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188

Research Report

Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool

Giriraj Amarnath, Surajit Ghosh and Niranga Alahacoon

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IWMI Research Report 188

Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool

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Project

The Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool was created as part of the *Afghanistan Drought Early Warning System* project with funding from the World Bank under Grant no. 7195415. The AF-DEWS Tool is an online platform that was created with the aim of building consensus, increasing coordination and supporting decision-making in efforts to mitigate the impacts of drought in Afghanistan.

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Contents

Acronyms and Abbreviations

AF-DEWS	Afghanistan Drought Early Warning Decision Support
API	Application Programming Interface
ASCAT	Advanced Scatterometer
AVHRR	Advanced Very High Resolution Radiometer
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CYA	Crop Yield Anomaly
DEWC	Drought Early Warning Committee
ECI	Evaporative Condition Index
FAO	Food and Agriculture Organization of the United Nations
GCP	Google Cloud Platform
GEE	Google Earth Engine
GoIRA	Government of the Islamic Republic of Afghanistan
IDSI	Integrated Drought Severity Index
MAIL	Ministry of Agriculture, Irrigation and Livestock
MODIS	Moderate Resolution Imaging Spectroradiometer
PCC	Percent crop cover
PCI	Precipitation Condition Index
PSC	Percent snow cover
SPI	Standardized Precipitation Index
TCI	Temperature Condition Index
VCI	Vegetation Condition Index
VHI	Vegetation Health Index

Summary

The 2018 drought, the worst in a decade, prompted the Government of the Islamic Republic of Afghanistan (GoIRA) to find a way to respond better to drought and other drivers of food insecurity. Several consultations were held with the government, humanitarian and development communities, and civil society to discuss how to address food insecurity and famine risk in Afghanistan. As an outcome of these rigorous consultations, GoIRA initiated the Early Warning, Early Finance and Early Action (ENETAWF) project, funded by the World Bank, to support medium- to long-term drought resilience initiatives. The objectives of the project are given below:

- Strengthen weather and climate services to develop a drought early warning decision support system.
- Establish a mechanism to distribute assistance to chronically food-insecure people.
- Develop financial instruments capable of scaling up resources during extreme weather events, such as drought, that result in increased food insecurity.

The International Water Management Institute (IWMI) developed the Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool, a cloud-based online platform, to provide decision-makers with maps and data to enable further analysis. The system combines satellite-based Earth observation data with weather forecasting model outputs to provide the following services:

- Twenty-eight days of precipitation and temperature forecasts are updated weekly to guide future trends.
- Near real-time drought indicators, based on multisource remote sensing data, covering meteorological, agricultural and hydrological droughts with related thresholds to determine drought severity.
- Calculation of a single, comprehensive composite drought index to monitor agricultural drought and support decision-making.

Developing the AF-DEWS Tool

In the last decade, Earth observation satellites and global environmental models have generated a large volume of geospatial data that is freely available to science and society. To support the storage and processing of these datasets, novel technologies have been developed.

These mostly rely on cloud computing technology and distributed databases, with web services used to access and process the data. This means that anyone with a desktop computer and internet connection can access and process datasets that would previously have required expensive computing equipment with a large processing capability.

The AF-DEWS Tool is based on Google Earth Engine, a web-based, global-scale geospatial analysis platform. It hosts a vast array of raw satellite images and generated datasets that can be accessed via a simple user interface. Users can view and perform their analyses on the datasets.

Each of the drought indices incorporated in the system has a set of defined thresholds that, if exceeded, will automatically trigger warnings to the user. For example, if the level of precipitation drops below a threshold for the time of a year, an initial drought warning is given. If the level breaches further thresholds, warnings for moderate or severe drought will be triggered. Data from drought events recorded over 20 years of historical satellite data were used to determine the appropriate threshold levels for each index.

The system makes it easy to quickly draw comparisons between, for example, conditions in different years. The AF-DEWS Tool provides regular outlook forecasts that include visual evidence of the state of different parameters. These clearly highlight conditions of concern, such as minimal snow cover, low reservoir levels and poor vegetation growth in areas that are usually irrigated.

Using Outputs from the AF-DEWS Tool to Inform Action

When there is a requirement to forecast future climate shocks, Afghanistan's authorities can confidently use the AF-DEWS Tool to identify the occurrence and trajectory of drought through a series of steps.

During December, January and February, the rainfall and snowfall indices reveal potential surface water deficits that may affect water availability in the following cropping season. If signs indicate that drought is emerging, the next step is to confirm this by analyzing, between February and March, indicators of impact, such as crop cover and vegetation health.

If it becomes clear that drought is evolving to the extent that vegetation is affected, examining the Integrated Drought Severity Index (IDSI) for April and May will help authorities identify the precise impacts of drought on agriculture and thus better plan the response measures.

In summary, the AF-DEWS Tool provides easily accessible, sub-seasonal forecasts and near real-time drought monitoring information at both national and district levels. For effective use of the AF-DEWS Tool, it is crucial to ensure multi-institutional arrangements for early action to mitigate drought risks and address long-term impacts on development.

Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool

Giriraj Amarnath, Surajit Ghosh and Niranga Alahacoon

Introduction

Background

In 2018, Afghanistan suffered the worst drought in a decade. Reduced snowfall and water availability, coupled with high temperatures, caused widespread crop failures. With 78% of the population reliant on agriculture for their livelihoods (FAO 2018), this led to more than 13 million people becoming severely food insecure. The migration of large numbers of people from rural to urban areas increased the nation's already high poverty rate (Helgason 2020).

Afghanistan's lack of an objective, forecast-based response mechanism meant it had been unable to identify the onset of drought early on. As a result, the humanitarian response for those affected came six months after the drought started. Such reactive responses necessarily focus on saving lives, rather than on making communities more resilient to future drought. They also come at a higher cost to affected economies (Eckstein et al. 2021).

The 2018 drought prompted the Government of the Islamic Republic of Afghanistan (GoIRA) to find a way to respond better to drought and other drivers of food insecurity. A nine-month consultation was held with stakeholders in government, humanitarian and development communities, and civil society on how to address water scarcity, food security and famine risk in Afghanistan. This led to GoIRA initiating the Early Warning, Early Finance and Early Action (ENETAWF) project in February 2021.

An effective end-to-end drought early warning decision support system has the following four building blocks:

- Robust capabilities in weather and climate monitoring and forecasting to ensure environmental signals are detected early enough for people to mitigate the hazard.
- Well-run institutions with standard operating procedures and clear roles and responsibilities to activate appropriate mitigation measures once environmental signals are detected.
- Alert systems to inform potentially affected households.
- Community-level preparedness plans that tell people what they should do in the event of a drought.

GoIRA commissioned the development of the Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool[1] to fulfill the first two of the above building blocks. This report provides an overview of how the AF-DEWS Tool was developed and how it can be used to systematically monitor, detect and forecast drought conditions in Afghanistan. The tool is aimed at providing decision-makers with the information required to activate mitigation actions and response measures.

The AF-DEWS Tool was established in 2020 as an online platform. It combines near real-time satellite data with weather forecasts to provide three main services: (1) weekly updates of daily precipitation and temperature forecasts for four weeks to provide guidance on future trends; (2) near real-time drought indicators covering meteorological, agricultural and hydrological droughts, with related thresholds to determine drought severity using multisource remote sensing data; and (3) calculation of a single, comprehensive composite index, the Integrated Drought Severity Index (IDSI), to support drought decision-making (Amarnath et al. 2021). This cloud-based online platform implemented using Google Earth Engine (GEE) and Google Cloud Platform (GCP) provides decision-makers with quick and easy access to drought-related information. This includes an easy-to-understand map, which can be downscaled from national to district level, and the tools needed to easily download information for conducting drought analyses. Data covering the period from 2001 to 2020 are available in the AF-DEWS Tool, enabling the user to gain insights on past events and weather patterns.

Assessing risks and vulnerabilities, and improving drought preparedness can minimize threats and avoid expensive post-event relief efforts. An early warning system is also required to detect signs of a slow onset of drought with a sufficient lead time for local decision-makers to mitigate drought threats, for example, by arranging the provision of emergency food supplies, initiating water conservation programs or introducing improved dryland farming initiatives.

[1] http://af-dews.demo.iwmi.org:3000/ (accessed on November 2, 2023).

Objectives

The AF-DEWS Tool represents an initial stage in the establishment of an end-to-end drought early warning system in Afghanistan. The objective is to use weather forecasts and near real-time meteorological and environmental data – based on satellite datasets and field observations – to provide decision-makers with accessible and objective information on the current status and future prediction of drought conditions in the country. Providing timely, comprehensive and geographically explicit information facilitates the targeting of alerts and warning messages to affected communities, and the triggering of appropriate response measures from the relevant agencies. A critical step in establishing a sound early warning platform is to strengthen the capacity of hydrometeorological (hydromet) agencies in Afghanistan towards providing modern and high-quality services to their user groups. The AF-DEWS Tool provides these agencies with access to ready-to-use remote sensing datasets covering the entire country and to regional forecast modelling. In doing so, it is helping to address limitations imposed by the country's scarce network of surface weather observatories.

Another important aspect of an early warning system is the institutional mechanism responsible for drought monitoring, declaring emergency conditions, and activating effective response actions in affected areas. In Afghanistan, while the legal framework and mandate for disaster declaration exist, the processes to support them are unclear. For example, there are many overlapping and fragmented responsibilities among entities mandated to take action before, during and after a drought event. There is, therefore, a critical need to put in place predetermined processes and standard operating procedures to ensure that response measures are timely and triggered based on evidence. The development of the AF-DEWS Tool will help to overcome the limited coordination among key relevant institutions.

Drought Monitoring and Early Warning using Satellite Remote Sensing

Drought in Afghanistan

Drought is a recurring phenomenon in Afghanistan, with at least one area affected almost every year since 1997, and two or three widespread droughts having occurred every 10 years for the past half century (FAO 2019). As shown in Figure 1, 22 out of the 34 provinces are chronically prone to droughts, with the northern plains and southern plateau having particularly high drought frequency (Qutbudin et al. 2019). Table 1 provides a summary of major drought events in Afghanistan. The worst event, in 2018, affected more than 13.5 million people. In recent years, drought has occurred more frequently.

Agroecological Region and Climatic Condition

The landscape of Afghanistan is characterized by high mountains with snow-covered peaks, fertile valleys and desert plains. The fertile lowland valleys and desert plains are located in the northern, western, southwestern and southeastern areas, while the highlands are located in the central, eastern and northeastern parts of the country. The total area of the country is 652,230 km^2, with a population of 34.9 million.

Agricultural lands represent 58% of the country's geographical area, with most areas designated as permanent pastures (48%), leaving only 11.8% as arable land (CIA 2019). Total arable land is 6.5 million hectares (Mha), of which 3.1 Mha is irrigated, and 3.4 Mha is under rainfed conditions (FAO 2016). The types of agriculture by province are summarized in Table 2. Wheat, rice, barley and maize are the main cereal crops grown in the country, with wheat accounting for 80.2% of total cereal production. Thus, wheat is the most important crop for the food security of the country (Chabot and Dorosh 2007). Agricultural production contributes to food security in Afghanistan and is largely dependent on irrigated farming, mostly utilizing surface water fed by snowmelt (Pervez et al. 2014).

Irrigated areas are generally found throughout Afghanistan, especially along floodplains of rivers. However, their greatest concentrations are in the lowlands of the northern, western and southwestern parts of the country. Because of the high contribution of irrigated crops (> 80%) to total agricultural production, knowing the spatial distribution and year-to-year variability in irrigated areas is imperative to monitoring food security for the country.

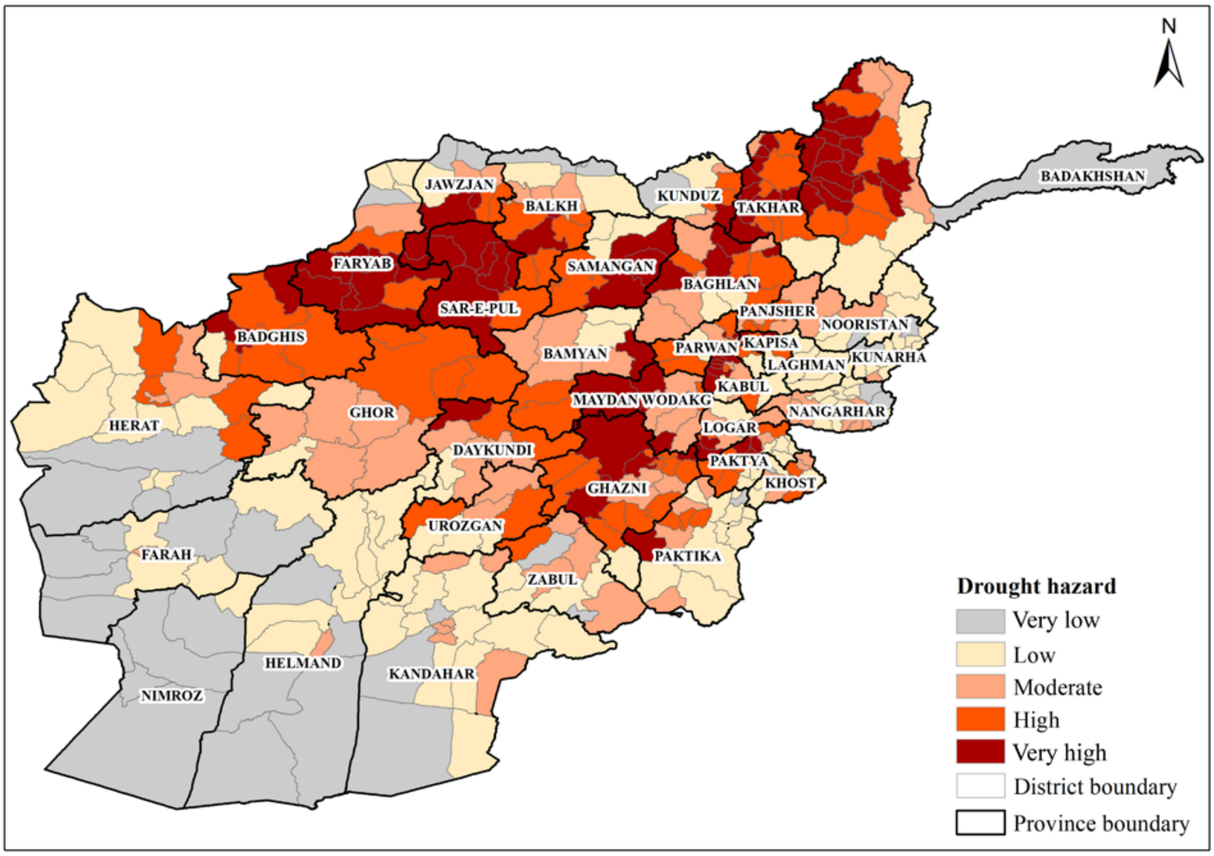


Figure 1. Drought hazard map derived using the composite Integrated Drought Severity Index (2001–2019).

Table 1. Summary of major drought events in Afghanistan.

Year	Province	Affected population	Total damages (USD '000)
1969	Pakteka province	48,000	200
1971	Central, Northwest, Northeast, West regions		
2000	Kandahar, Hilmand, Nimroz, Zabul, Uruzgan provinces (southwest), Hirat, Farah, Badghes provinces (west), Pakteka, Khost, Ghazni provinces (south), Baghlan, Kunduz, Takhar, Badakhshan provinces (northeast)	2,580,000	50
2006	Badakhshan, Badghes, Baghlan, Balkh, Bamyan, Daykundi, Faryab, Ghor, Jawzjan, Kunduz, Samangan, Sar-e-Pul, Takhar, Uruzgan provinces	1,900,000	
2008	Kunduz, Balkh, Faryab, Badghes provinces	280,000	
2011	Balkh, Samangan, Takhar, Sar-e-Pul, Hirat, Badghes, Faryab, Jawzjan, Baghlan, Kunduz, Badakshan, Bamyan, Daykundi, Ghor provinces	1,750,000	142,000
2018	Badghes, Daykundi, Hirat, Ghor, Daykundi, Badakhshan, Farah, Helmand, Kandahar, Zabul, Nangarhar	13,500,000	

Data source: EM-DAT The International Disaster Database (https://www.emdat.be/ - accessed on November 30, 2020).

Table 2. Land use statistics on major agricultural systems in Afghanistan.

Province	Irrigated area (%)	Rainfed area (%)	Rangeland area (%)	Irrigated and rainfed area (%)	Area (km²)
Badakhshan	1.15	6.58	56.66	7.73	43,391
Badghes	2.75	16.53	69.88	19.28	18,773
Baghlan	5.88	9.71	61.12	15.6	17,059
Balkh	15.33	15.58	21.92	30.92	17,486
Bamyan	3.39	0.87	79.59	4.26	18,023
Daykundi	3.86	0.6	67.19	4.46	13,650
Farah	5.31	0	11.39	5.32	39,373
Faryab	6.03	19.01	47	25.05	22,674
Ghazni	11.19	2.32	63.43	13.51	21,532
Ghor	1.7	2.64	84.18	4.35	38,972
Hilmand	5.24	0.66	8.61	5.91	59,988
Hirat	4.4	8.5	20.34	12.9	65,490
Jawzjan	16.74	8.41	12.72	25.15	8,745
Kabul	14.52	1.28	49.54	15.8	4,684
Kandahar	5.54	2.48	8.35	8.02	55,584
Kapisa	12.2	0.8	66.7	13	1,878
Khost	12.45	0.55	49.51	13	4,105
Kunarha	6.08	0.36	25.89	6.44	4,217
Kunduz	19.35	11.25	7.83	30.6	7,856
Laghman	5.65	0.02	37.44	5.66	3,898
Logar	10.11	3.65	45.25	13.76	4,368
Maydanwardag	5.88	1.95	75.89	7.83	10,791
Nangarhar	14.52	0.2	27.07	14.73	7,371
Nemroz	1.8	0	3.87	1.8	40,853
Noristan	0.79	0.06	61.14	0.85	9,578
Pakteka	7.37	0.63	49.42	8	18,857
Paktya	12.3	1.22	57.39	13.52	5,462
Panjsher	2.49	0.21	84.71	2.7	3,740
Parwan	6.39	2	66.99	8.39	5,577
Samangan	1.97	21.08	60.26	23.05	13,445
Sar-e-Pul	3.55	20.9	68.56	24.45	14,986
Takhar	6.94	34.15	38.96	41.09	12,414
Uruzgan	3.12	0.87	66.93	3.99	13,076
Zabul	7.73	0.56	44.57	8.3	15,833

Sources: Ministry of Agriculture, Irrigation and Livestock/Food and Agriculture Organization of the United Nations [FAO]).

The annual average precipitation in Afghanistan varies between 50 mm in the southwest to over 1,000 mm in the east (Aich et al. 2017). The lowland plains in the south of Afghanistan experience extreme seasonal variations in temperature, from an average winter (December to February) low of 10 °C to more than 33 °C in the summer (June to August). Also, the annual potential evapotranspiration is about six times higher than the annual average precipitation, implying that the direct recharge of precipitation to groundwater is likely to be extremely low (Banks and Soldal 2002; Reeling et al. 2012). As a result, 55–70% of total cultivated land is irrigated for successful production (Qureshi 2002; Tiwari et al. 2020), and 85% of that irrigation comes from surface water, mostly in the form of snowmelt (Pervez et al. 2014).

Crop calendars, such as the one presented in Figure 2, provide information on the sowing, growing and harvesting stages of crops. When assessing drought impacts, they are helpful, as they identify key growth periods when drought impacts are likely to be greatest. This is important when using satellite remote sensing data and weather forecast information. Broad crop calendars for major crops were provided by the Ministry of Agriculture, Irrigation and Livestock (MAIL); because of climatic variability and other factors, there can be a shift in the timing of sowing and harvesting of wheat over the years.

Drought Type and Definition

Drought can be defined as a long shortage of surface water and groundwater resources resulting from below

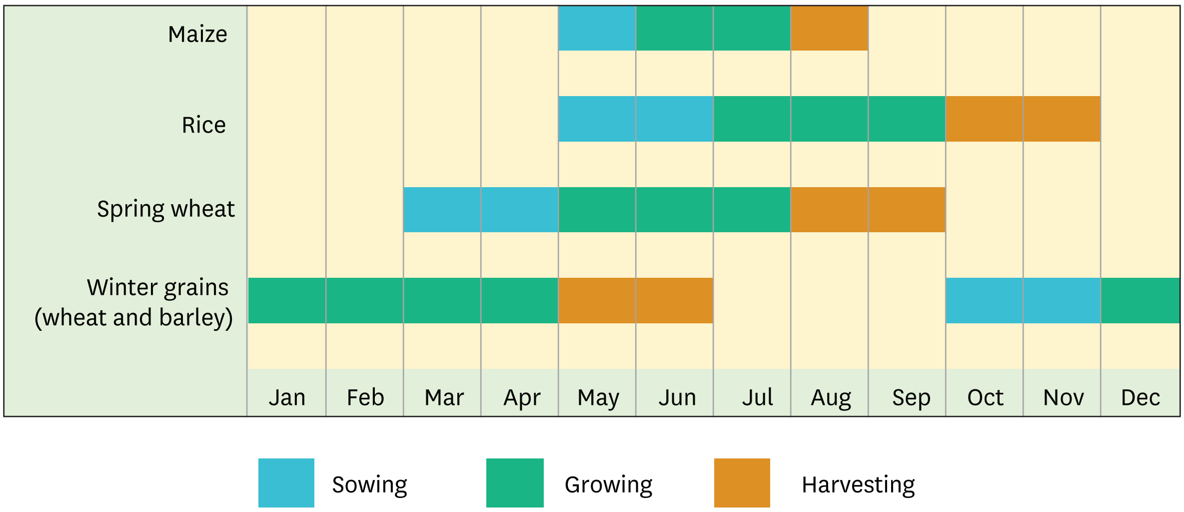


Figure 2. Crop calendar for Afghanistan.
Source: https://ipad.fas.usda.gov/countrysummary/default.aspx?id=AF (accessed on October 26, 2022).

average precipitation. Drought can last for months and years, and can even be detected after 15 days. Drought challenges the regional ecosystem and agriculture and brings the local and national economies under serious risk.

