirements to combat SDS in the frame of cross-sectoral contingency planning to mitigate SDS sources and impacts all over the country.

[1] Calculated using average of currency exchange rate from 2017-2021.

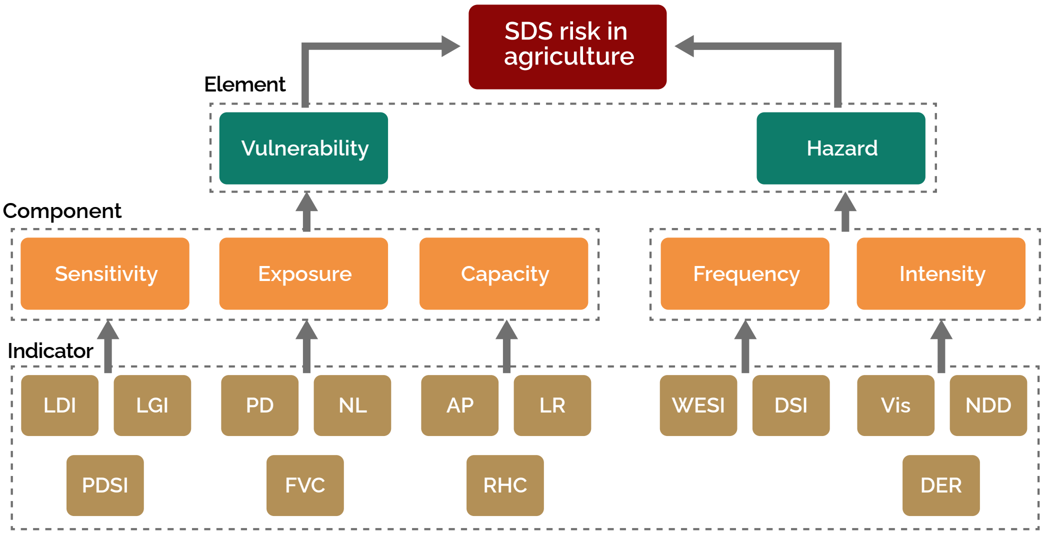
Chapter 1.
A geographic information system-based methodology for sand and dust storm disaster risk assessment in agriculture

Sand and dust storm (SDS) vulnerability reduction can be implemented in four main domains: human health, socioeconomic, environment and agroecology (from local to global) (UNCCD, 2022). Similarly, an SDS risk assessment can be carried out in these domains. A generic and neutral unbiased SDS risk assessment must be done, ensuring that the conceptualization, process and indicators for the assessment are not influenced by the individual perceptions or wishes of specific stakeholders. For instance, the use of different indicators can create different risk maps for the same dust event. Therefore, this contingency plan proposes a generic process for unbiased estimation of SDS risk. This chapter presents a stepwise procedure and the order of the main processing steps required to conduct the SDS risk assessment.

1.1. Risk conceptualization of sand and dust storms – an agricultural perspective

The proposed methodology for SDS risk assessment in agriculture is in line with the conceptualization of disaster risk as established by the United Nations Office for Disaster Risk Reduction (UNDRR, 2022) and the United Nations Convention to Combat Desertification (UNCCD) (UNCCD, 2022). It is thus designed with the assumption that SDS disaster risk is a function of vulnerability and hazard. As shown in Figure 1, risk is taken as the result of the interaction between the hazard and the vulnerability of the SDS-affected area (Fuchs, Heiss and Hübl, 2007). The assessment of vulnerability is conceptualized through integration of three components: sensitivity, exposure and coping capacity (UNDRR, 2022; Darvishi Boloorani *et al.*, 2021b; UNCCD, 2022). The hazard risk is characterized by two components of SDS events: frequency and intensity. Each component is described and analysed by a focused set of specific and measurable indicators from an SDS hazard risk in agriculture perspective.

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

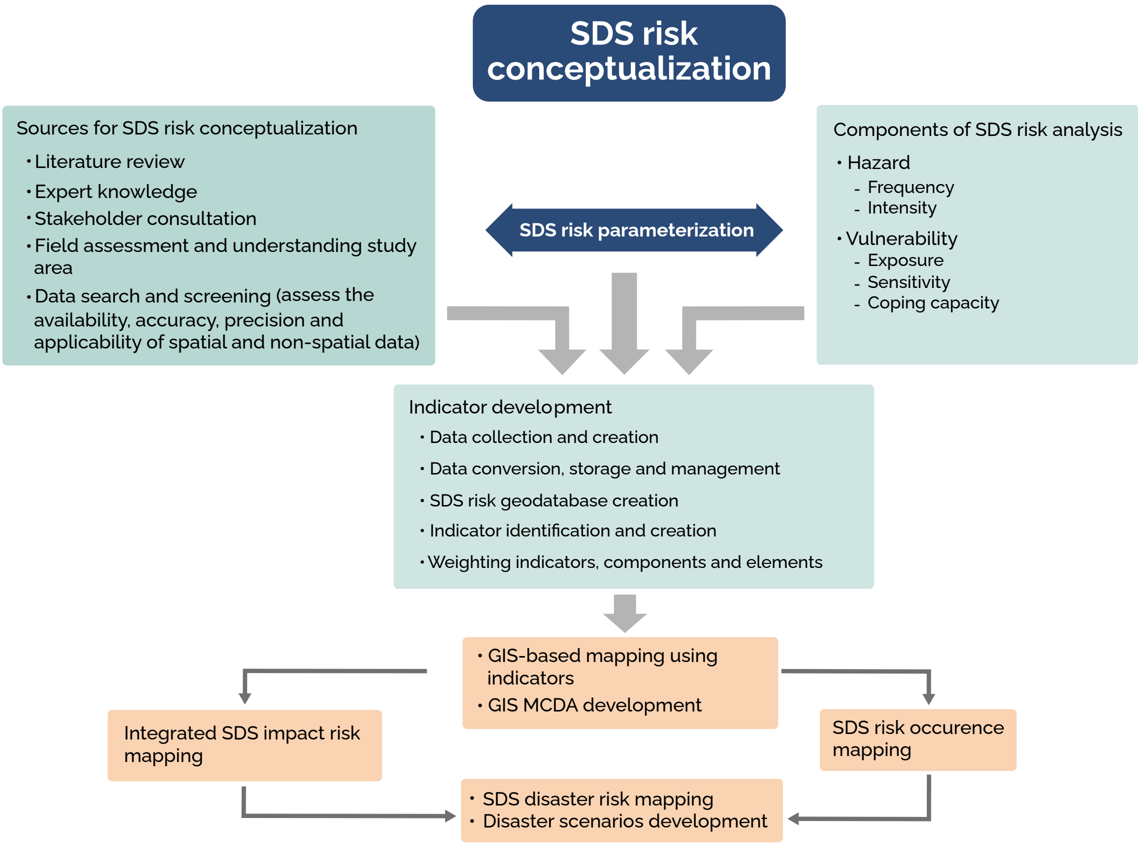


Notes: AP = active population; DER = dust emission rate; DSI = dust severity index; FVC = fractional vegetation cover; LDI = land degradability index; LGI = livestock grazing index; LR = literacy rate; NDD = net dust deposition; NL = number of livestock; PD = population density; PDSI = Palmer drought severity index; RHC = rural health centre; Vis = visibility; WESI = wind erosivity severity index. See Section 1.1.1 and Appendix 1 for details of these indicators.

Source: Author's own elaboration

As the proposed conceptual model focuses on the long-term circumstances that cause SDS risk in agriculture, the proposed indicators were developed in a comprehensive manner covering the spatio-temporal pattern of vegetation, soil erosion status, hydroclimate characteristics and human roles applicable to agriculture activities and rural communities. Using the measurable indicators allows the creation of geographic information system (GIS)-based mapping for each of these components, which can then be aggregated into SDS risk maps and SDS disaster risk scenarios. The flow chart in Figure 2 summarizes the process applied in this report.

Figure 2. | Stepwise procedure for SDS disaster risk assessment in agriculture



Note: GIS MCDA = Geographic information system multicriteria decision analysis

Source: Author's own elaboration

1.1.1. Indicator development

The selection of indicators for disaster risk assessment is often challenged by significant limitations in terms of data availability and applicability, assessment/mapping objectives, and the precision, accuracy and reliability of data. Careful identification of suitable and, at the same time available/accessible data, indices or proxy indicators for SDS risk assessment is thus a fundamentally important first step in the process. As it is impractical to develop and apply exclusive indicators for this topic, it was decided to use existing data, indicators, indices or SDS-related parameters as a basis for this work. This allows description and analysis of SDS phenomena, and can be transferred into measurable GIS layers. Defining, modelling and collecting indicators is therefore a function of some limiting parameters, such as characteristics of investigation area, expert knowledge, and data availability and consistency.

The following sections in this chapter present the methodological steps needed for the SDS risk assessment using Ahvaz County as an example. In this way, the results of the GIS-based assessment are presented in line with the flow of the methodological steps. Table 1 shows the indicators developed to address the concept of SDS disaster risk in agriculture. It also provides a short description of each of the indicators and shows the data sources. Appendix 1 provides further details on the indicators. Figure 3 provides the corresponding indicator application maps using the case study area of Ahvaz County for illustration.

Table 1. | Indicators for SDS disaster risk assessment in agriculture

Element	Component	Indicator	Description	Source	Alternative source
Hazard	Frequency	1. Dust severity index (DSI)	Dusty days in a year Direct impact to the exposed community/ecosystem	Moderate resolution imaging spectroradiometer (MODIS) products	Aerosol Robotic Network (AERONET)
		2. Wind erosivity severity index (WESI)	Wind speed (m/s) per dusty day Triggers dust emission and determines dust severity	Fifth-generation European Centre for Medium-Range Weather Forecasts atmospheric reanalysis of the global climate (ERA5)	National meteorological stations and Automated Surface Observing System (ASOS)/Automated Weather Observing System (AWOS) Meteorological Aerodrome Report (METAR) data
	Intensity	3. Visibility (Vis)	Average monthly visibility Measure of the concentration of the dust event with direct impact on exposed community/ecosystem	Meteorological station	ASOS/AWOS METAR data
		4. Net dust deposition (NDD)	Net deposition (wet deposition + dry deposition) Direct impact on ecosystem/agriculture	Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA2) reanalysis products	
		5. Dust emission rate (DER)	Direct impact on agriculture	MERRA2 reanalysis products	
Vulnerability	**Sensitivity** [a]	6. Palmer drought severity index (PDSI)	Drought results in vegetation loss and topsoil erosion that reduces agricultural productivity Hence, predominance of drought intensifies dust emission in a region	National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA-NCDC)	
		7. Livestock grazing index (LGI)	Net primary production (NPP)-based grazing index Direct impact on land degradation	FAO NPP	Ground-based NPP and livestock statistics
		8. Land degradability index (LDI)	Land degradation is one of the main drivers of dust formation		

Element	Component	Indicator	Description	Source	Alternative source
Vulnerability	Exposure[b]	9. Population density (PD)	Number of people per unit area The higher the PD, the more people will be exposed to dust events	National population and housing census	WorldPop
		10. Number of livestock (NL)	NL per unit area The higher the NL, the more livestock will be exposed to SDS	National agriculture census	
		11. Fractional vegetation cover (FVC)	Calculated using the normalized difference vegetation index (NDVI) Direct impact on dust mitigation impacts	MODIS NDVI	Landsat and Sentinel-2
	Coping capacity [c]	12. Active population (AP) (15<age<65)	Ratio of active people to population The AP provides the labour force of the agriculture domain of a community		National population and housing census
		13. Literacy rate (LR)	Ratio of literate people to population Literate people are generally better able to benefit from health protocols and dust alarm systems, so they are less exposed to this phenomenon		
		14. Rural health centre (RHC)	Ratio of number of health centres to population (1:8000) These centres provide health services related to dust storms to vulnerable rural communities		

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

Source: Author's own elaboration

Table 2 presents supplementary data that were used for validation and cross-checking some of the indicators and for decision-making in Ahvaz County. Figure 4 below further illustrates them as maps.

Table 2. | Sand and dust storm risk assessment/mapping supplementary data

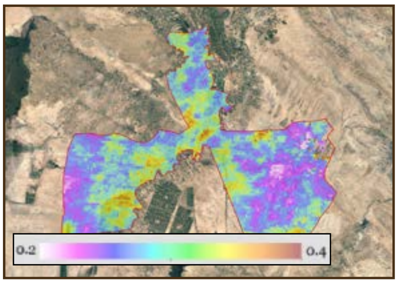
Data	Description	Source	Alternative source
Map of rangelands	Impacts on rural economy (livestock farming)	Natural Resources and Watershed Management Organization (NRWO)	Global Land-Use Dataset United States Geological Survey Land Cover MODIS Land Cover
Map of irrigated and rainfed agricultural lands	Impacts on rural economy		Global rainfed, irrigated and paddy cropland (http://www.gibbs-lab.com/wp-content/uploads/2015/09/Salmon_Global_rain_fed_irrigated_and_paddy_croplands_2015.pdf)
Dust deposition area	Ratio of dust deposition area to total agricultural areas, which affects land productivity losses		
Dust sources (emission) area	Ratio of dust source area to total agricultural lands areas with direct impacts on plant productivity losses		

Source: Author's own elaboration

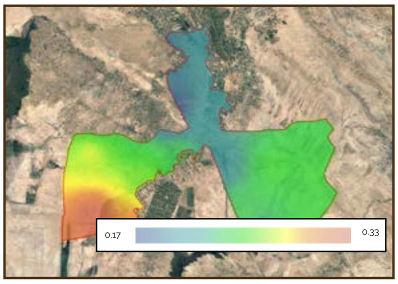
The maps presented in Figures 3 and 4 show that, even at the county level, a heterogeneous pattern can be observed spatially and in the intensity levels in which the individual indicators are feature. A first look indicates, for instance, that dust emission areas and dust deposition areas do not coincide in the county, whereas dust emission areas do coincide to a large extent with the rainfed areas used primarily as rangelands. High rates of land degradation, dust emission areas, DER and rangeland overlap in most of the southwestern parts of the county. The indicators for SDS coping capacity show that the highest capacities are not in the areas most exposed or sensitive to the SDS impacts. However, to allow overall consolidation of the data for risk and vulnerability assessment, further analytical steps to harmonize and overlay the data and maps are crucial. See Appendix 1 for further information on the indicators for SDS risk assessment.

