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Global inventory of drought hazard and risk modeling tools and resources

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Contents

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[1] *World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.*

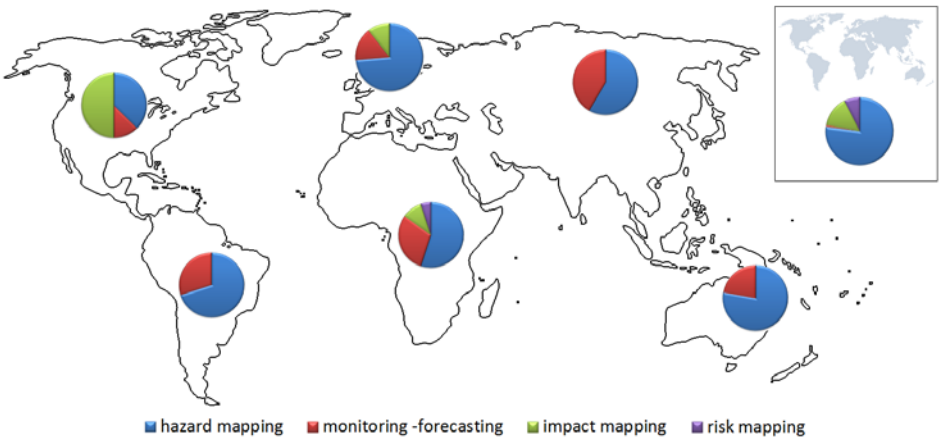
[2] *http://www.earth2observe.eu/*

Abstract

As global drought disaster impacts rise across the globe, there is an increasing need for the accurate assessment and monitoring of drought hazards, impacts, and risks to support decision making on drought risk reduction, risk financing and disaster response. Although numerous new products have been developed over the past years, there is currently no comprehensive overview of the available data and tools that can be used for drought hazard and risk assessments.

This report presents a global inventory of drought hazard and risk modeling tools and resources with global, regional, and national application scales. This global drought risk inventory focuses on a range of applications covering hazard mapping, monitoring and forecasting of hazards, impacts, and risks related to meteorological drought, hydrological drought, agricultural drought, and socio-economic drought. The almost 200 modeling tools and resources included in the inventory consist of indices, datasets, platforms, newsletters/bulletins, modeling software packages, and other tools. The report provides an overview per region and concise descriptions in reports of all drought hazard and risk modeling tools and resources that are currently collected. Besides a general description and its' main characteristics, for each drought modeling tool and resource, contact information, references, and online links are provided. This enables the user of this inventory to obtain more information and download the tool or resource of interest.

Based on this inventory it could be concluded that the majority of modeling tools and resources provide (real-time) information of meteorological, agricultural, and hydrological drought hazards (see image below). We recommend that more effort is put in the development of tools that focus on socio-economic drought hazards, drought impacts, and drought risks. In addition, in some areas in developing countries the available drought tools and resources mainly consist of newsletters/bulletins; it is recommended to improve the availability of (real-time) datasets and tools at the local level for such areas.



1. Introduction

1.1 Background, purpose and use of this document

As global disaster impacts rise across the globe, there is an increasing need for the accurate assessment and monitoring of hazards and risks to support decision making on risk reduction, risk financing and disaster response. Over the past few years, the Global Facility for Disaster Reduction and Recovery (GFDRR) has supported national-level disaster risk assessments for flooding, drought, earthquake, volcanic, landslide, avalanche and cyclone hazards across dozens of developing countries. These assessments cover a probabilistic mapping of hazard intensities, as well as the quantification of their impacts on population and economic assets.

Multiple models, methods and tools are available for hazard monitoring and risk assessment. This is especially true for drought. Over the past years, numerous new products have been developed that enable the monitoring and mapping of drought hazard from satellite observations and hydrological models; and estimate physical, economic and humanitarian impacts of drought. The products include academically published papers, online web platforms, bulletins and operational tools.

In spite of all these possibilities, there is currently no comprehensive inventory and comparison of the available data and tools. It is therefore currently very difficult to decide on the appropriate model or tool for a specific drought-related purpose, and to find these models and underlying data to perform the assessment. As a result, drought hazard monitoring programs and drought risk assessment studies may often use sub-optimal approaches and spend substantial resources on finding the appropriate models.

GFDRR aims to support professionals in assessing drought hazard and risk in data-scarce environments with clear information and guidance documents. Therefore, they initiated the development of this global inventory of drought hazard and risk modeling tools and resources. The inventory was carried out by a team of drought experts from Deltares, Institute for Environmental Studies, Vrije Universiteit Amsterdam (VU-IVM), IHE-Delft, University of California, Santa Barbara (UCSB) and the National Drought Mitigation Center (NDMC). The results of the inventory consist of this report, which provides an overview and description of all collected modeling tools and resources, and an online data catalogue.

The main objective of this document is to present a global inventory of drought hazard and risk modeling tools and resources and explain its' structure, content and background. The drought hazard and risk modeling tools and resources in this inventory include online platforms, newsletters or bulletins, datasets, indices as well as other model tools required to transform basic datasets (e.g. precipitation) into derived parameters (e.g. runoff, groundwater levels) which are required for drought (risk) characterization. The collected drought hazard and risk modeling tools and resources cover a range of applications, most importantly: drought detection and forecasting, drought hazard mapping and hotspot identification, as well as assessments of drought impacts and risks. It is important to note that even though efforts were made in order to create the inventory as complete as possible, such an inventory can never be fully complete as new resources are under constant development.

Prior to the overview of all drought hazard and risk modeling tools and resources, information on the methods of the global inventory is provided. This includes the description of the scope of the inventory, descriptions of the types of drought modeling tools and resources, the

drought types included, and the range of applications taken up. Also, an overview of the relevant characteristics is given for the different types of modeling tools and resources.

Most importantly, this report documents each drought modeling tool and resource in an information sheet containing a brief description, general characteristics, source and contact information, possible applications, costs of access to the model, scientific reporting and quality information as well as information on spatial and temporal scales. The information sheets are concise and have a consistent layout and structure. In addition to these information sheets, an overview of the drought risk modeling tools and resources is provided in a summary table.

The content of the inventory is available through an interactive, online drought catalogue (see section 1.2). Together, this report and the data catalogue enable professionals to select appropriate drought risk modeling tools and resources to assess drought hazards and risk for their region, country or area.

1.2 Online drought catalogue

The content of the inventory is available through an interactive, online drought catalogue that can be found at https://droughtcatalogue.com/. This website contains all the information collected for the different drought platforms, datasets, indices, modeling software, bulletins, and tools. In addition, the website contains a concise manual with information on how to use the drought catalogue as well as this report and a report presenting a comparative assessment of a selection of the drought hazard and risk modeling tools and resources. Moreover, a drought risk guidance document is available at the website. Through a “Contact” section, the user can suggest improvements or additions to the drought catalogue. The home page of the website is presented in Figure 1.1.

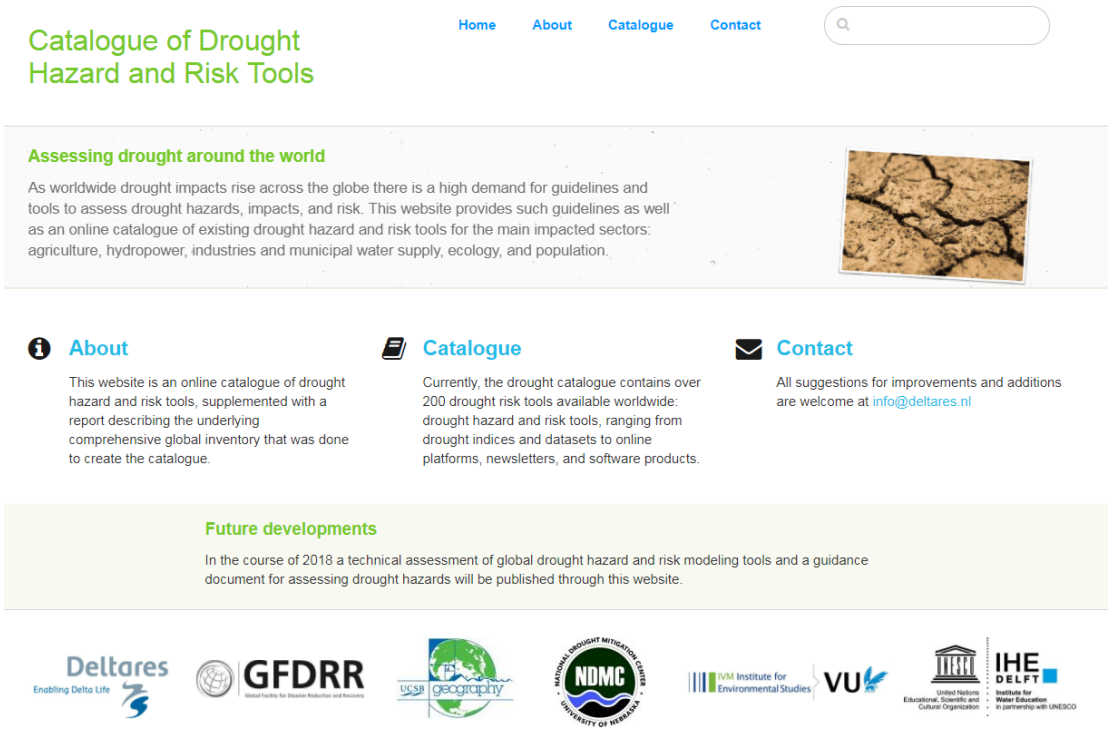


Figure 1.1 Homepage of the interactive online drought catalogue

2 Drought terms and definitions

In this report we follow the widely accepted definitions related to disaster risk used in the Sendai Framework[3].

Hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. It is characterized by its location, intensity or magnitude, frequency and probability.