The following types of drought are recognized:

- Meteorological drought: Deviation from the average precipitation (rainfall/snowfall). It is usually calculated taking into account the degree of dryness and the duration of the dry period (resulting from below-average precipitation).

- Agricultural drought: Deviation in vegetation health and crop production. It is calculated by measuring the amount of moisture in the soil, and the state of vegetation and yield.

- Hydrological drought: Deviation from the average level of surface water and groundwater. It is calculated as the decrease in water level below an established statistical average level in rivers, lakes, reservoirs and aquifers.

- Socioeconomic drought: Induced by a combination of meteorological, agricultural and hydrological drought. Socioeconomic drought is calculated using changes in economic levels (assets, income flows, poverty levels) and social factors (out-migration, adverse coping strategies).

The Importance of Early Warning

In several countries, the availability of reliable data to monitor and predict drought situations is not always sufficient (Pozzi et al. 2013). With the advent of Earth observation (EO) data and atmospheric models, remote sensing techniques, combined and verified with surface observations, made the monitoring and provision of early warning information to various stakeholders possible.

An effective end-to-end drought early warning decision support system has four building blocks. First, strengthening capacities and capabilities in weather and climate monitoring and forecasting is vital to ensure that environmental signals can be detected sufficiently early for people to take action to mitigate the hazard. Second, institutions must be prepared to activate and enact appropriate mitigation measures once environmental signals are detected. These include issuing an early warning, releasing assistance to affected households and providing targeted advisory services. Therefore, an enabling institutional setting, encompassing standard operating procedures and clear roles and responsibilities, is essential. Third, potentially affected households must be informed. This means that dissemination mechanisms, capable of alerting all relevant people of the forthcoming risk, are critical. Fourth, People must be aware of what to do in the event of an anticipated disaster or shock, such as drought. Therefore, preparedness at the community level is key to reducing disaster impacts.

Remote Sensing and Drought Monitoring

Recent technological advances in EO satellite data have helped to address the complexities of decision making around environmental issues. EO-based satellite datasets provide the opportunity for near real-time drought monitoring across a time period of two to three decades using satellite missions, such as National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua, Landsat, and European Space Agency (ESA) Copernicus. These large data sources can help in mapping and characterizing the onset, progression, extent and severity of drought over both space and time (Kogan 1997). Several indicators are relevant for monitoring and assessing drought using satellite data. These include rainfall, vegetation condition, soil moisture, evapotranspiration and many more. The presence of drought is made apparent through the reduction of different indicator values at specific times during the crop season and may continue for more than one season.

The use of remote sensing data to monitor and evaluate drought conditions over space and time is well established. Most of the indices used are based on long-term atmospheric and vegetation information (Martínez-Fernández et al. 2015; Cao et al. 2019), and include the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Precipitation Condition Index (PCI) (Hao et al. 2015) and Soil Moisture Condition Index (SMCI) (Kogan 1995; Bhuiyan et al. 2006). Based on the relationship between vegetation indices and Land Surface Temperature (LST), additional indices were developed to assess agricultural drought. These include the Temperature Vegetation Dryness Index (TVDI) (Sandholt et al. 2002) and Vegetation Supply Water Index (VSWI) (Rebel et al. 2012). Meanwhile, indices such as the Vegetation Health Index (VHI) (Kogan 1997) have been developed by combining VCI and TCI using a linear weighted method. Other helpful composite indices are the Composite Drought Index (CDI), which uses indicators such as precipitation, evapotranspiration and land surface temperature, and the Surface Water Supply Index (SWSI), which combines information on precipitation, streamflow, snow cover and storage.

Multiple indices derived from various indicator combinations have been used to quantify and understand drought in different parts of the world. However, because drought is caused by many drivers, such as precipitation, soil moisture and evapotranspiration, it is important to consider indicators for each of these relevant processes where datasets are available (Goodwell et al. 2018; Alahacoon and Edirisinghe 2022). The majority of existing drought monitoring programs rely on just one or two indicators, a limited approach that can undermine the accuracy of drought prediction. Considering the complexity of drought, the best approach is to use multiple indicators and composite indices across the season to ensure end users can accurately characterize the extent and severity of drought (Amarnath et al. 2019). This will help to underpin the early warning process and drought preparedness and mitigation measures.

Selection of Drought Indicators to Define the Types of Drought

The following section provides details of the satellite indices that are currently included in the AF-DEWS Tool. The aim is to explain the use of, and parameters monitored by, each index.

Monitoring Different Types of Drought (Meteorological, Agricultural, Hydrological and Socioeconomic)

The parameters utilized by the AF-DEWS Tool to monitor droughts rely on near real-time satellite remote sensing techniques. Satellite-based remote sensing of environmental parameters has been widely adopted globally due to its extensive spatial coverage, and regular return periods allow for the frequent monitoring of large swathes of land. Different parameters are useful in assessing the onset and magnitude of the different types of drought:

- Meteorological drought – rainfall anomaly, duration of dry spells.
- Agricultural drought – progression of sowing, vegetation health anomalies, vegetation density, vegetation growth, soil moisture content.
- Hydrological drought – levels of lakes and reservoirs, snow cover, streamflow and groundwater level.
- Socioeconomic drought – water storage resilience, inflow-demand reliability.

Of the various drought-related indices, each has its advantages and limitations when it comes to evaluating drought. The Standardized Precipitation Index (SPI) (McKee et al. 1993) is simple for monitoring meteorological drought, relying solely on precipitation data. The Moisture Adequacy Index (MAI) measures the ratio of actual and potential evapotranspiration (Thornthwaite and Mather 1955). The Consecutive Dry Days (CDD) index (Nastos and Zerefos 2009) uses threshold values of specific rainfall units to characterize the type of drought and its severity. Similarly, for hydrological and agricultural droughts, indices such as Streamflow Drought Index (SDI), Land Surface Water Index (LSWI), Snow Condition Index (SCI), Vegetation Health Index (VHI) and IDSI (Amarnath et al. 2021) are widely used.

The parameters available in the AF-DEWS Tool for monitoring the different types of drought are summarized in Table 3, together with basic information on the source of data, temporal resolution, data period, and spatial and temporal resolution.

Table 3. Summary of the indices available to monitor the different types of drought in the AF-DEWS Tool.

Category	Index	Datasets	Data period	Spatial and temporal resolution	Temporal resolution	Source
Meteorological drought	Precipitation	CHIRPS	1981–2022	5 km	Daily	GEE[a]
	Precipitation anomaly	CHIRPS	1981–2022	5 km	Daily	-Do-
	Dry spell	CHIRPS	1981–2022	5 km	Daily	-Do-
	Standardized Precipitation Index (SPI)	CHIRPS	1981–2022	5 km	Daily	-Do-
	Precipitation Condition Index (PCI)	MODIS	2001–2022	500 m	Daily	GEE[b]
Agricultural drought	Normalized Difference Vegetation Index (NDVI)	MODIS	2001–2022	500 m	Daily	GEE[c]
	NDVI monthly anomaly	MODIS	2001–2022	500 m	16 Day	GEE[d]
	Vegetation Condition Index (VCI)	MODIS	2001–2022	500 m	Daily	GEE[e]
	Temperature Condition Index (TCI)	MODIS	2001–2022	500 m	8 Day	GEE[f]
	Vegetation Health Index (VHI)	MODIS	2001–2022	500 m	Daily	GEE[g] GEE[h]
	Moisture Adequacy Index (MAI)	MODIS	2001–2022	500 m	8 Day	GEE[i]
	Soil Moisture Condition Index (SMCI)	FLDAS, SMAP	2001–2022	10 km	10 day	GEE[j, k]
	Soil Water Anomaly Drought Index (SWADI)	ASCAT	2001–2022	10 km	10 day	Google Cloud Storage
	Integrated Drought Severity Index (IDSI)	MODIS, FLDAS and CHIRPS	2001–2022	250 m	8 day	GEE and IWMI

Continued›

Table 3. Summary of the indices available to monitor the different types of drought in the AF-DEWS Tool. (Continued)

Category	Index	Datasets	Data period	Spatial and temporal resolution	Temporal resolution	Source
Hydrological drought	Snow cover	MODIS	2001–2022	500 m	Daily	GEE[l]
	Snow cover anomaly	MODIS	2001–2022	500 m	Daily	GEE[m]
	Normalized Difference Water Index (NDWI)	MODIS	2001–2022	500 m	Daily	GEE[n]
	Streamflow Drought Index (SDI)	Observed data	2001–2019	Station wise	Daily	-
	Surface Water Supply Index (SWSI)	Observed + satellite data	2001–2019	Station wise	Daily	GEE
Drought impact	Gross Primary Productivity (GPP)	MODIS	2001–2022	500 m	8 day	GEE[o]
	Drought hazard	MODIS	2001–2019	500 m	-	GEE Asset
	Drought exposure	WorldPop	2018	100 m	-	GEE Asset

Sources:

[a] https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_DAILY

[b] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13A1

[c] https://developers.google.com/earth-engine/datasets/catalog/MODIS_MOD09GA_006_NDVI

[d] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13A1

[e] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13A1

[f] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD11A2

[g] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13A1

[h] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD11A2

[i] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD16A2

[j] https://developers.google.com/earth-engine/datasets/catalog/NASA_USDA_HSL_SMAP_soil_moisture

[k] https://developers.google.com/earth-engine/datasets/catalog/NASA_FLDAS_NOAH01_C_GL_M_V001

[l] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD10A1

[m] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD10A1

[n] https://developers.google.com/earth-engine/datasets/catalog/MODIS_MOD09GA_006_NDWI

[o] https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD17A2H

Notes: CHIRPS - Climate Hazards Group InfraRed Precipitation with Station data; FLDAS - Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System; SMAP – Soil Moisture Active Passive; IWMI – International Water Management Institute; ASCAT – Advanced Scatterometer; NDWI – Normalized Difference Water Index.

Seasonal Weather Forecasts for Drought Early Warning

In addition to indices to monitor the different types of drought in near real-time, the AF-DEWS Tool includes a weather forecast component. Extended range forecasts[2] are made available by the India Meteorological Department (IMD) through the Ensemble Prediction System (EPS) model. This is based on the Climate Forecast System Version 2 (CFSv2) model (Chattopadhyay et al. 2018). The forecasts, automatically incorporated into the AF-DEWS Tool, include precipitation and minimum/maximum temperature. IMD provides rainfall and temperature datasets with a lead time of 31 days and a spatial resolution of 0.5 degrees.

A brief description of the datasets used for the weather forecast component of the AF-DEWS Tool is described in Table 4.

[2] Defined by the World Meteorological Organization (WMO) as: short range (from 12 hours to 72 hours); medium range (from 72 hours to 240 hours); extended range (from 10 days to 30 days); long range (from 30 days to 2 years), including seasonal outlook (loosely defined as a three-month period in the northern hemisphere, but varying in the tropical areas) - https://www.ecmwf.int/en/forecasts/documentation-and-support/extended-range-forecasts (accessed on November 9, 2022).

Table 4. Summary of the extended range forecast parameters obtained from the Extended Range Prediction and Analysis System (ERPAS) which are made available in the AF-DEWS Tool.

Category	Index	Datasets	Data period	Spatial resolution	Temporal resolution	Source
Weather forecasts	Precipitation	ERPAS	2020 – To date	50 km	Daily	IMD
	Maximum temperature	ERPAS	2020 – To date	100 km	Daily	IMD
	Minimum temperature	ERPAS	2020 – To date	100 km	Daily	IMD

Meteorological Drought

Meteorological drought is defined as a deficiency of precipitation over a certain period (Stagge et al. 2015). As such, it is measured as the anomaly (or deviation) relative to what would be expected over the period (norm). Meteorological drought is usually initiated by a long dry spell – defined by the World Meteorological Organization (WMO) as a period of abnormally dry weather lasting for at least five days with daily precipitation less than 1 mm (Huang et al. 2015; Baig et al. 2020).

Within the AF-DEWS Tool, several indices are included for the Afghanistan Meteorological Department (AMD) to track meteorological drought:

(i) Average daily temperature (T).

(ii) Average daily precipitation (P).

(iii) Precipitation anomaly: percentage of normal precipitation over a certain period.

(iv) Temperature anomaly: percentage of normal temperature over a certain period.

(v) Dry spell: duration of abnormally dry weather lasting for at least five days with daily precipitation less than 1 mm (as per Nastos and Zerefos 2009).

(vi) Standardized Precipitation Index (SPI): widely used to characterize meteorological drought on a range of timescales. It quantifies observed precipitation as a standardized departure from a selected probability distribution function of precipitation.

(vii) Precipitation Condition Index (PCI): used to normalize precipitation data over a certain period. Under meteorological drought conditions, the value of PCI is close to 0 (zero), while under wet conditions, the value of PCI is close to 1.

(viii) Temperature Condition Index (TCI): used to determine the stress on vegetation caused by temperature and excessive wetness. Conditions are estimated relative to the maximum and minimum temperatures and modified to reflect different vegetation responses to temperature.

Agricultural Drought

Soil moisture content and plant growth are commonly used to determine agricultural drought, along with secondary parameters such as precipitation and/or evapotranspiration (Feng et al. 2019; Modanesi et al. 2020). The following indices for monitoring plant growth and vegetation conditions are included in the AF-DEWS Tool:

(i) Normalized Difference Vegetation Index (NDVI) and NDVI anomaly: NDVI quantifies vegetation density and health. The NDVI anomaly captures the state of vegetated areas relative to average conditions for a specific time range (16 days or more).

(ii) Enhanced Vegetation Index (EVI) and EVI anomaly: similar to NDVI, EVI can be used to quantify vegetation greenness (density and health). However, EVI corrects for some atmospheric conditions and canopy background noise, and is more sensitive in areas with dense vegetation. The EVI anomaly captures the state of vegetated areas relative to average conditions for a specific range of time (16 days or more).

(iii) Vegetation Condition Index (VCI): this facilitates monitoring vegetation vigor versus climatic variations. The range of VCI is 0–1, reflecting changes in vegetation conditions from the most unfavorable to the conditions for optimal growth.

(iv) Vegetation Health Index (VHI): assesses the state of vegetation. It is often used to monitor and identify the impacts of agricultural drought.

(v) Moisture Adequacy Index (MAI): provides information on the moisture status of the soil relative to plant water needs. It is calculated as the ratio of actual evapotranspiration to potential evapotranspiration.

(vi) Soil Moisture Condition Index (SMCI): quantifies the moisture within the uppermost soil layer. The index values range from 0 to 1, with 0 indicating extreme dry conditions and 1 indicating extreme wet conditions.

(vii) Soil Water Anomaly Drought Index (SWADI): assesses the moisture of the soil against the long-term average.

(viii) Evaporative Condition Index (ECI): based on the current evaporation condition, with reference to historical condition. Actual evapotranspiration (ET) figures were used to calculate the ECI.

(ix) Integrated Drought Severity Index (IDSI): this composite index uses multiple indicators – precipitation (input to the system), soil moisture (storage within the system), actual ET (loss from the system) and VCI (vegetative response of the system). IDSI overcomes the drawback of using a single indicator/index to define drought and is reliable for assessing the impacts of agricultural drought.

(x) Percent crop cover (PCC): this drought indicator uses NDVI with a specific threshold to map the current vegetation extent.

Hydrological Drought

Over a prolonged period, meteorological drought affects surface and subsurface water supply, reducing streamflow, snow cover, groundwater, and reservoir and lake levels (Van Loon 2015). This leads to a hydrological drought that can persist long after the meteorological drought has ended. Several indices are aimed at comprehensively characterizing drought impacts on the hydrological cycle. Each of these indices requires different variables as input data for their formulas. The hydrological drought indices included in the AF-DEWS Tool are given below:

(i) Snow cover (and anomaly): represents the area covered by snow during a specific period and its difference from the long-term norm.

(ii) Snow Condition Index (SCI): used to normalize snow cover over a certain period. The SCI varies from 0 (zero) to 1, reflecting changes in the fraction of snow cover from extremely low to very high.

(iii) Normalized Difference Water Index (NDWI): estimates the leaf water content at canopy level, so is sensitive to drought conditions affecting plant vegetative processes.

(iv) Land Surface Water Index (LSWI) and Modified Land Surface Water Index (MLSWI): Very similar to the NDWI methodology, but uses two shortwave-infrared channels to monitor the water content within the vegetation canopy. Changes observed in the vegetation canopy help to identify periods of drought stress.

Socioeconomic drought

Socioeconomic drought evaluates the impacts of drought (meteorological, agricultural and hydrological) on the supply and demand of economic goods such as fruits, vegetables, grains and meat (WMO 2021). Socioeconomic drought occurs when the demand for a particular commodity exceeds supply as a result of a weather-related deficit in the water resource (Zisopoulou and Panagoulia 2021). The AF-DEWS Tool incorporates some indices for assessing socioeconomic drought, including the following:

(i) Gross Primary Productivity (GPP): this index measures changes in plant productivity, which is directly related to water availability. This index is derived from MODIS satellite data, which are available at the global level. It provides an eight-day mean GPP at 1 km spatial resolution for the whole of Afghanistan. The index was used in the development of the AF-DEWS Tool to validate the IDSI and identify drought years between 2001 and 2019.

(ii) Drought hazard: IDSI was used to identify drought years and quantify the severity between 2001 and 2019, with a view to developing a drought hazard map for Afghanistan. The map was prepared by overlaying each of the eight-day IDSI maps showing areas severely affected by drought. Seasonal to annual drought hazard maps are available in the AF-DEWS Tool.

(iii) Drought exposure: based on the Oak Ridge National Laboratory LandScan dataset. This is an estimate for global population distribution data, covering Afghanistan with a 1 km spatial resolution. This index is fundamental to readily estimating the number of people affected by a drought event across a particular at-risk district or region.

Key Indicators and Thresholds

This section provides an overview of the correlation between different meteorological and agricultural indices and agricultural yield, as provided by GoIRA through the National Statistics and Information Authority (NSIA) yearbook. Relating data from satellite-based indices to agricultural productivity is important as it can be used to forecast where people may become food insecure – for directing relief efforts as well as informing import requirements. Statistical metrics were used to evaluate how different indicators correlate with crop yield. This correlation has been used to (1) identify which index performs better, and (2) define precise thresholds to identify drought conditions (and their different levels of severity). Importantly, the choice of indicators/ indices is based on the specific characteristics of droughts most closely associated with the impacts of concern to the stakeholders.

The Pearson correlation coefficient (R) between various drought indices (3-month SPI - precipitation over a specific 3-month period, PCC, VHI and IDSI) and yield was tested. This exercise allowed the definition of a selection of indices to be used preferably to identify and monitor different types of drought (meteorological, agricultural and hydrological). These indices, defined as key indicators, have been selected because of their statistical performance in identifying past drought events, as revealed in the analyses conducted by IWMI and provided in Table 1.

To define drought thresholds, cumulative distribution functions were used. The cumulative distribution function (CDF) describes the probability that a continuous random variable, with a given probability distribution, will be found at a value less than or equal to a given value. Thus, the median value from the CDF will be 50% and the probability will not exceed a threshold value.

The probabilities and percentiles are interpreted as follows:

- The probability of a drought indicator value falling below z_1 is p_1. If the occurrence of this event represents an extreme drought, then the threshold value for an extreme drought is z_1, and the return period for an extreme drought is 1 in ($1/p_1$). For example, if p_1 is 0.05, then the return period for an extreme drought is one in 20 years.

- The probability of an indicator value falling between z_1 and z_2 is (p_2-p_1). If the occurrence of this event represents a very severe drought, then the thresholds for a very severe drought are z_1 and z_2, and the return period for a very severe drought is one in ($1/(p_2-p_1)$). For example, if p_1 and p_2 are 0.05 and 0.15, respectively, then the return period for a very severe drought is one in 10 years.

- The probability of an indicator value falling between z_2 and z_3 is (p_3-p_2). If the occurrence of this event represents a very severe drought, then the thresholds for a very severe drought are z_2 and z_3, and the return period for a moderate drought is one in ($1/(p_3-p_2)$). For example, if p_2 and p_3 are 0.15 and 0.35, respectively, then the return period for a moderate drought is one in 5 years.

- The probability of a drought indicator falling above z_3 is ($1-p_3$). If this represents an extremely wet year, then the threshold for an extremely wet year is when the drought indicator values fall above z_3, and the return period is one in ($1/(1-p_3)$) years. For example, if p_3 is 0.95, then the return period of an extremely wet year is one in 20 years.