Figure 3. | Maps of indicators for SDS disaster risk assessment in Ahvaz County

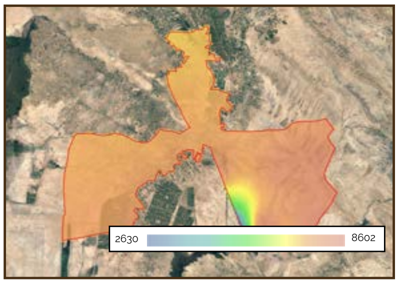
Dust severity index (DSI) (2000-2022)



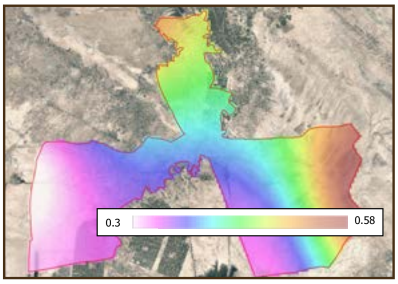
WindErosivity severity index (DSI) (2000-2022)



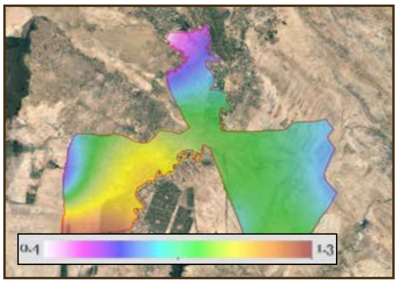
Visibility (m) (2000-2022)



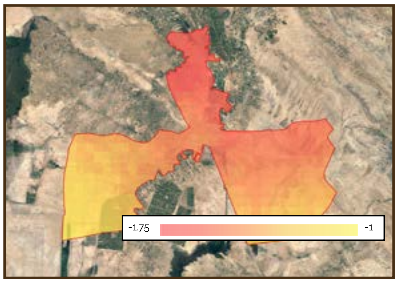
Net dust deposition (kg.m-2 y-1) (1980-2021)



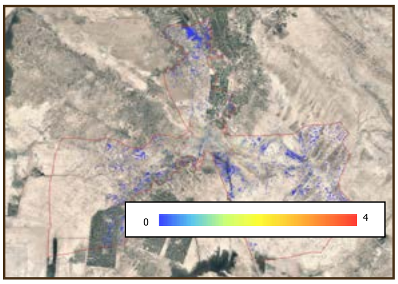
Dust emission rate (kg.m-2 y-1) (1980-2021)



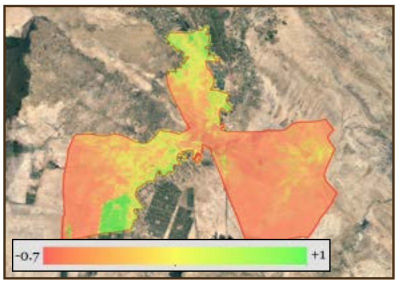
Palmer drought severity index (PDSI) (2000-2022)



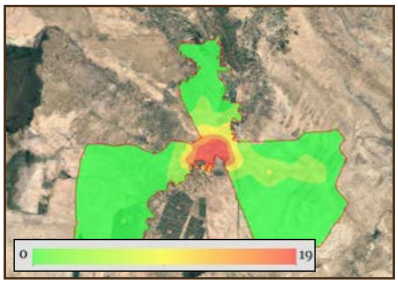
Livestock grazing index (LGI) (2009-2022)



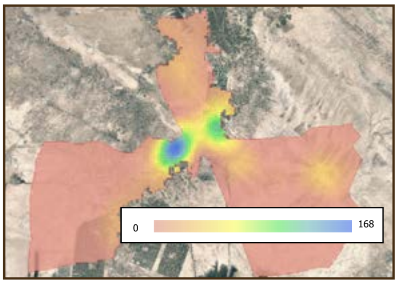
Fractional vegetation cover (FVC) (2000-2019)



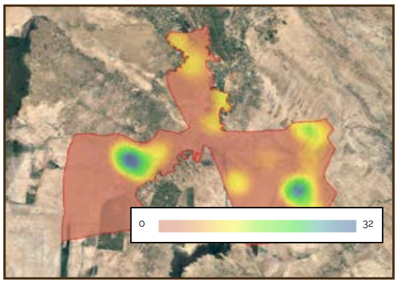
Population density (PD) (2020)



Literacy rate (LR) density (LR/km2)

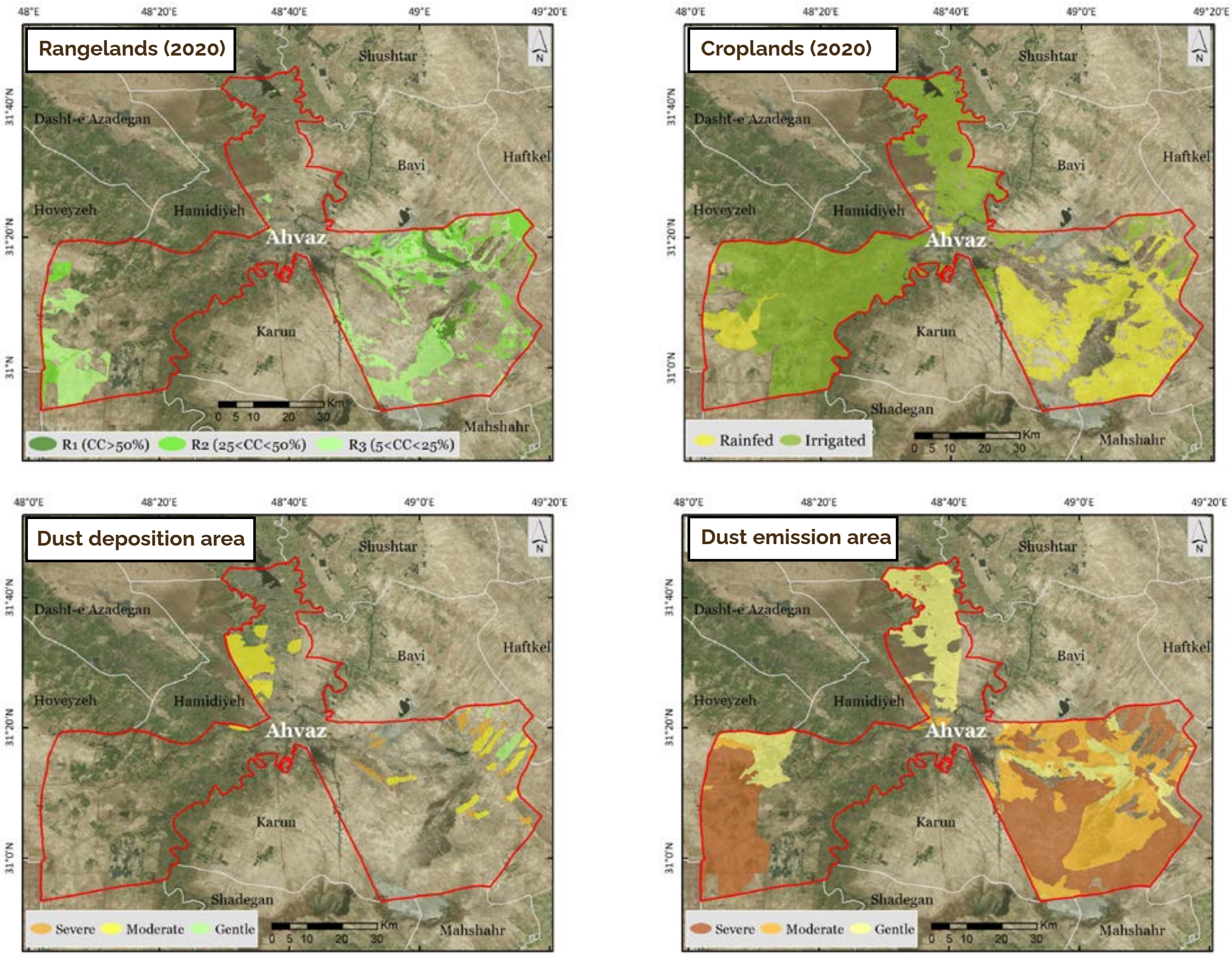


Rural health center (RHC) density (RHC/km2)



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

Figure 4. | Sand and dust storm disaster risk assessment supplementary maps in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

1.1.2. Indicator normalization and weighting

As the indicators were collected from different data sources with different data formats and units, it was necessary to transform them into comparable units for GIS modelling. The input indicators were normalized[2] based on the type of relationship among each of them with the related component of risk assessment. Accordingly, the indicators that are directly (+) and indirectly (−) related to the component were normalized using Equation (1) (minimum method) and Equation (2) (maximum method), respectively (Table 3):

$$a_{ij} = \frac{s_i - s_j^{\min}}{s_j^{\max} - s_j^{\min}} \quad (1)$$

[2] Normalization makes data comparable across indicators so the information can be combined in a meaningful way.

$$a_{ij} = \frac{S_j^{\max} - S_i}{S_j^{\max} - S_j^{\min}} \quad (2)$$

where a_{ij} represents the normalized value of pixel i in criterion j, S_i represents the original value of pixel i in criterion j, and S_j^{max} and S_j^{min} represent the maximum and minimum values in criterion j, respectively (Darvishi Boloorani *et al.*, 2020, 2021b).

Due to the unequal roles of indicators, components and elements in assessing/mapping the SDS risk for agriculture in different areas, it was necessary to assign unequal weights to them. There are several approaches to weighting (Malczewski and Rinner, 2015). For instance, the analytic hierarchy process (AHP) (Saaty, 1980) is a common method that is a robust and applicable tool for complex multicriteria decision analysis. Using AHP, a complicated problem is divided into a hierarchical system of elements to calculate their different weights. In this contingency plan, the method used for weight allocation was a GIS-based AHP multicriteria decision analysis method based on an expert knowledge panel. The indicators of SDS hazard (SDS frequency and SDS intensity) were treated equally, while the vulnerability indicators were given different weights.[3] Questionnaires (Appendix 3) were distributed and filled in by the SDS expert panel from the Natural Resources and Watershed Management Organization (NRWO) to allocate the weights of vulnerability indicators, as displayed in the "Weight" column of Table 3.

Table 3. | Adapted normalization methods and weights of indicators to calculate SDS risk in agriculture in Ahvaz County

Concept	Element	Component	Indicator	Weight	Relationship between indicator and component
SDS risk in agriculture	Hazard	Frequency	1. Dust severity index (DSI)	None [a]	+
			2. Wind erosivity severity index (WESI)		+
		Intensity	3. Visibility (Vis)		–
			4. Net dust deposition (NDD)		+
			5. Dust emission rate (DER)		+
	Vulnerability	Sensitivity	6. Palmer drought severity index (PDSI)	0.625	+
			7. Livestock grazing index (LGI)	0.238	+
			8. Land degradability index (LDI)	0.136	+
		Exposure	9. Population density (PD)	0.183	+
			10. Number of livestock (NL)	0.075	+
			11. Fractional vegetation cover (FVC)	0.742	+
		Coping capacity	12. Active population (AP)	0.265	–
			13. Literacy rate (LR)	0.063	–
			14. Rural health centre (RHC)	0.672	–

Notes: [a] According to an expert panel's opinion, no weights were considered for the indicators related to hazard; therefore, they were treated equally.

Source: Author's own elaboration

[3] In GIS modelling, the arithmetic operations (addition, subtraction, division and multiplication) are used to combine different variables. When addition and subtraction are used, the importance or weight of the variables should be considered, but this is not applicable for division and multiplication operations.

1.1.3. Vulnerability mapping

A vulnerability map can be created through arithmetic operations (addition, subtraction, multiplication and division) on the components and indicators (UNEP, 2003; Cardona *et al.*, 2012; Darvishi Boloorani *et al.*, 2021b). Here, Equation (3) is adapted to map the agriculture vulnerability to SDS (UNCCD, 2022):

$$\text{vulnerability} = (\text{exposure} + \text{sensitivity}) - \text{coping capacity} \tag{3}$$

where exposure is the degree to which a system could be affected by SDS hazards, sensitivity is the degree to which the system could be harmed by SDS exposure and coping capacity is the degree to which the system could mitigate the potential for harm by taking necessary actions to lessen exposure and sensitivity.

