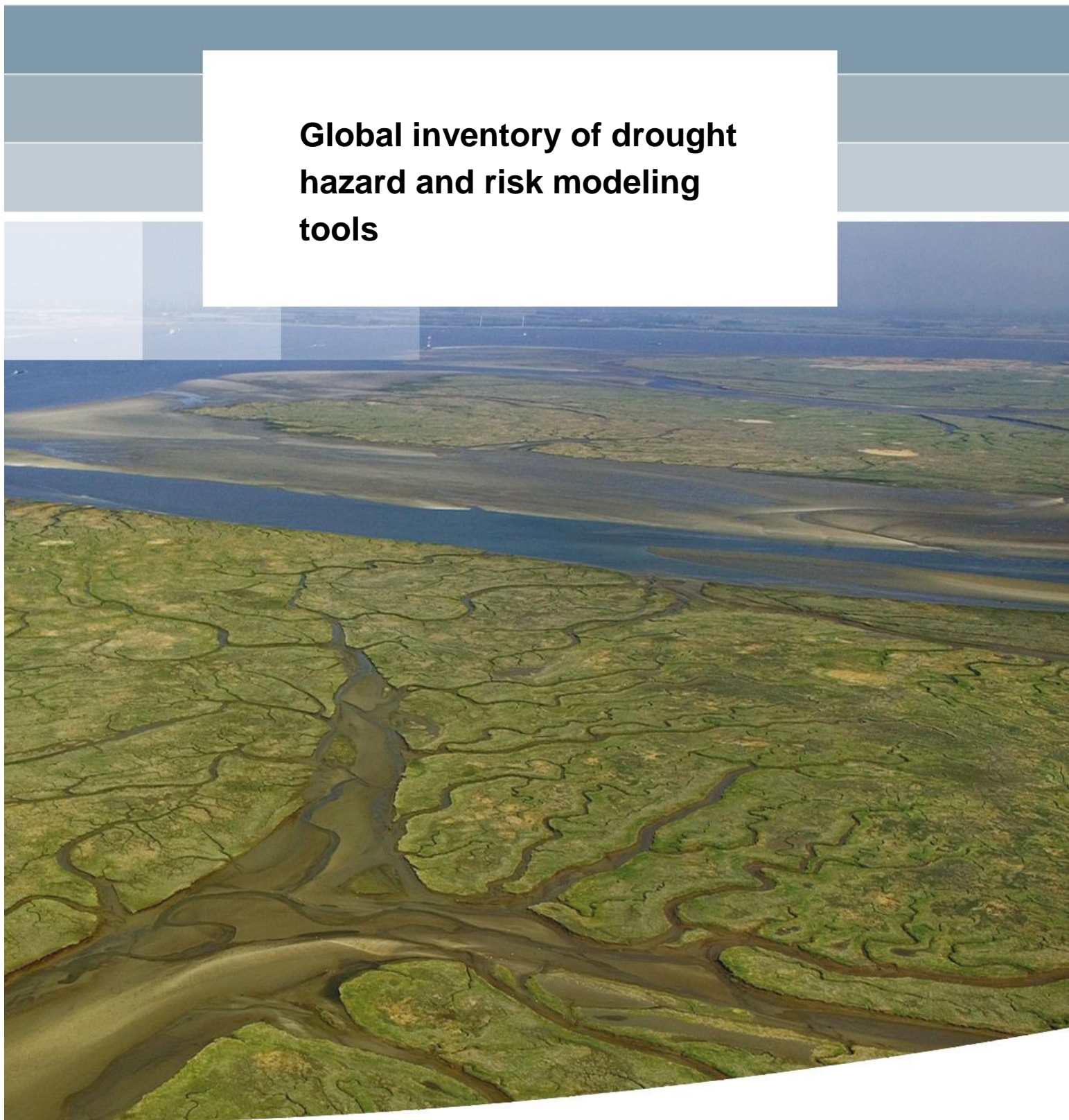


**Global inventory of drought
hazard and risk modeling
tools**



Global inventory of drought hazard and risk modeling tools

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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/>

Executive summary

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 risk assessments.

This report presents a global inventory of drought hazard and risk models, covering models 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 models 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 model reports of all drought risk models that are currently collected. Besides a description of the model and its' main characteristics, for each drought risk model contact information, references, and online links to the model are provided. This enables the user of this inventory to obtain more information and download the model.