The drought thresholds for 3-month SPI, PCC, VHI and IDSI based on the estimated CDF are given in Annex 1.

Determination of Drought

Having explained how drought indices were selected and drought thresholds were determined, this section explains the procedure used to quantify the presence and severity of drought for a specific month within a given year. The user will regularly monitor the weather forecasts, and follow how the crop season progresses as the wet season begins in October. As previously explained, the complexity of drought cannot be captured using just a single indicator or index from a specific month, but requires a more comprehensive understanding of various drought parameters, and supporting field inputs from the relevant agencies (Jiao et al. 2021). Table 5 provides a simple matrix for assessment of drought.

Steps in the Determination of Drought

The following steps are suggested for determining drought:

Step 1: The 'Mandatory Indices', namely SPI or snow cover, first evaluate whether the drought trigger has been set off. For example, if 3-month SPI for a specific district or province has values below -1.73 for December, this will indicate that an extreme drought is occurring. Similarly, other values will indicate different outcomes. In addition to SPI and snow cover, indices for rainfall deficit and dry spells can also be used to help determine the presence of meteorological drought. The monitoring of SPI or snow cover should continue during the entire wet season (December to April) to continuously capture the evolving meteorological conditions and, eventually, drought status.

Step 2: If the first drought trigger is set off during step 1, the 'Impact Indices' (PCC, VHI and IDSI) should be examined to assess the severity of the drought, potential impacts and required actions. The relevant agencies should consider any three of the five types of impact indicators.

Table 5. Steps for determining drought.

Monitoring period	Key variable	Indicator/indices	Thresholds		Use of the indicator
December-April	Rainfall (Met)	Standardized Precipitation Index (SPI)	≤ 1.73 -1.73 to -1.20 -1.20 to -0.68 > -0.68	ED SD MD No drought	Early Warning (December)
January-February	Snow cover (Hydro)	Percent snow cover (PSC)	< 5% 5% - 10% 10% - 15% > 15%	ED SD MD No drought	Early Warning (January)
January-April	Agri cover (Agri)	Percent crop cover (PCC)	< 5% 5 - 10% 10 - 15% > 15%	ED SD MD No drought	Early Warning (February)
February-April	Vegetation condition (Agri.)	Vegetation Health Index (VHI)	< 20% 20 - 30% 30 - 40% > 40%	ED SD MD No drought	Validate and assess agricultural drought (March)
April-May	Composite index	Integrated Drought Severity Index (IDSI)	< 20% 20 - 25% 25 - 30% > 30%	ED SD MD No drought	Initiate Early Action and Early Finance mechanisms (April)

Note: ED - Extreme drought; SD - Severe drought; MD - Moderate drought.

Rule-based Drought Declaration

The step-by-step procedure for monitoring indicators and determining whether to issue a drought declaration either at the national or provincial level is given below.

- The first step is to look at the Mandatory Indices – SPI and snow cover – for December, January and February to determine if meteorological or hydrological droughts are occurring. The SPI or snow cover monitoring should continue during the entire wet season (December to April) to continuously capture the evolving meteorological conditions and, eventually, drought status.

- If a drought is identified, the second step is to look at two or three impact indices/indicators – such as crop cover and vegetation health. Given the seasonal growth patterns, indices of agricultural drought such as crop cover and vegetation health (i.e., VHI, NDVI, etc.) should be monitored from February/March onwards because vegetation is dormant in most of the country (winter vegetation pause) prior to that. Impact indices will, therefore, be used to assess whether an agricultural drought is emerging and, if so, to determine the severity.

- The third step is to look at the districts that are critically affected by drought using the IDSI composite index for April and May to define the overall drought impacts.

- Drawing on data showing historical variation in drought conditions and the deviation of indices from the norm (recognized in district/province-level triggers), a drought bulletin can now be prepared giving early warning and to initiate preparedness measures.

- If at least two of the impact indices are in the 'extreme' category, this indicates the presence of an 'extreme drought'; if two of the three chosen impact indices are in the 'moderate' or 'severe' classes, this signifies a moderate or severe drought, respectively.

- The drought bulletin should be circulated for a rapid 'ground-truthing' survey at the provincial level to validate the drought severity.

Once the severity levels of drought are determined through these processes, a Drought Declaration Report can be produced by high-level policymakers.

Threshold Classification for Key Drought Indices

A threshold classification for five drought indices was developed by analyzing the frequency distribution of drought over 20 years throughout the country. Based on the CDF analysis (Annex 1), thresholds for the drought indices were set and classified into four classes. Three classes identify the different intensities of drought as '*extreme*', '*severe*' and '*moderate*' while the remaining class signifies '*no drought*'. The individual drought classes are illustrated in Table 6.

Table 6. Thresholds for key drought indices and their classification into four drought classes - ED - extreme drought, SD - severe drought, MD - moderate drought and ND - no drought.

Indicator/ indices	Drought category	Explanation and its possible impact	Drought intensity
Standardized Precipitation Index (SPI)	ED	Extremely dry conditions due to the lack of rainfall over several months	1 in 20 years Meteorological drought
	SD	Severe dry conditions due to the lack of rainfall over several months	1 in 10 years Meteorological drought
	MD	Moderately dry conditions with below average rainfall during the rainy season	1 in 5 years Meteorological drought
	ND	Good rainfall explains healthy vegetation condition	No drought
Percent Snow Cover (PSC)	ED	Extreme drought due to the lack of snow cover accumulation over several months, impacting agriculture, energy and livelihoods	1 in 20 years Hydrological drought
	SD	Severe drought due to the lack of snow cover accumulation over several months with widespread impacts across agricultural systems	1 in 10 years Hydrological drought
	MD	Moderate drought impact on the rainfed or rangeland areas due to a shortage in snow cover	1 in 5 years Hydrological drought
	ND	Good snow cover accumulation explains available soil moisture and healthy vegetation condition	No drought
Percent Crop Cover (PCC)	ED	With the lack of rainfall and snow cover over several months, there is an exceptional impact on the agricultural area, which will result in food insecurity among smallholder farmers and fodder shortages	1 in 20 years Agricultural drought
	SD	Major crop/pasture losses with widespread water shortages or restrictions	1 in 10 years Agricultural drought
	MD	Certain crop or pasture areas will have a lack of water availability or stress due to an unseasonal reduction in rainfall or snow cover	1 in 5 years Agricultural drought
	ND	Good crop cover explains an optimal condition which results in healthy crop production and increased incomes among smallholder farmers	No drought
Vegetation Health Index (VHI)	**ED**	Abnormal dry conditions in the agricultural areas due to a lack of rainfall/high temperature including water shortages in reservoirs and streams, and poor access to the irrigated system	1 in 20 years Agricultural drought
	SD	Severe drought due to the lack of snow cover accumulation over several months with widespread impacts across the region	1 in 10 years Agricultural drought
	MD	Moderate drought due to unseasonal rainfall or water shortages or reduced water availability across the agricultural system	1 in 5 years Agricultural drought
	ND	Healthy vegetation conditions are favorable with the availability of water and/or soil moisture	No drought

Continued›

Table 6. Thresholds for key drought indices and their classification into four drought classes - ED - extreme drought, SD - severe drought, MD - moderate drought and ND - no drought. (continued)

Indicator/ indices	Drought category	Explanation and its possible impact	Drought intensity
Integrated Drought Severity Index (IDSI)	ED	Exceptional and widespread crop/pasture losses, including shortages of water in reservoirs, streams and agro-wells	1 in 20 years Agricultural drought
	SD	Major crop/pasture losses with widespread water shortages or restrictions	1 in 10 years Agricultural drought
	MD	Crop or pasture losses due to unseasonal rainfall or water shortages or reduced water availability. Some damage to crops and pastures with unseasonal and delayed rainfall at different stages of crop growth as well as water shortages	1 in 5 years Agricultural drought
	ND	Conditions are favorable with optimal vegetation and the availability of water and/or soil moisture	No drought

Comparison of National- and Provincial-level Thresholds

The following section details the results of an analysis carried out to evaluate the appropriateness of national versus provincial thresholds. The country's wide climatic and geographic variability makes it appropriate to adopt localized, provincial-level thresholds rather than applying one set of thresholds to the entire country. However, applying provincial-level thresholds increases the overall complexity of the monitoring. The assessment, therefore, aimed to guide decision-makers on when: (1) a single set of thresholds for the various indicators at a national level would be appropriate, or (2) based on past observations, statistics indicate that a provincial-level approach would be more appropriate. The details of provincial-level thresholds are available in Annex 2 (3-month SPI, PSC, PCC, VHI and IDSI). Table 7 provides details of thresholds for these five indicators for selected provinces. Figure 3 provides a snapshot of the country and national thresholds for the drought year 2018. The national-level threshold was calculated by taking the average of indicator values for all provinces. This yielded the SPI index values of -1.73 for extreme drought (ED), -1.20 for severe drought (SD) and -0.68 for moderate drought (MD). These trigger values form the basis for defining meteorological droughts using a 3-month SPI at the country level.

When analyzing thresholds at the provincial level, the trigger values vary significantly. For example, VHI drought classes for ED are at various figures below 20%, the figures for SD range from 20 to 30%, and the figures for MD range from 30 to 40%. Such variability results from the complex climatic and agroecological conditions across Afghanistan. For PCC, the desert plain region of Nemroz shows minimum values of 0.03% (ED), 0.04% (SD) and 0.12% (MD), whereas the arable farming region of Badghes has values of 33.83% (ED), 35.26% (SD) and 36.32% (MD). It is estimated that PCC is 1,000 times larger in Badghes than in Nemroz province. The same scenario was observed for PSC, with the absence of snow cover in Nemroz, and Badakhshan showing 55%, 61% and 63% for ED, SD and MD, respectively.

In summary, GoIRA should utilize key drought indices and country-level thresholds during the initial phases of establishing drought monitoring in the country using the AF-DEWS Tool. It can be noted that all drought indices – the 3-month SPI, PSC, PCC, VHI and IDSI – were normalized and the CDF method was applied to develop drought trigger values. In the long term, given the varied agroclimatic conditions across the country, it would be appropriate to utilize provincial-level thresholds to enhance the reliability of drought forecasting from early warning to drought declaration. This requires a greater level of institutional coordination, as well as validating field observations from district to provincial level.

Table 7. Provincial thresholds for five indicators for selected provinces (see Annex 2 for more details).

Province	SPI (December)			PSC (January)			PCC (February)			VHI (March)			IDSI (April)		
	ED	SD	MD	ED	SD	MD	ED	SD	MD	ED	SD	MD	ED	SD	MD
Badakhshan	-1.75	-1.25	-0.94	55.44	61.04	63.22	1.91	3.30	4.48	0.35	0.37	0.38	0.35	0.35	0.36
Badghes	-2.40	-1.04	-0.52	0.50	1.01	2.33	33.83	35.26	36.32	0.16	0.19	0.32	0.17	0.19	0.29
Balkh	-1.91	-0.94	-0.57	0.87	1.04	1.37	11.40	12.57	19.12	0.19	0.20	0.34	0.17	0.18	0.29
Bamyan	-1.89	-1.06	-0.52	30.71	35.90	45.62	0.05	0.14	0.20	0.38	0.42	0.44	0.32	0.36	0.39
Daykundi	-1.45	-1.17	-1.04	7.08	10.14	17.22	0.32	0.97	1.95	0.43	0.43	0.45	0.37	0.40	0.41
Farah	-1.81	-0.86	-0.28	0.01	0.06	0.12	2.47	2.57	2.76	0.19	0.22	0.25	0.17	0.21	0.26
Faryab	-1.85	-1.15	-0.38	2.88	3.32	5.94	18.36	18.97	19.31	0.17	0.20	0.27	0.16	0.19	0.28
Hilmand	-1.49	-0.86	-0.66	0.08	0.09	0.14	3.94	4.32	4.83	0.22	0.23	0.30	0.16	0.21	0.29
Hirat	-2.29	-0.92	-0.24	0.43	1.00	1.46	6.95	8.02	9.08	0.24	0.25	0.28	0.21	0.26	0.28
Jawzjan	-2.15	-0.93	-0.57	0.02	0.03	0.07	12.91	13.98	15.64	0.19	0.22	0.27	0.07	0.11	0.20
Kunduz	-1.60	-1.01	-0.46	0.01	0.01	0.02	26.09	29.13	33.24	0.22	0.31	0.37	0.22	0.23	0.34
Nemroz	-1.22	-0.92	-0.62	0.00	0.00	0.00	0.03	0.04	0.12	0.18	0.20	0.26	0.24	0.24	0.34
Sar-e-Pul	-1.67	-1.04	-0.55	12.41	14.17	18.06	20.20	21.11	24.79	0.27	0.28	0.37	0.25	0.29	0.36
Takhar	-1.89	-1.23	-0.64	8.15	10.08	11.74	12.14	16.73	25.25	0.19	0.28	0.32	0.24	0.25	0.41

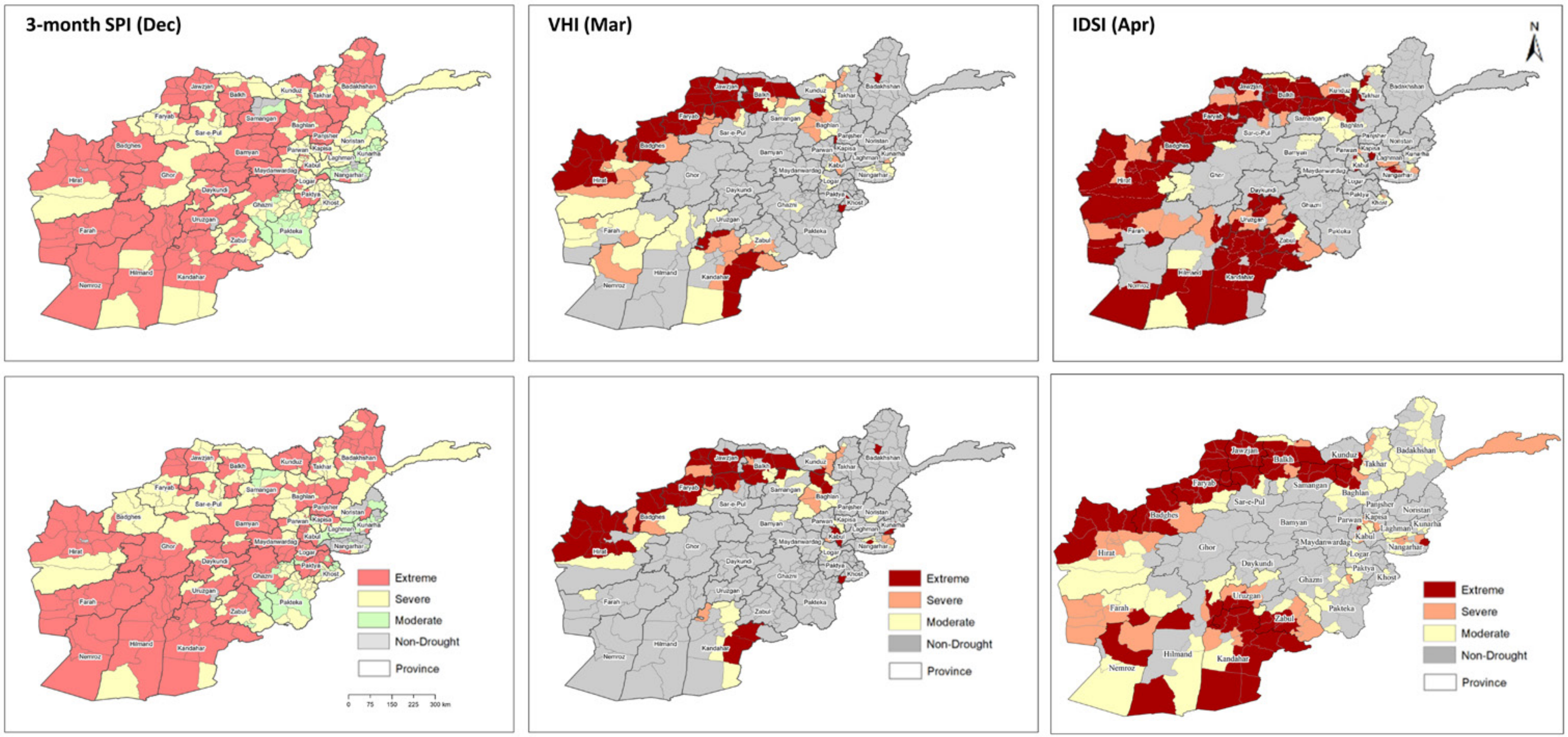


Figure 3. Three-month SPI, VHI and IDSI maps based on thresholds at the country level (top) and provincial level (bottom) for 2018.

Architecture of the AF-DEWS Tool

In recent decades, a variety of EO satellites and global models have generated a large volume of geospatial data that are freely available in the public domain and can be used to develop science-based knowledge products and tools to assist decision-making. However, making full use of this asset with standard computing technology calls for an innovative approach to data access, storage and processing. This is now being achieved through cloud infrastructure and platforms such as Google Cloud Platform (GCP), Amazon Web Services, and Microsoft Azure. Thus, the cloud platform and related systems offer enormous opportunities for scaling and sustainability of projects, even with limited resources.

GEE, which runs on GCP, is unique in that it offers free access to a large repository of near real-time satellite data suited to multiple land and water resources management applications – used by researchers, nonprofit organizations and government agencies.

The AF-DEWS Tool was developed using cloud services through GEE, which offers high security standards, easy access and straightforward maintenance. It incorporates data sources such as weather information and near real-time satellite data; a pre-configured drought algorithm that includes thresholds; and robust data analytics tools for rapid drought monitoring and early warning, supporting drought preparedness and response strategies. Figure 4 summarizes the AF-DEWS cloud-based drought early warning decision support tool.

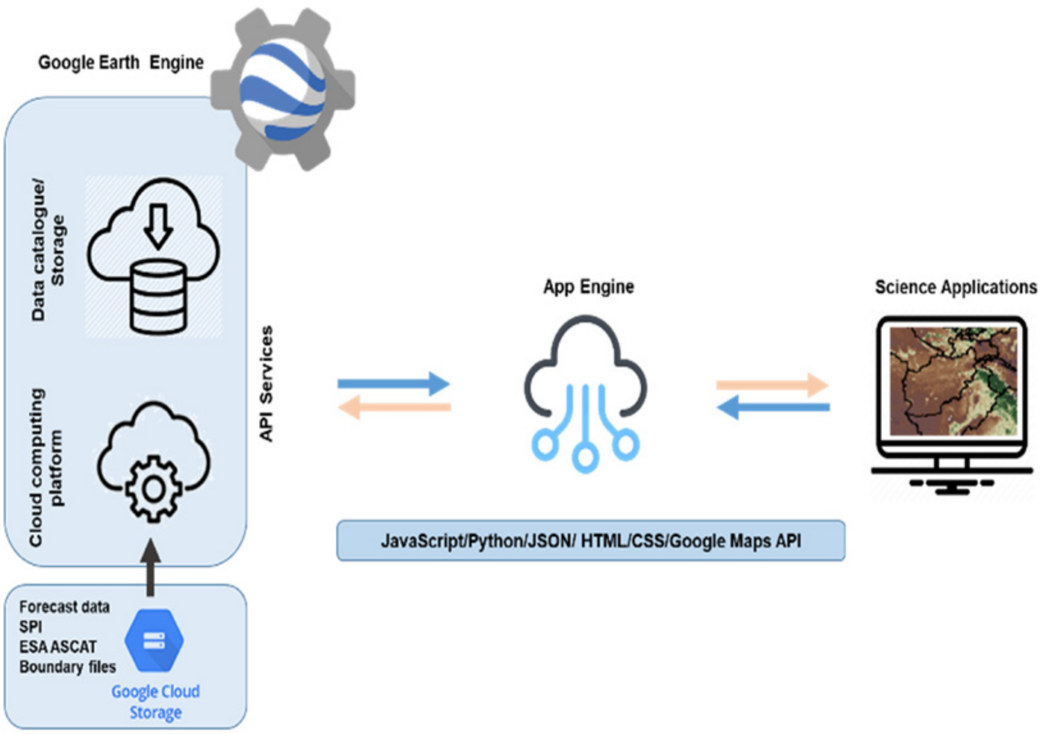


Figure 4. Conceptual diagram of the AF-DEWS Tool, which uses Google cloud services.

The AF-DEWS Tool architecture consists of three components (Figure 5):

a. Client: The web browser on the client side that renders the web application received from the server.

b. Node.js server: The server that handles and processes requests from users. Since the application is based on GEE Application Programming Interfaces (API), where most of the processing happens, the node.js server also acts as an intermediary between the client and the GEE server, where it processes user requests and forms that into appropriate GEE API requests. This server hosts all of the programming code, such as javascript (both on the server side and client side), Hyper Text Markup Language (HTML) and Cascading Style Sheets (CSS).

c. GEE servers: These are external servers for the application. Various data processing is chained through the javascript API. To access these servers, proper authentication is required.