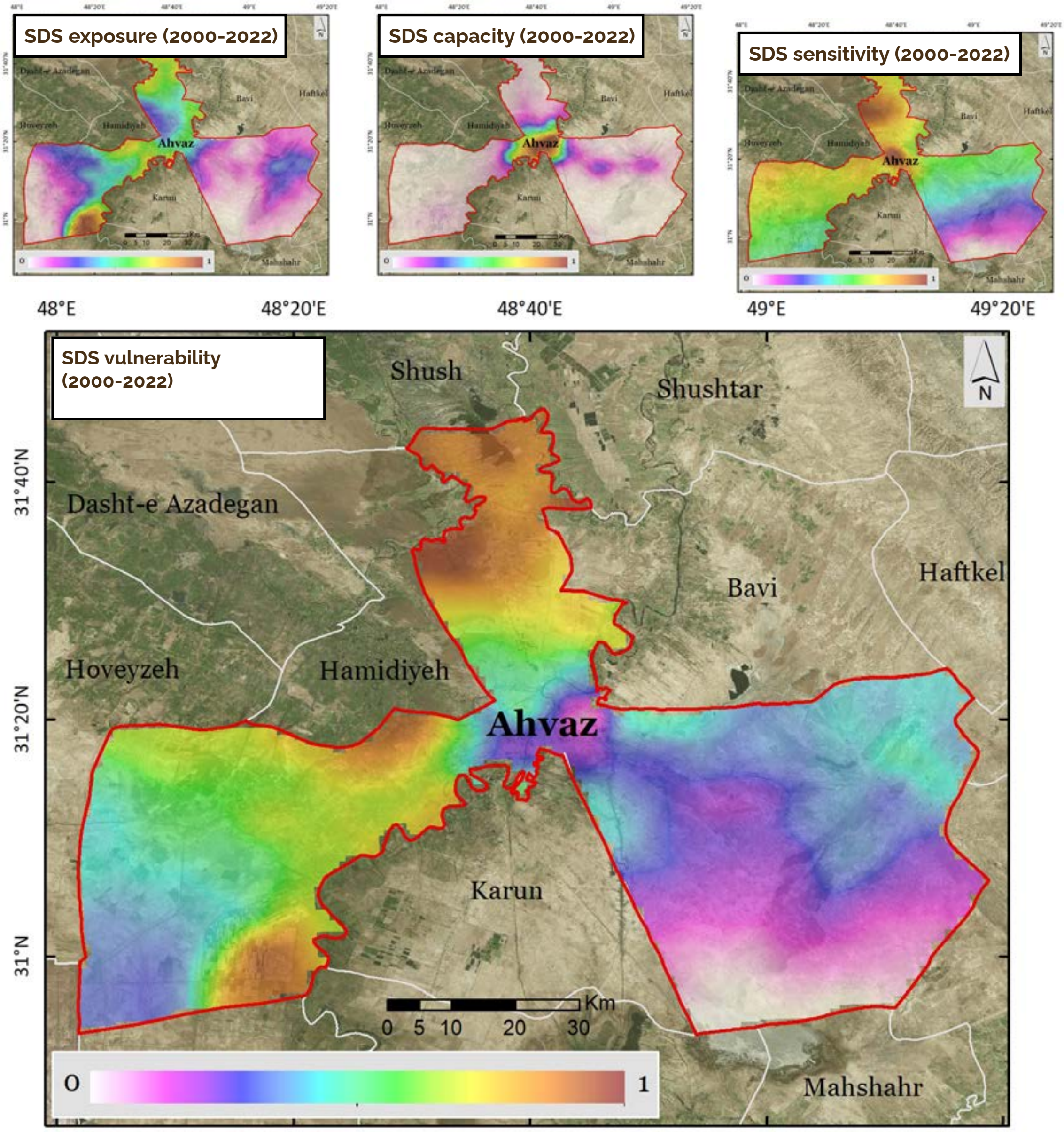
To create the map of vulnerability components (sensitivity, exposure and coping capacity), the weighted linear combination method (Geldermann, Zhang and Rentz, 2003) was used:

$$\text{component}_i = \sum_{j=1}^{n} W_j \times \text{indicator}_j \tag{4}$$

where i is the vulnerability's components of sensitivity, exposure and coping capacity, j is the component's indicators (Table 3), W_j is the weight of jth indicators and n is the total number of the component's indicators. Figure 5 provides the maps of SDS vulnerability and corresponding components.

In the displayed sequence of maps in Figure 5, sensitivity was calculated and mapped using indicators 6–8, exposure using indicators 9–11 and coping capacity using indicators 12–14. The consolidated SDS vulnerability map overlays indicators 6-14. The spatial areas in Ahvaz County showing highest overall vulnerability to SDS in the period 2000–2022 are in the northern parts of Ahvaz County and in the southwest (brown areas on the vulnerability map).

Figure 5. | Vulnerability map of SDS obtained from exposure, coping capacity and sensitivity in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

1.1.4. Hazard assessment and mapping

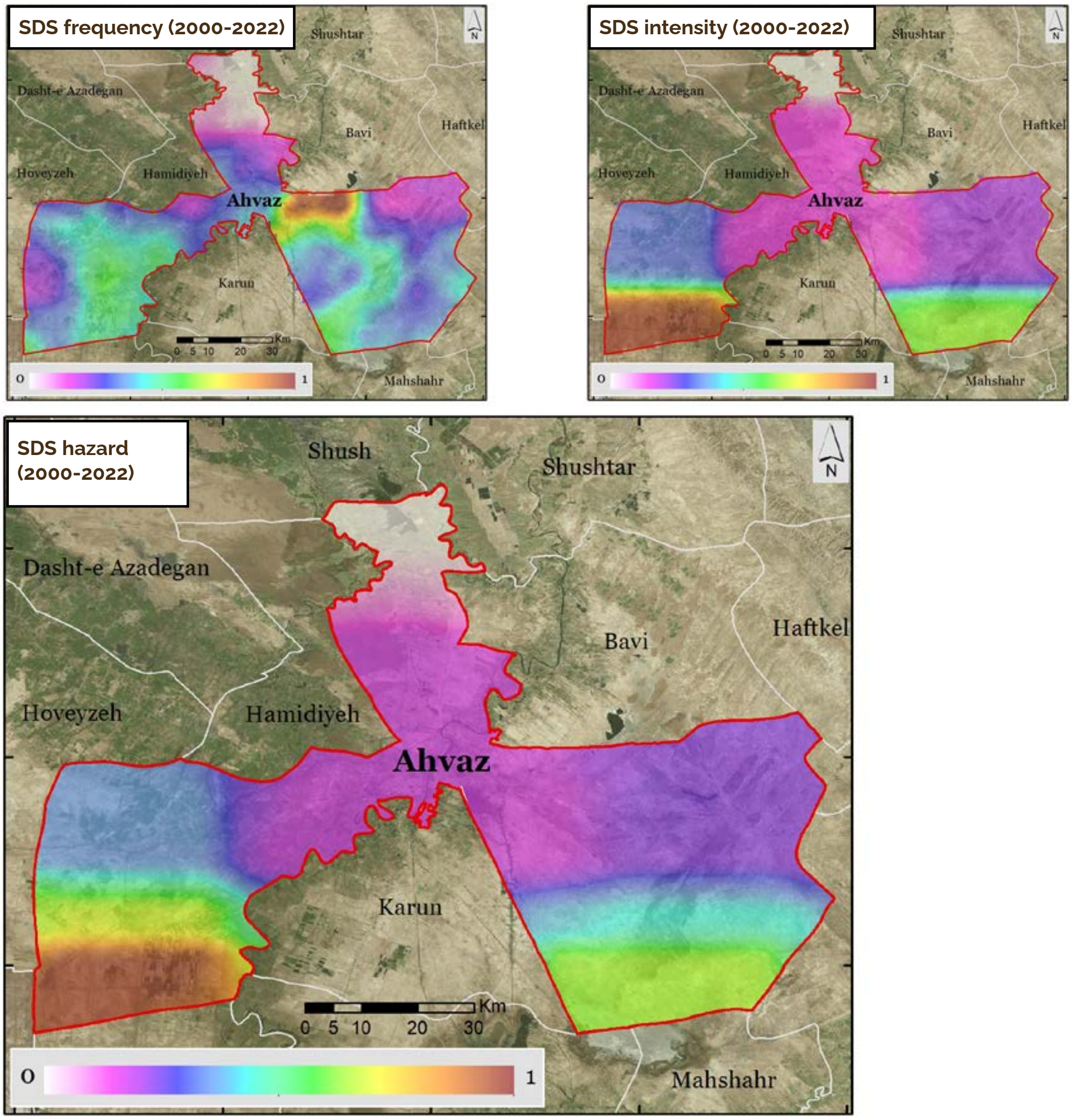
Another part of risk that needs further analysis is the detrimental phenomenon itself, in this case, the SDS hazardous event. In SDS, the hazards are the physical events that may hit the agro-ecosystem and population and have different effects according to the location-specific levels of vulnerability. However, the hazard itself, and accordingly the risk of impact from the SDS event, differ at any time, as does the potential for a major incident. This term refers to the "hazard," namely the probability of occurrence, within a specified period of time in each area, of a potentially damaging natural phenomenon (Wilhite, 2000). Since the SDS frequency (Equation [5]) and SDS intensity (Equation [6]) independently describe SDS impact potentials, their linear sum expresses the overall SDS hazardous level. Hence, SDS hazard can be obtained through Equation (7), with SDS frequency obtained as a function of indicators 1 and 2, and SDS intensity obtained as a function of indicators 3–5 in Table 1 and Appendix 1. Figure 6 provides maps of the SDS hazard and its components (frequency and intensity) for Ahvaz County.

$$\text{SDS frequency} = \text{DSI} \times \text{WESI} \tag{5}$$

$$\text{SDS intensity} = \frac{\text{NDD} + \text{DER}}{\text{Vis}} \tag{6}$$

$$\text{SDS hazard} = \text{SDS frequency} + \text{SDS intensity} \tag{7}$$

Figure 6. | Sand and dust storm hazard map obtained from frequency and intensity in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

The hazard map in Figure 6 indicates that in the past two decades, the southwestern area was the part most exposed to SDS hazards in Ahvaz County, which has caused detrimental impacts. The overlaying of the maps also shows that, based on this approach to conceptualize and contextualize extreme events, SDS intensity was given a higher importance compared to SDS frequency.

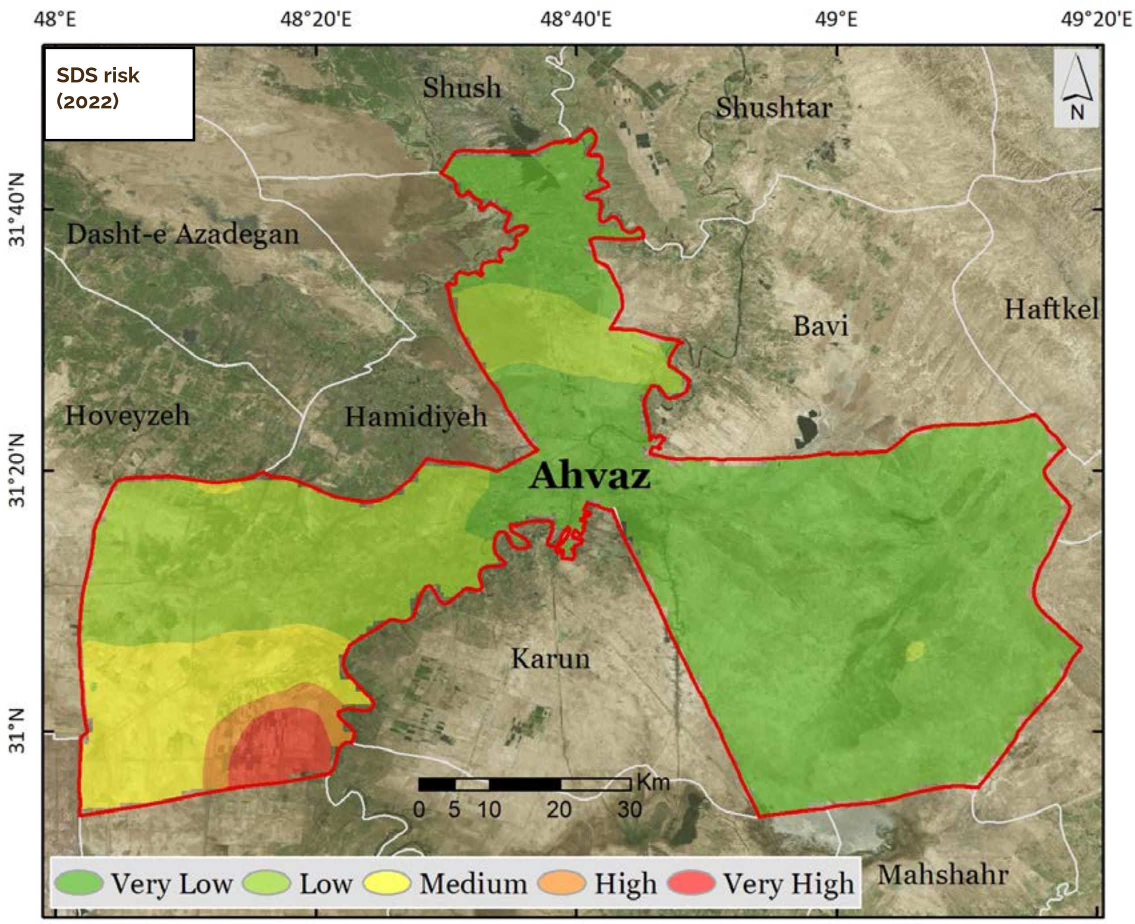
1.2. Risk mapping of sand and dust storms – a stepwise approach

1.2.1. Areas with different risks of impact

As an interim step and input to conceptualize an SDS disaster risk map, an SDS impact risk map (Figure 7) can be calculated and generated according to Equation (8) by multiplying the components of hazard and vulnerability:

$$\text{SDS risk} = \text{hazard} \times \text{vulnerability} \quad (8)$$

Figure 7. | Map of SDS impact risk in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

Looking at the potential impact of an SDS event considering the underlying vulnerability of the agroecosystem and the farming population, as well as the severity of potential hazards as observed in the past, the eastern part of the southwestern area of Ahvaz ranked highest in the county in 2022. However, to achieve a more meaningful picture of current SDS disaster risk, it is crucial to also consider the parameters of the likelihood of occurrence and hazard severity, as observed over the last two decades.