Based on this inventory it could be concluded that the majority of models provide (real-time) information of meteorological, agricultural, and hydrological drought hazards. We recommended that more effort is put in the development of models that focus on socio-economic drought hazards, drought impacts, and drought risks. In addition, in some areas regions in developing countries the available drought risk models 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 Purpose and use of this document

The main objective of this document is to present a global inventory of drought hazard and risk models and explain its' structure, content and background. Drought risk models 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 risk models 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.

Most importantly, this report documents each drought risk model 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 models is provided in a summary table.

Prior to the overview of all drought risk models, information on the methods of the global inventory is provided. This includes the description of the scope of the inventory, descriptions of the types drought risk models, the drought types included, the range of applications taken up. Also, an overview of the relevant model characteristics is given for each model type.

The content of the inventory will be made available through an interactive, online data catalogue. Together, this report and the data catalogue enable professionals to select appropriate drought risk models to assess drought hazards and risk for their region, country or area.

1.2 Background

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 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 of drought hazard from satellite observations; map drought hazard levels using hydrological models; and compute physical, economic and humanitarian impacts of drought. The products include academically published papers, online web platforms 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 models. The inventory was carried out by a team of drought risk experts from Deltares, VU-IVM, IHE-Delft, UCSB and NDMC. The results of the project consist of this report, which provides an overview and description of all collected models, and an online data catalogue.

2 Methods

2.1 Scope of this inventory

According to IPCC³ meteorological droughts refer to deficits of precipitation and hydrological droughts refer to deficits in water availability from surface water or groundwater, not including human demand. Each of these drought phenomena can also be defined over different timescales, which are relevant for different issues (e.g. damages to infrastructure vs. agricultural losses). Drought risk is defined as those risks appearing as a consequence of drought hazards (meteorological, agricultural, hydrological, and socio-economic), the exposure to drought hazards (e.g. population, municipal and industrial water needs, agricultural crop and livestock production, hydropower production, and the overall economy) and vulnerability of these exposed aspects⁴. Vulnerability is defined as ‘society’s ability to prepare and recover from a natural disaster’⁵.

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

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

2.2 Types of drought

There are numerous definitions of drought⁶. For the purpose of this global inventory of drought hazard and risk models 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, short description of these drought types is given based on information from the United States’ National Drought and Mitigation Centre⁷.

³IPCC: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change, 2012b.*

⁴Carrao, H., Naumann, G., and Barbosa, P., 2016. *Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability. Global Environmental Change 39 (2016) 108–124.*

⁵Faneca Sánchez, M., Aalst, M. van, Duijine, H. van, Hendriks, D., Vermooten, S. 2017. *Assessing water related risks to the industry and other stakeholders in 2 watersheds in Colombia. Deltares report nr. 1230409-002.*

⁶Wilhite, D.A., and M.H. Glantz. 1985. *Understanding the Drought Phenomenon: The Role of Definitions. Water International 10(3):111–120.*

⁷National Drought and Mitigation Centre: <http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx>



Meteorological drought is defined usually on the basis of the degree of dryness (i.e. lack of precipitation) in comparison to some “normal” or average amount, and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region².



Agricultural drought Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Important in this context is the plant water demand, which depends on weather conditions, biological plant characteristics, growth stage, and soil properties.



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 with 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 the occurrence of meteorological and agricultural droughts as it takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream flow, and groundwater and reservoir levels².



Socio-economic drought definitions associate the supply and demand of some economic goods with elements of meteorological, hydrological, and agricultural drought. It differs from the aforementioned types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather- or human-related shortfall in water supply.

2.3 Model types

This inventory of drought hazard and risk models 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 models 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 models in the inventory is indicated in the model information sheets. The online data catalogue provides automated links between related models. Below, a short description of the six types of drought risk models 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 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 risk (e.g. runoff, groundwater levels). In general, the ease of use of datasets can be described as more complicated; they can be used and processed by (agro-)hydrological or water management experts and drought professionals.