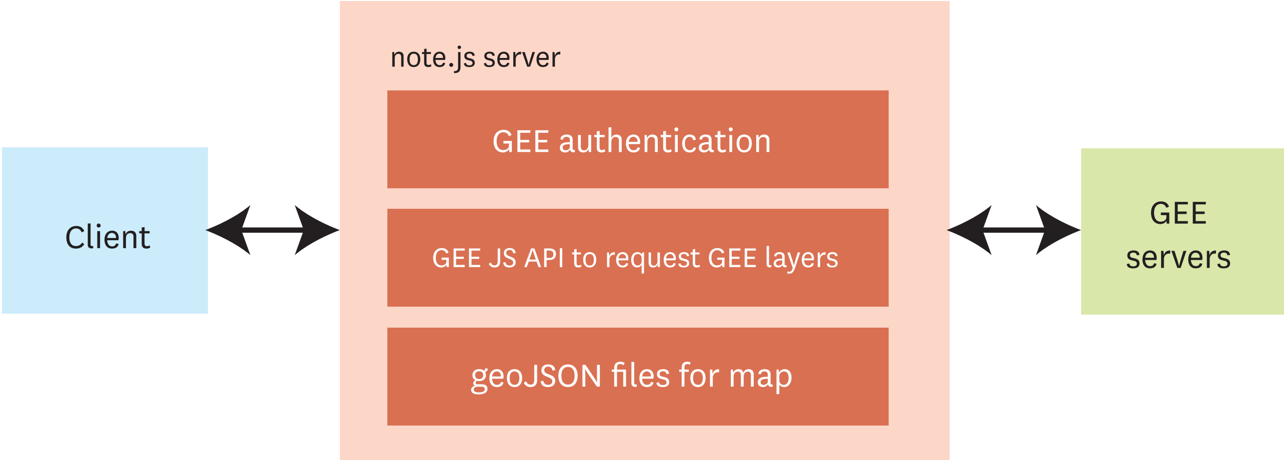


Figure 5. The system architecture of the AF-DEWS Tool.

The AF-DEWS Tool has powerful visualization capabilities that facilitate the rapid display of drought indices through maps, charts and other statistical data (Figure 6). These alert users to the current weather situation and any need to instigate early warning procedures. Through easy-to-use interfaces, users can filter large collections of images to quickly select areas of interest, choose drought indices, and compute statistics through space and time without the need to download derived products.

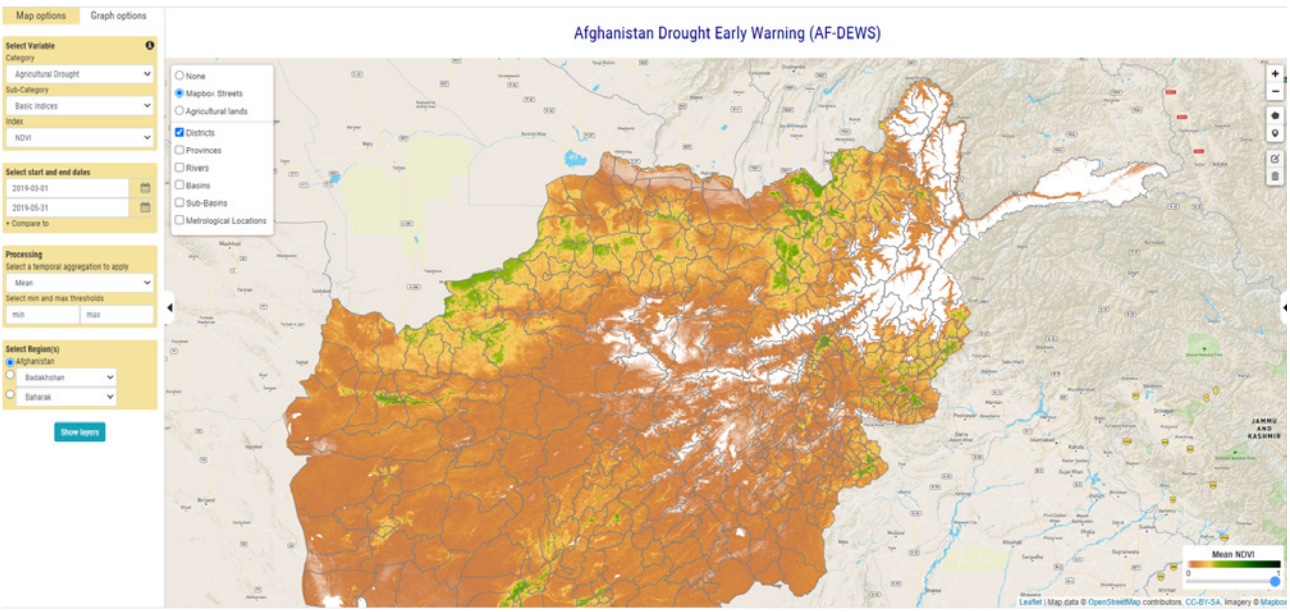


Figure 6. Screenshot of the AF-DEWS Tool displaying the NDVI map and time series data.

Evaluation of Two Decades of Drought Events in Afghanistan

The focus is on the 2018 drought in Afghanistan because it was one of the most severe during the last two decades. It spanned 22 out of the 34 provinces and directly affected two-thirds of the population. The impacts were felt across the country's agriculture, livestock, irrigation, water, health and economic sectors. At least 300,000 people were internally displaced due to drought, and 13.5 million people faced a 'crisis' or worse levels of food insecurity in September 2018 (according to the Integrated Food Security Phase Classification [IPC] Acute Food Insecurity Classification in September 2018).[3]

Using the AF-DEWS Tool to assess the 2018 drought in Afghanistan

- Using LandScan gridded population data, the AF-DEWS Tool successfully identified that the 2018 drought affected more than 13 million people.

- The tool identified that 22 out of the 34 provinces were affected by drought, with 14 provinces falling under the severe to extreme drought category.

- The tool helps in mapping the drought frequency and severity using the predetermined thresholds for individual drought indicators, such as SPI and IDSI.

- A comprehensive assessment was carried out to identify the type of drought (meteorological, hydrological and agricultural) using various drought indices; this quantified the impacts on the population and agricultural systems.

- The assessment of the 2018 drought using the AF-DEWS Tool correlated with the IPC analysis of September 2018, which highlighted that: 13.5 million people were facing a 'crisis' or worse levels of food insecurity, of which 9.8 million people (43.6% of the rural population) were estimated to be in a 'crisis' while 3.6 million were facing 'emergency' levels nationwide. This was six million more than in 2017 (FEWS NET).

Meteorological Drought Assessment

Rainfall Anomaly

Rainfall anomalies are known to have deleterious impacts on agricultural yields (Modanesi et al. 2020). The Rainfall Anomaly Index calculates the deviation from the long-term average, whether positive or negative. It is a comparison of current rainfall variation from the historical period. The maps in Figure 7 show rainfall anomalies in units of mm/month for January 2018 and 2019, based on precipitation estimates from the CHIRPS dataset. The period used for computing the climatology was 2000–2019. Blue areas in Figure 7(b) indicate where precipitation is above the long-term normal for the month, and the red areas in Figure 7(a) indicate where precipitation is below the normal. Total rainfall during the period December–January (Table 8) indicates that there is a 35% deficit in 2017–2018, and a more than 50% excess during 2018–2019. The December 2017–January 2018 period was the third driest for the past 20 years.

(a) (b)

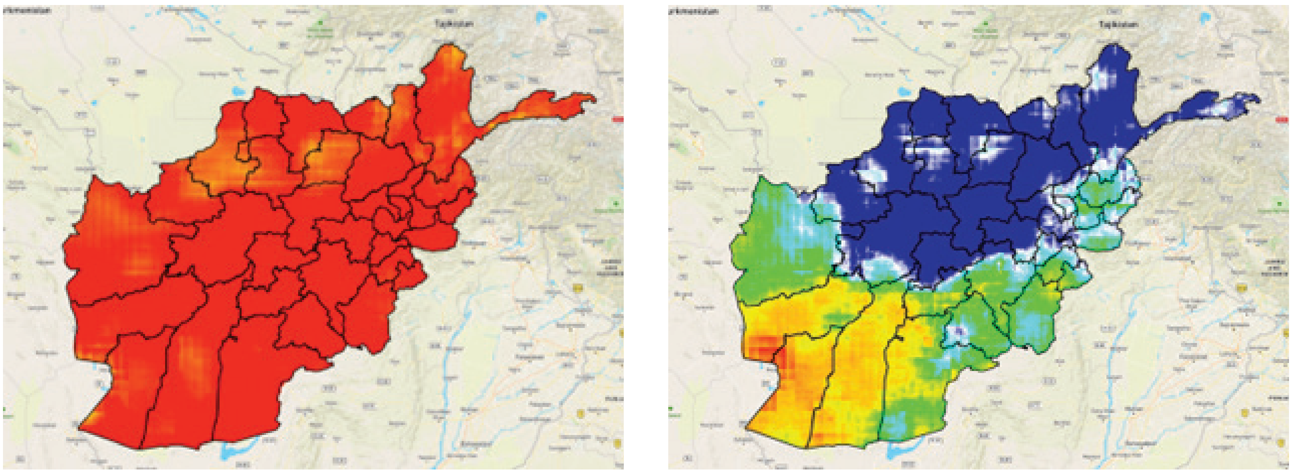


Figure 7. Rainfall anomaly map for (a) January 2018 (drought), and (b) January 2019 (normal weather conditions).

[3] https://www.ipcinfo.org/ipc-country-analysis/details-map/en/c/1151733/?iso3=AFG

Table 8. Accumulated rainfall obtained from CHIRPS gridded rainfall products (December–January) for the period 2000–2019 for the whole of Afghanistan.

Year	Rainfall (December–January) (mm)
2000–2001	50.57
2001–2002	80.28
2002–2003	97.07
2003–2004	77.23
2004–2005	97.48
2005–2006	104.51
2006–2007	102.22
2007–2008	81.90
2008–2009	112.77
2009–2010	106.94
2010–2011	103.50
2011–2012	91.48
2012–2013	96.35
2013–2014	64.87
2014-2015	118.03
2015-2016	45.76
2016–2017	165.00
2017–2018	62.66
2018–2019	150.24

Standardized Precipitation Index (SPI)

The 3-month SPI values were calculated from December to March to characterize meteorological drought and its severity. The analysis was extended from December to April to coincide with the rainfall season in Afghanistan. The key finding of this analysis was that changes in rainfall indicate drought in two ways. First, it indicates very low 3-month SPI values as a result of decreased rainfall due to the delayed onset of the rainy season. For the 2018 drought, the lowest 3-month SPI values were observed in December 2017. This signifies a decrease in the rainfall required for the early stages of crop cultivation. Second, it indicates a decrease in 3-month SPI values during the months when maximum rainfall is expected (February and March). For example, low 3-month SPI values were observed for February and March in Afghanistan's 2001 and 2008 drought years. Since positive 3-month SPI values were observed in both December 2018 and February 2019, it was possible to accurately predict 2019 as a drought-free year (Table 9). These indicators made it possible to accurately estimate drought or non-drought conditions.

Table 9 shows the changes in 3-month SPI values at the provincial level, with the two scenarios of December and January described above clearly able to define drought conditions. The provinces shown in Table 9 are the areas where most of Afghanistan's rainfed agriculture is practiced and which are, therefore, highly prone to changes in rainfall. During the period 2000-2019, the average 3-month SPI values for the drought years in the provinces shown in Table 9 ranged from -1.94 to -0.67. This indicates that most droughts range from moderate to extreme, according to the SPI classification. The lowest 3-month SPI values in Table 9 reveal that most provinces experienced droughts (SPI <= -1.75) during the drought period. Table 9 further highlights the difference in 3-month SPI values in both December and February in drought and non-drought years.

The maps shown in Figure 8 were generated using the drought thresholds calculated using the CDF to understand the spatial distribution of the drought based on the 3-month SPI values (i.e., December SPI values include rainfall information between October and December) at the country level. Results of the 3-month SPI show that the drought in 2018 affected all provinces of Afghanistan with varying degrees of severity, and more than 75% of the provinces were in the extreme drought category. However, no province was affected by the drought in 2009, and northern, northeastern and northwestern provinces were mostly affected by the drought in 2008.

The classification scheme used at the provincial level shows how drought can vary within a province. Figure 9 clearly shows the changes in drought severity within the province at the district level.

SPI was also calculated to understand the variation of the index at different timescales over the past 30 years. SPI with different timescales provides meaningful information about short- and long-term droughts in a very simple way. SPI values at different timescales were plotted for two locations in Kunduz and Badghes provinces (Figure 10). It is clearly apparent from Figure 10 that a meteorological drought occurred in 2001, 2008 and 2018, and that there was a prolonged drought condition before early 2000 as well.

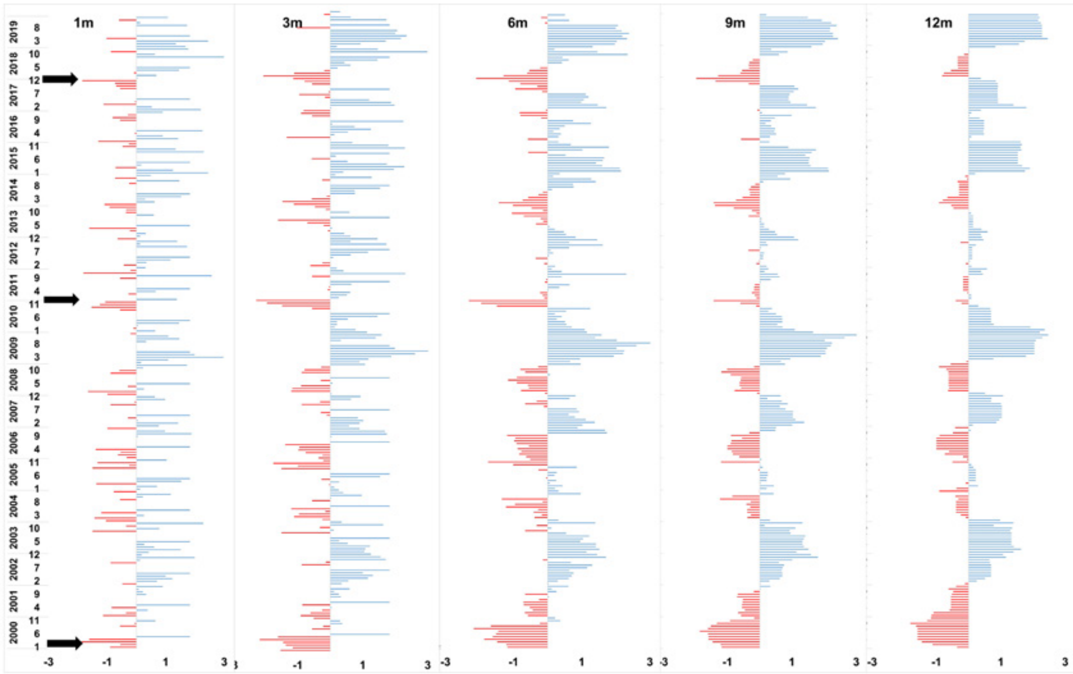
Table 9. Historical drought and non-drought events detected by the December and February 3-month SPI values.

Provinces	3-month SPI (December)				3-month SPI (February)			
	2000	2007	2017	2018	2001	2008	2018	2019
Badakhshan	0.33	-0.39	-1.86	0.88	-2.17	-1.26	-1.22	0.47
Badghes	-0.58	-0.24	-2.19	0.43	-1.46	-1.11	0.16	2.00
Baghlan	-0.51	-1.00	-1.83	1.68	-2.12	-1.07	-0.38	2.25
Balkh	-0.84	-0.41	-1.72	1.67	-1.24	-1.21	-0.29	2.75
Bamyan	-0.41	-0.24	-2.10	1.73	-1.71	-0.49	0.21	2.36
Daykundi	0.05	0.21	-2.18	1.30	-1.58	-0.27	1.62	1.73
Farah	-0.08	-0.63	-2.22	-0.22	-1.69	-1.58	0.31	0.79
Faryab	-1.08	0.13	-1.91	0.63	-1.83	-1.12	-0.31	2.26
Ghazni	0.05	0.11	-1.37	0.49	-1.83	-0.05	-0.01	1.04
Ghor	-0.32	0.26	-1.93	0.99	-1.74	-0.20	1.12	1.77
Hilmand	-0.37	0.51	-2.09	-0.47	-1.27	-0.01	0.28	1.54
Hirat	0.26	-0.14	-2.38	0.23	-1.18	-1.27	0.12	2.08
Jawzjan	-0.80	-0.01	-2.05	0.98	-1.66	-1.05	-0.36	2.75
Kabul	-0.72	-0.55	-1.71	1.08	-1.69	-0.42	-0.91	0.97
Kandahar	0.23	0.43	-1.82	-0.37	-0.95	-0.14	-0.13	1.35
Kapisa	-0.73	-0.58	-1.58	1.34	-1.58	-0.39	-0.96	1.42
Khost	-0.81	-0.03	-1.34	0.12	-1.72	-1.29	-0.49	-0.08
Kunarha	-0.56	0.50	-1.18	-0.01	-2.11	-0.84	-1.49	0.10
Kunduz	-0.39	-1.21	-1.77	1.52	-1.06	-1.83	-0.46	2.01
Laghman	-0.68	-0.21	-1.45	0.37	-1.98	-0.83	-1.01	0.46
Logar	-0.54	0.09	-1.67	0.78	-1.88	-0.36	-0.76	0.81
Maydanwardag	-0.27	0.04	-1.86	1.33	-1.81	-0.03	-0.34	1.56
Nangarhar	-1.33	0.08	-1.03	0.07	-2.07	-1.03	-0.95	-0.05
Nemroz	-0.89	0.15	-2.12	-1.22	-1.63	-0.48	-0.40	0.30
Noristan	-0.02	0.19	-1.33	0.24	-2.08	-0.80	-1.42	0.38
Pakteka	-0.47	-0.08	-1.13	0.24	-1.86	-0.90	-0.47	0.56
Paktya	-0.63	0.09	-1.72	0.29	-1.81	-1.00	-0.76	0.26
Panjsher	-0.53	-0.76	-2.00	1.19	-2.26	-0.58	-0.94	1.56
Parwan	-0.41	-0.57	-1.51	1.43	-1.79	-0.28	-0.82	1.69
Samangan	-0.59	-0.59	-1.53	1.53	-1.47	-1.26	0.26	2.64
Sar-e-Pul	-0.97	-0.36	-1.56	1.72	-1.67	-1.29	0.55	2.65
Takhar	-0.24	-1.04	-1.82	1.27	-1.79	-1.88	-0.54	1.49
Uruzgan	-0.18	0.27	-1.82	0.63	-1.43	-0.04	1.08	1.50
Zabul	-0.09	0.43	-1.65	0.01	-1.62	-0.02	0.05	1.02

Figure 8. Spatial distribution of drought thresholds derived from the 3-month SPI values for (a) 2008, (b) 2009, and (c) 2018.

Figure 9. Spatial distribution of provincial drought thresholds derived from 3-month SPI values for (a) 2008, (b) 2009, and (c) 2018.

(a)



(b)

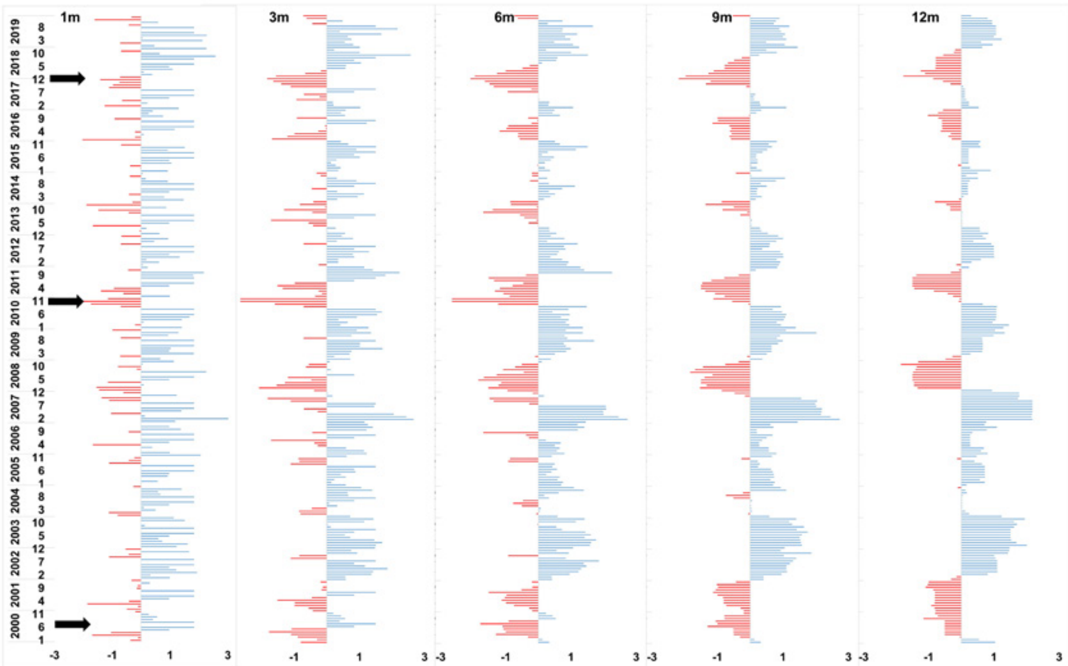


Figure 10. SPI values of two locations in (a) Badghes and (b) Kunduz provinces, and (c) 2018.