1.2.2. Occurrence of risk

The level of risk of a hazardous phenomenon materializing can be obtained based on the likelihood of occurrence and its severity (Vatanpour, Hrudey and Dinu, 2015). Here, the frequency, intensity and duration of SDS events were used to develop and add as a next interim step an SDS occurrence risk map (Equation [11]). The SDS likelihood (Equation [9]) and severity (Equation [10]) are defined as follows:

$$\text{SDS likelihood} = \frac{\sum \text{frequency}}{n} \tag{9}$$

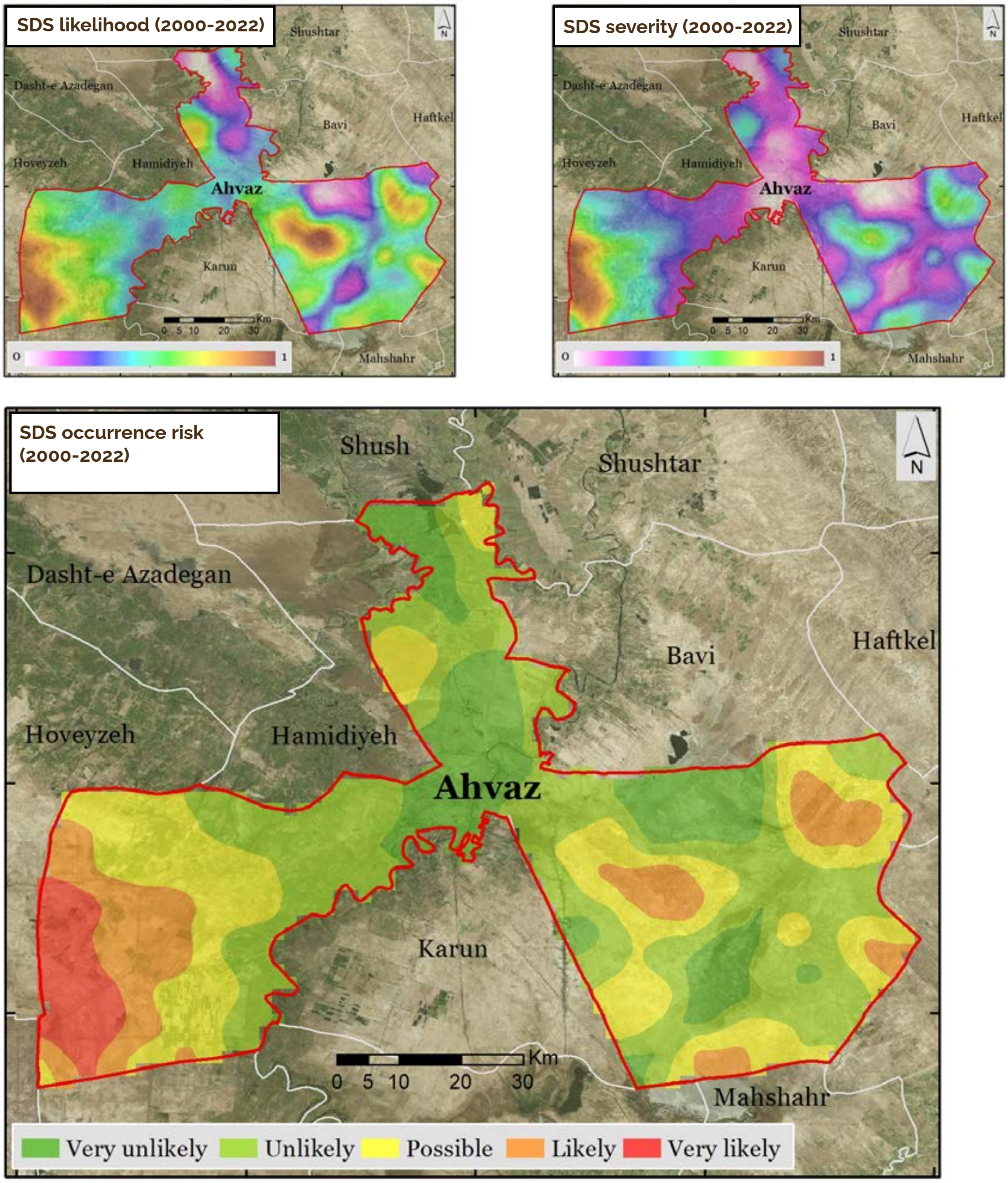
$$\text{SDS severity} = \text{intensity} \times \text{continuity} \tag{10}$$

$$\text{SDS occurrence risk} = \text{likelihood} \times \text{severity} \tag{11}$$

where i is the number of days with MODIS aerosol optical depth (AOD) ≥ 0.85, j is the total days of the study period, intensity is obtained using Equation (6) and continuity is defined as the number of consecutive days with AOD ≥ 0.85. Maps of SDS occurrence risk and its components (likelihood and severity) were created as shown in Figure 8. The areas that combine the highest likelihood of occurrence and severity of SDS events are in the western and southwestern parts of the county, which are used as rangeland or rainfed cropland (Figure 8).

Pockets where SDS events are likely to occur were also identified in the eastern and southeastern parts of Ahvaz, which are used either as grazing areas or for rainfed cropland. In the eastern and western parts, the areas with the highest risk of severe SDS event occurrence are those with the lowest rates in perennial vegetation cover.

Figure 8. | Sand and dust storm occurrence risk map based on likelihood and severity in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

1.2.3. Disaster risk mapping

According to the definition of the United Nations Office for Disaster Risk Reduction, disaster risk is 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" (UNDRR, 2022). The SDS disaster risk map is obtained from the intersection of the SDS risk map (Figure 7) and the SDS occurrence risk map (Figure 8). Overlaying the SDS impact risk map (from very low to very high) with the SDS occurrence risk map (from very unlikely to very likely), creates 25 possible combinations (scenarios) based on which an SDS disaster risk matrix can be established (Table 4).

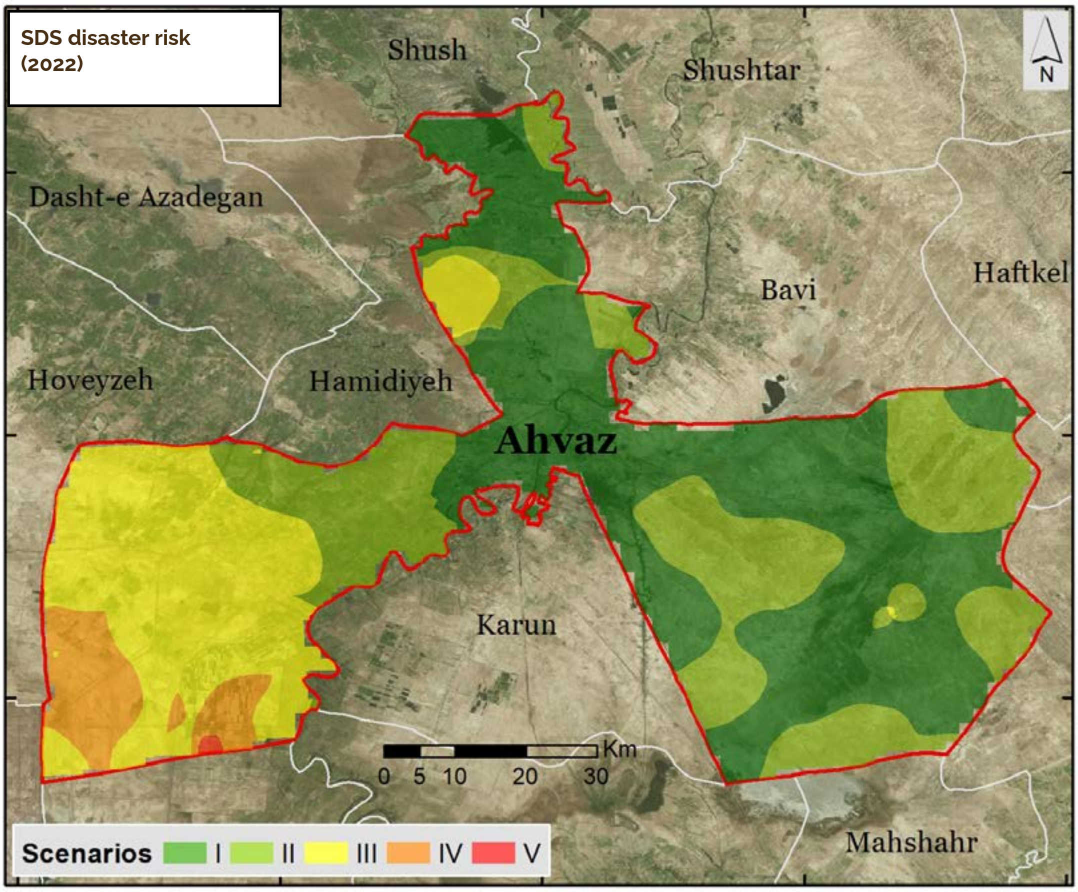
Table 4. | Sand and dust storm disaster risk scenarios

SDS risk occurrence	SDS impact risk				
	Very low	Low	Medium	High	Very high
Very likely	III	III	IV	V	V
Likely	II	III	III	IV	V
Possible	II	III	III	III	IV
Unlikely	I	II	III	III	III
Very unlikely	I	I	II	II	III

Source: Author's own elaboration

Figure 9 displays the SDS risk scenarios in spatial dimensions, from the lowest impact areas (green) to the areas with the highest risk (red) where SDS events could easily develop into a disastrous situation. The areas with the highest SDS disaster risk are in the southwestern part of Ahvaz County.

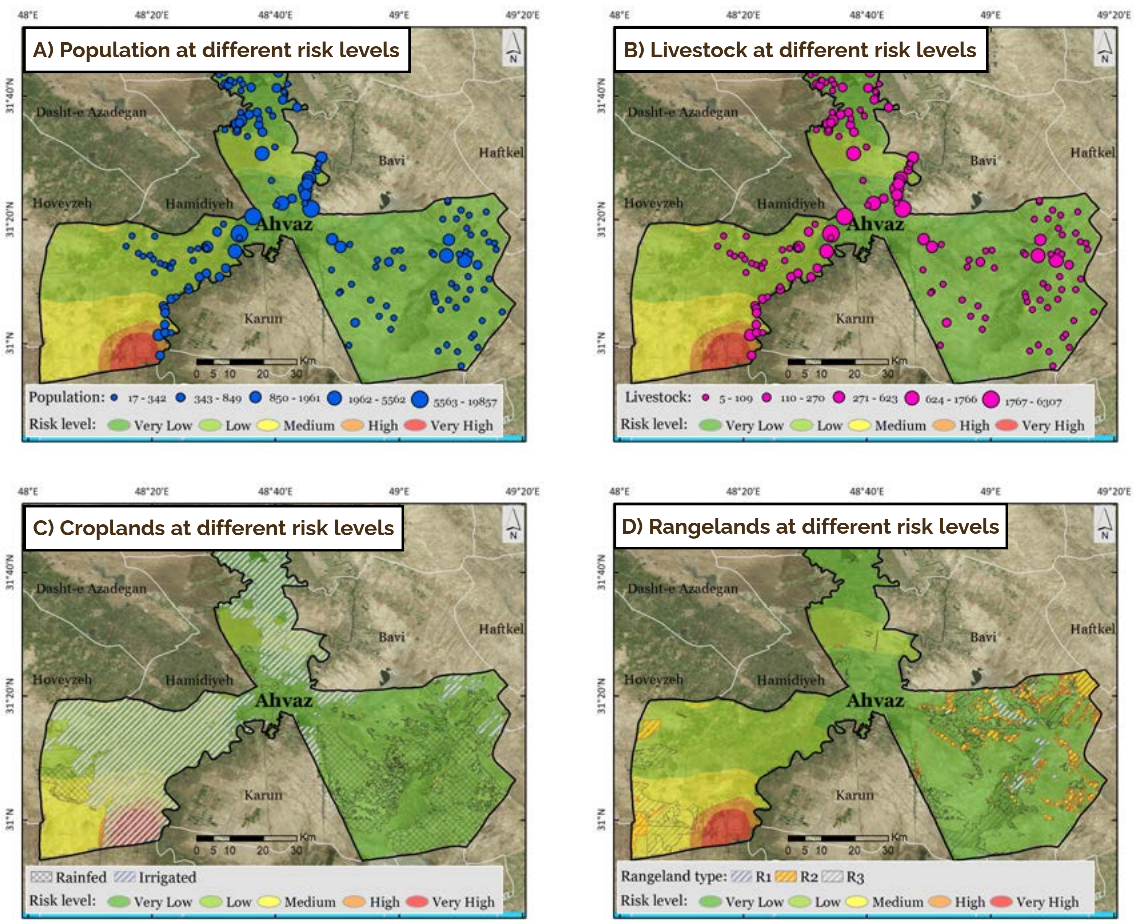
Figure 9. | Sand and dust storm disaster risk scenarios in Ahvaz County



Source: Author's own elaboration. Google Maps. (n.d.). [Ahvaz Khuzestan Province, Iran]. Retrieved October 1, 2022, from https://maps.app.goo.gl/zUxHVx1MRfgxYqDKA. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations

For the next steps of SDS contingency planning in agriculture, these SDS risk and vulnerability assessment data and maps need to be correlated and interpreted by additional agriculture-specific parameters and information. These include (farming) population distribution, livestock concentrations, and the overarching patterns of crop and pastureland distribution and uses. As shown in Figure 10, an important finding is that the irrigated areas in the southwest of Ahvaz with potentially high agricultural production levels are in the area with the highest SDS disaster risk. Damage and loss to agricultural production in those areas could be especially high. This demonstrates the need for careful anticipatory planning for SDS impact mitigating measures in those communities.

Figure 10. | Maps of SDS risk for population, livestock, cropland and rangeland zones in Ahvaz County



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Based on this stepwise mapping approach, in addition to assessing the places where action is needed, agriculture-specific actions for SDS impact mitigation for persons, livestock and areas of crop and rangelands can be obtained, classified and addressed according to severity/priority levels, as tentatively shown in Table 5. In this way, the parts of the county at high risk of SDS disasters can be classified according to risk levels, and countermeasures can be planned in a location-specific and tailor-made way through proactive SDS prevention and contingency planning.