Hazardous event is the manifestation of a hazard in a particular place during a particular period of time.

Exposure is defined as the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Vulnerability is defined as the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Drought risk is defined as the potential loss of life, injury, or destroyed or damaged assets that could occur to a system, society or a community in a specific period of time, determined probabilistically as a function between: drought hazard, exposure and vulnerability.

Drought impact is the total effect, including negative effects (e.g., economic losses) and positive effects (e.g., economic gains), of a drought event. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being.
The sub-sections below consecutively describe the terms drought hazard, exposure to drought, vulnerability to drought, and drought risk in more detail.

2.1 Drought hazard

Drought is normally defined as a prolonged period of abnormally dry weather condition leading to a severe shortage of water. Drought is a natural temporary feature of the climate cycle that causes damages and can have severe impacts in most regions of the globe[4].
Droughts are recurring and worldwide phenomena with spatial and temporal characteristics that vary significantly from one region to another. There are numerous definitions of drought; covering all parts of the hydrological cycle. The types of droughts commonly identified are meteorological drought, hydrological drought, agricultural drought, and socio-economic

[3] *UN General Assembly, Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction, 2016.*

[4] *AMS: Drought- An Information Statement of the American Meteorological Society (Adopted by AMS Council on 19 September 2013), https://www.ametsoc.org/index.cfm/ams/about-ams/ams-statements/statements-of-the-ams-in-force/drought/, accessed August 2018, 2013.*

drought[5] (see section 3.2). The first three of these types of drought are based on physical phenomena, although anthropogenic influence on drought increases as drought propagates from meteorological to hydrological. Socio-economic drought describes droughts in terms of supply and demand of water. The length of time over which precipitation deficits accumulate becomes extremely important and functionally separates different types of drought. Agricultural (soil moisture) droughts, for example, typically have a much shorter time scale than hydrologic (groundwater, streamflow and reservoir) droughts[6]. Section 3.2 presents a short description of these four drought types based on Wilhite[7].

Drought should not be confused with low flow, aridity, water scarcity, or desertification, or with related hazards such as heat waves and forest fires[8]. While aridity is a permanent condition of some regional climates with very low annual precipitation, water shortage is a temporary water imbalance that can occur due to drought or due to human activities. Van Loon et al. (2015)[9] defines "water scarcity" as a water supply shortage or a situation in which anthropogenic influence on the water system plays an important role in the development of below-normal water availability. Water scarcity is caused at least in part by human activities and reflects conditions with *long-term* imbalances between available water resources and demands. The MEDROPLAN[10] project nicely illustrates these concepts related to water availability (Table 2.1).

Table 2.1 Schematic overview of the terms drought, aridity, water shortage, and water scarcity, classified according to duration and cause of water shortage. Based on a figure from MEDROPLAN project.

Duration of limited water availability	**Cause of limited water availability**	
	Natural	**Anthropogenic**
Temporary	Drought	Water shortage
Long-term / permanent	Aridity	Water scarcity Desertification

2.2 Exposure to drought

Exposure to drought comprises all assets and sectors located in a drought-prone area. Examples of sectors that are susceptible to droughts and are relevant to include as exposure in a drought (risk) assessment are among others, agriculture, energy and industry, drinking/domestic water supply, navigation, ecosystems, tourism, forestry, aquaculture and fisheries, and the financial sector (investors, insurances, asset owners).

[5] *Wilhite, Donald A. and Glantz, Michael H., "Understanding the Drought Phenomenon: The Role of Definitions" (1985). Drought Mitigation Center Faculty Publications. 20. http://digitalcommons.unl.edu/droughtfacpub/20.*

[6] *McKee, T. B., Doesken, N. J., and Kleist, J.: The relationship of drought frequency and duration to time scales, Proceedings of the 8th Conference on Applied Climatology, Vol. 17. No. 22, Boston, MA: American Meteorological Society, 17, 179-183, 1993*

[7] *Wilhite, Donald A., "Understanding the Phenomenon of Drought" (1993). Drought Mitigation Center Faculty Publications. 50. http://digitalcommons.unl.edu/droughtfacpub/50.*

[8] *Van Loon, A. F. (2015), Hydrological drought explained. WIREs Water, 2: 359-392. doi:10.1002/wat2.1085.*

[9] *Van Loon, A. F. (2015), Hydrological drought explained. WIREs Water, 2: 359-392. doi:10.1002/wat2.1085.*

[10] *European Commission – Europe Aid Co-operation Office Euro-Mediterranean Regional Programme for Local Water Management (MEDA Water) Mediterranean Drought Preparedness and Mitigation Planning (MEDROPLAN). Drought Management Guidelines*

In a drought risk assessment it is important to collect data on exposure characteristics that will influence the magnitude of the potential impact of the drought. Population relying on each sector (for income, food supply, water and electricity supply, etc.) and the economic value of each sector are relevant exposure characteristics to determine the impact of drought for all sectors. For example, the larger the share of exposed GDP, the larger the potential impact of a drought on the economy of a country.

However, there are also many sector specific characteristics that are relevant to include in drought risk assessments. For example, certain crop types are more vulnerable to droughts than others. Therefore, it is important to include the exposed crop types to determine the drought risk for the agriculture sector. We highlight a few of these sectors to illustrate what type of exposure characteristics could be relevant when determining the magnitude of drought risk to a specific sector.

Variables that can be used to measure and/or express drought exposure for the **agriculture sector** are, among others:

(a) agricultural land area,
(b) agricultural crop types,
(c) potential agricultural yield in volume or monetary value, and
(d) livestock density (e.g. cattle, pigs, and poultry).

Relevant, spatial and temporal information has to be collected for these variables. For example, moving livestock to other, less drought-prone pastures during the drought season will considerably lower the drought impact to the agriculture sector. Therefore it is important to know when and where livestock is present.

Variables that can be used to measure and/or express drought exposure for the **energy and industry sector** is spatial and temporal information on industrial and energy producing activities, such as:

(a) type of industry,
(b) specific location of industries,
(c) density of industrial activities, and
(d) location and capacity (water, energy production) of dams and reservoirs used for hydropower production.

Variables that can be used to measure and/or express drought exposure for the **drinking/domestic water supply sector** are, for example:

(a) population density (distinguishing between rural and urban population),
(b) domestic water consumption per capita, and
(c) location, capacity, action radius, and economic value of drinking water utility firms.

Variables that can be used to measure and/or express drought exposure for the **navigation sector** are, among others:

(a) spatial information (following the river network) identifying the main navigation transportation routes or most important harbours,
(b) shipping density and specific shipping characteristics, and
(c) economic value associated with navigation activities.

Examples of exposure datasets that can be used to address the potential impacts of drought on **ecosystems** are, for example:

(a) location and size of highly valued and/or protected nature areas (e.g. RAMSAR),

(b) location and density of existing species of flora and fauna, particularly when these are protected species, and
(c) spatial information on highly-valued rare ecosystems.

Variables that can be used to measure and/or express drought exposure for the **financial sector** are, for example:
(a) location of investments,
(b) value of investments,
(c) water use of companies in investment portfolio

2.3 Vulnerability to drought

The magnitude of the impact of a drought depends on the vulnerability of the exposed assets and sectors. Here, vulnerability can be referred to as the predisposition of assets or sectors to suffer adverse effects when exposed to a drought event. The level of vulnerability to a drought (type) is determined by the intrinsic characteristics of the asset or sector. For example, certain crop types are more vulnerable to droughts than others; and proximity of a drinking water plant to the coast makes it more vulnerable to salt intrusion during a drought. Therefore, it is important to collect the intrinsic exposure characteristics for the asset or sector as addressed in the exposure section above. Not all sectors are, however, vulnerable to all types of droughts. Below we describe for a few sectors why they are susceptible to certain specific droughts.

Agriculture is affected by all drought hazard types. Rain fed agriculture is susceptible to meteorological and agricultural drought, while irrigated agriculture is susceptible to hydrological droughts.

Energy and industry are often dependent on riverine water abstractions, and therefore on volume and quality of the stream flow. This means that the energy and industry sector is susceptible to hydrological droughts. In addition to streamflow, in specific regional cases (**hydropower** supply) reservoirs levels (absolute levels, deviations from normal, or relative to a critical threshold level) are also used to identify the hydrological drought hazard for this sector.

Drinking water/domestic water supply can be affected by hydrological droughts, as the drinking water supply utilities usually extract their resources from either riverine-fed reservoirs or groundwater resources.

Navigation is susceptible to hydrological droughts as it is the riverine stream flow that determines whether there is sufficient draft for ships to navigate or enter harbours.

Ecosystems can be affected by meteorological, hydrological and agricultural droughts due to the varied nature of ecosystems. Terrestrial ecosystems are susceptible to meteorological and agricultural droughts, while aquatic ecosystems are susceptible to hydrological droughts.

As the different sectors are impacted in different ways by droughts, there is no single way to quantify vulnerability and many different vulnerability indicators and variables are used to determine the potential impacts of droughts of specific sectors. To assess drought vulnerability in a more generic way, for instance for large scale or exploratory drought risk assessments, a distinction can be made between three vulnerability categories as vulnerability to droughts can be quantified by means of social, economic and infrastructural

factors. For each of these indicators proxies have been identified to quantify the level of vulnerability[11].

Economic vulnerability can be quantified by proxies like energy consumption per capita; agricultural value added (% of GDP); GDP per capita; poverty headcount.

Social vulnerability can be quantified by proxies such as the percentage of the population below poverty line; literacy rate; improved water sources; life expectancy at birth; population ages 15-64; refugee population; government effectiveness; human development index; disaster prevention and preparedness finances; conflicts.

Infrastructural vulnerability can be quantified by proxies like agricultural irrigated land; % of retained renewable water; recycling ratios; irrigation efficiencies; road density; age of the infrastructure.