The number of districts and provinces that experienced drought during the period 2001-2019 were calculated at the provincial and district levels using the country-level drought threshold. As shown in Table 10, more provinces and districts were affected by drought in 2001, 2004, 2008, 2011 and 2018, but less drought or no drought was experienced in other years. The severity of each drought event can be determined based on the number of districts and provinces affected. On this basis, 2001, 2011 and 2018 can be identified as years with extreme drought, 2004 as a severe drought, and 2002 and 2008 as years with moderate drought. Drought years are indicated by the use of a color, with the different intensities used to indicate the severity of the drought.

Table 10. Assessment of past drought events using 3-month SPI (December and February) for a country threshold in Afghanistan.

Year	Districts				Provinces			
	Extreme	Severe	Moderate	No drought	Extreme	Severe	Moderate	No drought
2001	231	137	22	11	16	15	3	0
2002	54	75	110	162	2	12	6	14
2003	0	1	16	384	0	0	2	32
2004	92	140	129	40	5	17	12	0
2005	0	0	0	401	0	0	0	34
2006	0	4	18	379	0	0	0	34
2007	0	0	1	400	0	0	0	34
2008	22	105	87	187	2	7	10	15
2009	0	0	28	373	0	0	0	34
2010	0	0	52	349	0	0	4	30
2011	285	90	23	3	23	10	1	0
2012	0	0	2	399	0	0	0	34
2013	0	0	12	389	0	0	1	33
2014	2	21	113	265	0	1	9	24
2015	1	13	90	297	0	0	10	24
2016	0	1	0	400	0	0	0	34
2017	0	0	40	361	0	0	0	34
2018	209	124	46	22	18	13	3	0
2019	3	6	8	384	0	1	0	33

Notes: Extreme drought is shown in dark orange, severe drought in light orange, and moderate drought in yellow.

Hydrological Drought Assessment

Hydrological droughts relate to a period with inadequate surface and subsurface water resources for established water uses in a given water resources management system (Srivastava and Chinnasamy 2021). It is important to investigate how drought evolves from a meteorological to hydrological drought, and to examine the factors that may drive the drought propagation process, as understanding this is key to mitigation measures. The SCI, SDI and SWSI were used to characterize hydrological droughts. The transmission of meteorological droughts to hydrological droughts was also investigated.

Snow Cover Index (SCI)

The Moderate Resolution Imaging Spectroradiometer (MODIS) products MODIS/Terra (MOD10A1) and Aqua (MYD10A1), which provide cloud-free daily snow cover at 500 m grid cells, were extracted to represent the snow cover area (SCA). This serves as a reliable source of snow measurements for hydrological studies. The assessment was carried out for monthly time intervals over 19 years (2001–2019) to understand the variation in snow cover during the critical months that were used in determining a hydrological drought. Table 11 shows the lack of snow cover for January and February for selected provinces in drought years, i.e., 2001, 2008, 2011 and 2018, in reference to normal years i.e., 2006, 2007 and 2010, highlighting a strong correlation between snow cover and meteorological drought.

Table 11. Variation in snow cover between 2001 and 2019 for selected provinces in Afghanistan.

Year	Badghes			Balkh			Faryab			Hirat			Jawzjan			Kunduz			Sar-e-Pul		
	J	F	M	J	F	M	J	F	M	J	F	M	J	F	M	J	F	M	J	F	M
2001	2.8	6.8	0.7	1.4	5.7	0.7	5.9	12.1	1.5	6.6	5.1	1.8	0.0	0.1	0.0	0.0	0.0	0.0	19.3	27.7	11.3
2002	32.0	24.9	4.2	23.2	9.2	1.6	25.0	21.1	6.3	16.1	15.7	4.7	5.5	2.1	0.5	28.4	1.9	0.3	62.9	36.8	21.2
2003	12.4	14.9	12.4	3.1	4.5	12.4	10.7	13.2	15.2	7.2	17.0	7.7	0.0	0.0	1.4	0.0	0.0	5.6	25.4	27.4	40.3
2004	25.1	5.1	2.6	6.2	2.2	1.4	16.3	10.3	6.5	21.9	5.2	3.2	0.1	0.1	0.1	0.0	0.0	0.0	31.8	26.5	22.1
2005	32.8	57.0	2.2	17.3	26.8	1.2	24.8	25.0	5.4	35.7	39.4	5.0	2.9	3.1	0.3	2.6	6.9	0.1	57.9	76.2	19.9
2006	89.2	33.3	2.2	17.4	14.0	1.4	75.0	26.8	5.4	40.9	12.5	3.2	16.7	5.1	0.0	5.7	23.4	0.0	62.8	75.8	23.2
2007	94.7	15.1	14.6	32.1	5.1	3.4	61.1	15.8	15.9	51.6	16.2	10.4	16.1	0.5	0.6	15.8	6.1	0.0	89.2	29.3	29.9
2008	10.5	24.8	10.3	7.0	17.7	8.4	12.9	27.2	18.5	5.9	11.3	11.5	0.6	5.7	3.0	0.1	8.4	2.4	27.6	65.2	34.0
2009	7.0	25.7	13.3	1.1	11.7	3.4	6.8	22.1	12.0	9.7	23.2	17.6	0.0	4.7	0.1	0.0	4.1	0.1	21.9	43.6	27.3
2010	20.7	13.7	77.7	25.3	4.3	37.4	24.2	17.1	61.1	13.8	10.8	20.8	4.7	1.4	31.5	6.7	0.0	70.1	80.3	36.0	95.0
2011	0.0	20.9	19.9	0.5	10.7	10.2	0.0	17.6	17.2	0.0	15.9	23.1	0.0	1.5	1.0	0.0	1.2	0.4	3.8	32.1	39.0
2012	9.9	27.2	58.2	31.1	8.2	30.9	22.1	22.3	40.3	4.2	18.6	27.7	7.3	1.6	12.1	40.6	1.0	20.3	68.5	34.6	82.6
2013	23.1	42.4	20.0	8.7	14.1	4.1	22.4	29.7	15.9	18.6	16.4	18.3	1.4	6.1	0.4	2.8	16.2	64.9	35.6	67.3	27.7
2014	25.9	3.0	41.0	20.5	1.7	44.2	21.2	7.8	34.1	5.0	4.0	23.8	7.9	0.0	25.8	10.1	0.0	79.6	66.7	17.3	89.1
2015	1.1	18.8	12.5	0.9	10.2	7.5	3.3	22.4	15.0	1.2	10.6	10.4	0.1	1.8	0.0	0.2	0.5	0.1	14.4	39.1	30.9
2016	15.8	9.1	5.0	26.3	7.1	11.3	30.7	12.4	8.8	1.6	8.0	4.1	11.4	0.3	0.1	12.0	0.0	15.4	62.3	31.2	33.0
2017	1.7	33.7	7.9	3.0	36.3	4.1	5.9	28.2	11.0	1.1	23.7	6.6	0.4	5.6	0.0	0.7	67.2	29.2	16.3	83.2	30.0
2018	0.6	23.0	1.3	1.4	24.5	1.1	3.2	17.0	3.6	0.5	11.9	2.4	0.1	0.7	0.1	3.4	37.3	0.0	13.4	66.3	22.2
2019	30.5	23.3	13.3	17.4	21.4	3.7	22.7	23.6	13.6	13.5	22.7	15.7	2.4	5.1	0.1	4.5	27.8	0.0	44.0	54.7	29.7

Note: J – January, F – February, M – March.

Streamflow Drought Index (SDI)

Streamflow data are widely used in hydrological analyses because the agricultural response to drought is a crucial variable in determining drought severity (Aghelpour et al. 2021). To study a hydrological drought, the SDI was developed using cumulative monthly flow data spanning 30 years. Specifically, flow data of Pul-i-Bang and Chahar Dara stations in the Panj Amo River Basin (Figure 11) were used to calculate SDI.

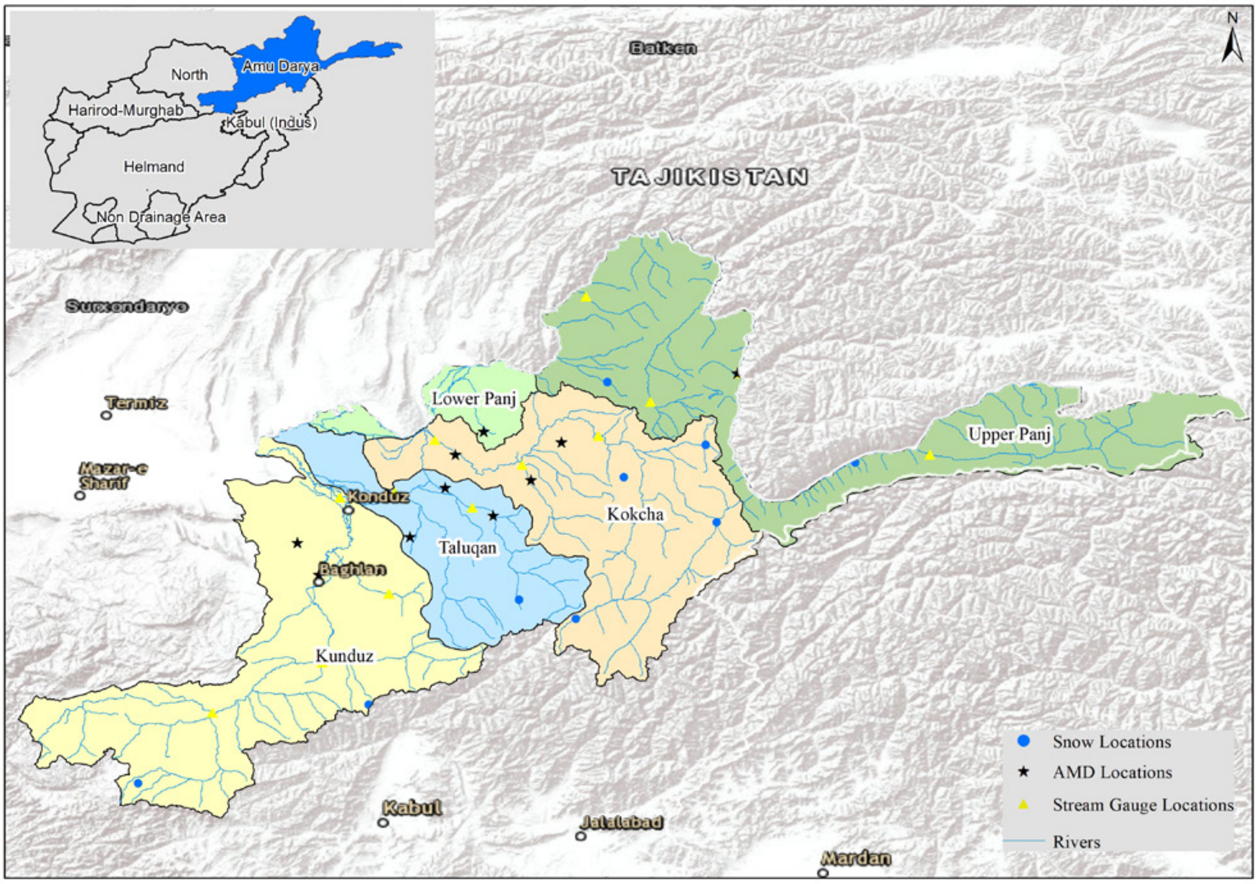


Figure 11. Geographical location of the Panj Amo River Basin and spatial distribution of hydrometric stations.

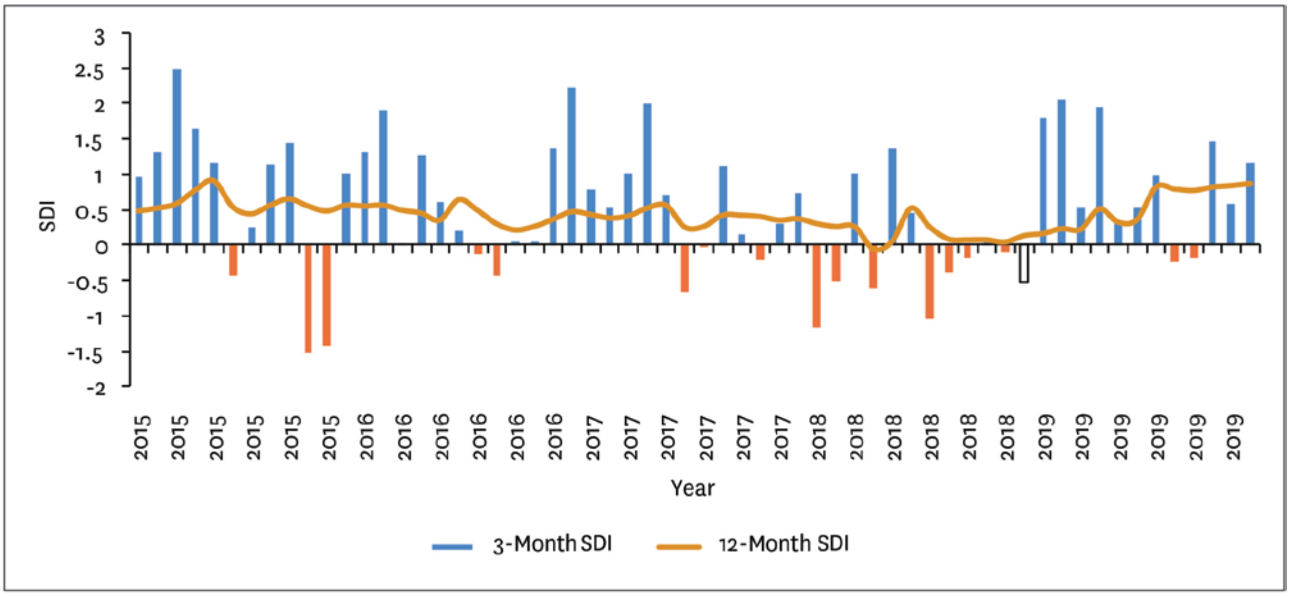
Monthly SDI values for Pul-i-Bang and Chahar Dara stations are shown in Figure 12. This station has higher negative values of SDI for 2018, explaining the long duration of drought severity. A similar observation is noticed for Pul-i-Bang station in 2018, where the months between March and May show an SDI value of −2.53. During normal years, the SDI has higher positive values between 2.5 and 3 in reference to the period 2016-2019. The lag time for peak drought severity was, on average, 0.59 months between SDI, SPI and SCI. In comparison with SDI, the maximum delay was two months for SPI and SCI. Although the severity levels of a meteorological drought are relatively low, the impacts of a hydrological drought are extreme because factors such as surface water and groundwater depletion lead to an agricultural drought and have large-scale implications for current crops and cultivation in the next season.

Surface Water Supply Index (SWSI)

The SWSI (Shafer and Dezman 1982) was selected because it is a well-known hydrological drought index. SWSI is advantageous because it can flexibly utilize various hydrometeorological components depending on the characteristics of the basin in question. SWSI is based on probability distributions of monthly time series of individual component indices and is calculated using four hydrometeorological components: snow cover, precipitation, streamflow and reservoir storage. It is a particularly appropriate drought indicator to use in snow-dominated regions within the northern provinces of Afghanistan.

In this study, the years 2001, 2008 and 2018 were considered because severe drought occurred nationally. In the 2018 drought event, the average rainfall amount was as high as 62 mm from December 2017 to January 2018, which is a deficit of 35% from the average rainfall received between December and January over the last 20 years across Afghanistan. On the other hand, the country received excess rainfall of 57% during the same period (2018-2019). Annual water use for irrigation is estimated to be around 20 billion cubic meters (BCM), drawn mostly from surface water.

(a)



(b)

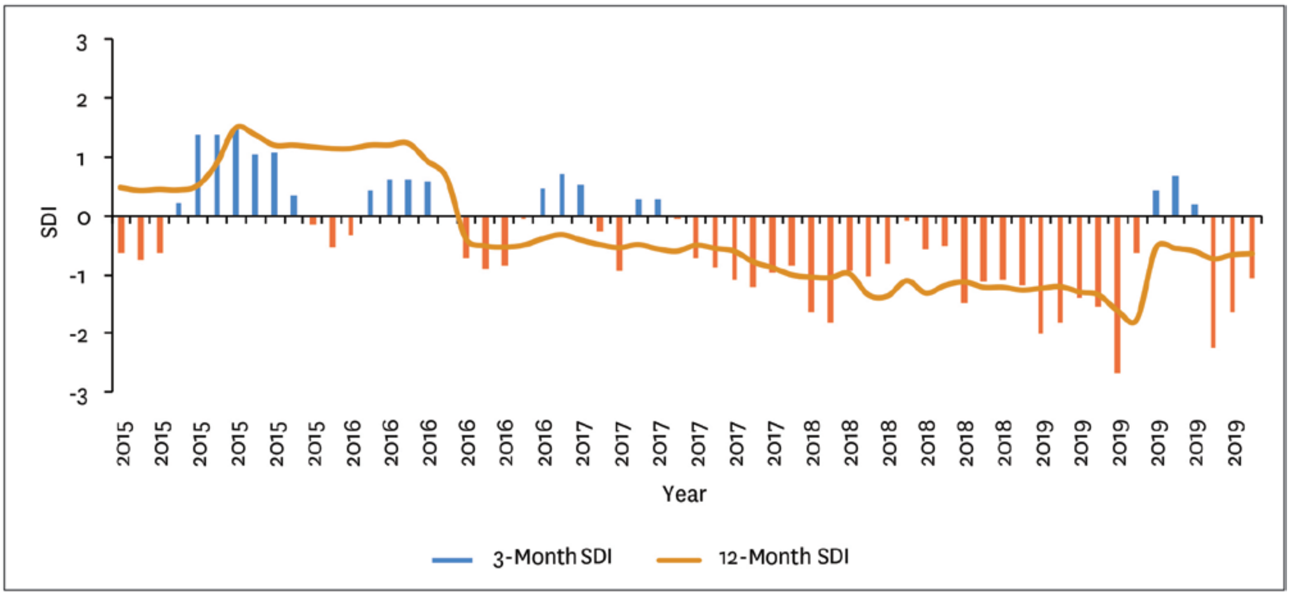


Figure 12. SDI series for the (a) Pul-i-Bang, and (b) Chahar Dara stations in Panj Amo River Basin for the reference period 2015–2019.

Figure 13 shows that, in 2018, the values of SWSI from April were mostly negative in the Panj Amo River Basin, with the peak deficit occurring in October. A similar drought trend existed across the country, with the central provinces appearing near normal or experiencing a slight drought. In 2018, the values of SWSI showed stronger drought intensities in some sub-basins for each hydrometeorological component – precipitation, streamflow and snow cover. In the normal year, i.e., 2017, which is considered as one of the wetter years, the values of SWSI were highly positive (2 to 3 index values) with increased precipitation (up to 143%) and snow cover (23%). Therefore, it is reasonable to conclude that a hydrological drought occurred in the Panj Amo River Basin in 2018. It can be argued that integrating observations from existing stations into the AF-DEWS Tool can help to monitor drought severity accurately, and can contribute to managing water resources in more spatially segmented sub-basins to mitigate droughts and guide early warning strategies.

Agricultural Drought Monitoring

Three parameters, primarily VHI, IDSI and PCC, were used at different periods of the crop season to map agricultural drought in Afghanistan. The April IDSI value was used to determine the impact of drought; the spatial distribution of 2001, 2008 and 2018 drought events derived using IDSI is presented in Figure 14, and a comparison of PCC, VHI and IDSI is given in Table 12. As an example, the province of Jawzjan has low IDSI values (2.80 in 2001 and 8.81 in 2018) for the drought years in reference to a normal year (36.83 in 2019). This is well correlated with PCC, with less than 5% in 2018 compared to over 21.4% in the normal year. Similar observations can be made in several provinces across the country.

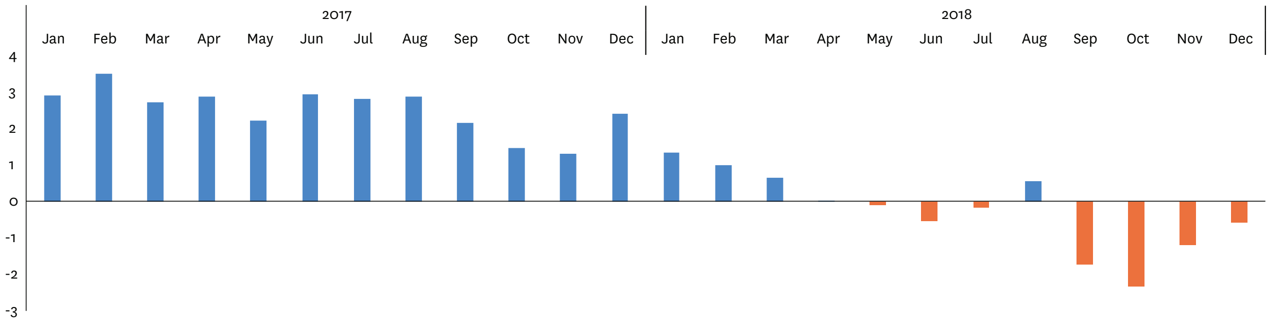


Figure 13. SWSI time series between normal (2017) and drought (2018) years for the Panj Amo River Basin.