Table 5. | Population, livestock, rainfed and irrigated cropland, and rangeland with different levels of SDS risk in Ahvaz County

Risk level	Population	Livestock	Rainfed cropland	Irrigated cropland	R1	R2	R3
Unit	Number		km²				
Very high	3 603	1 141	111	26	2	39	73
High	53 326	16 941	194	187	35	84	190
Medium	37 219	11 822	348	411	25	59	154
Low	16 538	5 253	346	766	5	46	129
Very low	5 538	1 760	142	435	0	25	98

Note: R1 = rangeland with canopy coverage (CC) ≥ 50 percent; R2 = rangeland with 25 < CC < 50 percent; R3 = rangeland with 5 ≤ CC ≤ 25 percent, where CC = canopy coverage

Source: Author's own elaboration

Chapter 2. Conceptualizing the sand and dust storm contingency planning process for agriculture

This chapter looks at the basic institutional features and planning components needed for SDS contingency planning and implementation in agriculture (cropland and rangeland). It first focuses on the overall legal and institutional frameworks in the Islamic Republic of Iran that are relevant for SDS implementation at and across various institutional and administrative levels within the county. In doing so, it also points to existing organizational responsibilities for implementing an SDS contingency plan.

This chapter thus outlines the institutional context for SDS contingency planning and implementation at the county level. It is intended to be applicable beyond the Ahvaz County case study area. Chapter 3 will thereafter zoom in and showcase the application of this methodology using Ahvaz County as an example county, while linking the institutional context and specific measures proposed for agriculture at the county level to address SDS source and impact mitigation.

2.1. Strategic direction

The strategic direction of SDS contingency planning for agriculture is based on the following:

Vision: control and management of SDS sources and mitigating their impacts on cropland and rangeland, thus contributing to making agriculture SDS-resilient;

Scope: sustainable land and water resources management, soil conservation, sustainable agriculture, integrated disaster risk management (DRM) and sustainable land management (SLM) planning;

Objectives: minimizing adverse impacts of SDS on agriculture (cropland and rangeland) and rural communities; Increasing the preparedness of vulnerable rural communities for undertaking timely and effective mitigation actions before, during and after SDS through a better understanding of their SDS risk, vulnerability and coping capacity; using legal and policy frameworks to mobilize financial resources, deploy capacity and optimize practices to increase resilience of the rural communities and their livelihoods against SDS;

Guiding principles: resilient and sustainable agriculture, enhanced SDS source and impact mitigation coping capacities, integrated multi-hazard risk reduction, preparedness and response strategies, strong stakeholder participation, clearly defined responsibilities for enhanced accountability, and coping capacities for SDS within and across sectoral agencies;

Outcomes: strengthened SDS governance, SDS contingency planning with a focus on agriculture formulated and regularly monitored at all relevant institutional levels, SDS contingency plans implemented as integral aspects of national DRM and sectoral development planning to achieve resilient and safe rural communities with regard to SDS.

2.2. Institutional context for sand and dust storm contingency planning and implementation (rules and regulations)

The legal frameworks required to implement the SDS contingency plan in agriculture of Islamic Republic of Iran:

- Law of Clean Air (16 July 2017)
- Soil Conservation Law (10 June 2019)
- Law on Protection, Rehabilitation and Management of the Country's Wetlands (24 April 2017)
- Disaster Management Law (National Disaster Management Organization [NDMO]) (No. 9044473, 25 August 2019)
- National and Provincial Plans for Preparedness and Response (subject to Article 2 of the Disaster Management Law)
- Regulation on Coordination of Prevention and Management of Dust Phenomenon (No. 27962 / T 57929 H, 2 June 2021)
- Executive Regulations to Prepare for the Dust Phenomenon (47362/T 53227 H, 16 July 2016)
- Amended Regulations for Preparation and Dealing with the Harmful Effects of Dust Phenomenon in the Country (31625/T 46610 H, 9 May 2012)
- National Disaster Risk Reduction Program (Paragraph T of Article 4 of the Crisis Management Law, November 2021)
- National Preparedness and Response Program (Paragraph T of Article 4 of the Crisis Management Law, November 2021)

Sand and dust storms are also addressed in the FAO country programming framework entitled Country Programming Framework for the Islamic Republic of Iran 2020 to 2022 (Output 3.3: Disaster Risk Reduction Strategies in the Agricultural Sector and Coordinated Responses Frameworks Further Developed. SDG Target 13.1).

Sand and dust storm terminology is not directly mainstreamed in the above laws and policies, although "dust storm," "sand storm" and "air pollution" are terms that have been specifically addressed. There are also laws and policies with no direct link to SDS, yet their consequences will mitigate SDS. For instance, the Law on Protection, Rehabilitation and Management of the Country's Wetlands (24 April 2017) will contribute to reducing SDS emissions from wetlands.

Despite the capacities of these laws and policies, there is a lack of evidence to show specific SDS-related mitigation good practices in agriculture in the country. For implementation of this contingency plan, it is strongly recommended that these laws and policies be comprehensively reviewed in terms of institutional coping capacities to strengthen the agricultural sector with regard to SDS mitigation.

2.3. Strategic elements and inputs needed for sand and dust storm contingency planning in agriculture

The design and development of a contingency plan for SDS requires a set of inter/intra-organizational actions. Figure 11 suggests key elements needed for SDS-oriented contingency planning in agriculture in the Islamic Republic of Iran, but that could also be considered for other countries with similar characteristics.

Figure 11. | Proposed elements and tasks to develop an SDS-oriented contingency plan in agriculture

Knowledge creation/sharing

- Conduct research to identify emission sources, transport pathways and deposition areas of SDS and the impacts on agriculture, and rural comunities to create baselines for each region.
- Coordinate with regional countries/institutions and United Nations entities to share knowledge.
- Raise awareness about SDS drivers and consequences

Forecast and early warning system

- Forecast the occurrence of SDS
- Provide agriculture-specific esrly warning messages in rural areas for SDS impact mitigation.
- Develop an online interorganizational warning network for syncronized action planning

Enhanced cohesion between the national and local action plans for agriculture, DRM, SDS and with other sectors

- Develop national DRR and DRM plans to combat SDS.
- Create national master plan to combat SDS in agriculture.
- Implement agriculture-specific local plans at county/district levels.

Capacity development in agriculture to enhance resilience and adaptability of agriculture towards SDS

- Multihazard risk reduction and role and responsibilities of agriculture.
- Create protocols for prevention, mitigation and adaptation towards SDS impacts.
- Create and implement operational response plans during SDS events.
- Create recovery protocols and operational plans to mitigate SDS impacts.

Agriculture damage and loss estimation

- Develop time series remote sensing indicators to model vegetation cover and plant phonology behaviours to be combined with field data to estimate damage and loss caused by SDS on agricultural lands.
- Utilize the FAO damage and loss methodology to generate precise and holistic data for the agricultural sector (https://elearning.fao.org/course/view.php?id=608).
- Apply the Sendai Framework Monitor Indicator C-2 measuring "Direct agricultural loss attributed to disasters" (https://www.preventionweb.net/sendai-framework/sendai-framework-indicators).

Multiscale SDS (geo)database development

- Create and develop an SDS (geo)database management system, which contains the maps of SDS sources, transport and deposition areas, vulnerability, hazard and risk assessment/ mapping procedures, decision support system and to regularly updated protocols.

Determining the responsible organizations

- Further define the responsibilities of key stakeholders, institutions and government agencies. SDS includes several domains (croplands, rangelands and rural comunities) in a transparent way, and in accordance with existing laws, regulations and programmes.
- Enhance the intra- and inter-agency interactions as the prerequisite to better SDS risk management.
- The transnational nature of the SDS phenomenon dictates the need for strengthening regional cooperation, international relations and use of the capacities of United Nations entities.

Source: Author's own elaboration

2.4. Planning and implementation responsibilities relating to sand and dust storms

In the Islamic Republic of Iran, the Department of Environment (DoE) National Committee for Combating Sand and Dust Storms and the Ministry of Agriculture-Jahad NRWO are responsible for preparing a master plan and action plans to control dust phenomena in identified districts as well as for the whole country and for notifying the relevant agencies to provide the necessary funds.

Mitigation measures of SDS risk should be implemented in accordance with the general principles and the methodology of risk management/reduction planning and implementation in Islamic Republic of Iran. The Planning and Budget Organization (PBO) of the Islamic Republic of Iran is responsible for earmarking the financial resources required for SDS planning and implementation in the annual SDS control costs budget. The NRWO is responsible for SDS project implementation and evaluation. The national committee and governors of the provinces monitor implementation of projects. The Iran Meteorological Organization (IRIMO), in collaboration with the World Meteorological Organization (WMO) Sand and Dust Storm Warning Advisory and Assessment System will deliver timely, quality SDS forecasts, observations, information and knowledge to users, through a dedicated mobile telephone/web service.

Table 6 summarizes the main agricultural planning and action frameworks relating to SDS planning and implementation in the Islamic Republic of Iran. It also shows the responsible lead institutions and collaborating partners. For a complex issue, such as SDS, there is a range of stakeholders who have shared responsibilities in certain domains. To introduce SDS planning at national or sectoral levels (e.g. for agriculture), it is crucial to inform and consult all stakeholders of any additional planning processes.

Table 6. | Frameworks and institutions responsible for SDS preparedness, response and recovery

Action frameworks	Lead institutions	Support institutions
National master plan	DoE National Committee for Combating Sand and Dust Storms	Ministry of Agriculture-Jahad NRWO, NDMO and universities
Action plan	Ministry of Agriculture-Jahad NRWO	Research institutes
Contingency plan	Ministry of Agriculture-Jahad NRWO	NDMO, IRIMO and Ministry of Health, Treatment and Medical Education
Control desertification and SDS sources	Ministry of Agriculture-Jahad NRWO	General governorates and PBO
Water, soil and agriculture resources management (Appendix 4)	Ministry of Agriculture-Jahad (Deputy of Water and Soil)	NRWO and Ministry of Energy
Compensate and provide financial support to affected rural communities	Government of the Islamic Republic of Iran and insurance companies	General governorates and PBO and state and private banks
Protection plan and protocols for livestock, bees and aquatics	Ministry of Agriculture-Jahad (Agricultural Research, Education and Extension Organization)	Research institutes and NRWO
Orchardists support and fruit preservation plan	Ministry of Agriculture-Jahad NRWO	Research institutes
Emergency food and water supplies plan	NDMO and Iranian Red Crescent Society (IRCS)	Ministry of Agriculture-Jahad NRWO and provincial governorate
Biodiversity and medicinal plants programme	Research institutes	Ministry of Agriculture-Jahad (Deputy of Water and Soil) NRWO
SDS awareness-raising culture for preparedness, response and recovery	Ministry of Agriculture- Jahad (Agricultural Research, Education and Extension Organization)	Research institutes and universities

Source: Author's own elaboration

When implementing SDS planning in agriculture, it is also crucial to consider the existence and role of the institutions of key actors at decentralized institutional levels since ultimately SDS contingency planning for agriculture crosses four main administration levels (national, provincial, county and district) in the Islamic Republic of Iran (Table 7).

Table 7. | Overview of relevant stakeholders at institutional/administrative levels

	Institutional/administrative level*			
	National	Provincial	County	District
Cropland	Ministry of Agriculture-Jahad	General Directory of Agriculture-Jahad of province	Directory of Agriculture-Jahad of county	Stakeholders (farmers, beekeepers, ranchers, aquatic breeders, rural cooperatives, etc.)
Rangeland	Ministry of Agriculture-Jahad NRWO	General directory of NRWO of province	Directory of NRWO of county	
Rural communities and economy	Government of Iran (Islamic Republic of) and insurance companies	Agriculture funds of province, insurance companies, and available rural development funds and resources	Agriculture funds of province and insurance companies in county	Stakeholders and landowners

** Legal endorsements including laws, regulations, programmes and plans govern the institutional/administrative levels.*

Source: Author's own elaboration

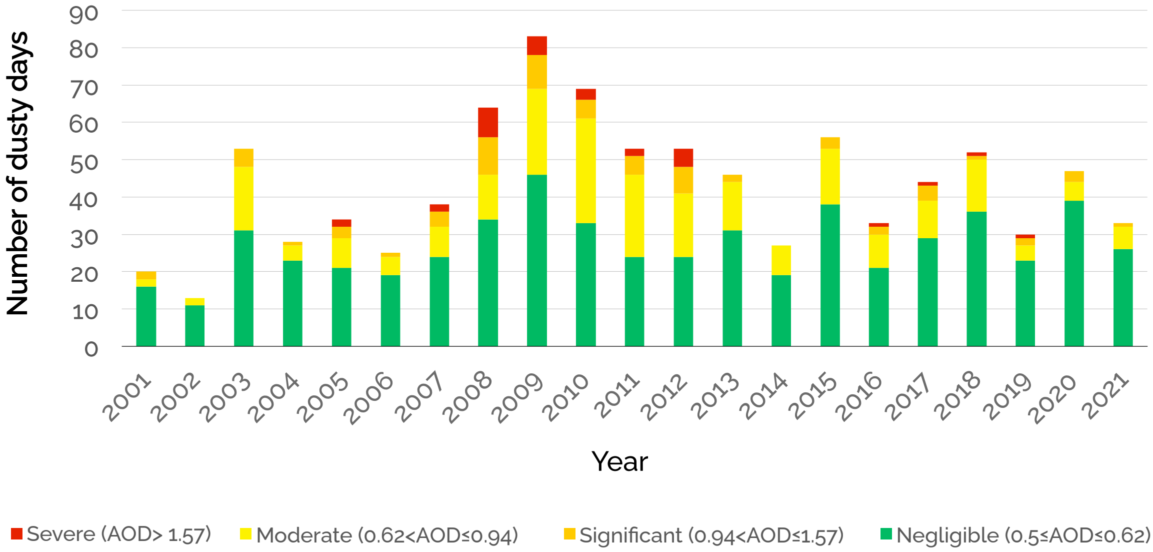
Chapter 3. Sand and dust storm contingency planning for agriculture in Ahvaz County

This chapter presents an initial effort to apply existing knowledge on and from Ahvaz County, and the results from the risk assessment presented in Chapter 1 to establish a generic list of SDS operational activities that will help to establish a proactive approach towards SDS contingency planning in Ahvaz County. It can serve as a generic tool to initiate SDS action planning at all levels within the Islamic Republic of Iran.