2.4 Drought risk

In the classical approach to drought risk assessment, vulnerability factors are combined with information on hazard and exposure to assess drought risk (see Figure 2.1). The magnitude of a drought event, the exposure and vulnerability information together determine the impact of that specific drought event. In other words, the impact of a drought event is determined by hazard x exposure x vulnerability. Drought risk can then be expressed as annual average losses (AAL) or annual expected damages (AED) through a probabilistic analysis of either potential annual damages or potential damages for drought events for different return periods. However, it is often not straightforward to determine the direct and indirect impacts of a drought on assets, economy or population, due to the longevity and the diffuse nature of drought effects. As an alternative approach when a full probabilistic approach is not possible, e.g. in large scale or exploratory drought risk assessments, the levels of risk may be considered in broad categories (low risk to very high risk) or estimated using a combination of proxy values for exposure (e.g. GDP, km^2 agricultural area) and vulnerability (e.g. population below poverty line, GDP per capita).

Figure 2.1 Classical approach to drought risk assessment

[11] *Naumann, G., Barbosa, P., Garrote, L., Iglesias, A., and Vogt, J.: Exploring drought vulnerability in Africa: an indicator based analysis to be used in early warning systems, Hydrol. Earth Syst. Sci., 18, 1591-1604, https://doi.org/10.5194/hess-18-1591-2014, 2014.*

3 Methods

3.1 Scope of this inventory

This inventory of drought hazard and risk modeling tools and resources includes global as well as regional and national scale modeling tools and resources, grouped by continent. The scope of the inventory includes modeling tools and resources addressing drought hazard, drought impact (*exposure x vulnerability*) as well as risk (*hazard x impact*). Many drought modeling tools and resources in the inventory deal with either one or several specific aspects of drought risks. The key aspects of the categorization and description of the modeling tools and resources consist of the type of drought that it has focus on, the model type (indices, datasets, platforms, bulletins, modeling software, or global tools), as well as the drought application of the model, tool or resource.

In this chapter, we provide an overview of the types of drought that are included in this global inventory of drought risk modeling tools and resources. Also, the different types of modeling tools and resources in the inventory are described as well as the various drought applications that are available.

3.2 Types of drought

There are numerous definitions of drought[12]. For the purpose of this global inventory of drought hazard and risk modeling tools and resources we have focused on meteorological drought, hydrological drought, agricultural drought and socio-economic drought. The first three droughts are based on physical phenomena. The fourth deals with drought in terms of supply and demand. Below, a short description of these drought types is given based on information from the United States' National Drought and Mitigation Centre[13].

Meteorological drought is usually defined based on the degree of dryness (i.e. lack of precipitation) in comparison to some "normal" or average amount of precipitation, and the duration of the dry period. Definitions of meteorological drought are region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region.

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) deficit on surface or subsurface water supply (i.e., stream flow, reservoir and lake levels, groundwater). The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate from a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag behind meteorological and agricultural droughts as it takes longer for precipitation deficiencies to show up in components of the hydrological system such as stream flow, and groundwater and reservoir levels.

[13] *National Drought and Mitigation Centre: http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx*

Agricultural drought (sometimes referred to as soil moisture drought) links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, and soil water deficits that can lead to crop failure. A few days or weeks of a lack of moisture in the root zone, especially during the growing season, may already create stress on crops resulting in reduced crop yields. Important in this context is the plant water demand, which depends on weather conditions, biological plant characteristics, growth stage, and soil properties.

Socio-economic drought occurs when the demand of economic goods exceeds supply as a result of a weather-related shortfall in water supply. It is associated with the impacts of meteorological, hydrological and agricultural droughts on social and economic aspects of the population affected.

3.3 Types of modeling tools and resources

This inventory of drought hazard and risk modeling tools and resources is composed of six types of “models”: online platforms, newsletters/bulletins, datasets, indices, model tools, and modeling software. Each of these “models” provides the possibility to detect and monitor drought hazard, impact, and/or risks, either by itself or in combination with other “models”. In many cases, interrelations between modeling tools and resources exist. For instance, online platforms and newsletters/bulletins make use of datasets, indices and perhaps tools. Also, certain indices or tools are combined with specific datasets to provide relevant drought risk information. Existing relationships between different modeling tools and resources in the inventory is indicated in the “model” information sheets. Below, a short description of the six types of drought modeling tools and resources is given.

Online platforms: interactive (real-time) web-applications that combine datasets, indices and/or tools to present historic, current and/or future drought hazard or drought risk. It enables users to select hazards, impacts, or risks and/or specific indices, time periods, and regions and easily visualize the data in terms of spatial maps and/or time series plots. In general, the ease of use of online platforms can be described as relatively simple; they can be directly used by decision-makers, other non-expert stakeholders, as well as the general public.

Newsletters/bulletins: periodic documents about the drought status of countries, regions or continents issued by the coordinating water management organizations. Based on a combination of datasets, indices and tools, they inform water users and other relevant stakeholders on the level of drought hazard, availability of water and /or drought risks. In general, the ease of use of platforms / bulletins can be described as relatively simple; they can be directly used by decision-makers, other non-expert stakeholders, as well as the general public.

Datasets: collection of data, historic or real-time, related to drought hazard and risk. A dataset can consist of a collection of gridded data or a time series of datasets. A dataset can be a collection of measurements/observations (e.g. precipitation, evapotranspiration, temperature, soil moisture, snow pack),

indices (e.g. standardized precipitation index, groundwater table declining trend, crop moisture index), or the outcome of a numerical model related to drought hazard or risk (e.g. runoff, groundwater levels). In general, the ease of use of datasets varies from medium to complex (depending if the dataset already provides the required drought index or if the dataset needs to be used for an index calculation). They can be used and processed by (agro-)hydrological or water management experts and drought professionals.

Indices: methods used to compute (numerical) representations of drought severity, using climatic or hydro-meteorological and/or socio-economic inputs (e.g. datasets). They aim to measure the qualitative state of droughts on the landscape over the current time period relative to a historical period (usually 30 years or longer). Examples include standardized precipitation index, groundwater table declining trend, crop moisture index, vegetation health index, and inflow-demand reliability. The ease of use of indices varies from medium to complex as they all require some sort of computation. Some are easier to compute, while others are more integrated or compound indices that require expertise of drought professionals, (agro-)hydrologists, and/or water management experts.
Note: The Handbook of Drought Indicators and Indices, published by WMO and GWP[14], provides an important overview and description of drought indices that was used as the basis of many indices' descriptions in this global inventory of drought hazard and risk models.

Modeling software: modeling software that enables users to transform basic datasets into derived parameters required for drought hazard and/or risk characterization. In this inventory we included some used and open source modeling software for runoff, groundwater, and agro-hydrology as well as modeling software for water distribution and allocation. In general, the ease of use of modeling software can be described as complex; software can be used and processed by (agro-)hydrological or water management experts with a technical background.

Tools: numerical models that have been parameterized for global or regional applications. Both the software and the parameterization of these global tools are available online. In most cases, previously generated model output is also available online as big datasets. In general, the ease of use of tools can be described as complex; tools can be used and processed by (agro-)hydrological or water management experts with a technical back-ground.

3.4 Applications

Different drought modeling tools and resources aim for different types of applications, either focusing on drought hazards, drought impact, drought risk, or forecasting of drought. Below,

[14] *World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.*

all applications that are collected in our *global inventory of drought modeling tools and resources* are listed:

Drought Hazard Mapping
The category of drought hazard mapping is divided in the following sub-categories:

- Meteorological drought hazard mapping: drought hazard modeling tools and resources related to precipitation (rain and snow), evapo(trans)piration, and temperature.
- Hydrological drought hazard mapping: drought hazard modeling tools and resources related to runoff, discharge, and groundwater levels.
- Agricultural drought hazard mapping: drought hazard modeling tools and resources related to agricultural water deficits.
- Socio-economic drought hazard mapping: drought hazard modeling tools and resources related to supply and demand of water in relation to economic goods.

Drought Impact Mapping

Mapping the impact of drought requires information of both the exposure and the vulnerability to drought hazards. The drought impact can be mapped for various different aspects of the society and economy in a region, country or basin. The following categories are taken up in this global inventory of drought hazard and risk models.

- Mapping drought impact to population
- Mapping drought impact to municipal and industrial water needs
- Mapping drought impact to agriculture and livestock
- Mapping drought impact to hydropower
- Mapping drought impact to the overall economy

Drought Risk Mapping
Mapping the risk of drought requires information of both the drought hazard and the potential impact (exposure x vulnerability) of drought hazards. Drought risk can be mapped for various different aspects of the society and economy in a region, country or basin. The following categories are taken up in this global inventory of drought hazard and risk models.

- Mapping drought risk to population
- Mapping drought risk to municipal and industrial water needs
- Mapping drought risk to agriculture and livestock
- Mapping drought risk to hydropower
- Mapping drought risk to the overall economy

Drought monitoring and forecasting
The category of (real-time) drought monitoring and forecasting contains modeling tools and resources that have their focus on real time drought monitoring and forecasting of the different types of drought hazards, impacts, or risks.