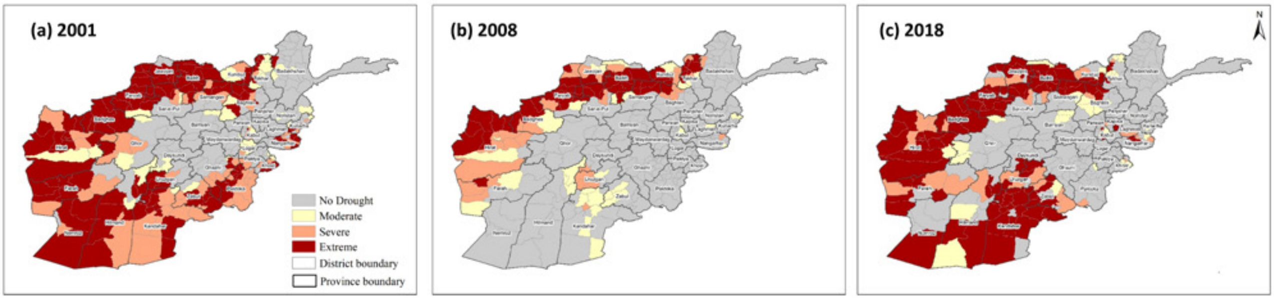


Figure 14. Spatial distribution of provincial drought derived from April IDSI value in (a) 2001, (b) 2008, and (c) 2018.

Since the agricultural and meteorological drought monitoring parameters represent a close relationship, a linear regression analysis was performed between SPI-VHI and SPI-PCC for Jawzjan, Kunduz, Faryab and Hirat provinces separately to understand the correlation among these drought indicators as discussed in the section *Meteorological Drought Assessment*.

Comparison of Multiple Indicators

This study analyzed two major drought events, i.e., in 2008 and 2018. During these times, the country experienced a severe to extreme precipitation deficit (Table 8). The lack of snow cover and the resulting impact on streamflow gave rise to a hydrological drought (Figure 12). We selected key drought indices – 3-month SPI, PCC, VHI and IDSI – to undertake a detailed evaluation of the major drought events and their impacts on crop production. We used both satellite-derived (MODIS) Gross Primary Productivity (GPP) data and observed wheat production data provided by NSIA.[4]

Spatio-temporal characterization of drought severity and extent was developed using selected drought indices derived from a range of satellite products. Figure 15 shows the drought condition for 2018 for affected provinces in western and northwestern Afghanistan, using the 3-month SPI, PCC, VHI and IDSI indices with reference to the 2019 normal year. It is clear that the composite index IDSI reflects an agricultural drought; this also relates well with the other drought indices and their impacts on rainfed and rangeland areas. In summary, all the key drought indices accurately illustrate the likely situation of an agricultural drought, which can be monitored from the peak stage to the end of the crop season. Combining the drought indices with crop calendars across the crop growth stages will help stakeholders to determine the onset of drought and quantify the likely severity of drought impacts.

Figure 15 shows how multiple indicators in the months from December reveal the 2018 drought and 2019 non-drought conditions across the country. Combining the relevant drought information, i.e., the 3-month SPI for December and February, explains the severity of meteorological drought, which, in 2018, subsequently led to hydrological and agricultural droughts and related yield loss. Using PCC for February, derived from NDVI, can help in identifying the crop sown area, e.g., wheat, which is either in the early or delayed stage due to the drought situation. In March, VHI can help to determine the health condition of crops. It is clear that crop cover and VHI generally increased from January to March in the normal year, indicating a healthy condition. This correlates well with the IDSI for April, the peak crop maturity stage as per the crop calendar, which reflects good yields. For the drought year, the situation is very different. The IDSI for April indicates the drought condition and related yield losses. Thus, the remote sensing-derived indices provide comprehensive drought monitoring indicators to identify the progression, extent, duration and severity of drought.

[4] http://www.data.gov.af/about-us (accessed on April 6, 2020).

Table 12. PCC, VHI and IDSI distribution in drought (2001 and 2018) and non-drought (2009 and 2019) years.

Province	PCC (February)				VHI (March)				IDSI (April)			
	2001	2018	2009	2019	2001	2018	2009	2019	2001	2018	2009	2019
Badakhshan	5.15	5.75	5.08	5.90	0.41	0.48	0.40	0.39	30.59	54.60	44.93	69.51
Badghes	29.29	18.51	34.57	36.92	0.28	0.18	0.56	0.59	3.32	13.34	89.85	73.69
Baghlan	10.31	8.35	9.56	16.56	0.41	0.49	0.45	0.46	17.08	37.01	62.98	72.21
Balkh	12.62	12.19	17.08	20.37	0.26	0.32	0.44	0.45	10.78	27.94	62.85	53.89
Bamyan	0.24	0.56	0.16	0.26	0.48	0.57	0.35	0.36	25.96	51.49	25.75	51.99
Daykundi	1.09	2.13	1.04	2.29	0.48	0.58	0.44	0.39	26.90	53.45	43.30	46.55
Farah	1.06	5.38	4.84	6.25	0.22	0.39	0.36	0.44	8.43	17.78	42.03	36.89
Faryab	16.73	11.98	20.50	18.71	0.21	0.20	0.46	0.40	4.45	17.45	76.96	60.58
Ghazni	0.72	1.59	1.00	0.92	0.55	0.67	0.61	0.35	23.82	44.40	52.55	30.62
Ghor	0.43	2.03	0.30	0.70	0.58	0.66	0.62	0.41	22.56	50.41	63.61	47.44
Hilmand	2.45	6.29	5.81	6.90	0.22	0.54	0.51	0.52	10.04	18.42	54.56	37.15
Hirat	6.79	4.94	10.05	9.81	0.37	0.29	0.57	0.34	15.34	20.06	73.10	47.41
Jawzjan	14.45	4.11	14.99	13.41	0.24	0.20	0.47	0.36	2.80	8.81	63.37	36.83
Kabul	3.03	7.24	4.56	3.01	0.42	0.52	0.48	0.36	23.76	30.84	45.93	29.91
Kandahar	0.31	1.21	2.05	1.85	0.20	0.30	0.43	0.35	13.65	16.00	65.99	38.81
Kapisa	12.17	14.85	13.73	12.49	0.42	0.60	0.50	0.43	34.47	33.79	50.26	27.17
Khost	8.68	12.50	10.97	10.89	0.28	0.57	0.56	0.43	15.33	46.33	54.94	47.34
Kunarha	6.55	9.17	7.43	7.78	0.42	0.58	0.53	0.56	28.02	43.09	No data	52.84
Kunduz	35.02	23.75	32.32	35.66	0.47	0.39	0.53	0.58	22.45	23.41	73.12	48.69
Laghman	5.29	10.45	8.99	7.36	0.56	0.58	0.59	0.55	23.15	39.07	61.07	37.05
Logar	2.65	3.49	2.83	0.09	0.51	0.62	0.61	0.32	21.70	35.53	48.91	25.62
Maydanwardag	0.15	1.05	0.04	0.00	0.54	0.68	0.46	0.29	28.61	45.01	29.55	37.53
Nangarhar	8.54	13.20	9.72	10.31	0.36	0.51	0.51	0.50	13.40	34.75	52.16	45.13
Nemroz	0.04	0.18	0.08	0.17	0.24	0.44	0.29	0.36	9.51	12.48	18.18	14.46
Noristan	1.29	1.33	0.91	1.06	0.41	0.53	0.35	0.35	37.97	45.81	45.03	36.94
Pakteka	0.62	1.10	0.65	0.13	0.36	0.58	0.51	0.36	6.83	37.63	58.44	28.72
Paktya	3.72	4.49	2.67	1.95	0.53	0.66	0.58	0.38	27.98	48.08	36.85	21.12
Panjsher	0.50	1.50	0.08	0.00	0.46	0.55	0.32	0.34	39.27	52.47	4.08	54.07
Parwan	8.25	9.74	9.37	9.41	0.40	0.58	0.43	0.36	37.15	42.70	48.02	43.28
Samangan	10.35	8.67	10.34	11.92	0.44	0.48	0.48	0.45	17.70	37.16	56.17	57.84
Sar-e-Pul	24.77	12.22	17.94	27.94	0.40	0.34	0.44	0.53	20.61	37.08	74.93	68.77
Takhar	24.52	15.75	18.94	32.94	0.51	0.46	0.49	0.58	22.65	43.06	69.80	64.60
Uruzgan	1.94	2.54	4.90	4.86	0.37	0.51	0.50	0.50	17.52	22.49	79.36	34.49
Zabul	0.25	0.69	0.59	0.59	0.27	0.42	0.52	0.33	14.20	23.77	76.67	25.31

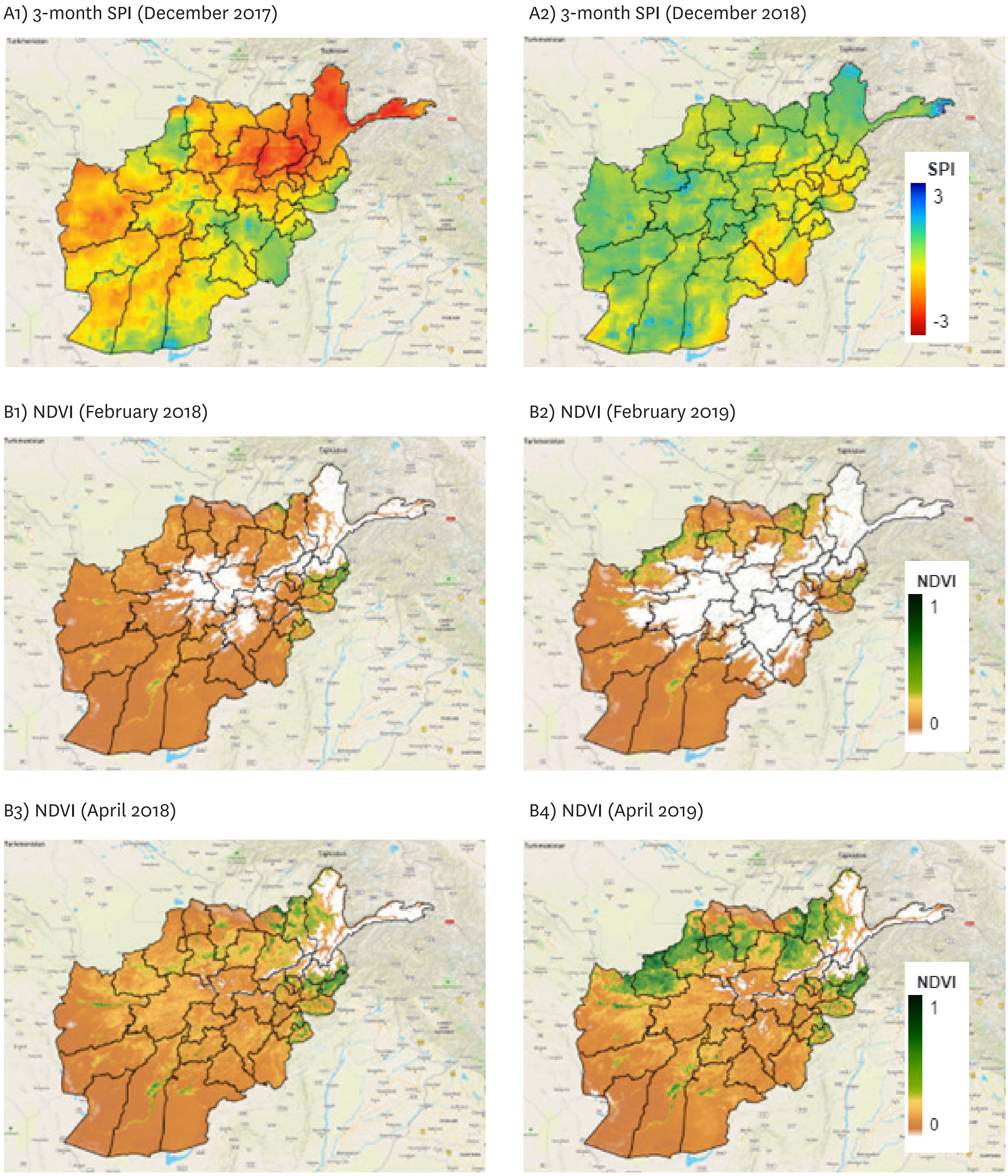


Figure 15. The use of multiple drought indices, and comparison of drought and normal years across Afghanistan.

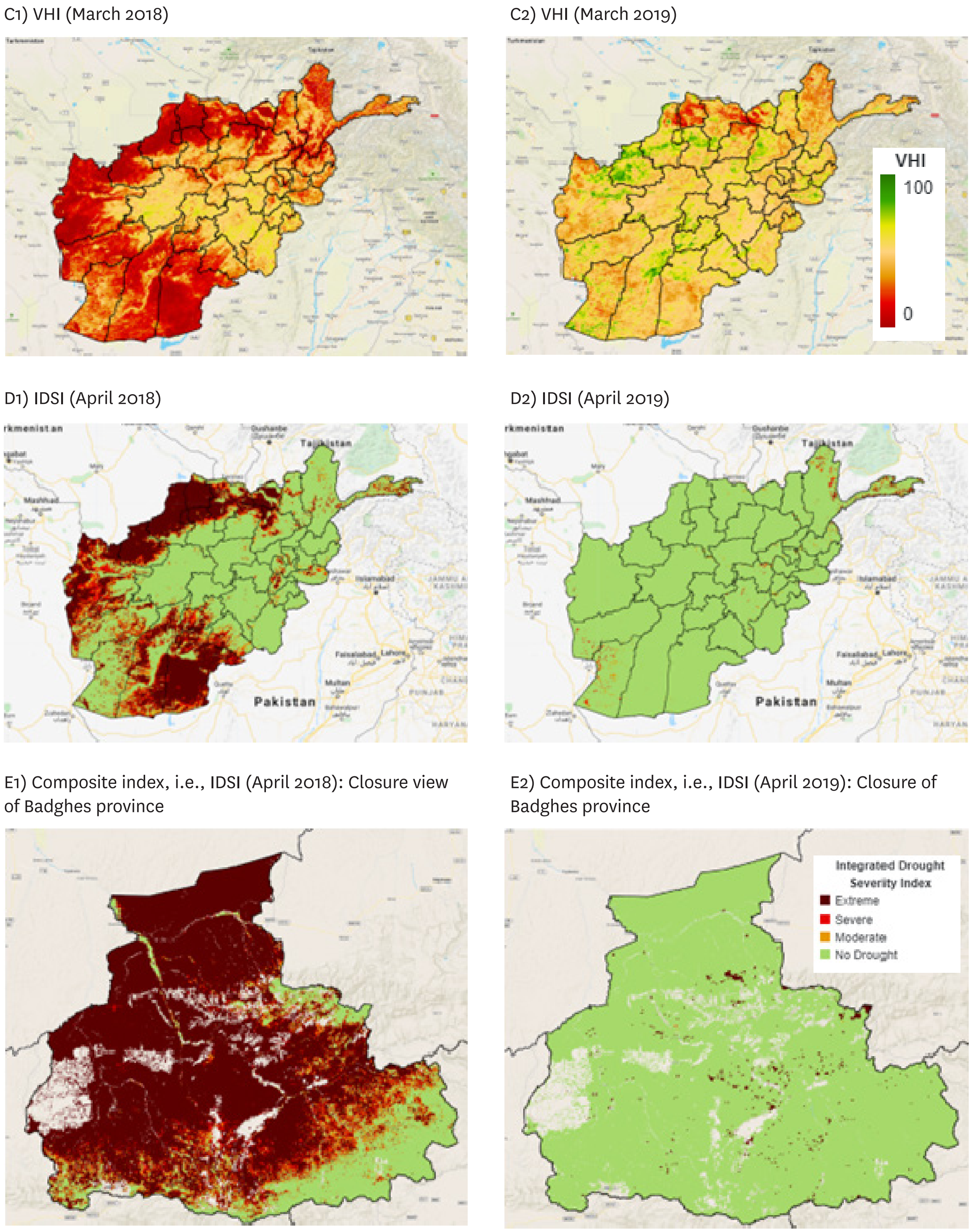


Figure 15. The use of multiple drought indices, and comparison of drought and normal years across Afghanistan.

Drought Impact Analysis using Crop Production

The above section compared the use of key drought indices for assessing drought progression from the start to the end of the crop season. This section describes the comparative analysis of drought indicators in reference to ground-based Crop Yield Anomaly (CYA) and satellite-derived CYA using MODIS GPP in rainfed and irrigated areas.

Correlation Analysis of Drought Indices and CYA

The SPI and VHI scatterplots in Figure 16 correspond to the 3-month SPI for December and the VHI for March. Similarly, the SPI and PCC values relate well with the 3-month SPI for December and the PCC for February. One point in the scatterplot corresponds to a one-year value, so there are 19 records to represent the study period from 2001 to 2019. Since 3-month SPI and VHI have shown a good correlation for all provinces, it is clear that studying the rainfall conditions using the 3-month SPI for December will provide an indicator of drought behavior for the following months. Therefore, the 3-month SPI can be used as the first drought warning indicator at the beginning of the rainy season. It is also emphasized that crop cover in February can be correlated with more than 55% accuracy using the December rainfall variation, as there is a good correlation between 3-month SPI and PCC.

Pearson correlation analysis (Table 13) was carried out in reference to CYA and key drought indices – 3-month SPI (December), PSC (January), PCC (February), VHI (March) and IDSI (April) – data to evaluate statistical significance. The analysis was undertaken for both drought and normal years, and it is evident that the CYA (Dutta et al. 2013) is highly correlated with the drought indices (Figure 16; Table 13). The correlation of IDSI (April) with CYA is 0.83, for example, while that of VHI (March) and CYA is 0.82 and that of 3-month SPI (December) and CYA is 0.78. Among all the drought indices, the combined IDSI of April has the highest significance with CYA.

Table 13. Correlation (Pearson) matrix between crop yield anomaly (CYA) and key drought indices.

	3-month SPI	PSC	PCC	VHI	IDSI	CYA
3-month SPI	1	0.31	0.52	0.74	0.84	0.78
PSC	0.31	1	0.2	0.14	0.29	0.32
PCC	0.52	0.2	1	0.67	0.91	0.6
VHI	0.74	0.14	0.67	1	0.91	0.82
IDSI	0.84	0.29	0.61	0.91	1	0.83
CYA	0.78	0.32	0.6	0.82	0.83	1

Ground-based Crop Yield Anomaly (CYA) in Rainfed and Irrigated Areas

Crop yield anomaly was measured for the current year in reference to historical yields. Table 14 shows year-wise CYA for wheat production in rainfed and irrigated areas at the provincial level from 2006 to 2018 using data obtained from NSIA.[5] It is evident from the interannual comparison that for the drought years 2008, 2011 and 2018, CYA shows higher negative values. Similarly, for normal years, such as 2007, 2009 and 2013, CYA has higher positive values. It is evident from the analysis that CYA has the potential to help identify the impact of drought and assist in developing drought-response strategies.

Assessment of Satellite-derived CYA and its Comparison with Observed Crop Production Data

Table 15 shows estimated crop yield (kgha^{-1}) derived from satellite data covering the rainfed and irrigated areas for selected provinces of Afghanistan. It is evident from the table that the yield estimates for the drought years 2008, 2011 and 2018 are very low compared to the normal years.

[5] http://www.data.gov.af/dataset/wheat-area-and-production-province (accessed on August 10, 2020).