3.1. An agricultural response to the sand and dust storm risk situation

To prepare the SDS calendar of Ahvaz County for the last two decades, two parameters have been considered: SDS frequency and SDS intensity (Appendix 1, Equation [A1.1 and A1.2]). The hazard severity of an SDS is a function of these two parameters, as described in Chapter 1. For this purpose, daily AOD (2000–2021) values were acquired and those above a threshold of 0.5 were determined as a dusty day. Figure 12 shows the yearly frequency of SDS and the intensity in four classes: negligible, moderate, significant and severe. It reveals that 2002 and 2009 experienced the lowest and highest severity of SDS hazard, respectively.

Figure 12. | The SDS calendar (frequency and intensity of dusty days) in Ahvaz County



Source: Author's own elaboration

The results from the risk and vulnerability assessment, the number of people and livestock and the size of cropping areas (rainfed and irrigated) and rangelands exposed to the different SDS risk levels were presented in Figure 10 of Chapter 1. These data establish the spatial dimension and quantified magnitude of SDS disaster risk and guide the county-specific selection of operational activities and targets of the SDS contingency plan at the county level.

Specific measures and actions are required that correspond to the requirements of the vulnerable areas, including for prevention, preparedness, forecast and early warning, emergency response and recovery. These are developed by determining the affected agriculture (cropland and rangeland) and rural communities in different SDS risk scenarios in Ahvaz County and considering the existing limitations of financial resources and SDS DRM infrastructures, as well as the policies of the organizations in charge of SDS mitigation.

Hence, several different operational activities were identified and consolidated based on literature review and expert knowledge obtained through an interactive stakeholder consultation process (Table 8). These proposed activities may aid better SDS DRM in Ahvaz County and provide overall guidance for further fine-tuning and selection by local authorities and communities of priority activities according to their location-specific situations, SDS risk exposure level and existing coping capacities.

Table 8. | Operational activities to reduce SDS disaster risk for agriculture in Ahvaz

Operational activities	Timing	Responsibility
Preparedness		
Collect and provide regular data about water, soil, agriculture and the socioeconomy, , meteorology and air quality of Ahvaz County to the geodatabase management system	As soon as possible	General governate of Khuzestan, General Meteorolocal Organization of Khuzestan, General Agriculture-Jahad organization of Khuzestan, General NRWO of Khuzestan, General DoE of Khuzestan and research institutes
Soil conservation activities (soil enrichment, no tillage, low tillage and crop rotation)	Before the cultivation season	Land users, including herders and farmers
Water resources management (runoff collection and wetland management)	In wet seasons	Ministry of Energy, Ministry of Agriculture-Jahad and land users
Restoration (afforestation, reforestation, shrub planting and farming)	When needed	NRWO and land users
Land-use planning (rangeland management and livestock grazing management)	In 3–7 years	General governorates and PBO
Farm-side wind-breaks, roadside tree planting and non-living wind-breaks	When needed	NRWO and land users
Agricultural and livestock insurance	Annually	Agriculture Bank of Iran
Establish a financial mechanism to support anticipatory actions	When needed	Ministry of Agriculture-Jahad NRWO, international support funds and agricultural investment funds
Capacity-building and awareness-raising about SDS	When needed	Ministry of Agriculture-Jahad, universities, NDMO and United Nations agencies (FAO, UNCCD, World Health Organization and WMO)
Climate-smart agriculture practices, including avoiding cultivating crops with high water consumption, developing an efficient water resource management framework to integrate the agricultural and industrial drainage water with the Karun River water for agricultural irrigation systems and wetting dust sources, development and expansion of the use of new irrigation approaches, use of new technologies, such as superabsorbents to preserve soil moisture, and reduction of rural migration to other areas	As soon as possible	Ministry of Agriculture-Jahad NRWO
Prevent SDS deposition in aquaculture systems	As close as possible to an SDS occurence	Iranian/State Fishery Organization, universities, United Nations agencies (FAO, UNCCD, World Health Organization, WMO, etc.) and aquafarmers
Prevent bees from leaving hives	As close as possible to an SDS occurence	NDMO, beekeepers and land users
SDS sources control and mitigation measures, including stabilizing soil surface by mulching, planting climate-compatible shrubs and trees, and building wind-breaks and mechanical and biological barriers (see Appendix 4 for an overview of additional agricultural measures)	When needed	NRWO helps land users

Operational activities	Timing	Responsibility
Response		
SDS early warning system (spatial spread, durability and intensity)	Real/near real time	WMO Sand and Dust Storm Warning Advisory and Assessment System and IRIMO
SDS agriculture-specific information (television, text messages and social media)	Real/near real time	NDMO, provincial NDMO and IRIMO
Emergency rescue teams for lost people and livestock	When needed	Provincial NDMO and International Federation of Red Cross and Red Crescent Societies (IFRC)
Health services for people affected by dust	When needed	Ministry of Health, Treatment, and Medical Education (health house and centres and hospital emergency departments)
Recovery		
Estimate the impact/costs of SDS for crop and livestock subsectors	When needed	NDMO, provincial NDMO, universities and research institutions
Provide health services for people affected by dust	When needed	Ministry of Health, Treatment, and Medical Education (health house and centres and hospital emergency departments)
Use sprinkler irrigation system to wash plant leaves in irrigated agriculture systems	As soon as possible	Land users
Provide veterinary services to herders	As soon as possible	County veterinary network
Provide financial support to farmers and herders	When needed	Ministry of Agriculture-Jahad NRWO, international support funds and agricultural investment funds

Source: Author's own elaboration

3.2. An implementation strategy according to sand and dust storm risk levels

The institutional implementation framework and responsibilities for SDS contingency planning for agriculture in Ahvaz County build on and mirror the institutional/administrative responsibilities at the national level, as presented in Chapter 2. Table 9 proposes a specific institutional responsibility framework for Ahvaz County, with preparedness, response and recovery actions by responsible institutions in line with the different risk levels identified.

Table 9. | Proposed management structure/responsibilities, coordination, operational activities and communication mechanisms for implementing the contingency plan according to different SDS risk scenarios in Ahvaz County

Risk scenario	Prepare	Response	Recovery	Fund	Responsible(s)
V	CSD, APA	FWS, FFP, DEG, CMT, TNCM	TNCM, WFPL, CAI	PBO, governorate, and agriculture development funds	NDMO (CMT, FWS and TNCM) IRIMO (EWS) NRWO (CSD and PGP) DoE (DEG and PGP) Stakeholders, ranchers, farmers, etc. (APA, FFP, WFPL, CAI and PGP) IRCS (CMT, FWS and TNCM) Insurance companies (AHPI and DEG) Rural development funds (AHPI and DEG) Water user associations (FWS and WFPL) Road maintenance directory (TNCM)
IV	CSD, APA	FWS, FFP, DEG, CMT, TNCM	TNCM, WFPL, CAI		
III	CSD		CAI		
II					
I					
Independent of risk scenarios	EWS, AHPI, PGP				

Notes: For operational activities: AHPI = agriculture, health and property insurance; APA = animal protective actions (keep livestock in stables, keep bees in hives and cover fishponds with nylon or glass when SDS occurs); CAI = cleaning agriculture infrastructures; CMT = crisis management team (If an SDS is categorized as a crisis, this group will form, and by implementing the mitigation measures, it will manage the SDS crisis). CSD = cadaster system development to make a systematic and target-oriented resources allocation to combat SDS; DEG = damage estimation group led by the Ministry of Jahad-Agriculture (If an SDS is associated with damage, this group will form and, by developing measurable indicators of Sendai Framework Monitor Indicator C-2, it will estimate the amount of damage). EWS = early warning system; FFP = fruit and food protection; FWS = food and water supply; PGP = promoting good practices related to agriculture (available local knowledge, implemented practices and technologies, and successful projects to mitigate SDS in agriculture); TNCM = transport network crisis management; WFPL = washing fruits and plant leaves. For responsible organizations: DoE = Department of Environment; IRCS = Iranian Red Crescent Society; IRIMO = Iran Meteorological Organization; NDMO = National Disaster Management Organization; NRWO = Natural Resources and Watershed Management Organization; PBO = Planning and Budgeting Organization

Source: Author's own elaboration

3.3. Monitoring and evaluation of contingency plan

Several indicators can be used to evaluate the implementation status of a contingency plan for SDS risk reduction. They are based on the investigation domains of the vulnerable rural communities and include agricultural activities for cropland and rangeland, SDS sources and socioeconomics (Table 10). These indicators are suggested based on consultation with experts and available knowledge of the issue. These monitoring and evaluation indicators have not been directly addressed to the identified responsible organizations.

Table 10. | Evaluation methods and tools to monitor the impacts of contingency planning in SDS risk reduction in agriculture

Domain	Methods and tools	Responsible(s)
Cropland and rangeland	Weekly vegetation cover monitoring using remote sensing indices, e.g. NDVI and FVC Monthly agricultural productivity monitoring using satellite-based NPP Yearly land degradation assessment by LDI	NRWO DoE General governorates Universities and research institutes
SDS sources	Monitoring changes in the extent of SDS emission sources by NDD Time series analysis of the intensity and frequency of SDS events by DSI, DER and Vis	
Socioeconomics	Human development: Income stability due to SDS mitigation in agriculture by periodic agriculture census Awareness about SDS evaluated using questionaries Migration status of SDS-affected rural areas by national population and housing census	

Source: Author's own elaboration

3.4. Follow-up recommendations and management actions

Due to the COVID-19 situation faced during the implementation period of this project, the fieldwork foreseen at the county level could not be realized to the degree anticipated. The strong limitations, including travel restrictions, prevented implementation of stakeholder consultations, particularly at the subcounty level, but also at the county level. The situation did not allow the intended fine-tuning nor the involvement of local stakeholders in the operational activities at subcounty and community levels. Showcasing an example of how the contingency plan for SDS in agriculture could be addressed in practice at the local level and included into existing county and subcounty level planning processes or planning documents was not possible.

Thus, a final step to share the proposed analytical framework proposed, as well as the results of the risk, vulnerability and coping capacity assessment, with local authorities and other local stakeholders, including community representatives and farmers, in the highly at-risk areas, is a key recommendation of this report.

It is also recommended to design SDS plans in selected communities and to consolidate thereafter a county-level plan that combines, in a balanced way, higher-level priorities with bottom-up planning perspectives and demands. This would better counteract future SDS source development on agricultural land and reduce SDS impacts on cropland and rangeland.

Local authorities and farmers should plan together following the process guidance for this contingency plan. This could be achieved by implementing the following recommendations to adopt the required localized SDS planning responses for the agriculture sector and beyond.

3.4.1. Within Ahvaz County

- Hold capacity development workshops (meetings and administrative discussions) for SDS stakeholders in Ahvaz County to enhance awareness about SDS risks in agriculture (cropland and rangeland) and to achieve a common understanding of a proactive contingency planning approach to reduce future impacts of SDS in the Islamic Republic of Iran.

- Establish a cross-sectoral SDS expert group in Ahvaz County to guide enhanced SDS contingency planning and implementation across SDS-affected sectors.

- Design and conduct a training workshop for the SDS expert group and selected representatives from local authorities to learn how to collect the required data and implement remote sensing data collection and analysis in combination with GIS modelling procedures for SDS risk mapping.

- Further raise awareness among local communities living in SDS high-risk areas of Ahvaz County. Effective cooperation mechanisms with local communities should be established to ensure their active participation and contribution to the design and implementation of location- and situation-specific SDS contingency plans. This should be done in line with existing capacities at the local level, and government actions and responsibilities according to the risk and vulnerability levels and needs identified for different stakeholder groups.

- At the decentralized institutional level, adopt a multisectoral and intersectoral lens in the development and implementation of SDS contingency planning, while ensuring agriculture is included, and that SDS source mitigation and impact mitigation issues are addressed adequately.

- In cooperation with local communities and non-governmental organizations, the Government of the Islamic Republic of Iran should conduct the feasibility assessments needed for implementing and adopting new SDS risk-reducing technologies and implementing successful projects (based on the options presented in Appendix 4) for Ahvaz County.

- Based on the feasibility study results and in line with its overall responsibilities, the Government of the Islamic Republic of Iran should reconfirm its SDS priority interventions for the different agricultural subsectors and rural communities based on different levels of risk (as presented in Table 9) and allocate appropriate budgets to implement SDS contingency plans through pilot projects in Ahvaz County, including at the farm/field level.

3.4.2. Beyond Ahvaz County

- For further upscaling of SDS activities beyond Ahvaz County, develop countrywide SDS risk and vulnerability maps. Based on those maps, develop related contingency plans at local scales for other areas affected by SDS, with a focus on agriculture.

- The Government of the Islamic Republic of Iran should integrate an SDS contingency plan into the national DRR programme following Table 8.

- The Government of the Islamic Republic of Iran should consider adapting, implementing and distributing this SDS contingency planning approach to other SDS-affected counties.