Indices: typically computed (numerical) representations of drought severity, assessed using climatic or hydro-meteorological and/or socio-economic inputs including the indicators listed above. 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. Some are relatively easy 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 Risk Indicators and Indices, published by WMO and GWP⁸, provides an important overview and description of drought risk indices that was used as the basis of many indices' descriptions in this global inventory of drought hazard and risk models.



Modeling software: numerical modeling software that enables users to transform basic datasets into derived parameters required for drought risk characterization. In this inventory we included most 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 complicated; software can be

⁸ 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.

used and processed by (agro-)hydrological or water management experts with a technical background.



Tools: numerical modeling software that has 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 complicated; tools can be used and processed by (agro-)hydrological or water management experts with a technical background.

2.4 Applications

Different drought risk models aim for different types of applications, either focusing on drought hazards, drought impact, drought risk or forecasting of drought. Below, all applications that are collected in our *global inventory of drought modeling tools* are listed:

Drought Hazard Mapping

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

- Meteorological drought hazard mapping: drought hazard models related to precipitation (rain and snow), evapo(trans)piration, and temperature.
- Hydrological drought hazard mapping: drought hazard models related to runoff, discharge, and groundwater levels.
- Agricultural drought hazard mapping: drought hazard models related to agricultural water deficits.
- Socio-economic drought hazard mapping: drought hazard models 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 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 models that have their focus on real time drought monitoring and forecasting of the different types of drought hazards, impacts, or risks.

2.5 Selecting Models

Drought risk models were selected based on three main criteria. First, the model should be open access, will become open access in the near future, or the World Bank has access to the model. Secondly, the drought risk model 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.

2.6 Model characteristics

For each of the drought risk models, 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 model, type(s) of drought, type(s) of application, status (operational or in development), countries where available, availability of future scenarios via the model, and costs of obtaining the model. Next, relevant contact information and web-links are provided, followed by information on the datasets used in the model 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 model, its strengths and weaknesses, and literature references that can be consulted to obtain more detailed information.

3 Overview of drought hazard and risk models

3.1 Overview of available models

In total 198 drought risk models were identified: 56 platforms, 63 indices, 27 datasets, 15 newsletters/bulletins, 5 tools, and 32 modeling software types. The tables below (Table 3.1, Table 3.2, Table 3.3, and Table 3.4) give an overview of the distribution of the models over the regions of the world, the drought type that are assessed as well as the main applications. Most of the identified drought risk models consist of platforms or indices, have a global extend, and focus on mapping hazards. In addition, multiple global datasets of drought hazards are available. On the other hand, drought risk models that assess socio-economic drought hazards and models that can be applied for studies on drought impact and drought risk are scarce. On the global scale some models are available that provide these types of information, but on regional scale such drought risk models are mostly lacking. In the paragraphs below, an overview of all available models is given per region. The Appendices of this report contain model reports with detailed information for each of the models.

Table 3.1 Number of drought hazard and risk models 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 3.2 Number of drought hazard and risk models 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 3.1.

	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 3.3 Number of drought hazard and risk models 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 3.1.

	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 3.4 Number of drought hazard and risk model applications that is available per model type. Some Models have more than one application; hence the total number of models in this table is higher in Table 3.1.

	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

3.2 Global drought risk models

This paragraph provides an overview of available drought risk models with a global extend. A detailed overview of all model characteristics can be found in the model reports in Appendix A.

Table 3.5 Overview of available drought hazard and risk platforms with global extend.