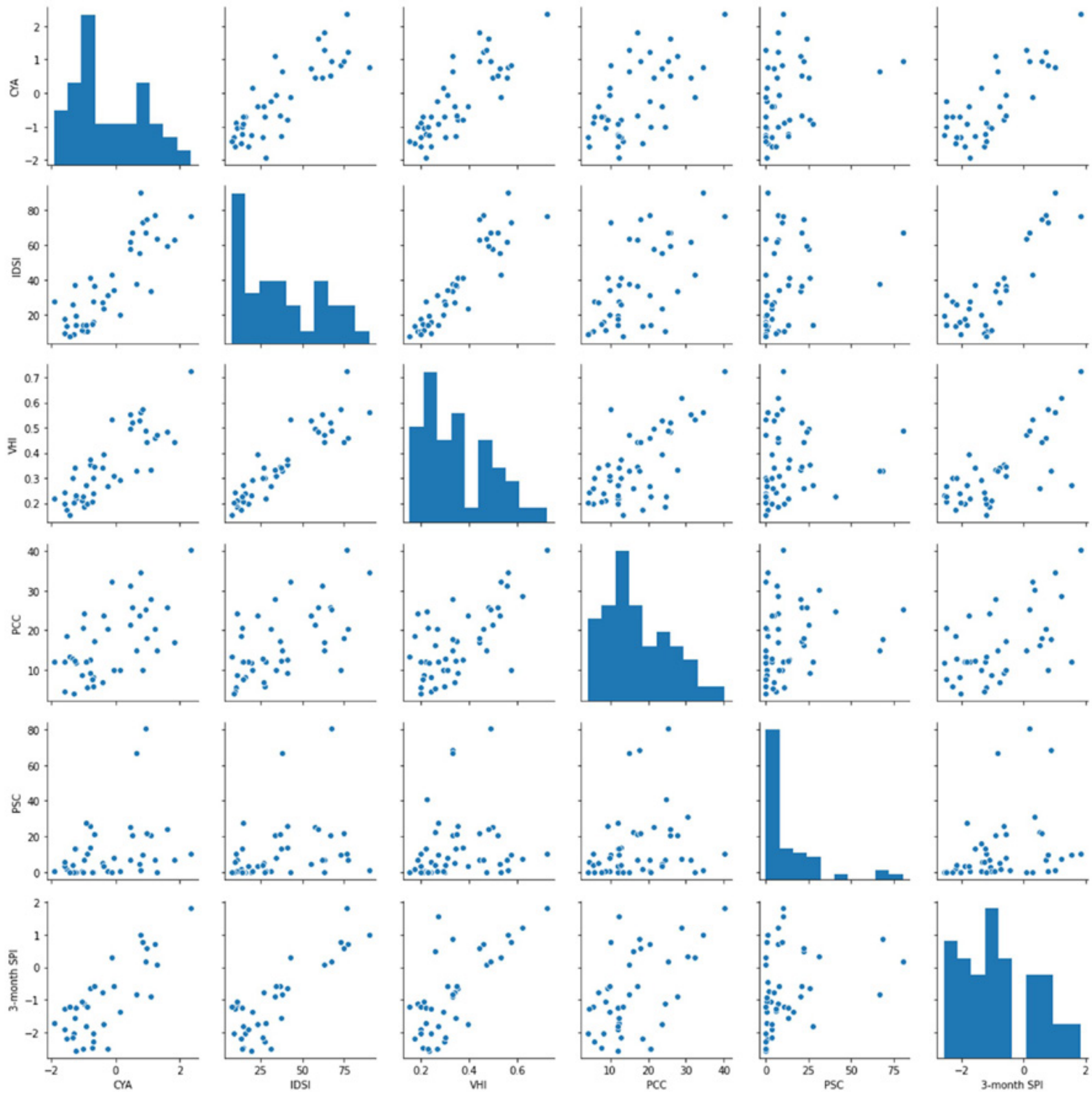


Figure 16. Scatterplot and histogram comparison of crop yield anomaly (CYA) and drought indices.

Table 14. Assessment of Crop Yield Anomaly (CYA) for selected provinces in rainfed (R) and irrigated (I) areas. The years highlighted indicate when severe drought affected those provinces.

Year	Balkh		Badghes		Faryab		Hirat		Jawzjan		Kunduz		Sar-e-Pul	
	R	I	R	I	R	I	R	I	R	I	R	I	R	I
2006	1.00	0.33	1.58	0.52	1.33	0.34	0.87	-0.25	0.68	1.08	-0.71	-0.59	1.47	0.19
2007	1.09	0.40	1.51	1.19	1.19	0.34	1.50	-0.25	0.97	1.28	-0.52	-0.54	1.34	0.31
2008	-1.01	-0.80	-1.09	0.05	-1.42	-0.44	-1.01	-1.26	-1.01	-0.97	-1.29	-1.35	-1.07	-0.42
2009	1.01	0.40	1.41	2.23	1.44	0.44	1.39	0.21	1.37	0.95	-0.04	-0.13	1.12	0.39
2010	0.07	0.79	0.12	0.10	1.02	2.22	-0.30	-0.72	0.61	0.88	-0.01	0.57	0.43	1.65
2011	-1.24	0.79	-1.09	0.62	-1.24	-0.84	-0.80	-0.36	-0.63	-0.77	-1.22	-0.84	-1.52	-0.62
2012	1.22	0.64	0.66	0.41	1.36	-0.21	-0.16	-0.55	2.16	1.52	0.12	0.31	0.32	0.72
2013	1.36	1.04	0.75	-0.04	-0.43	-0.68	1.86	-0.40	0.52	0.14	0.41	0.23	0.81	2.08
2014	1.05	0.97	-0.47	-1.03	-0.58	-0.59	-0.26	-0.31	0.40	-0.93	2.32	2.14	0.75	0.32
2015	0.02	1.09	-0.44	-1.39	-0.88	0.34	-0.05	0.38	-0.65	-0.07	0.90	1.14	-0.68	-0.24
2016	-0.49	-0.15	-0.26	0.36	-0.03	0.88	-0.07	1.96	-0.99	-1.26	0.67	-0.03	-0.71	-0.85
2017	-1.25	-1.93	-0.34	-0.59	0.12	1.24	-0.53	1.51	-1.15	-0.71	1.46	0.82	-1.11	-1.80
2018	-1.39	-1.35	-1.65	-1.58	-1.12	-1.93	-1.66	1.05	-1.20	-1.32	-1.35	-0.01	-1.37	-0.75

Table 15. Yield estimates obtained using MODIS Terra and Aqua GPP ($kgha^{-1}$) covering rainfed and irrigated areas for selected provinces of Afghanistan. The shades from red to green color show lower to higher production values.

Year	Balkh	Badghes	Faryab	Hirat	Jawzjan	Kunduz	Sar-e-Pul
2005	90.84	100.01	86.73	75.86	96.31	142.90	80.20
2006	82.79	73.66	74.83	60.59	83.76	135.21	80.20
2007	85.75	103.92	87.98	75.74	92.44	137.20	82.65
2008	50.28	57.56	51.93	50.50	46.56	87.05	52.00
2009	107.69	125.47	106.39	87.21	116.67	174.28	99.42
2010	107.67	108.25	99.73	80.24	103.19	157.46	98.36
2011	55.49	78.71	59.83	59.41	47.51	98.45	62.05
2012	82.91	94.13	75.18	61.05	76.25	132.85	79.66
2013	89.45	100.72	94.79	75.52	89.29	156.29	88.44
2014	75.90	70.68	69.20	57.34	68.39	141.04	69.96
2015	89.31	93.66	86.78	67.21	89.57	150.43	83.78
2016	76.67	93.26	86.95	71.74	75.14	132.62	78.61
2017	86.33	79.03	74.72	65.69	76.96	137.22	77.77
2018	66.24	56.63	49.97	60.45	37.62	139.72	62.77
2019	109.51	128.12	103.41	87.00	90.78	174.31	102.84

It is clear from Figure 17 that the satellite-derived production estimates indicate drought for the years 2008 and 2018, in contrast to the normal year 2019. The rainfed-dominated provinces, such as Badghes, Jawzjan and Faryab, are severely affected by drought compared to the irrigated areas such as Kunduz, Balkh and Helmand, which are dependent on water released from reservoirs. The comparative analysis (Figure 18) of production estimates using ground-derived and satellite-derived CYA shows a high correlation, indicating that this satellite-derived yield estimation can be used to assess the impact of drought on yield losses to support drought declaration and food security.

Drought Impact Assessment

The project evaluated the frequency and intensity of drought using the April IDSI value in relation to historical data (2001–2019) for the three drought classes – extreme, severe and moderate – in agricultural areas to assess the impact on the population. Figure 19(a) shows a district-level drought hazard map for the whole of Afghanistan. Out of 401 districts, 80 districts fall under the 'very high' drought hazard category, 80 districts are in the 'high' category, 86 districts are classified as 'moderate', 113 districts are 'low', and the remaining 42 districts are 'very low' or have 'no' likelihood of being affected by drought. According to Figure 19(b), the north, northwestern and central provinces are critical areas, where drought could have severely impacted the population in terms of food availability and livelihoods.

Finally, the drought risk analysis combined drought hazard and population exposure to determine the overall impact, using spatial aggregation to define drought-risk classes from 'very high' to 'very low'. Out of 401 districts, there are 60 districts categorized as 'very high' risk, 107 districts are 'high' risk, 63 are 'moderate' risk, 111 are 'low' risk, and 60 are 'very low ' risk (Figure 20). The map highlights where agricultural drought risks are highest, and indicates where the greatest impacts are likely to be on population and food security. The critical drought-prone provinces are mostly in the rainfed and rangeland areas such as Badghes, Faryab, Kunduz, Sar-e-Pul, Balkh, Jawzjan and Hirat.

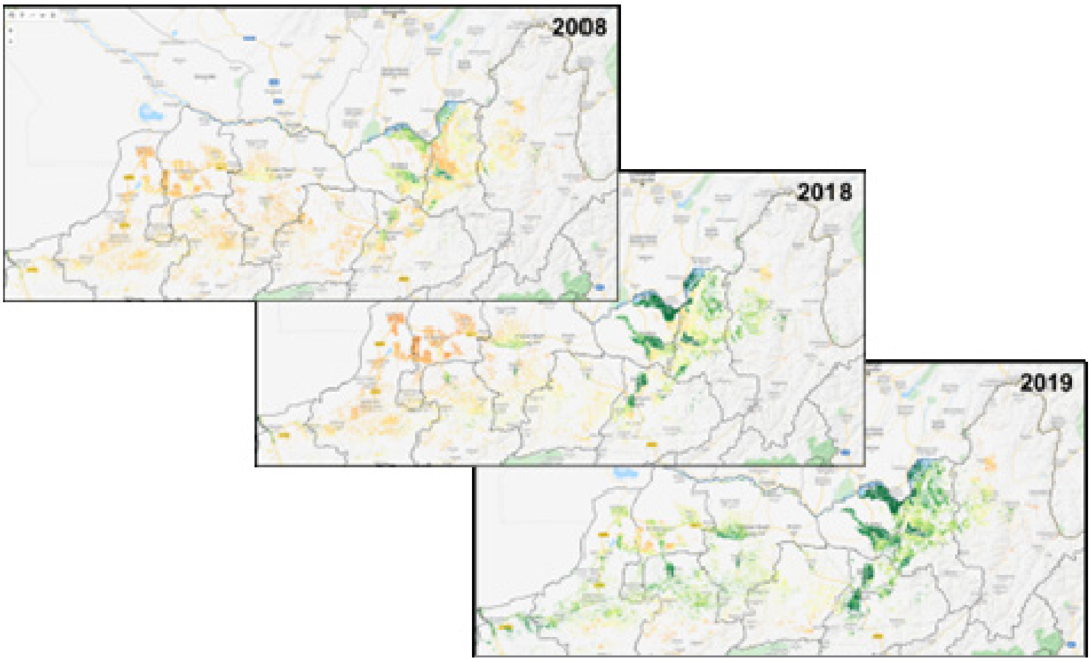


Figure 17. MODIS-based GPP for the drought years 2008 and 2018, and the normal year 2019. The shades of orange indicate lower production in rainfed areas and the shades of green indicate higher production in both rainfed and irrigated areas.

Figure 18. Comparison of crop yield anomaly (CYA) of (a) Jawzjan, and (b) Badghes with Observed (OBS) and GPP-based estimation.

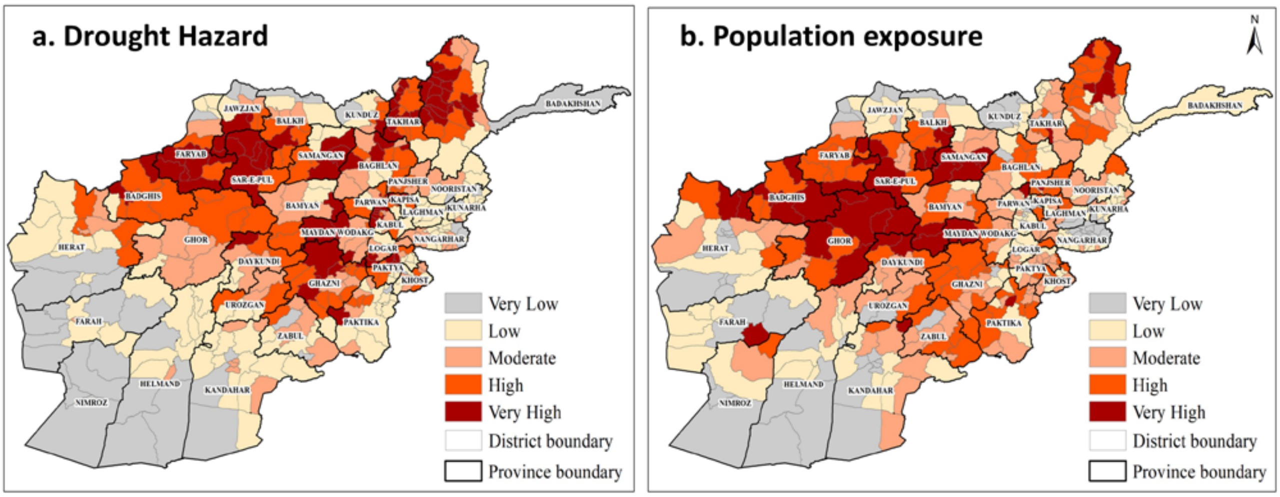


Figure 19. (a) Drought hazard map developed with the AF-DEWS Tool, using historical IDSI data from 2001 to 2019, and (b) population exposure to drought.

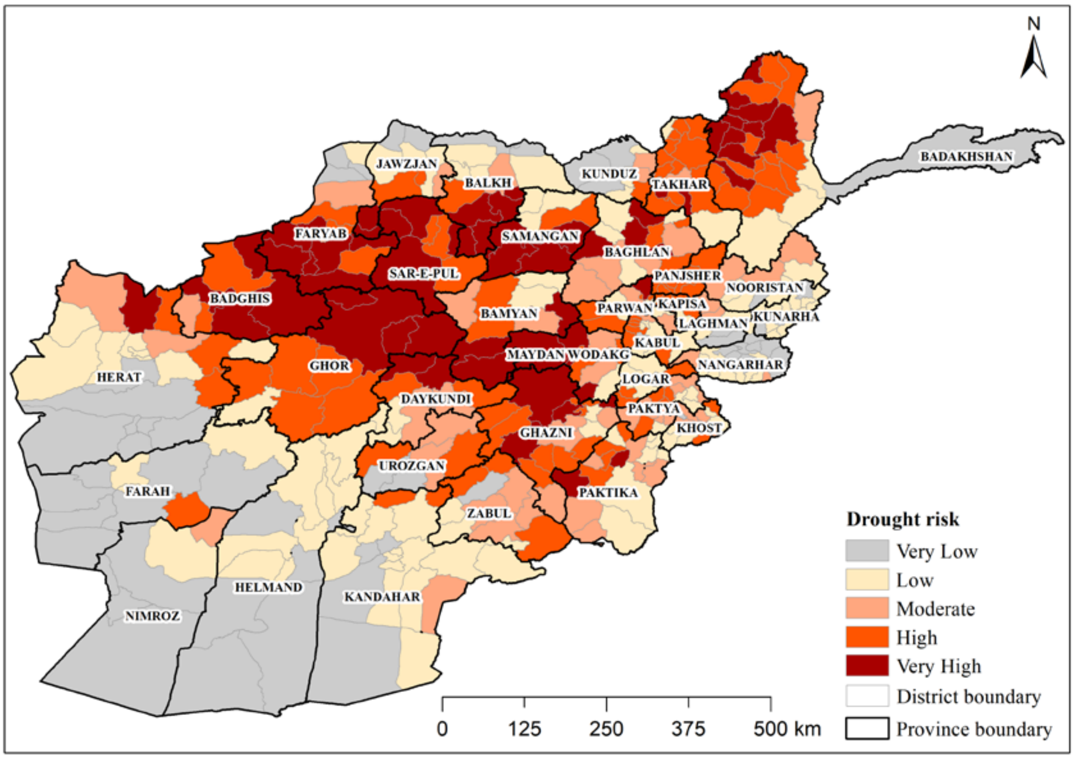


Figure 20. Drought risk map created using drought hazard and population exposure for Afghanistan.

Validation of the AF-DEWS Tool with Other Sources

There have been several years of drought in Afghanistan in the last 20 years. According to our assessment, localized droughts have a periodicity of between three and five years, with droughts covering large areas and recurring every 9 to 11 years. Importantly, the 2018 drought affected more than two-thirds of Afghanistan (22 out of the 34 provinces), with more than 10.5 million people (of the total 17 million in these 22 provinces) severely affected (UNDRR 2020).

The agricultural production losses reported by the AF-DEWS Tool for the drought years 2001 and 2018 were also reported by FAO. These were the most severe droughts ever recorded in Afghanistan (Figure 21) (FAO 2019). The drought risk maps produced using the AF-DEWS Tool compare well with other published sources, such as reports of the drought in The International Disaster Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED) and maps published by FEWS NET and United Nations agencies (Figure 22). This demonstrates the capabilities of the AF-DEWS Tool in supporting drought early warning and informing preparedness and risk reduction measures.

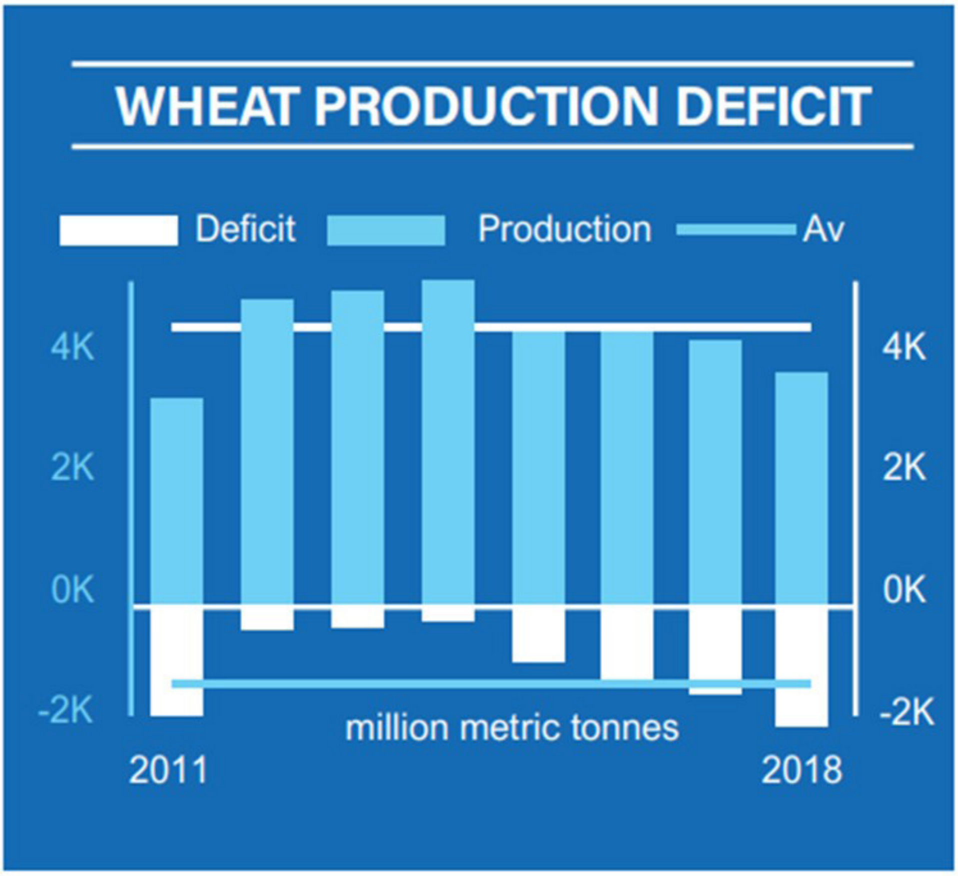
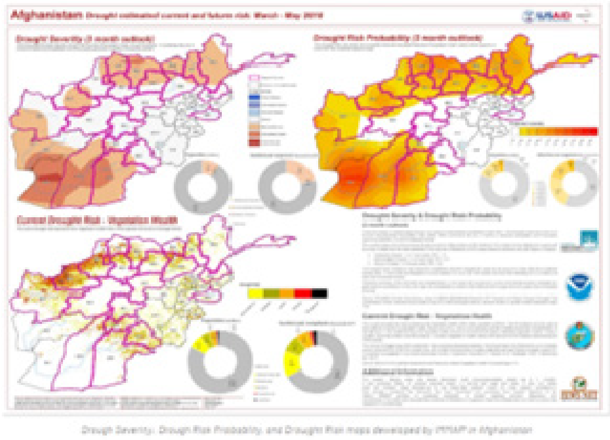
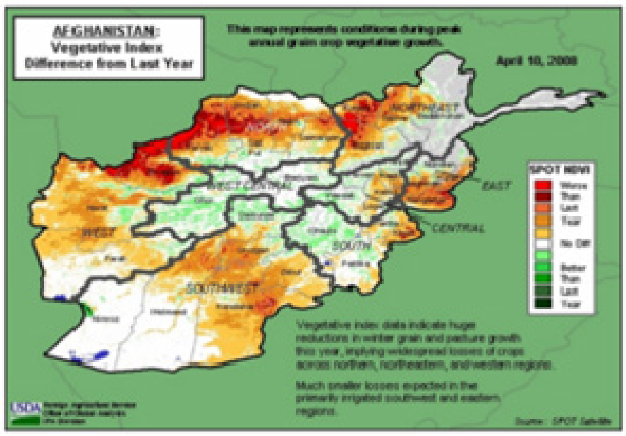


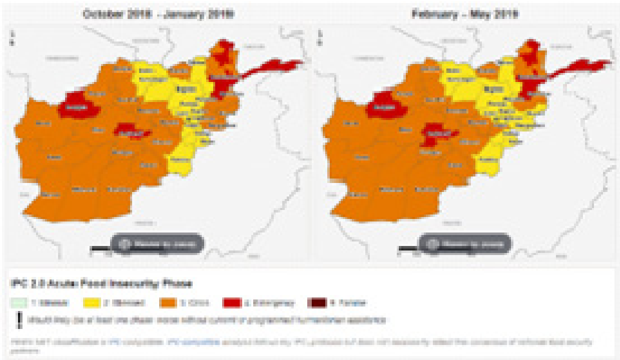
Figure 21. Wheat production statistics for Afghanistan between 2011 and 2018.
Source: FAO 2019.