Appendix 1. Indicators for sand and dust storm risk assessment

A1.1. Dust severity index

Satellite aerosol indices are widely used as important and practical data sources in dust studies. Remotely sensed AOD is a quantitative estimate of the amount of aerosol in the atmosphere and can be used as an indicator of dust concentration (Darvishi Boloorani *et al.*, 2021a). The dust severity index (DSI) is developed here to express the intensity of dust events:

$$\text{DSI} = \frac{\text{dust frequency}_{p.t}}{\text{average dust frequency}_{a.t}} \times \text{dust intensity}_{[0,1]} \quad \text{(A1.1)}$$

where *dust frequency*$_{p.t}$ is the number of dusty days with AOD ≥ 0.85 (Moridnejad Karimi and Ariya, 2015; Nabavi, Haimberger and Samimi, 2016), *p* is pixel, *t* is a specific period of time (here, *t* is annual intervals from 2000 to 2022), $_{a.t}$ is the average number of dusty days with AOD ≥ 0.85 and *a* is the area of the investigation county.

The daily MODIS (Terra+Aqua) Multi-angle Implementation of Atmospheric Correction blue band (0.47 µm) land AOD gridded Level 2 product (with a threshold of AOD ≥ 0.85) was used to obtain the frequency of dust occurrence (here called dusty days) in the study area with a 1 km spatial resolution from 2000 to 2022. As the value of AOD exceeding the mentioned threshold can be variable, in addition to dust frequency, dust intensity must also be considered:

$$\text{dust intensity}_{[0,1]} = \frac{\text{dusty AOD}_{p.t} - \text{minimum dusty AOD}_{a.t}}{\text{maximum dusty AOD}_{a.t} - \text{minimum dusty AOD}_{a.t}} \quad \text{(A1.2)}$$

where dusty AOD$_{p.t}$ is the average AOD ≥ 0.85, *p* is pixel, *t* is a specific period of time (here, *t* is annual intervals from 2000 to 2022), maximum dusty AOD$_{a.t}$ is the minimum of average AOD ≥ 0.85 and maximum dusty AOD$_{a.t}$ is the maximum of average AOD ≥ 0.85.

A1.2. Wind erosivity severity index

There are no SDS without wind, even if other SDS formation conditions are met. Among all environmental factors, wind is the most influential in the formation of SDS and wind erosion (Goudie and Middleton, 2006; Shi *et al.*, 2004) with a dominantly limiting role[4] (Darvishi Boloorani *et al.*, 2022a). As the literature shows, there is a significant relationship between the surface wind erosion threshold and dust event occurrence. The wind erosion threshold for dust formation tends to vary spatially and temporally. The reported threshold for the dominant Shamal wind in Western Asia (Parajuli, Yang and Kocurek, 2014) is 6 m/s (Darvishi Boloorani *et al.*, 2020). Accordingly, using daily wind speed data from ERA5 aggregates (the latest climate reanalysis produced by the European Centre for Medium-Range Weather Forecasts/Copernicus Climate Change Service with a 28 km spatial resolution) (Copernicus Climate Change Service, 2017), the number of days with wind speed values above 6 m/s are counted (1979–2020) to obtain the wind erosivity severity index (WESI):

$$\text{WESI} = \frac{\text{erosive wind frequency}_{p.t}}{\text{average erosive wind frequency}_{a.t}} \times \text{WEI}_{[0,1]} \quad \text{(A1.3)}$$

where erosive wind frequency $_{p.t}$ is the number of dusty days with wind speed ≥6 m/s, *p* is pixel, *t* is a specific period of time (here, *t* is annual intervals from 1979 to 2020), *p* is the average number of days with wind speed ≥ 6 m/s, *a* is the area of the investigation site and WEI is the wind erosivity intensity.

Considering that the intensity of the wind speeds exceeding the threshold can be variable, the rate of intensity must be considered as well as the frequency of days with wind speed above the erosivity threshold. Therefore, WEI is calculated using:

$$\text{WEI}_{[0,1]} = \frac{\text{erosive wind}_{p.t} - \text{minimum erosive wind}_{a.t}}{\text{maximum erosive wind}_{a.t} - \text{minimum erosive wind}_{a.t}} \quad \text{(A1.4)}$$

where erosive wind $_{p.t}$ is the average wind speed ≥ 6 m/s, *p* is pixel, *t* is a specific time (here, *t* is annual intervals from 1979 to 2020), minimum erosive wind $_{a.t}$ is the minimum of average wind speed ≥ 6 m/s and erosive wind $_{a.t}$ is the maximum of average wind speed ≥ 6 m/s.

A1.3. Visibility

The occurrence of SDS causes a reduction in the visibility across a region. Visibility is an atmospheric variable recorded at meteorological stations. The presence of smoke, pollution, moisture and suspended mineral dust in the atmosphere can all result in a reduction in visibility (Baddock *et al.*, 2014). Regardless of the horizontal visibility, WMO has defined weather phenomena codes

4 Wind speed is considered a determining factor for SDS formation.

related to SDS events, including 06–09, 31–35 and 98 (Darvishi Boloorani *et al.*, 2022b) which can be used to calculate vulnerability, coping capacity, hazard and risk. To convert point data from meteorological stations into raster layers, interpolation methods such as geostatistics and inverse distance weighting are used.

A1.4. Net dust deposition

Areas exposed to dust deposition are naturally vulnerable to a wide range of SDS-related hazards. The net dust deposition (NDD) (wet + dry) can be obtained from the gridded monthly MERRA2 reanalysis data (1980–2021) at 0.5° × 0.625° spatial resolution to analyse long-term dust deposition in the study area. As this product is produced on a global scale, it is necessary to determine its validity before using it on a local scale.

A1.5. Dust emission rate

The dust emission rate (DER) is an indicator of soil erodibility status. The importance of this indicator in calculating vulnerability, coping capacity, hazard and risk is that it provides the necessary information for spatio-temporal analysis of erodibility. It can be obtained from the gridded monthly MERRA2 reanalysis data (1980–2021) at 0.5° × 0.625° spatial resolution to analyse the long-term dust emission status in the study area.

A1.6. Palmer drought severity index

The consequences of drought include declining agricultural production, widespread livestock mortality, increasing disease, land degradation, wetland drying and SDS occurrence (Hameed, Ahmadalipour and Moradkhani, 2020). The Palmer drought severity index (PDSI) combines temperature and precipitation data to estimate relative drought that promotes SDS in an area (Javadian, Behrangi and Sorooshian, 2019).

A1.7. Livestock grazing index

Generally, to calculate the number of livestock (e.g. cattle, sheep and goats), the total available forage per unit area in proportion to rangeland capacity is divided by the total forage required for livestock grazing in a grazing season. Accordingly, the total amount of available forage in rangeland (kg/area) is equal to the product of the rangeland area multiplied by the amount of forage produced (kg/area). The allowed exploitable grazing area is usually equal to 50 percent of the rangeland area. The remaining 50 percent is considered a protected area for soil conservation:

$$F_E = A_T \times F_P \times A_E \tag{A1.5}$$

where F_E is exploitable forage (kg), A_T is total rangeland area (ha), F_P is produced/available forage (kg) and A_E is exploitable rangeland area ~ 50 percent.

The main determining factor for forage availability in rangelands is the above-ground net primary production (NPP) (Paruelo *et al.*, 2000). Due to the inaccessibility of field data on the amount of forage production in the study area, satellite imagery was used in this report. Generally, remotely-sensed NPP is examined as a fundamental component of the ecosystem that determines the conversion of carbon dioxide into biomass through photosynthesis (FAO, 2020). As shown in Figure A1.1, a stepwise procedure is developed to calculate livestock grazing index (LGI). It provides an estimate of the state of rangeland management and soil conservation in a given region.

Net primary production is considered a representative measure of forage availability for livestock due to the low diversity of rangeland plant species in the study area (Zimmer *et al.*, 2021). Here, the ten-day time series of remotely sensed FAO NPP (g/m2) datasets with 250 m spatial resolution have been acquired from 2009 to 2021. A land-cover map was generated using Landsat 8 satellite imagery with 30 m spatial resolution and the random forest supervised classifier for the 2020–2021 crop year (95 percent overall accuracy). Then, the 13-year average NPP (2009–2021) for the rangeland area was calculated. Next, using the long-term average NPP and rangeland area, the total amount of available forage for grazing was calculated using:

$$F_E = A_P \times \mathrm{NPP}_{\mathrm{Avg},P} \times 0.5 \tag{A1.6}$$

where A_P is the pixel size of NPP (here,~250 m = 62 500 m2 = 6.25 ha) and NPP $_{Avg.P}$ is the long-term average NPP per pixel (kg/m^2).

In the next step, the amount of forage required for livestock grazing in one year is calculated by multiplying the livestock weight (kg) by the number of grazing days (365 days) by the daily dry matter intake (2 percent of the livestock body weight):

$$F_R = 365 \times 0.02\ (W_L) \tag{A1.7}$$

where F_R is the forage requirements for livestock (kg) and W_L is the average livestock weight (kg).

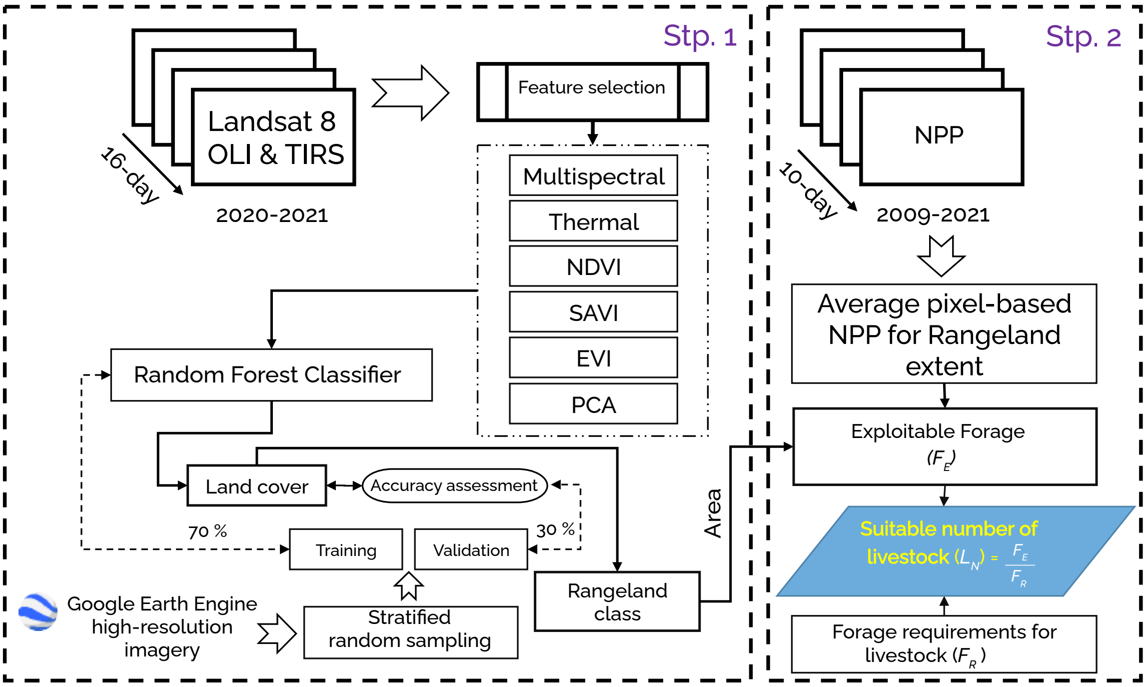
In the next step, Equation (A1.6) is divided by Equation (A1.7) to calculate the suitable number of livestock in the rangeland:

$$L_N = \frac{F_E}{F_R} \tag{A1.8}$$

where L_N is the suitable number of livestock for grazing on the rangeland per pixel (250 × 250 m^2). Finally, LGI is calculated by comparing the suitable number of livestock (proportional to exploitable forage) and the available number of livestock (L_A) in the area:

$$\text{LGI} = \frac{L_A}{L_N} \quad (A1.9)$$

Figure A1.1. | Stepwise methodology to model LGI for estimating the appropriate number of livestock for grazing in rangelands using remote sensing data



Note: EVI = enhanced vegetation index; OLI = operational land imager; PCA = principal component analysis; RF = random forest; SAVI = soil adjusted vegetation index; Stp. = step; TIRS = thermal infrared sensor

Source: Author's own elaboration

A1.8. Land degradability index

Land degradation is recognized as one of the main drivers of SDS (Kimura, 2017), leading to agricultural, social and economic losses (Bakhtiari *et al.*, 2021). The occurrence of land degradation is a function of various environmental parameters, including climatic characteristics, soil and vegetation. An indicator of land degradability can be obtained by modelling the relationships between these parameters. Increasing temperature differences between day and night has a negative effect on soil microorganisms and causes physical weathering of the soil. The long-term process of land degradation that decreases soil functionality can be measured by monitoring changes in NPP (Higginbottom and Symeonakis, 2014). Decreased precipitation (Pr) leads to a decrease in soil moisture (SM) and vegetation cover; as a result, fine soil particles are exposed to wind erosion (Sissakian, Al-Ansari and Knutsson, 2013; Darvishi Boloorani *et al.*, 2022a). Soil organic carbon (SOC) has an important role in the physical, chemical and biological functions of agricultural soils. It increases soil porosity, adhesion and cohesion, which can increase the SM capacity and reduce the risk of soil erosion and thus SDS occurrence (Hugar and Soraganvi, 2014).

Among all environmental factors, wind speed (WS) can be considered the most influential and limiting factor in wind erosion occurrence. Wind blowing can also increase surface evapotranspiration (ET) and decrease SM and adhesivity and subsequently increase soil erodibility through the movement of air and increased atmospheric moisture capacity (Darvishi Boloorani *et al.*, 2022a). Accordingly, it can be said that WS intensifies other factors affecting land degradation.