No.	Name	Model type Platform	Drought type	Application
A1	Standardized Precipitation Index - IRI data library	Platform	Meteorological	Meteorological drought hazard mapping
A2	Global Drought Observatory	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A3	E2O Water Cycle Integrator	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A4	NOAA Global Drought Map	Platform	Meteorological	Meteorological drought hazard mapping
A5	SPEI global drought monitor	Platform	Meteorological	Meteorological drought hazard mapping
A6	Global Drought Information System / National Integrated Drought Information System	Platform	Meteorological	Meteorological drought hazard mapping
A7	Global Integrated Drought Monitoring and Prediction System (GIDMaPS)	Platform	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
A8	IWMI water data portal	Platform	Socio-economic	Socio-economic drought hazard mapping
A9	Aqueduct Water Risk Atlas	Platform	Meteorological, Socio-economic	Mapping drought risk to the overall economy, Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping, Socio-economic drought hazard mapping
A10	Global Agricultural Drought Monitoring and Forecasting System	Platform	Agricultural	Mapping drought impact to agriculture and livestock, Agricultural drought hazard mapping
A11	Famine Early Warning Systems Network	Platform	Agricultural	Mapping drought risk to population, Mapping drought risk to agriculture and livestock, Agricultural drought hazard mapping
A12	Agricultural Stress Index and precipitation anomalies (FAO)	Platform	Agricultural	Mapping drought impact to agriculture and livestock, Agricultural drought hazard mapping
A13	Earth Observation for crop monitoring - Global Information and Early Warning	Platform	Agricultural, Meteorological	Agricultural drought hazard mapping, Meteorological drought hazard mapping
A14	GEOGLAM Crop Monitor (MENA REGION)	Platform	Agricultural	Mapping drought impact to agriculture and livestock
A15	Standardized Precipitation Index (SPI) for Global Land Surface (1949-2012)	Dataset	Meteorological	Meteorological drought hazard mapping

Table 3.6 Overview of available drought hazard and risk datasets with global extend.

No.	Name	Model type Dataset	Drought type	Application
A16	GRACE	Dataset	Hydrological	Hydrological drought hazard mapping
A17	EM-DAT	Dataset	Socio-economic	Mapping drought impact to the overall economy
A18	The Early Warning eXplorer (EWX)	Dataset	Meteorological, Agricultural	Drought forecasting, Meteorological drought hazard mapping, Agricultural drought hazard mapping
A19	Global Precipitation Climatology Centre Drought Database	Dataset	Meteorological	Meteorological drought hazard mapping
A20	ISI-MIP	Dataset	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
A21	MODIS Global Terrestrial Drought Severity Index	Dataset	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
A22	Global map of drought risk	Dataset	Socio-economic	Mapping drought risk to population, Socio-economic
A23	NOAA - daily weather records	Dataset	Meteorological	Meteorological drought hazard mapping
A24	E2O drought indicators	Dataset	hydrological, meteorological	Meteorological drought hazard mapping

Table 3.7 Overview of available drought hazard and risk indices with global extend.

No.	Name	Model type Indices	Drought type	Application
A25	Standardized Precipitation Index (SPI)	Indices	Meteorological	Meteorological drought hazard mapping
A26	Groundwater Table Declining Trend	Indices	Hydrological	Hydrological drought hazard mapping
A27	Standardized Groundwater Index (SGI)	Indices	Hydrological	Hydrological drought hazard mapping
A28	Groundwater Resource Index (GRI)	Indices	Hydrological	Hydrological drought hazard mapping
A29	Groundwater Drought Index (GWI)	Indices	Hydrological	Hydrological drought hazard mapping
A30	Drought deficit volume	Indices	Hydrological	Mapping drought risk to population, Mapping drought risk to municipal and industrial water needs
A31	Threshold Level Indicators (Deficit Indices)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A32	Palmer Drought Severity Index (PDSI)	Indices	Meteorological	Meteorological drought hazard mapping
A33	Aridity Anomaly Index (AAI)	Indices	Meteorological	Meteorological drought hazard mapping
A34	Deciles	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
A35	Keetch-Byram Drought Index (KBDI)	Indices	Agricultural	Agricultural drought hazard mapping
A36	Percent of Normal Precipitation	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
A37	Weighted Anomaly Standardized Precipitation Index (WASP)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
A38	Aridity Index (AI)	Indices	Meteorological	Meteorological drought hazard mapping
A39	China Z Index (CZI)	Indices	Meteorological	Meteorological drought hazard mapping
A40	Crop Moisture Index (CMI)	Indices	Agricultural	Agricultural drought hazard mapping
A41	Drought Area Index (DAI)	Indices	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
A42	Drought Reconnaissance Index (DRI)	Indices	Meteorological	Meteorological drought hazard mapping
A43	Effective Drought Index (EDI)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A44	NOAA Drought Index (NDI)	Indices	Agricultural	Agricultural drought hazard mapping
A45	Palmer Z Index	Indices	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
A46	Rainfall Anomaly Index (RAI)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A47	Self-Calibrated Palmer Drought Severity Index (sc-PDSI)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A48	Standardized Anomaly Index (SAI)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A49	Standardized Precipitation Evapotranspiration Index (SPEI)	Indices	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A50	Agricultural Reference Index for Drought (ARID)	Indices	Agricultural	Agricultural drought hazard mapping
A51	Crop Specific Drought Index (CSDI)	Indices	Agricultural	Mapping drought impact to agriculture and livestock, Agricultural drought hazard mapping
A52	Reclamation Drought Index (RDI)	Indices	Hydrological	Hydrological drought hazard mapping
A53	Soil Moisture Anomaly (SMA)	Indices	Agricultural	Agricultural drought hazard mapping
A54	Evapotranspiration Deficit Index (ETDI)	Indices	Agricultural	Agricultural drought hazard mapping
A55	Soil Moisture Deficit Index (SMDI)	Indices	Agricultural	Agricultural drought hazard mapping
A56	Palmer Hydrological Drought Index (PHDI)	Indices	Hydrological	Hydrological drought hazard mapping
A57	Standardized Reservoir Supply Index (SRSI)	Indices	Hydrological	Mapping drought impact to municipal and industrial water needs, Mapping drought impact to hydropower
A58	Standardized Streamflow Index (SSFI)	Indices	Hydrological	Hydrological drought hazard mapping