3.5 Selecting Modeling tools and resources

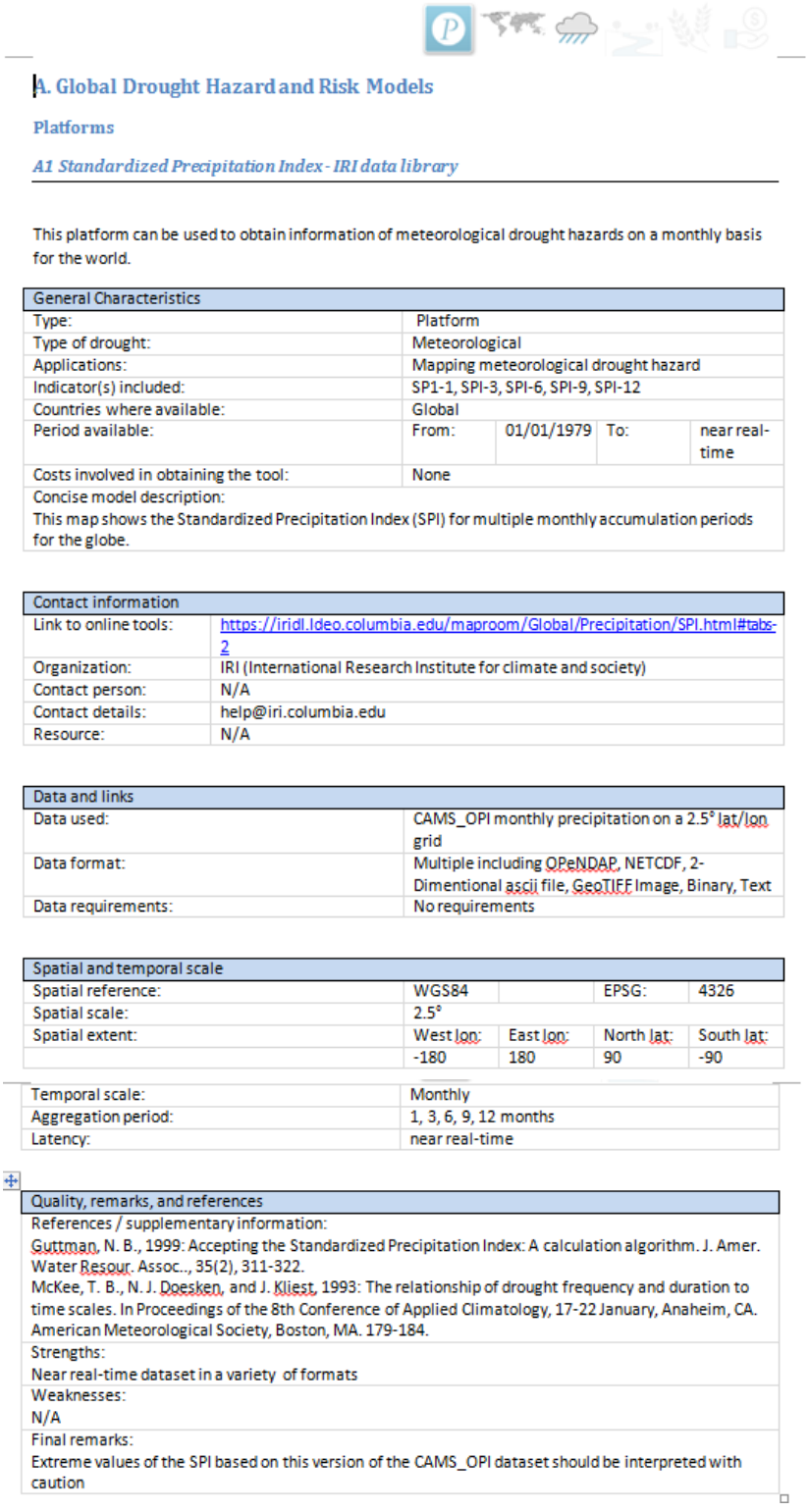
Drought modeling tools and resources were selected to be included in this inventory based on three main criteria. First, the model, tool or resource should be ***open access***, will become open access in the near future, or the World Bank has access to the modeling tool or resource. Secondly, the drought modeling tool or resource should have a ***quality*** label, consisting of either one or more peer reviewed literature references or an equivalent

indication of good performance. Finally, datasets should be available in a ***documented data-standard*** that can be used by professionals.

3.6 Model characteristics

For each drought modeling tool or resource, the relevant characteristics are collected and presented in the information sheets in the Appendices of this report. Each “model” information sheet starts with a short description of the main “model” characteristics and its goal. Next, a tabular overview of the general characteristics is given, including type of modeling tool or resource, type(s) of drought, type(s) of application, status (operational or in development), countries where available, availability of future scenarios via the modeling tool or resource, and costs of obtaining the “model”. Next, relevant contact information and web-links are provided, followed by information on the datasets used in the modeling tool or resource and information on how to access these data as well as information on spatial and temporal extent and scales. To conclude, each information sheet provides information on the quality of the modeling tool or resource, its strengths and weaknesses, and literature references that can be consulted to obtain more detailed information. The following tables present information sheet examples for the different modeling tools and resources.

Figure 3.1 Information sheet example for Platforms



A. Global Drought Hazard and Risk Models

Platforms

A1 Standardized Precipitation Index - IRI data library

This platform can be used to obtain information of meteorological drought hazards on a monthly basis for the world.

General Characteristics				
Type:	Platform			
Type of drought:	Meteorological			
Applications:	Mapping meteorological drought hazard			
Indicator(s) included:	SP1-1, SPI-3, SPI-6, SPI-9, SPI-12			
Countries where available:	Global			
Period available:	From:	01/01/1979	To:	near real-time
Costs involved in obtaining the tool:	None			
Concise model description: This map shows the Standardized Precipitation Index (SPI) for multiple monthly accumulation periods for the globe.				

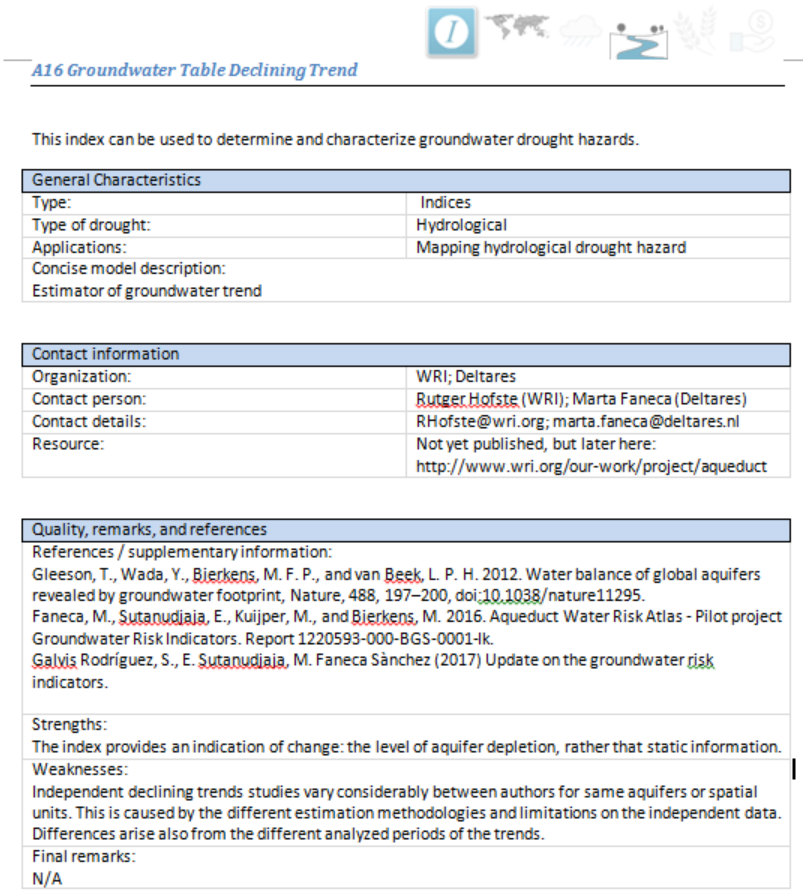
Contact information	
Link to online tools:	https://iridl.ldeo.columbia.edu/maproom/Global/Precipitation/SPI.html#tabs-2
Organization:	IRI (International Research Institute for climate and society)
Contact person:	N/A
Contact details:	help@iri.columbia.edu
Resource:	N/A

Data and links	
Data used:	CAMS_OPI monthly precipitation on a 2.5° lat/lon grid
Data format:	Multiple including OPeNDAP, NETCDF, 2-Dimentional ascii file, GeoTIFF Image, Binary, Text
Data requirements:	No requirements

Spatial and temporal scale				
Spatial reference:	WGS84		EPSG:	4326
Spatial scale:	2.5°			
Spatial extent:	West lon:	East lon:	North lat:	South lat:
	-180	180	90	-90
Temporal scale:	Monthly			
Aggregation period:	1, 3, 6, 9, 12 months			
Latency:	near real-time			

Quality, remarks, and references
References / supplementary information: Guttman, N. B., 1999: Accepting the Standardized Precipitation Index: A calculation algorithm. J. Amer. Water Resour. Assoc.., 35(2), 311-322. McKee, T. B., N. J. Doesken, and J. Kliest, 1993: The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference of Applied Climatology, 17-22 January, Anaheim, CA. American Meteorological Society, Boston, MA. 179-184.
Strengths: Near real-time dataset in a variety of formats
Weaknesses: N/A
Final remarks: Extreme values of the SPI based on this version of the CAMS_OPI dataset should be interpreted with caution

Figure 3.2 Information sheet example for Indices



A16 Groundwater Table Declining Trend

This index can be used to determine and characterize groundwater drought hazards.

General Characteristics	
Type:	Indices
Type of drought:	Hydrological
Applications:	Mapping hydrological drought hazard
Concise model description: Estimator of groundwater trend	

Contact information	
Organization:	WRI; Deltares
Contact person:	Rutger Hofste (WRI); Marta Faneca (Deltares)
Contact details:	RHofste@wri.org; marta.faneca@deltares.nl
Resource:	Not yet published, but later here: http://www.wri.org/our-work/project/aqueduct

Quality, remarks, and references
References / supplementary information: Gleeson, T., Wada, Y., Bierkens, M. F. P., and van Beek, L. P. H. 2012. Water balance of global aquifers revealed by groundwater footprint, Nature, 488, 197–200, doi:10.1038/nature11295. Faneca, M., Sutanudjaja, E., Kuijper, M., and Bierkens, M. 2016. Aqueduct Water Risk Atlas - Pilot project Groundwater Risk Indicators. Report 1220593-000-BGS-0001-Ik. Galvis Rodríguez, S., E. Sutanudjaja, M. Faneca Sànchez (2017) Update on the groundwater risk indicators.
Strengths: The index provides an indication of change: the level of aquifer depletion, rather that static information.
Weaknesses: Independent declining trends studies vary considerably between authors for same aquifers or spatial units. This is caused by the different estimation methodologies and limitations on the independent data. Differences arise also from the different analyzed periods of the trends.
Final remarks: N/A

Figure 3.3 Information sheet example for Datasets

A80 EM-DAT

This dataset can be used to obtain data on impacts of socio-economic droughts to the overall economy for the world.