This report uses time series of land surface temperature differences between day and night (ΔT_S), ET, NPP, SOC, SM, Pr and WS in the period from 2000 to 2021 to develop the land degradability index (LDI) (Equation [A1.10]). In fact, LDI shows the amount of land degradation potential. Accordingly, the required data were acquired from MODIS (land surface temperature, day and night), FAO (NPP), TerraClimate (ET, SM, Pr and WS), and the International Soil Reference and Information Centre (ISRIC). The result was verified in comparison with the land degradation map produced by Bakhtiari *et al.* (2021):

$$\mathrm{LDI} = \left(\frac{(\Delta T_S + \mathrm{ET})}{(\mathrm{NPP} + \mathrm{SOC} + \mathrm{SM})\mathrm{Pr}}\right)^{\mathrm{WS}} \tag{A1.10}$$

A1.9. Fractional vegetation cover

Fractional vegetation cover (FVC) is the percentage of vegetated area including roots, stems and leaves. It is calculated using an equation that reflects the growth conditions of vegetation effectively (Jing *et al.*, 2011; Zhang *et al.*, 2019):

$$\mathrm{FVC} = \frac{\mathrm{NDVI} - \mathrm{NDVI_S}}{\mathrm{NDVI_V} - \mathrm{NDVI_S}} \tag{A1.11}$$

where NDVI is an index that describes the difference between visible and near infrared reflectance of vegetation cover and can be used to estimate the density of green on an area of land (Weier and Herring, 2000), $\mathrm{NDVI_S}$ is the vegetation index of the bare soil, and $\mathrm{NDVI_V}$ is the vegetation index of the whole vegetation cover. The FVC can be obtained from a variety of remotely sensed satellite imagery such as Landsat, Sentinel2 and MODIS. Monthly MODIS NDVI products were acquired at 250 m spatial resolution (2000–2019).

Appendix 2. Freely available web-based data

Aerosol Robotic Network (AERONET) is a federation of ground-based remote sensing aerosol networks established by the National Aeronautics and Space Administration and the Photométrie pour le Traitement Opérationnel de Normalisation Satellitaire and is greatly expanded by networks (e.g. RIMA, AeroSpan, AEROCAN and CARSNET) and collaborators from national agencies, institutes, universities, individual scientists and partners. For more than 25 years, the project has provided a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution. (https://aeronet.gsfc.nasa.gov).

Automated Surface Observing System (ASOS)/Automated Weather Observing System (AWOS) Meteorological Aerodrome Report (METAR) data is an ever-growing archive of automated airport weather observations from around the world. These observations are typically called "ASOS" or sometimes "AWOS" sensors. A more generic term may be "METAR data", which describes the format in which the data is transmitted. This archive simply provides the as-is collection of historical observations, and little quality control is done. (https://mesonet.agron.iastate.edu/request/download.phtml?network=SYASOS#).

ERA5 is the fifth-generation European Centre for Medium-Range Weather Forecasts reanalysis for the global climate and weather for the past four to seven decades. Data are available from 1950, split into Climate Data Store entries for 1950–1978 (preliminary back extension) and from 1979 onwards (final release plus timely updates). This ERA5 replaces the ERA-Interim reanalysis, and provides hourly estimates for a large number of atmospheric, ocean-wave and land-surface quantities. (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-pressure-levels?tab=overview).

Global rainfed, irrigated and paddy cropland provides global mapping of irrigated, rainfed and paddy cropland by combining information from multiple data sources. (http://www.gibbs-lab.com/wp-content/uploads/2015/09/Salmon_Global_rain_fed_irrigated_and_paddy_croplands_2015.pdf).

Moderate resolution imaging spectroradiometer (MODIS) Terra/Aqua monitors the ambient aerosol optical thickness over the oceans continents. Furthermore, the aerosol size distribution is derived over the oceans, and the aerosol type is derived over the continents. "Fine" aerosols (anthropogenic/pollution) and "course" aerosols (natural particles, e.g. dust) are also derived. Daily Level 2 (MOD 04) data are produced at a spatial resolution of a 10 × 10 1 km (at nadir) pixel array. The aerosol product includes the "deep-blue" algorithm recently developed to monitor aerosol optical thickness over bright land areas. (https://modis.gsfc.nasa.gov/data/dataprod/mod04.php).

Net primary production (NPP) is a fundamental characteristic of an ecosystem, expressing the conversion of carbon dioxide into biomass driven by photosynthesis. The pixel value represents the mean daily NPP for that specific decade. (https://data.apps.fao.org/catalog/organization/079f3092-b035-443b-a50c-6a984c26399f?res_format=PNG&license_id=CC-BY-SA-4.0&page=3).

Palmer drought severity index (PDSI) uses temperature and precipitation data to estimate relative dryness. It is a standardized index that generally spans -10 (dry) to +10 (wet). (https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi)

The Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA2) provides data beginning in 1980. It was introduced to replace the original MERRA dataset because of advances that enable assimilation of modern hyperspectral radiance and microwave observations, along with global positioning system radio occultation datasets. It also uses National Aeronautics and Space Administration ozone profile observations that began in late 2004. Additional advances in the GEOS model and the GSI assimilation system are included in MERRA2. Spatial resolution is about the same (approximately 50 km in the latitudinal direction) as in MERRA. (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2).

United States Geological Survey Land Cover provides links to many land-cover, forestry, albedo, agriculture, river observations and other datasets. (www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/land-cover-data-download?qt-science_center_objects=0#qt-science_center_objects).

WorldPop develops peer-reviewed research and methods for the construction of open and high-resolution geospatial data on population distributions, demographic and dynamics, with a focus on low- and middle-income countries. (www.worldpop.org).

Appendix 3. Questionnaires based on the analytic hierarchy process for mapping sand and dust storm vulnerability components

This appendix adapts an AHP method (Saaty, 1980) for weight allocation in a GIS-based multicriteria decision analysis method. The indicators (Table A3.1) of the vulnerability were considered to get different weights. The questionnaire (Table A3.2) was filled in by an NRWO SDS expert panel to allocate the weights of vulnerability indicators, as displayed in the last column of Table A3.3.

Table A3.1. | Sand and dust storm vulnerability components and indicators

	Component	Indicator/criteria
SDS vulnerability	Sensitivity	Palmer drought severity index (PDSI)
		Livestock grazing index (LGI)
		Land degradability index (LDI)
	Exposure	Population density (PD)
		Number of livestock (NL)
		Fractional vegetation cover (FVC)
	Coping capacity	Active population (AP)
		Literacy rate (LR)
		Rural health centre (RHC)

Source: Author's own elaboration

Table A3.2. | Pairwise comparison between sensitivity, exposure and coping capacity using the 1–9 Saaty scale

Sensitivity

Criterion j	Priority																	Criterion i
LGI	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LDI
PDSI	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LDI
PDSI	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LGI

Exposure

Criterion j	Priority																	Criterion i
NL	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	PD
FVC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	PD
FVC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	NL

Coping capacity

Criterion j	Priority																	Criterion i
LR	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	AP
RHC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	AP
RHC	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	LR

Note: Ratio scale and definition of AHP: 1 = equal importance; 3 = somewhat more important; 5 = much more important; 7 = very much more important; 9 = absolutely more important; 2, 4, 6, 8 = intermediate values

Source: Author's own elaboration

Table A3.3. | Analytic hierarchy process weights allocated to indicators by an SDS expert panel for pilot counties

Vulnerability component	Criterion/indicator	Weight
Sensitivity	PDSI	0.625
	LGI	0.238
	LDI	0.136
Exposure	PD	0.183
	NL	0.075
	FVC	0.742
Coping capacity	AP	0.265
	LR	0.063
	RHC	0.672

Source: Author's own elaboration

Appendix 4. Implemented projects, local knowledge and new technologies to combat sand and dust storms in agriculture

Tables A4.1, A4.2 and A4.3 list the technologies, good practices and local knowledge (TPKs) that are useful to combat SDS in the Islamic Republic of Iran. These TPKs have been collected using a literature review, insight into backup documents (the signed contracts and related project reports) and several meetings with the NRWO SDS expert panel. Sustainable land management and non-SLM TPK to mitigate SDS sources and impacts on agriculture were considered. For instance, mulching is a non-SLM TPK that prevents the creation of SDS. The four main domains of SDS impacts (health, environment, socioeconomics and agroecosystems [agropastoral, cropland and agroforestry]) are considered. The ranking is on a scale of 1 to 5 (1 being the worst, 5 the best).

All TPKs related to the issue of dealing with SDS have been collated. However, it should be noted that the mentioned TPKs in the lists are location- and context-specific, therefore they cannot necessarily be a solution to deal with SDS everywhere. To use these TPKs, it is necessary to conduct preliminary and feasibility studies carefully.

Table A4.1. | Implemented technologies to combat SDS in the Islamic Republic of Iran

Technology	Implementing area	SLM	Success rate (1–5)	Applicability to other places (1–5)	Impact on rural economy (1–5)	Public participation (1–5)	Land-use planning (1–5)	Water and soil management (1–5)	Costs (USD/ha)	Implementing year
Oil mulch	300 000 ha	1	5	5	5	1	1	4	100	Since 1960
Mulching	Urmia and Khuzestan	5	5	5	5	1	1	5	30	2018
Mix mulch	Urmia and Khuzestan	5	5	5	5	1	1	5	30	2018
Crop fibres	Urmia and Khuzestan	5	5	5	5	1	1	5	30	2018
Crushed stone	Semnan and Khuzestan	5	5	5	5	1	1	5	30	2018
Gasoline	Kerman and Khuzestan	1	3	3	3	1	1	5	100	2010
Molasses	Khuzestan	1	3	3	3	1	1	5	30	2010
Tree planting	2.2 million ha	1	3	3	3	1	1	5	30	2010
Water-absorbing polymers	Kerman and Khuzestan	1	3	3	3	1	1	5	40	2010
Starch mulch	Kerman and-Khuzestan	1	3	3	3	1	1	5	40	2010
Soil microorganisms	Laboratory	1	3	3	3	1	1	5	40	2010

Technology	Implementing area	SLM	Success rate (1–5)	Applicability to other places (1–5)	Impact on rural economy (1–5)	Public participation (1–5)	Land-use planning (1–5)	Water and soil management (1–5)	Costs (USD/ha)	Implementing year
Flood spreading	30 sites	1	3	3	3	1	1	5	40	2010
Pitting	30 sites	1	3	3	3	1	1	5	40	2010
Using halofits	5 sites	1	3	3	3	1	1	5	40	2010
Nano clay	Kerman and-Khuzestan	1	3	3	3	1	1	5	100	2010
Windbreak	30 sites	1	3	3	3	1	1	5	40	2010
Soil modifier	3 sites	1	3	3	3	1	1	5	40	2010
Soilization	-	1	3	3	3	1	1	5	40	2010
Microbial polymers	-	1	3	3	3	1	1	5	40	2010
Straw checkerboard	3 sites	1	3	3	3	1	1	5	40	2010
Fibre checkerboard	3 sites	1	3	3	3	1	1	5	40	2010
Local checkerboard	3 sites	1	3	3	3	1	1	5	40	2010

Table A4.2. | Implemented projects (good practices) to combat SDS in the Islamic Republic of Iran

Project	Implementing area	SLM (1–5)	Success rate (1–5)	Land use type: agriculture, rangeland, forest, desert	Public participation (1–5)	Land-use planning (1–5)	Water and soil management (1–5)	Costs (USD/ha)	Implementing year
Plantation	Southeast Ahvaz	4.5	4.5	Cropland and desert lands	3	4	4	1 000	2014
Cutting plantation on sand dunes	Kavire Mesr in Isfahan	4.5	4	Sand dunes and sandy plains	3	4	3	500	1986
Oil mulch spraying with plantation	West Karkheh River	5	3	Erg[1]	3	3	4	5 000	1972
Gravel mulching	Semnan Province	4	4	Desert lands	3	3	3	1000	2016
Sediment traps	Rigan in Kerman Province	4.5	5	Desert lands	2.5	3	4	100	2015
Living windbreaks around farmland	South of Kerman Province	4	5	Cropland and orchard	5	5	5	80	1990
Non-living windbreaks	Lake Urmia basin (Ajab shir)	4.5	4	Cropland and dried bed of Urmia Lake	3	4	1	2 000	2016
Half-moon construction (a method of runoff management in arid lands)	Sistan and Baluchistan Province (Fanooj)	4	5	Rangeland	5	5	5	100	2017
Construction of earth dam	Hormozgan Province (Minab)	4	5	Floodplains, upstream of farmland	5	5	5	200	2010
Sowing on sand dunes	Khorasan Razavi Province	4	2.5	Sand dunes	3	4	3	10	1963

Source: Author's own elaboration

[1] An erg (also sand sea or dune sea or sand sheet if it lacks dunes) is a broad, flat area of desert covered with wind-swept sand with little or no vegetative cover.

Table A4.3. | Documented local knowledge to combat SDS in the Islamic Republic of Iran

Local knowledge	Implementing area	SLM (1–5)	Success rate (1–5)	Land-use type	Impacts on local rural economy (1–5)	Public participation (1–5)	Land-use planning (1–5)	Water and soil management (1–5)	Cost (USD/ha)
Bandsar	Hormuzgan province (Basta) and Khorasan Razavi Province (Sabzevar)	SLM based on local knowledge	5	Cropland	5	5	5	5	50
Hutak	Sistan va Baluchistan Province (Chabahar)		5	Flood farming (cropland)	5	5	5	5	100
Khooshab	Khorasan Razavi Province (Sabzevar)		5	Flood farming (cropland)	5	5	5	5	100
Muddy walls around orchards	Yazd Province (Abarkooh)	Side benefits Indirect effects	5	Orchards	2	5	5	4	100
Living windbreaks around farmland	South of Kerman Province (Roodbar)								
Establishing the palm orchards using flood irrigation	Bushehr Province (Dashti)		5	Orchards	5	5	5	5	4 000
Set up fence around farmland	Kerman Province (Rigan)		5	Farmland	2.5	5	2	2	20
Flood spreading	Sabzevar (Kalshoor)		4	Floodplains	4	5	4	5	8 500
Afforested arid lands	Isfahan Province (Aran va Bidgol)		5	Agroforestry	5	5	5	4	1 100

Source: Author's own elaboration

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