No.	Name	Model type Indices	Drought type	Application
A59	Standardized Water-Level Index (SWI)	Indices	Hydrological	Hydrological drought hazard mapping
A60	Streamflow Drought Index (SDI)	Indices	Hydrological	Hydrological drought hazard mapping
A61	Surface Water Supply Index (SWSI)	Indices	Hydrological	Hydrological drought hazard mapping
A62	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
A63	Standardized Snowmelt and Rain Index (SMRI)	Indices	Hydrological	Hydrological drought hazard mapping
A64	Enhanced Vegetation Index (EVI)	Indices	Agricultural	Agricultural drought hazard mapping
A65	Evaporative Stress Index (ESI)	Indices	Agricultural, Hydrological	Agricultural drought hazard mapping, Hydrological drought hazard mapping
A66	Normalized Difference Vegetation Index (NDVI)	Indices	Agricultural	Agricultural drought hazard mapping, Mapping drought impact to agriculture and livestock
A67	Temperature Condition Index (TCI)	Indices	Agricultural	Agricultural drought hazard mapping, Mapping drought impact to agriculture and livestock
A68	Vegetation Condition Index (VCI)	Indices	Agricultural	Agricultural drought hazard mapping, Mapping drought impact to agriculture and livestock
A69	Vegetation Drought Response Index (VegDRI)	Indices	Agricultural	Agricultural drought hazard mapping
A70	Vegetation Health Index (VHI)	Indices	Agricultural	Agricultural drought hazard mapping, Mapping drought impact to agriculture and livestock
A71	Water Requirement Satisfaction Index (WRSI) and Geo WRSI	Indices	Agricultural	Mapping drought impact to agriculture and livestock, Agricultural drought hazard mapping
A72	Normalized Difference Water Index (NDWI)	Indices	Agricultural	Agricultural drought hazard mapping
A73	Soil Adjusted Vegetation Index (SAVI)	Indices	Agricultural	Agricultural drought hazard mapping
A74	Multivariate Standardized Drought Index (MSDI)	Indices	Meteorological, agricultural and hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
A75	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
A76	Inflow-Demand Reliability (IDR)	Indices	Hydrological	Hydrological drought hazard mapping, Socio-economic drought hazard mapping
A77	Water Storage Resilience indicator (WSR)	Indices	Socio-economic	Socio-economic drought hazard mapping

Table 3.8 Overview of available drought hazard and risk tools with global extend.

No.	Name	Model type Tools	Drought type	Application
A78	PCRGLOB-WB	Tools	Hydrological	Hydrological drought hazard mapping
A79	Global Groundwater Model (UU, Deltares)	Tools	Hydrological	Hydrological drought hazard mapping

Table 3.9 Overview of available drought hazard and risk modelling software with global extend.