General Characteristics				
Type:	Dataset			
Type of drought:	Socio-economic			
Applications:	Mapping drought impact to the overall economy, Mapping drought impact to the population			
Indicator(s) included:	Total deaths, Total affected people, Total damage (US$)			
Countries where available:	Global			
Period available:	From:	1900	To:	near real-time
Costs involved in obtaining the tool:	None			
Concise model description: EM-DAT is a global database on natural and technological disasters, containing essential core data on the occurrence and effects of more than 21,000 disasters in the world, from 1900 to present. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the School of Public Health of the Université catholique de Louvain located in Brussels, Belgium.				

Contact information	
Link to online tools:	http://www.emdat.be/database
Organization:	CRED (Centre for Research on the Epidemiology of Disasters)
Contact person:	Via contact form: http://emdat.be/contact
Contact details:	contact@emdat.be.
Resource:	A password is required to enter the database. Can be obtained through registration or via contact details.

Data and links	
Data used: UN agencies, non-governmental organizations, insurance companies, research institutes and press agencies. Priority is given to data from UN agencies, governments, and the International Federation of Red Cross and Red Crescent Societies.	
Data format:	CSV
Data requirements:	No requirements

Spatial and temporal scale				
Spatial reference:	WGS84		EPSG:	4326
Spatial scale:	Country			
Spatial extent:	West lon:	East lon:	North lat:	South lat:
	-180	180	90	-90
Temporal scale:	Year			
Aggregation period:	Year			
Latency:	N/A			

Quality, remarks, and references
References / supplementary information: http://www.emdat.be/publications
Strengths: It provides impacts for a wide variety of natural hazards.
Weaknesses: Impacts are only provided on a yearly basis, so it might not be easy to match the impacts to an event. For some countries the database is quite sparse.
Final remarks: Drought event overviews reported by national sources often indicate more drought events than EM-DAT. Advised is to combine EM-DAT with national sources.

Figure 3.4 Information sheet template for Tools

Tools

A88 PCR-GLOBWB

This tool can be used to simulate and obtain information of (future scenarios of) hydrological drought hazards.

General Characteristics					
Type:	Tools				
Type of drought:	Hydrological				
Applications:	Mapping hydrological drought hazard				
Indicator(s) included:	water demands, groundwater and surface water withdrawal, water consumption, return flows, river discharge.				
Countries where available:	Global				
Period available:	From:	1958	To:	2017	
Costs involved in obtaining the tool:	None				
Concise model description: PCR-GLOBWB is a large-scale process-based hydrological model intended for global to regional studies. It provides a grid-based representation of terrestrial hydrology with a typical spatial resolution of less than 50×50 km (currently 0.5° globally) on a daily basis. For each grid cell, PCR-GLOBWB uses process-based equations to compute moisture storage in two vertically stacked soil layers as well as the water exchange between the soil and the atmosphere and the underlying groundwater reservoir. Exchange to the atmosphere comprises precipitation, evapotranspiration and snow accumulation and melt, which are all modified by the presence of the canopy and snow cover.					

Contact information	
Link to online tools:	http://pcraster.geo.uu.nl/projects/applications/pcrglobwb/; https://github.com/UU-Hydro/PCR-GLOBWB_model
Organization:	Dept. of Physical Geography, Utrecht University (Netherlands)
Contact person:	Rens van Beek, Marc Bierkens
Contact details:	r.vanbeek at geo.uu.nl, m.f.p.bierkens@uu.nl, E.H.Sutanudjaja@uu.nl,
Resource:	N/A

Spatial and temporal scale				
Spatial reference:	WGS84		EPSG:	4326
Spatial scale:	0.5			
Spatial extent:	West lon:	East lon:	North lat:	South lat:
	-180	180	90	-90
Temporal scale:	daily, monthly			
Aggregation period:	monthly, daily			
Latency:	historic or future simulation periods			

Quality, remarks, and references
References / supplementary information: Bierkens, M.F.P. and L.P.H. van Beek (2009): Seasonal predictability of European Discharge: NAO and Hydrological Response Time. J. Hydrometeor, 10, 953–968. Loos, S., H. Middelkoop, M. van der Perk and R. van Beek (2009). Large scale nutrient modelling using globally available datasets: A test for the Rhine basin. Journal of Hydrology. Volume 369, Issues 3-4, 15 May 2009, Pages 403-415. Sperna Weiland, F.C., L. P. H. van Beek, J. C. J. Kwadijk, and M. F. P. Bierkens (2010). Hydrol. Earth Syst. Sci., 14, 1595-1621. Petrescu, A. M. R., L. P. H. van Beek, J. van Huissteden, C. Prigent, T. Sachs, C. A. R. Corradi, F. J. W. Parmentier, and A. J. Dolman (2010), Modeling regional to global CH4 emissions of boreal and arctic wetlands, Global Biogeochem. Cycles, 24, GB4009, doi:10.1029/2009GB003610. Wada, Y., L. P. H. van Beek, C. M. van Kempen, J. W. T. M. Reckman, S. Vasak, and M. F. P. Bierkens (2010), Global depletion of groundwater resources, Geophys. Res. Lett., 37, L20402, doi:10.1029/2010GL044571.
Strengths: The model has a water use scheme that is integrated at each time step, i.e. at every time step sector specific water demands are calculated, resulting in groundwater and surface water withdrawal, water consumption and return flows. The model computes several hydrological variables that can be used to compute different drought indices. Results from the global model are available for the period 1979 to 2012 at https://wci.earth2observe.eu/portal/?
Weaknesses: The global model has quite a low resolution (0.5°), and setting up a higher resolution model for a specific region is not easy; The model does not solve full surface energy balance (e.g. as done by VIC). The current version of PCR-GLOBWB uses Penman-Monteith;The model does not have a user interface.
Final remarks: Peer-reviewed

Figure 3.5Information sheet example for Modeling Software

A90 Global RIBASIM Model (Deltares)

This tool can be used to simulate and obtain information of (future scenarios of) drought hazards and effects of interventions and water use(rs).

General Characteristics				
Type:	Tools (upcoming)			
Type of drought:	Hydrological, Socio-economic			
Applications:	Mapping hydrological drought hazard, mapping socio-economic drought hazard			
Indicator(s) included:	N/A			
Countries where available:	Global			
Period available:	From:	N/A	To:	N/A
Costs involved in obtaining the tool:	N/A			
Concise model description: Global RIBASIM is an water allocation model based on water balances approach intended for global to regional to local studies. It provides a network representation of water availability, demand, infrastructure, distribution and priority rules for water allocation.				

Contact information	
Link to online tools:	N/A
Organization:	N/A
Contact person:	Judith ter Maat, Karen Meijer, Frederiek Sperna Weiland
Contact details:	N/A
Resource:	N/A

Spatial and temporal scale				
Spatial reference:	WGS84		EPSG:	4326
Spatial scale:	N/A			
Spatial extent:	West lon:	East lon:	North lat:	South lat:
	water provinces	N/A	N/A	N/A
Temporal scale:	daily, monthly			
Aggregation period:	N/A			
Latency:	N/A			

Quality, remarks, and references
References / supplementary information: N/A
Strengths: N/A
Weaknesses: N/A
Final remarks: N/A

4 Overview of drought hazard and risk modeling tools and resources

4.1 Overview of available modeling tools and resources

In total 198 drought hazard and risk modeling tools and resources were identified: 56 platforms, 63 indices, 27 datasets, 15 newsletters/bulletins, 5 tools, and 32 modeling software types. The tables below (Table 4.1, Table 4.2, Table 4.3, and Table 4.4) give an overview of the distribution of the modeling tools and resources over the regions of the world, the drought type that are assessed as well as the main applications. Most of the identified modeling tools and resources consist of platforms or indices, have a global extent, and focus on mapping hazards. In addition, multiple global datasets of drought hazards are available. On the other hand, the modeling tools and resources that assess socio-economic drought hazards and those that can be applied for studies on drought impact and drought risk are scarce. On the global scale some modeling tools and resources are available that provide these types of information, but on regional scale these are mostly lacking. In the paragraphs below, an overview of all available modeling tools and resources is given per region. The Appendices of this report contain reports with detailed information for each of the modeling tools and resources.

The collection of all the data for the different modeling tools and resources required a substantial effort. We collected all the data to the best of our knowledge and tried to create a catalogue that is as complete as possible. We acknowledge that some (important) modeling tools and resources might be missing in the catalogue and the tables might not be complete, but it would be impossible to provide an exhaustive inventory as new tools and resources are under constant development.

Moreover, there are numerous indirect products that can be used in drought analysis but not specific to drought, such as hydrological models, agricultural models, or satellite products. We did not list all of them in this inventory, but we only listed some hydrological models and one satellite product (GRACE, A79) to provide some examples. Any hydrological model that represents the water balance components that are important for drought assessment can be used for drought analysis. Other useful satellite products can be found in the Earth2Observe Water Cycle Integrator OpenEarth platform (see Appendix A3).

Table 4.1 Number of drought hazard and risk modeling tools and resources per model type and region.