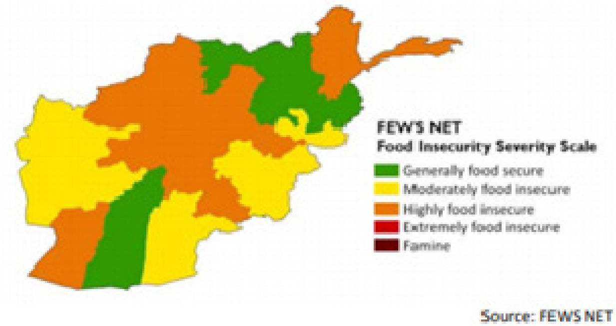
Source: https://immap.org/news/immap-presents-its-contributions-to-drr-in-afghanistan-during-national-conference/ (accessed on October 27, 2020)



Source: https://ipad.fas.usda.gov/highlights/2008/08/Afghanistan%20Drought/(accessed on November 30, 2021).



Source: https://fews.net/central-asia/afghanistan/food-security-outlook/october-2018 (accessed on October 25, 2022).



Source: https://fews.net/sites/default/files/documents/reports/afghanistan_OL_Q3Q4_final.pdf (accessed on November 30, 2019).

Figure 22. Drought maps produced by other agencies.

The Way Forward

This section explains coordination of the AF-DEWS Tool with other initiatives in Afghanistan, and strengthening drought risk management from early warning to early action and early finance.

Convergence of the AF-DEWS Tool with Other Initiatives

There is great potential for the convergence of the AF-DEWS Tool with other initiatives, such as FEWS NET (created by the United States Agency for International Development [USAID]) for monitoring food insecurity and iMMAP for humanitarian coordination, and national- to provincial-level institutions in Afghanistan. It can support efforts to improve drought management[6] across three pillars: monitoring and early warning systems; vulnerability and impact assessment; and mitigation, preparedness and response. Table 16 highlights the strengths and opportunities presented by the AF-DEWS Tool towards building a strategic partnership with GoIRA, United Nations and other partners.

[6] https://www.droughtmanagement.info/about/ (accessed on November 30, 2021).

Table 16. Comparison of the AF-DEWS Tool with FEWS NET and iMMAP.

Features	AF-DEWS	FEWS NET	iMMAP
Background	The prototype was developed in 2020 and funded by the World Bank and GoIRA. IWMI is the prime contractor to implement the AF-DEWS Tool in the wider framework of drought Early Warning, Early Action and Early Finance to promote comprehensive drought risk management.	Established in 1985 in East and West Africa, and funded by USAID; works in cooperation with three other US government agencies – National Aeronautics and Space Administration (NASA), United States Geological Survey (USGS) and United States Department of Agriculture (USDA). Chemonics is the prime contractor to provide critical data to monitor rising or waning food insecurity situations specific to Afghanistan.	Established in 2020 and funded by USAID, the organization provides information management services to humanitarian and development communities, which will support informed decision-making processes.
Pros and cons	**Pros**: provides ready-to-use, constantly updated satellite-based indices for monitoring meteorological, agricultural and hydrological droughts. **Cons**: skilled capacities needed to ensure platform sustainability and usability.	**Pros**: combines many parameters from climate to food prices; frequently updated; very comprehensive. **Cons**: not specifically intended for drought; information embedded within the system cannot be directly accessed by GoIRA.	**Pros**: integrates spatial and non-spatial data for emergency response by all actors. **Cons**: mostly static maps; limited applicability to drought monitoring and early warning.
Platform	Robust, transparent and operational. It is the first drought early warning system (DEWS) available in the cloud environment to enable rapid drought declaration.	FEWS NET Data Center provides a range of products through multiple services/platforms for food security assessment, and is limited for drought declaration purposes.	iMMAP Afghanistan Spatial Data Center is a dissemination platform for disaster risk reduction data and other baseline information. It is not implemented in the cloud framework.
Cost and maintenance	Very low (~USD 200 per month) through Microsoft Azure and Google Cloud Platform with basic maintenance and limited Human Resource involvement.	High cost with the involvement of several commercial partners.	High cost with the involvement of several commercial partners.
FAIR data principles (Findable, Accessible, Interoperable, Reusable)	High	Moderate	Moderate

Figure 23 highlights the strengths of the AF-DEWS Tool, from accurate and efficient monitoring and early warning to using historical drought records for long-term impact assessments, guiding institutions at the national, provincial and district levels. It also allows emergency and relief agencies to provide timely drought alerts for promoting early action, and bring together multiple sectoral and service delivery agencies towards mitigating the worst impacts of drought.

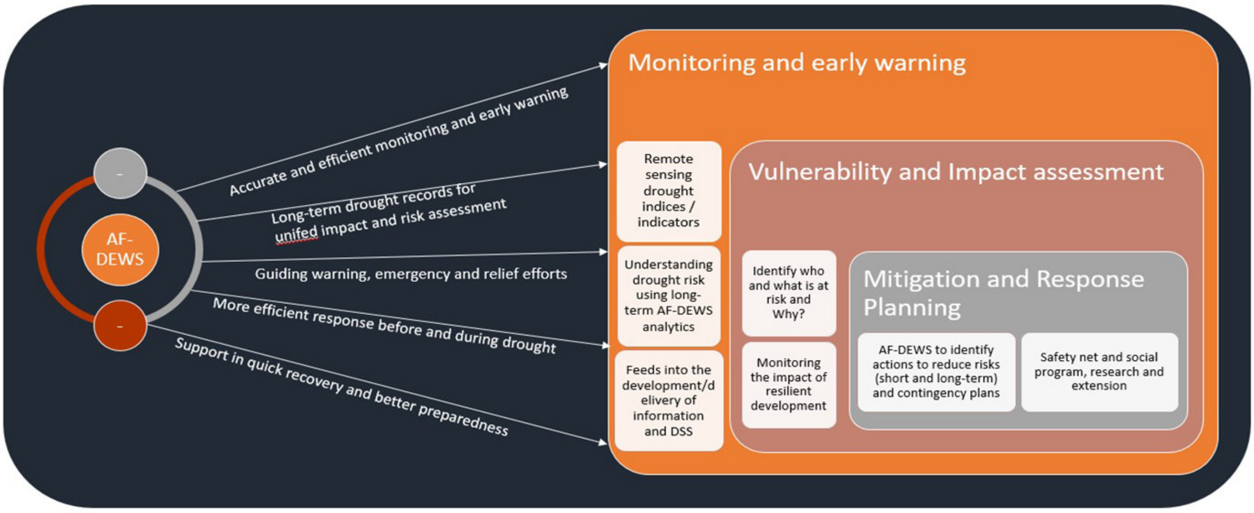


Figure 23. Use of the AF-DEWS Tool within broader drought risk management initiatives.

Capacity Building and Knowledge Transfer

With the AF-DEWS Tool now functional, it needs to be embedded within short- and long-term drought mitigation plans developed as part of the Early Warning, Early Finance and Early Action (ENETAWF) project. Useful next steps include the following:

- Efforts to promote cooperation among Afghanistan's technical agencies, so they can easily share data, technologies and knowledge.
- Use of the AF-DEWS Tool for weather forecasting, monitoring and forecasting drought events, and initiating early warning procedures will need to be operationalized by the appropriate parties. Training will be needed in GEE and relevant programming languages to facilitate the development and maintenance of the AF-DEWS Tool.
- Make appropriate institutions aware of the potential to integrate drought knowledge products in broader agricultural and water management processes to underpin food security.
- Conduct training workshops at the national and provincial levels.
- Invest more human and financial resources in research on drought monitoring and early warning methods, and geospatial technologies to enhance drought preparedness and mitigation capabilities.
- Build capacity to implement emergency response and recovery measures that reinforce national drought management policy goals.[7]
- Strengthen the capacity of national and provincial agencies to disseminate information generated by the AF-DEWS Tool in local languages.
- Establish a dedicated national drought monitoring center to promote comprehensive drought risk management strategies – ranging from compiling data to monitoring drought and reporting impacts through drought bulletins issued by GoIRA's Drought Early Warning Committee (DEWC).

[7] https://www.droughtmanagement.info/find/library/

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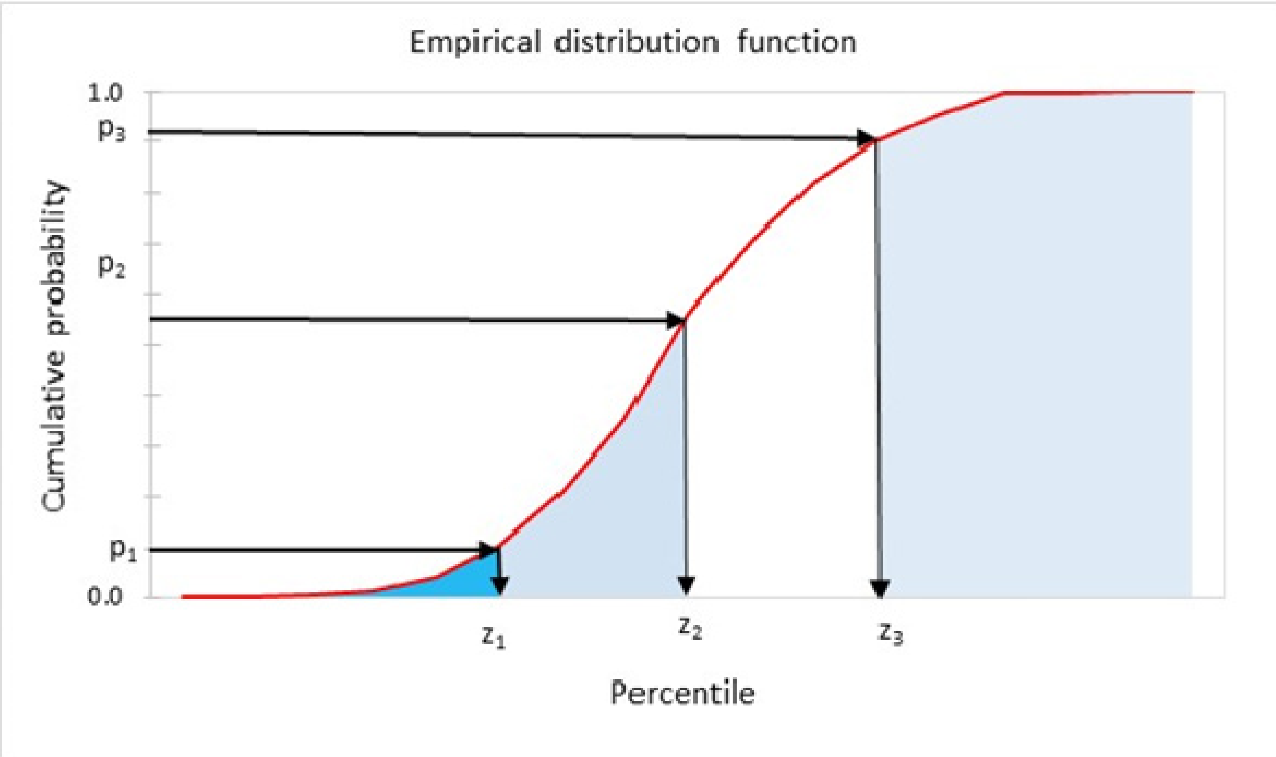
Annex 1. Cumulative Distribution Function.



Annex 2. Provincial-level Threshold Values for Different Drought Classes.

Province	SPI (December)			PSC (January)			PCC (February)			VHI (March)			IDSI (April)		
	ED	*SD*	*MD*	*ED*	*SD*	*MD*	*ED*	*SD*	*MD*	*ED*	*SD*	*MD*	*ED*	*SD*	*MD*
Badakhshan	-1.75	-1.25	-0.94	55.44	61.04	63.22	1.91	3.30	4.48	0.35	0.37	0.38	0.35	0.35	0.36
Badghes	-2.4	-1.04	-0.52	0.50	1.01	2.33	33.83	35.26	36.32	0.16	0.19	0.32	0.17	0.19	0.29
Baghlan	-1.9	-1.27	-0.52	12.55	16.52	18.98	7.97	9.47	13.17	0.28	0.29	0.42	0.32	0.35	0.38
Balkh	-1.91	-0.94	-0.57	0.87	1.04	1.37	11.40	12.57	19.12	0.19	0.20	0.34	0.17	0.18	0.29
Bamyan	-1.89	-1.06	-0.52	30.71	35.90	45.62	0.05	0.14	0.20	0.38	0.42	0.44	0.32	0.36	0.39
Daykundi	-1.45	-1.17	-1.04	7.08	10.14	17.22	0.32	0.97	1.95	0.43	0.43	0.45	0.37	0.40	0.41
Farah	-1.81	-0.86	-0.28	0.01	0.06	0.12	2.47	2.57	2.76	0.19	0.22	0.25	0.17	0.21	0.26
Faryab	-1.85	-1.15	-0.38	2.88	3.32	5.94	18.36	18.97	19.31	0.17	0.20	0.27	0.16	0.19	0.28
Ghazni	-1.39	-1.16	-0.73	1.64	2.25	6.40	2.04	2.33	2.94	0.30	0.32	0.33	0.26	0.31	0.33
Ghor	-1.51	-1.36	-0.58	12.15	14.61	27.48	0.25	0.45	0.71	0.35	0.36	0.38	0.30	0.31	0.36
Hilmand	-1.49	-0.86	-0.66	0.08	0.09	0.14	3.94	4.32	4.83	0.22	0.23	0.30	0.16	0.21	0.29
Hirat	-2.29	-0.92	-0.24	0.43	1.00	1.46	6.95	8.02	9.08	0.24	0.25	0.28	0.21	0.26	0.28
Jawzjan	-2.15	-0.93	-0.57	0.02	0.03	0.07	12.91	13.98	15.64	0.19	0.22	0.27	0.07	0.11	0.20
Kabul	-1.58	-1.48	-0.82	1.84	3.67	5.66	5.17	5.72	7.40	0.33	0.34	0.36	0.33	0.33	0.34
Kandahar	-1.66	-1.25	-0.82	0.01	0.01	0.02	0.54	0.99	1.40	0.17	0.19	0.26	0.09	0.17	0.23
Kapisa	-1.54	-1.43	-0.83	1.18	2.30	5.33	11.90	12.37	13.36	0.40	0.41	0.42	0.33	0.35	0.36
Khost	-1.79	-1.29	-0.65	0.00	0.00	0.00	9.20	9.53	10.62	0.27	0.33	0.43	0.24	0.31	0.38
Kunarha	-1.62	-1.49	-0.95	2.60	4.45	7.16	7.47	7.97	8.30	0.37	0.41	0.44	0.28	0.31	0.33
Kunduz	-1.6	-1.01	-0.46	0.01	0.01	0.02	26.09	29.13	33.24	0.22	0.31	0.37	0.22	0.23	0.34
Laghman	-1.65	-1.45	-0.87	6.32	7.25	9.62	6.20	6.73	9.04	0.43	0.47	0.49	0.33	0.34	0.36
Logar	-1.67	-1.46	-0.73	0.27	0.69	1.26	2.35	2.77	3.79	0.31	0.32	0.36	0.34	0.35	0.40
Maydanwardag	-1.74	-1.18	-0.65	11.89	15.36	18.05	0.35	0.37	0.38	0.35	0.37	0.38	0.29	0.32	0.39
Nangarhar	-1.49	-1.34	-1.04	0.70	1.21	2.45	9.43	9.89	10.29	0.31	0.35	0.42	0.21	0.27	0.32
Nemroz	-1.22	-0.92	-0.62	0.00	0.00	0.00	0.03	0.04	0.12	0.18	0.20	0.26	0.24	0.24	0.32
Noristan	-1.68	-1.52	-1.03	39.81	51.62	55.09	1.06	1.16	1.25	0.37	0.38	0.42	0.28	0.29	0.32
Pakteka	-1.6	-1	-0.64	0.00	0.01	0.06	0.65	0.79	1.10	0.24	0.26	0.30	0.22	0.25	0.27
Paktya	-1.62	-1.6	-0.64	0.06	0.08	0.16	1.69	1.89	3.01	0.34	0.34	0.36	0.32	0.37	0.41
Panjsher	-1.75	-1.45	-0.74	40.57	43.98	55.85	0.57	0.71	0.94	0.34	0.36	0.42	0.32	0.33	0.34
Parwan	-1.62	-1.33	-0.93	12.41	16.86	19.81	8.60	8.98	9.56	0.35	0.39	0.42	0.32	0.35	0.36
Samangan	-2.13	-0.96	-0.52	6.99	7.74	16.48	10.12	14.25	15.71	0.22	0.25	0.39	0.26	0.32	0.44
Sar-e-Pul	-1.67	-1.04	-0.55	12.41	14.17	18.06	20.20	21.11	24.79	0.27	0.28	0.37	0.25	0.29	0.36
Takhar	-1.89	-1.23	-0.64	8.15	10.08	11.74	12.14	16.73	25.25	0.19	0.28	0.32	0.24	0.25	0.41
Uruzgan	-1.83	-1.06	-0.75	1.15	1.60	2.68	0.96	1.11	1.83	0.33	0.34	0.36	0.24	0.29	0.34
Zabul	-1.61	-1.27	-0.72	0.39	0.50	0.60	0.21	0.36	0.42	0.18	0.20	0.27	0.13	0.22	0.28

Annex 3. Glossary.

Climate – The prevailing weather conditions in a particular area over a long period of time.

Climatology – The study of climate.

Composite Drought Index – Multiple indicators, such as the Vegetation Health Index, Integrated Drought Severity Index and Surface Water Supply Index, can be used in combination to indicate drought presence and severity.

Drought – When less rainfall than the long-term average occurs over an extended period, usually several months or longer. Or, more formally, a deficiency of rainfall over a period of time, resulting in a water shortage for some activity, group or the environmental sector.

Drought early warning system – Drought early warning systems typically aim to track, assess and deliver relevant information about climatic, hydrologic and water supply conditions and trends. Ideally, they incorporate a monitoring component (including impacts) and a forecasting component. The objective is to provide timely information in advance of, or during, the early onset of drought to instigate action (via threshold triggers) to implement a drought risk management plan as a means of reducing adverse impacts.

Indicators – Indicators are variables used to describe drought conditions. They include precipitation, temperature, streamflow, groundwater and reservoir levels, soil moisture and snow cover.

Indices – Indices are used to quantitatively assess the severity, timing and duration of drought events.

Single index – A single indicator, such as the Standardized Precipitation Index (measuring rainfall or snowfall), can be used on its own to indicate drought condition and severity.

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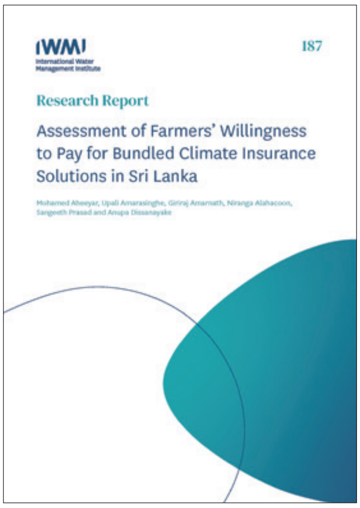
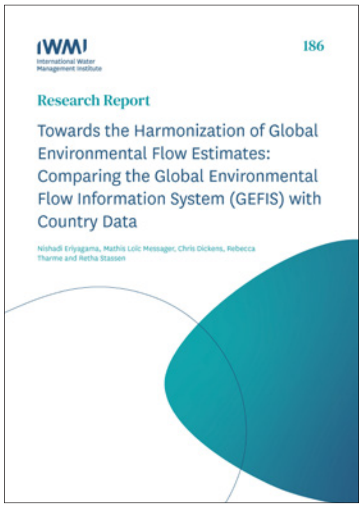
188 Afghanistan Drought Early Warning Decision Support (AF-DEWS) Tool
https://doi.org/10.5337/2023.223



187 Assessment of Farmers' Willingness to Pay for Bundled Climate Insurance Solutions in Sri Lanka
https://doi.org/10.5337/2023.222



186 Towards the Harmonization of Global Environmental Flow Estimates: Comparing the Global Environmental Flow Information System (GEFIS) with Country Data
https://doi.org/10.5337/2023.224

185 Institutional Gender Mainstreaming in Small-Scale Irrigation: Lessons from Ethiopia
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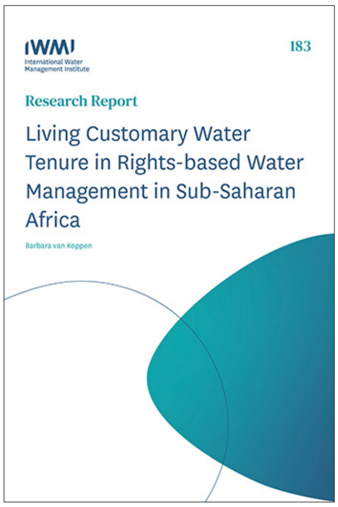

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