No.	Name	Model type Modelling Software	Drought type	Application
A80	RIBASIM	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
A81	Cropwat	Modelling Software	Agricultural	Mapping drought impact to agriculture and livestock
A82	Aquacrop	Modelling Software	Agricultural	Mapping drought impact to agriculture and livestock
A83	HBV	Modelling Software	Hydrological	Hydrological drought hazard mapping
A84	TOPMODEL	Modelling Software	Hydrological	Hydrological drought hazard mapping
A85	WFLOW	Modelling Software	Hydrological	Hydrological drought hazard mapping

No.	Name	Model type Modelling Software	Drought type	Application
A86	Sacramento Model	Modelling Software	Hydrological	Hydrological drought hazard mapping
A87	GR4J	Modelling Software	Hydrological	Hydrological drought hazard mapping
A88	SIMHYD	Modelling Software	Hydrological	Hydrological drought hazard mapping
A89	SIMGRO	Modelling Software	Agricultural	Agricultural drought hazard mapping
A90	DRAINMOD	Modelling Software	Agricultural	Agricultural drought hazard mapping
A91	SWAP	Modelling Software	Agricultural	Agricultural drought hazard mapping
A92	HYDRUS-1D	Modelling Software	Agricultural	Agricultural drought hazard mapping
A93	DSSAT	Modelling Software	Agricultural	Agricultural drought hazard mapping
A94	CROPSYST	Modelling Software	Agricultural	Agricultural drought hazard mapping
A95	SWAT	Modelling Software	Agricultural	Agricultural drought hazard mapping
A96	STICS	Modelling Software	Agricultural	Agricultural drought hazard mapping
A97	RZWQM	Modelling Software	Agricultural	Agricultural drought hazard mapping
A98	WOFOST	Modelling Software	Agricultural	Agricultural drought hazard mapping
A99	WARM	Modelling Software	Agricultural	Agricultural drought hazard mapping
A100	MODFLOW	Modelling Software	Hydrological	Hydrological drought hazard mapping
A101	SUTRASUITE	Modelling Software	Hydrological	Hydrological drought hazard mapping
A102	FEFLOW	Modelling Software	Hydrological	Hydrological drought hazard mapping
A103	Interactive Ground Water - IGW	Modelling Software	Hydrological	Hydrological drought hazard mapping
A104	ParFlow	Modelling Software	Hydrological	Hydrological drought hazard mapping
A105	IWFM: Integrated Water Flow Model	Modelling Software	Hydrological	Hydrological drought hazard mapping
A106	HydroGeoSphere (HGS)	Modelling Software	Hydrological	Hydrological drought hazard mapping
A107	MIKE SHE	Modelling Software	Hydrological	Hydrological drought hazard mapping
A108	MODSIM-DSS	Modelling Software	Hydrological	Hydrological drought hazard mapping
A109	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
A110	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
A111	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

3.3 Drought risk models for Africa

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

Table 3.10 Overview of available drought hazard and risk models with for Africa.

No.	Name	Model type	Drought type	Application
B1	African Flood and Drought Monitor	Platform	Meteorological, Agricultural, Hydrological	Drought forecasting , Hydrological drought hazard mapping, Meteorological drought hazard mapping, Agricultural drought hazard mapping
B2	African Drought Observatory	Platform	Meteorological, Agricultural, Hydrological	Drought forecasting , mapping drought impact to the overall economy, Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
B3	IGAD Climate Prediction and Applications Centre	Platform	Meteorological	Meteorological drought hazard mapping
B4	Seasonal Monitor for Southern Africa, Horn of Africa, West Africa Sahel and Eastern Regions	Platform	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
B5	FLDAS - Eastern Africa	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B6	FLDAS - Southern Africa	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B7	FLDAS - Western Africa	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B8	Famine Early Warning Systems Network - Africa	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B9	NOAA CPC RFE2	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B10	NOAA CPC ARC2	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
B11	ITHACA Drought Monitoring	Platform	Meteorological, Agricultural	mapping drought risk to agriculture and livestock, mapping drought risk to population
B12	African drought monitor and continental seasonal climate forecast service	Dataset	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Socio-economic drought hazard mapping
B13	SARCOF SADC seasonal climate outlook	Newsletter/ Bulletin	Meteorological	Drought forecasting
B14	GHACOF Climate Outlook	Newsletter/ Bulletin	Meteorological, Agricultural, Socio-economic	Drought forecasting , mapping drought impact to agriculture and livestock, mapping drought impact to population
B15	National Drought Management Authority (Kenya)	Newsletter/ Bulletin	Meteorological, Agricultural, Hydrological	Drought forecasting
B16	Veg-Out Ethiopia	Tools	Meteorological, Agricultural, Hydrological	Drought forecasting , Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping

3.4 Drought risk models for Asia

This paragraph provides an overview of available drought risk models for Asia. A detailed overview of all model characteristics can be found in the model reports in Appendix C.