	Platform	Indices	Dataset	Newsletter /Bulletin	Tools	Modelling Software	*total*
A. Global	14	63	10	0	3	32	***122***
B. Africa	10	0	1	3	1	0	***15***
C. Asia	8	0	3	1	0	0	***12***
D. Europe	5	0	10	0	0	0	***15***
E. North America	7	0	0	0	0	0	***7***
F. Pacific, Australia, New Zealand	5	0	2	1	1	0	***9***
G. South America	7	0	1	10	0	0	***18***
totals	***56***	***63***	***27***	***15***	***5***	***32***	***198***

Table 4.2 Number of drought hazard and risk modeling tools and resources per drought type and per region. Many Models address more than one type of drought; hence the total number of models in this table is higher than in Table 4.1.

	Meteorological drought	Agricultural drought	Hydrological drought	Socio-economic drought	*total*
A. Global	35	57	57	12	***161***
B. Africa	15	13	10	1	***39***
C. Asia	12	6	2	0	***20***
D. Europe	9	8	3	0	***20***
E. North America	2	6	2	1	***11***
F. Pacific, Australia, New Zealand	7	1	7	0	***15***
G. South America	17	6	8	0	***31***
total	***97***	***97***	***89***	***14***	***297***

Table 4.3 Number of drought hazard and risk modeling tools and resources per application and region. Some Models have more than one application; hence the total number of models in this table is higher than in Table 4.1.

	hazard mapping	monitoring - forecasting	impact mapping	risk mapping	*total*
A. Global	104	1	20	10	***135***
B. Africa	11	6	2	1	***20***
C. Asia	7	5	0	0	***12***
D. Europe	14	3	2	0	***19***
E. North America	3	1	4	0	***8***
F. Pacific, Australia, New Zealand	7	2	0	0	***9***
G. South America	14	6	0	0	***20***
total	***160***	***24***	***28***	***11***	***223***

Table 4.4 Number of drought hazard and risk applications that is available per "model" type. Some modeling tools and resources have more than one application; hence the total number of modeling tools and resources in this table is higher in Table 4.1.

	hazard mapping	monitoring-forecasting	impact mapping	risk mapping	*total*
Dataset	22	7	2	1	***32***
Indices	54	0	9	2	***65***
Modelling Software	26	0	6	4	***36***
Newsletter/Bulletin	10	7	1	0	***18***
Platform	44	8	10	4	***66***
Tools	4	2	0	0	***6***
total	***160***	***24***	***28***	***11***	***223***

4.2 Global drought risk modeling tools and resources

This paragraph provides an overview of available drought risk modeling tools and resources with a global extent. A detailed overview of all "model" characteristics can be found in the model reports in Appendix A.

Table 4.5 Overview of available drought hazard and risk platforms with global extent.

No.	Name	Model type Platform	Drought type	Application
A1	Standardized Precipitation Index - IRI data library	Platform	Meteorological	Mapping meteorological drought hazard
A2	Global Drought Observatory	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard, Mapping likelihood of drought impact
A3	E2O Water Cycle Integrator	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A4	NOAA Global Drought Map	Platform	Meteorological	Mapping meteorological drought hazard
A5	SPEI global drought monitor	Platform	Meteorological	Mapping meteorological drought hazard
A6	Global Drought Information System / National Integrated Drought Information System	Platform	Meteorological	Mapping meteorological drought hazard
A7	Global Integrated Drought Monitoring and Prediction System (GIDMaPS)	Platform	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard
A8	IWMI water data portal	Platform	Socio-economic	mapping socio-economic drought hazard, drought risk mapping
A9	Aqueduct Water Risk Atlas	Platform	Meteorological, Socio-economic	Mapping drought risk to the overall economy, Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard, mapping socio-economic drought hazard
A10	Global Agricultural Drought Monitoring and Forecasting System	Platform	Agricultural	Mapping drought impact to agriculture and livestock, Mapping agricultural drought hazard
A11	Famine Early Warning Systems Network	Platform	Agricultural	Mapping drought risk to population, Mapping drought risk to agriculture and livestock, Mapping agricultural drought hazard
A12	Agricultural Stress Index and precipitation anomalies (FAO)	Platform	Agricultural	Mapping drought impact to agriculture and livestock, Mapping agricultural drought hazard
A13	Earth Observation for crop monitoring - Global Information and Early Warning System on Food and Agriculture (GIEWS)	Platform	Agricultural, Meteorological	Mapping agricultural drought hazard, Mapping meteorological drought hazard
A14	GEOGLAM Crop Monitor	Platform	Agricultural	Mapping drought impact to agriculture and livestock

Table 4.6 Overview of available drought hazard and risk indices with global extent.

No.	Name	Model type Indices	Drought type	Application
A15	Standardized Precipitation Index (SPI)	Indices	Meteorological	Mapping meteorological drought hazard
A16	Groundwater Table Declining Trend	Indices	Hydrological	Mapping hydrological drought hazard
A17	Standardized Groundwater Index (SGI)	Indices	Hydrological	Mapping hydrological drought hazard
A18	Groundwater Resource Index (GRI)	Indices	Hydrological	Mapping hydrological drought hazard
A19	Groundwater Drought Index (GWI)	Indices	Hydrological	Mapping hydrological drought hazard
A20	Drought deficit volume	Indices	Hydrological	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs
A21	Threshold Level Indicators (Deficit Indices)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A22	Palmer Drought Severity Index (PDSI)	Indices	Meteorological	Mapping meteorological drought hazard
A23	Aridity Anomaly Index (AAI)	Indices	Meteorological	Mapping meteorological drought hazard
A24	Deciles	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
A25	Keetch-Byram Drought Index (KBDI)	Indices	Agricultural	Mapping agricultural drought hazard
A26	Percent of Normal Precipitation	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
A27	Weighted Anomaly Standardized Precipitation Index (WASP)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
A28	Aridity Index (AI)	Indices	Meteorological	Mapping meteorological drought hazard
A29	China Z Index (CZI)	Indices	Meteorological	Mapping meteorological drought hazard
A30	Crop Moisture Index (CMI)	Indices	Agricultural	Mapping agricultural drought hazard
A31	Drought Area Index (DAI)	Indices	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
A32	Drought Reconnaissance Index (DRI)	Indices	Meteorological	Mapping meteorological drought hazard
A33	Effective Drought Index (EDI)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A34	NOAA Drought Index (NDI)	Indices	Agricultural	Mapping agricultural drought hazard
A35	Palmer Z Index	Indices	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard
A36	Rainfall Anomaly Index (RAI)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A37	Self-Calibrated Palmer Drought Severity Index (sc-PDSI)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A38	Standardized Anomaly Index (SAI)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A39	Standardized Precipitation Evapotranspiration Index (SPEI)	Indices	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A40	Agricultural Reference Index for Drought (ARID)	Indices	Agricultural	Mapping agricultural drought hazard
A41	Crop Specific Drought Index (CSDI)	Indices	Agricultural	Mapping drought impact to agriculture and livestock, Mapping agricultural drought hazard
A42	Reclamation Drought Index (RDI)	Indices	Hydrological	Mapping hydrological drought hazard
A43	Soil Moisture Anomaly (SMA)	Indices	Agricultural	Mapping agricultural drought hazard
A44	Evapotranspiration Deficit Index (ETDI)	Indices	Agricultural	Mapping agricultural drought hazard
A45	Soil Moisture Deficit Index (SMDI)	Indices	Agricultural	Mapping agricultural drought hazard
A46	Palmer Hydrological Drought Index (PHDI)	Indices	Hydrological	Mapping hydrological drought hazard
A47	Standardized Reservoir Supply Index (SRSI)	Indices	Hydrological	Mapping drought impact to municipal and industrial water needs , Mapping drought impact to hydropower

No.	Name	Model type Indices	Drought type	Application
A48	Standardized Streamflow Index (SSFI)	Indices	Hydrological	Mapping hydrological drought hazard
A49	Standardized Water-Level Index (SWI)	Indices	Hydrological	Mapping hydrological drought hazard
A50	Streamflow Drought Index (SDI)	Indices	Hydrological	Mapping hydrological drought hazard
A51	Surface Water Supply Index (SWSI)	Indices	Hydrological	Mapping hydrological drought hazard
A52	Aggregate Dryness Index (ADI)	Indices	Meteorological, agricultural and hydrological	Mapping drought impact to population, Mapping drought impact to municipal and industrial water needs , Mapping drought impact to agriculture and livestock
A53	Standardized Snowmelt and Rain Index (SMRI)	Indices	Hydrological	Mapping hydrological drought hazard
A54	Enhanced Vegetation Index (EVI)	Indices	Agricultural	Mapping agricultural drought hazard
A55	Evaporative Stress Index (ESI)	Indices	Agricultural, Hydrological	Mapping agricultural drought hazard, Mapping hydrological drought hazard
A56	Normalized Difference Vegetation Index (NDVI)	Indices	Agricultural	Mapping agricultural drought hazard, Mapping drought impact to agriculture and livestock
A57	Temperature Condition Index (TCI)	Indices	Agricultural	Mapping agricultural drought hazard, Mapping drought impact to agriculture and livestock
A58	Vegetation Condition Index (VCI)	Indices	Agricultural	Mapping agricultural drought hazard, Mapping drought impact to agriculture and livestock
A59	Vegetation Drought Response Index (VegDRI)	Indices	Agricultural	Mapping agricultural drought hazard
A60	Vegetation Health Index (VHI)	Indices	Agricultural	Mapping agricultural drought hazard, Mapping drought impact to agriculture and livestock
A61	Water Requirement Satisfaction Index (WRSI) and Geo WRSI	Indices	Agricultural	Mapping drought impact to agriculture and livestock, Mapping agricultural drought hazard
A62	Normalized Difference Water Index (NDWI)	Indices	Agricultural	Mapping agricultural drought hazard
A63	Soil Adjusted Vegetation Index (SAVI)	Indices	Agricultural	Mapping agricultural drought hazard
A64	Multivariate Standardized Drought Index (MSDI)	Indices	Meteorological, agricultural and hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
A65	Multivariate Standardized Reliability and Resilience Index (MSRRI)	Indices	Socio-economic	Mapping drought impact to population, Mapping drought impact to municipal and industrial water needs , Mapping drought impact to hydropower
A66	Inflow-Demand Reliability (IDR)	Indices	Hydrological	Mapping hydrological drought hazard, mapping socio-economic drought hazard
A67	Water Storage Resilience indicator (WSR)	Indices	Socio-economic	mapping socio-economic drought hazard
A68	Falkenmark Index	Indices	socio-economic	Mapping socio-economic drought
A69	Standardized Runoff Index (SRI)	Indices	Hydrological	Mapping hydrological drought hazard
A70	Watergap index	Indices	Socio-economic	Mapping socio-economic drought
A71	Socioeconomic Drought Vulnerability Index (SDVI)	Indices	Socio-economic	Mapping socio-economic drought vulnerability
A72	Agricultural Stress Index (ASI)	Indices	Agricultural	Mapping agricultural drought hazard
A73	Seasonal Small Integral Deviation (SSID) index	Indices	Agricultural	Mapping agricultural drought hazard
A74	Drought Warning Index (DWI)	Indices	Agricultural	Mapping agricultural drought hazard
A75	Vegetation Productivity Anomaly (VPA)	Indices	Agricultural	Mapping agricultural drought hazard
A76	Drought Vulnerability Index (DVI)	Indices	Socio-economic	Mapping socio-economic drought vulnerability
A77	Drought Risk Index (DRI)	Indices	Socio-economic	Mapping drought risk to population, Socio-economic