Table 3.11 Overview of available drought hazard and risk models for Asia.

No.	Name	Model type	Drought type	Application
C1	Drought Monitoring - Bangladesh	Platform	Meteorological	Meteorological drought hazard mapping
C2	India Agromet Advisory Bulletins	Platform	Meteorological, Agricultural	Drought forecasting
C3	Famine Early Warning Systems Network - Middle East	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
C4	Famine Early Warning Systems Network - Central Asia	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
C5	FLDAS - Central Asia Snow Modeling	Platform	Meteorological	Meteorological drought hazard mapping
C6	IMWI South Asia drought monitoring system	Platform	Meteorological	Drought forecasting
C7	NWP (Numerical Weather Prediction) Products - Bangladesh	Dataset	Meteorological	Drought forecasting
C8	Agromet Products (India) - Agricultural Meteorology Division	Dataset	Meteorological, Agricultural	Drought forecasting
C9	Weekly Agromet Forecast - Bangladesh	Newsletter/ Bulletin	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
C11	Climate Model Prediction - China	Platform	Meteorological	Meteorological drought hazard mapping
C12	Agromet Products (India) - Agricultural Meteorology Division	Dataset	Meteorological	Forecasting
C13	India Agromet Advisory Bulletins	Platform	Meteorological, Agricultural	Forecasting

3.5 Drought risk models for Europe

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

Table 3.12 Overview of available drought hazard and risk models for Europe.

No.	Name	Model type	Drought type	Application
D1	European Drought Centre Impact Report Inventory	Platform	Meteorological	mapping drought impact to the overall economy
D2	European Drought Centre SPI	Platform	Meteorological	Meteorological drought hazard mapping
D3	European Drought Observatory	Platform	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
D4	German Drought Monitor	Platform	Agricultural	Agricultural drought hazard mapping
D5	Drought monitor - Drought management Centre for Southeast Europe	Platform	Meteorological	Meteorological drought hazard mapping
D6	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
D7	European Drought Observatory - Combined Drought Indicator	Dataset	Meteorological, agricultural and	Meteorological drought hazard mapping, Hydrological drought hazard mapping
D8	European Drought Observatory -Daily soil moisture	Dataset	Agricultural	Drought forecasting , Agricultural drought hazard mapping
D9	European Drought Observatory -Daily soil moisture anomaly	Dataset	Agricultural	Drought forecasting , Agricultural drought hazard mapping
D10	European Drought Observatory - Forecasted soil moisture anomaly	Dataset	Agricultural	Drought forecasting , Agricultural drought hazard mapping
D11	European Drought Observatory - Standardized Precipitation Index	Dataset	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
D12	European Drought Observatory - Standardized SnowPack Index	Dataset	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
D13	European Drought Observatory -Fraction of absorbed photosynthetically active	Dataset	Agricultural	Agricultural drought hazard mapping
D14	European Drought Observatory -Fraction of absorbed photosynthetically active radiation (fAPAR) anomaly	Dataset	Agricultural	Agricultural drought hazard mapping
D15	Old World Drought Atlas	Dataset	Meteorological	Meteorological drought hazard mapping

3.6 Drought risk models for North America

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

Table 3.13 Overview of available drought hazard and risk models for North America.

No.	Name	Model type	Drought type	Application
E1	Famine Early Warning Systems Network - C.America/Caribbean/Mexico	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
E2	GOES Evapotranspiration and Drought (GET-D)	Platform	Agricultural	mapping drought impact to agriculture and livestock
E3	North American Drought Monitor (NADM)	Platform	Meteorological, agricultural and hydrological	Meteorological drought hazard mapping
E4	Vegetation Drought Response Index (VegDRI)	Platform	Agricultural	mapping drought impact to agriculture and livestock
E5	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
E6	Canadian agroclimate impact reporter	Platform	Agricultural	mapping drought impact to agriculture and livestock
E7	Evaporative Demand Drought Index (EDDI) for the Continental U.S.	Platform	Agricultural, Hydrologic	Drought forecasting , Hydrological drought hazard mapping, Agricultural drought hazard mapping

3.7 Drought risk models for the Pacific, Australia, New Zealand

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

Table 3.14 Overview of available drought hazard and risk models for the Pacific, Australia, New Zealand.