Table 4.7 Overview of available drought hazard and risk datasets with global extent.

No.	Name	Model type Dataset	Drought type	Application
A78	Standardized Precipitation Index (SPI) for Global Land Surface (1949-2012)	Dataset	Meteorological	Mapping meteorological drought hazard
A79	GRACE	Dataset	Hydrological	Mapping hydrological drought hazard
A80	EM-DAT	Dataset	Socio-economic	Drought impact to the overall economy, Drought impact to the population
A81	The Early Warning eXplorer (EWX)	Dataset	Meteorological, Agricultural	Drought forecasting , Mapping meteorological drought hazard, Mapping agricultural drought hazard
A82	Global Precipitation Climatology Centre Drought Database	Dataset	Meteorological	Mapping meteorological drought hazard
A83	ISI-MIP	Dataset	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
A84	MODIS Global Terrestrial Drought Severity Index	Dataset	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
A85	Global map of drought risk	Dataset	Socio-economic	Mapping drought risk to population, Socio-economic
A86	NOAA - daily weather records	Dataset	Meteorological	Mapping meteorological drought hazard
A87	E2O drought indicators	Dataset	hydrological , meteorological	Mapping meteorological drought hazard

Table 4.8 Overview of available drought hazard and risk tools with global extent.

No.	Name	Model type Tools	Drought type	Application
A88	PCR-GLOBWB	Tools	Hydrological	Mapping hydrological drought hazard
A89	Global Groundwater Model (UU, Deltares)	Tools	Hydrological	Mapping hydrological drought hazard
A90	Global RIBASIM Model (Deltares)	Tools	Hydrological, Socio-economic	Mapping hydrological drought hazard, mapping socio-economic drought hazard

Table 4.9 Overview of available drought hazard and risk modeling software with global extent.

No.	Name	Model type Modelling Software	Drought type	Application
A91	RIBASIM	Modelling Software	Hydrological, Socio-economic	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower
A92	Cropwat	Modelling Software	Agricultural	Mapping drought impact to agriculture and livestock
A93	Aquacrop	Modelling Software	Agricultural	Mapping drought impact to agriculture and livestock
A94	HBV	Modelling Software	Hydrological	Mapping hydrological drought hazard
A95	TOPMODEL	Modelling Software	Hydrological	Mapping hydrological drought hazard
A96	WFLOW	Modelling Software	Hydrological	Mapping hydrological drought hazard
A97	Sacramento Model	Modelling Software	Hydrological	Mapping hydrological drought hazard
A98	GR4J	Modelling Software	Hydrological	Mapping hydrological drought hazard
A99	SIMHYD	Modelling Software	Hydrological	Mapping hydrological drought hazard
A100	SIMGRO	Modelling Software	Agricultural	Mapping agricultural drought hazard
A101	DRAINMOD	Modelling Software	Agricultural	Mapping agricultural drought hazard
A102	SWAP	Modelling Software	Agricultural	Mapping agricultural drought hazard
A103	HYDRUS-1D	Modelling Software	Agricultural	Mapping agricultural drought hazard
A104	DSSAT	Modelling Software	Agricultural	Mapping agricultural drought hazard
A105	CROPSYST	Modelling Software	Agricultural	Mapping agricultural drought hazard
A106	SWAT	Modelling Software	Agricultural, Hydrological	Mapping agricultural and hydrological drought hazard
A107	STICS	Modelling Software	Agricultural	Mapping agricultural drought hazard
A108	RZWQM	Modelling Software	Agricultural	Mapping agricultural drought hazard
A109	WOFOST	Modelling Software	Agricultural	Mapping agricultural drought hazard
A110	WARM	Modelling Software	Agricultural	Mapping agricultural drought hazard
A111	MODFLOW	Modelling Software	Hydrological	Mapping hydrological drought hazard
A112	SUTRASUITE	Modelling Software	Hydrological	Mapping hydrological drought hazard
A113	FEFLOW	Modelling Software	Hydrological	Mapping hydrological drought hazard
A114	Interactive Ground Water - IGW	Modelling Software	Hydrological	Mapping hydrological drought hazard
A115	ParFlow	Modelling Software	Hydrological	Mapping hydrological drought hazard
A116	IWFM: Integrated Water Flow Model	Modelling Software	Hydrological	Mapping hydrological drought hazard
A117	HydroGeoSphere (HGS)	Modelling Software	Hydrological	Mapping hydrological drought hazard
A118	MIKE SHE	Modelling Software	Hydrological	Mapping hydrological drought hazard
A119	MODSIM-DSS	Modelling Software	Hydrological	Mapping hydrological drought hazard
A120	Source	Modelling Software	Hydrological	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower
A121	Water Evaluation And Planning system (WEAP)	Modelling Software	Hydrological	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower
A122	GSFLOW	Modelling Software	Hydrological	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower

4.3 Drought risk modeling tools and resources for Africa

This paragraph provides an overview of available drought risk modeling tools and resources for Africa. A detailed overview of all "model" characteristics can be found in the model reports in Appendix B.

Table 4.10 Overview of available drought hazard and risk models with for Africa.

No.	Name	Model type	Drought type	Application
B123	African Flood and Drought Monitor	Platform	Meteorological, Agricultural, Hydrological	Drought forecasting , Mapping hydrological drought hazard, Mapping meteorological drought hazard, Mapping agricultural drought hazard
B124	African Drought Observatory	Platform	Meteorological, Agricultural, Hydrological	Drought forecasting, Mapping drought impact to agriculture and livestock, Mapping drought impact to the overall economy, Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
B125	IGAD Climate Prediction and Applications Centre	Platform	Meteorological	Mapping meteorological drought hazard
B126	Seasonal Monitor for Southern Africa, Horn of Africa, West Africa Sahel and Eastern Regions	Platform	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard
B127	FLDAS - Eastern Africa	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
B128	FLDAS - Southern Africa	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
B129	FLDAS - Western Africa	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
B130	Famine Early Warning Systems Network - Africa	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
B131	NOAA CPC	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
B132	ITHACA Drought Monitoring	Platform	Meteorological, Agricultural	Mapping drought risk to agriculture and livestock, Mapping drought risk to population
B133	African drought monitor and continental seasonal climate forecast service	Dataset	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Socio-economic drought hazard
B134	SARCOF SADC seasonal climate outlook	Newsletter/ Bulletin	Meteorological	Drought forecasting
B135	GHACOF Climate Outlook	Newsletter/ Bulletin	Meteorological, Agricultural, Socio-	Drought forecasting , Mapping drought impact to agriculture and livestock, Mapping drought impact to
B136	National Drought Management Authority (Kenya)	Newsletter/ Bulletin	Meteorological, Agricultural, Hydrological	Drought forecasting
B137	Veg-Out Ethiopia	Tools	Meteorological, Agricultural, Hydrological	Drought forecasting , Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard

4.4 Drought risk modeling tools and resources for Asia

This paragraph provides an overview of available drought risk modeling tools and resources for Asia. A detailed overview of all “model” characteristics can be found in the model reports in Appendix C.

Table 4.11 Overview of available drought hazard and risk models for Asia.

No.	Name	Model type	Drought type	Application
C138	Drought Monitoring - Bangladesh	Platform	Meteorological	Mapping meteorological drought hazard
C139	India Agromet Advisory Bulletins	Platform	Meteorological, Agricultural	Drought forecasting
C140	Famine Early Warning Systems Network - Middle East	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
C141	Famine Early Warning Systems Network - Central Asia	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
C142	FLDAS - Central Asia Snow Modeling	Platform	Meteorological	Mapping meteorological drought hazard
C143	South Asia drought monitoring system	Platform	Meteorological	Drought monitoring
C144	Climate Model Prediction - China	Platform	Meteorological	Hazard mapping
C145	India Agromet Advisory Bulletins	Platform	Meteorological, Agricultural	Drought forecasting
C146	NWP (Numerical Weather Prediction) Products - Bangladesh	Dataset	Meteorological	Drought forecasting
C147	Climate System Monitoring (CSMD) - China	Dataset	Meteorological	Mapping meteorological drought hazard
C148	Agromet Products (India) - Agricultural Meteorology Division	Dataset	Meteorological, Agricultural	Drought forecasting
C149	Weekly Agromet Forecast - Bangladesh	Newsletter/ Bulletin	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping meteorological drought hazard, Mapping Mapping agricultural drought hazard

4.5 Drought risk modeling tools and resources for Europe

This paragraph provides an overview of available drought risk modeling tools and resources for Europe. A detailed overview of all "model" characteristics can be found in the model reports in Appendix D.

Table 4.12 Overview of available drought hazard and risk models for Europe.

No.	Name	Model type	Drought type	Application
D150	European Drought Centre Impact Report Inventory	Platform	Meteorological	Mapping drought impact to the overall economy
D151	European Drought Centre SPI	Platform	Meteorological	Mapping meteorological drought hazard
D152	European Drought Observatory	Platform	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard
D153	German Drought Monitor	Platform	Agricultural	Mapping agricultural drought hazard
D154	Drought monitor - Drought management Centre for Southeast Europe	Platform	Meteorological	Mapping meteorological drought hazard
D155	European Drought Centre Reference Database	Dataset	Meteorological	Hazard mapping, Mapping drought impact to population, Mapping drought impact to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower, Mapping drought impact to the overall economy
D156	European Drought Observatory - Combined Drought Indicator	Dataset	Meteorological, agricultural and hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
D157	European Drought Observatory -Daily soil moisture	Dataset	Agricultural	Drought forecasting , Mapping agricultural drought hazard
D158	European Drought Observatory -Daily soil moisture anomaly	Dataset	Agricultural	Drought forecasting , Mapping agricultural drought hazard
D159	European Drought Observatory - Forecasted soil moisture anomaly	Dataset	Agricultural	Drought forecasting , Mapping agricultural drought hazard
D160	European Drought Observatory - Standardized Precipitation Index	Dataset	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
D161	European Drought Observatory - Standardized SnowPack Index	Dataset	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
D162	European Drought Observatory -Fraction of absorbed photosynthetically active radiation (fAPAR)	Dataset	Agricultural	Mapping agricultural drought hazard
D163	European Drought Observatory -Fraction of absorbed photosynthetically active radiation (fAPAR) anomaly	Dataset	Agricultural	Mapping agricultural drought hazard
D164	Old World Drought Atlas	Dataset	Meteorological	Mapping meteorological drought hazard

4.6 Drought risk modeling tools and resources for North America

This paragraph provides an overview of a selection of available drought risk modeling tools and resources for North America. Detailed descriptions of these “models” can be found in the model reports in Appendix E.

Table 4.13 Overview of available drought hazard and risk models for North America.

No.	Name	Model type	Drought type	Application
E165	Famine Early Warning Systems Network - C. America/Caribbean/Mexico	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
E166	GOES Evapotranspiration and Drought (GET-D)	Platform	Agricultural	Mapping drought impact to agriculture and livestock
E167	North American Drought Monitor (NADM)	Platform	Meteorological, agricultural and hydrological	Mapping meteorological drought hazard
E168	Vegetation Drought Response Index (VegDRI)	Platform	Agricultural	Mapping drought impact to agriculture and livestock
E169	US Drought Impact Reporter (DIR)	Platform	Socio-economic	Mapping drought impact to population, Mapping drought impact to municipal and industrial water needs , Mapping drought impact to agriculture and livestock, Mapping drought impact to hydropower, Mapping drought impact to the overall economy
E170	Canadian agroclimate impact reporter	Platform	Agricultural	Mapping drought impact to agriculture and livestock
E171	Evaporative Demand Drought Index (EDDI) for the Continental U.S.	Platform	Agricultural, Hydrologic	Drought forecasting , Mapping hydrological drought hazard, Mapping agricultural drought hazard

4.7 Drought risk modeling tools and resources for the Pacific, Australia, New Zealand

This paragraph provides an overview of available drought risk modeling tools and resources for the Pacific, Australia, New Zealand. A detailed overview of all “model” characteristics can be found in the model reports in Appendix F.

Table 4.14 Overview of available drought hazard and risk models for the Pacific, Australia, New Zealand.

No.	Name	Model type	Drought type	Application
F172	Drought - Australia	Platform	Meteorological, Agricultural	Mapping meteorological drought hazard, Mapping agricultural drought hazard
F173	Monthly weather review - Australia	Platform	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
F174	Australian Groundwater Insight	Platform	Hydrological	Mapping hydrological drought hazard
F175	Seasonal Climate Outlooks for Pacific Island Countries (SCOPIC)	Platform	Meteorological, Hydrological	Drought forecasting
F176	New Zealand Drought Monitor	Platform	Meteorological	Mapping meteorological drought hazard
F177	Climate data online - BOM	Dataset	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
F178	Australian landscape Water balance	Dataset	Hydrological	Mapping hydrological drought hazard
F179	NIWA - South Pacific	Newsletter/ Bulletin	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
F180	Predictive Ocean-Atmosphere Model for Australia (POAMA)	Tools	Meteorological, Hydrological	Drought forecasting

4.8 Drought risk modeling tools and resources for South America

This paragraph provides an overview of available drought risk modeling tools and resources for South America. A detailed overview of all "model" characteristics can be found in the model reports in Appendix G.

Table 4.15 Overview of available drought hazard and risk modeling tools and resources for South America.

No.	Name	Model type	Drought type	Application
G181	Regional Hydroclimate Variability and Land Surface Processes	Platform	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard, Drought forecasting
G182	Centro Regional Climático para el Sur de América del Sur	Platform	Meteorological	Mapping meteorological drought hazard
G183	Portal Experimental Monitoréo y Pronóstico del Clima	Platform	Meteorological	Mapping meteorological drought hazard
G184	Peruvian National Drought Observatory	Platform	Meteorological	Mapping meteorological drought hazard
G185	Latin American Food and Drought Monitor	Platform	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
G186	G-Wadi-LAC	Platform		
G187	Centro Internacional para la Investigación del Fenómeno de El Niño	Platform	Meteorological	Mapping meteorological drought hazard
G188	CPTEC-INPE	Dataset	Meteorological	Drought forecasting
G189	SIRCSAN - Sistema de Información sobre Riesgo Climático y Seguridad Alimentaria y Nutricional	Newsletter /Bulletin	Meteorological	Drought forecasting , Mapping meteorological drought hazard
G190	Monitor de Sequía en México (MSM)	Newsletter /Bulletin	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard, Mapping agricultural drought hazard
G191	CEMADEN - Brazil	Newsletter /Bulletin	Meteorological, Hydrological	Mapping meteorological drought hazard, Mapping hydrological drought hazard
G192	Pronóstico Climático Trimestral para Argentina	Newsletter /Bulletin	Meteorological	Drought forecasting
G193	Boletín Agrometeorológico Mensual - Paraguay	Newsletter /Bulletin	Meteorological, Agricultural,	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological
G194	Boletín de Recursos Hidricos y Agricultura-Uruguay	Newsletter /Bulletin	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
G195	Boletín Informativo - Condiciones ENSO	Newsletter /Bulletin	Meteorological	Drought forecasting
G196	Boletín - Monitoreo de las Condiciones Climáticas & Pronóstico de Sequia	Newsletter /Bulletin	Meteorological	Mapping meteorological drought hazard, Drought forecasting
G197	Boletín de Recursos Hidricos y Agricultura-INAMHI, Ecuador	Newsletter /Bulletin	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard
G198	Boletín de Recursos Hidricos y Agricultura-IDEAM, Colombia	Newsletter /Bulletin	Meteorological, Agricultural, Hydrological	Mapping meteorological drought hazard, Mapping agricultural drought hazard, Mapping hydrological drought hazard

5 Conclusions and recommendations

This inventory of global and regional drought risk modeling tools and resources shows that there is a vast amount of indices, platforms, datasets, newsletters/bulletins, modeling software and tools available that each covers one or several aspects of drought risk. Especially the number of modeling tools and resources that provide insight on meteorological and agricultural drought hazards is large (160). Models that provide hydrological droughts are mainly focusing on streamflow, while modeling tools and resources about groundwater drought are hardly available. Modeling tools and resources that provide information or data of socio-economic drought hazards, drought impacts, and drought risks are relatively scarce (39). Figure 5.1 presents a map summarizing for each region the proportion of the tools and resources covering the different application types. 68 models and resources provide near real-time information by updating the information every week, month, or season. Based on these findings, we recommend that future efforts should be focused increasingly on integrated drought risk modeling tools and resources that include groundwater drought, socio-economic drought and/or focus on drought impacts or drought risks. In addition, since only a very small amount of modeling tools and resources provides information on future prognoses or scenarios of drought hazard and risk, we recommended that more effort is put on this aspect.

In some regions (e.g. South America, Pacific) the available drought modeling tools and resources mainly consist of newsletters/bulletins, while (real-time) datasets and tools that can be used by professionals to perform a more detailed or focused drought risk assessment or forecast are less available. In general, global datasets and tools do not provide information at the necessary spatial scale to fill this gap. It is recommended to improve the availability of (real-time) datasets and tools at the regional level with appropriate spatial and temporal scale.

During this inventory it was noted that the list of drought hazard, impact, and risk indices is very extensive. Several indices exist that are fully or almost similar, but have a different name (e.g. “standardized stream flow index” and “standardized runoff index”). It is recommended that an analysis is made of the comparability of the existing indices. A reduction of the number of indices and more uniformity in the use of indices for a specific application could improve the comparability of drought assessment results. Creating more uniformity amongst the drought indices may be useful in research projects. Moreover, it will be especially beneficiary for (local) professionals that have to develop an approach for assessing drought hazards, impacts, and/or risks.

Figure 5.1 Summary map of drought hazard and risk models per application and region