No.	Name	Model type	Drought type	Application
F1	Drought - Australia	Platform	Meteorological, Agricultural	Meteorological drought hazard mapping, Agricultural drought hazard mapping
F2	Monthly weather review - Australia	Platform	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
F3	Australian Groundwater Insight	Platform	Hydrological	Hydrological drought hazard mapping
F4	Seasonal Climate Outlooks for Pacific Island Countries (SCOPIIC)	Platform	Meteorological, Hydrological	Drought forecasting
F5	New Zealand Drought Monitor	Platform	Meteorological	Meteorological drought hazard mapping
F6	Climate data online - BOM	Dataset	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
F7	Australian landscape Water balance	Dataset	Hydrological	Hydrological drought hazard mapping
F8	NIWA - South Pacific	Newsletter/Bulletin	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
F9	Predictive Ocean-Atmosphere Model for Australia (POAMA)	Tools	Meteorological, Hydrological	Drought forecasting

3.8 Drought risk models for South America

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

Table 3.15 Overview of available drought hazard and risk models for South America.

No.	Name	Model type	Drought type	Application
G1	Regional Hydroclimate Variability and Land Surface Processes	Platform	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
G2	Centro Regional Climático para el Sur de América del Sur	Platform	Meteorological	Meteorological drought hazard mapping
G3	Portal Experimental Monitoréoy Pronóstico del Clima	Platform	Meteorological	Meteorological drought hazard mapping
G4	Peruvian National Drought Observatory	Platform	Meteorological	Meteorological drought hazard mapping
G5	Latin American Food and Drought Monitor	Platform	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
G6	G-Wadi-LAC	Platform		
G7	Centro Internacional para la Investigación del Fenómeno de El Niño	Platform	Meteorological	Meteorological drought hazard mapping
G8	CPTEC-INPE	Dataset	Meteorological	Drought forecasting
G9	SIRCSAN - Sistema de Información sobre Riesgo Climático y Seguridad Alimentaria y Nutricional	Newsletter/Bulletin	Meteorological	Drought forecasting , Meteorological drought hazard mapping
G10	Monitor de Sequía en México (MSM)	Newsletter/Bulletin	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping, Agricultural drought hazard mapping
G11	CEMADEN - Brazil	Newsletter/Bulletin	Meteorological, Hydrological	Meteorological drought hazard mapping, Hydrological drought hazard mapping
G12	Pronóstico Climático Trimestral para Argentina	Newsletter/Bulletin	Meteorological	Drought forecasting
G13	Boletín Agrometeorológico Mensual - Paraguay	Newsletter/Bulletin	Meteorological, Agricultural,	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought
G14	Boletín de Recursos Hidricos y Agricultura- Uruguay	Newsletter/Bulletin	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
G15	Boletín Informativo - Condiciones ENSO	Newsletter/Bulletin	Meteorological	Drought forecasting
G16	Boletín - Monitoreo de las Condiciones Climáticas & Pronóstico de Sequia	Newsletter/Bulletin	Meteorological	Drought forecasting
G17	Boletín de Recursos Hidricos y Agricultura- INAMHI, Ecuador	Newsletter/Bulletin	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping
G18	Boletín de Recursos Hidricos y Agricultura- IDEAM, Colombia	Newsletter/Bulletin	Meteorological, Agricultural, Hydrological	Meteorological drought hazard mapping, Agricultural drought hazard mapping, Hydrological drought hazard mapping

4 Conclusions and recommendations

This inventory of global and regional drought risk models 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 models that provide (real-time) insight on meteorological and agricultural drought hazards is large. Models that provide hydrological droughts are mainly focusing on streamflow, while models about groundwater drought are hardly available. Models that provide information or data of socio-economic drought hazards, drought impacts, and drought risks are relatively scarce. Based on these findings, we recommend that future efforts should be focused increasingly on integrated drought risk models 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 models 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 risk models 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.

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