Drought Risk Assessment - Quantifying the Impacts of Droughts

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Abstract

One type of natural hazards are droughts. To quantify the Impacts of Droughts we have to respect the different dimensions like economic, environmental and social impacts.
To meet these requirements exits besides various indices also exist frameworks to analyse for the economic impact. Technical solution like Remote Sensing and GIS help to create measurable value from these impacts to make it useable insurances, calculation of potential crop yields or for guest numbers in tourism.

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Introduction and general description of the problem

Drought means lack of water. Many people in industrialized nations find it difficult to imagine what acute water shortage means. In many arid areas of the world, however, water shortages are commonplace. Persistent droughts can destroy the livelihoods of millions of people, lead to famine and thus threaten the lives of many children, women and men. Drought is a creeping phenomenon that approaches over a long period of time. It is difficult to predict because it occurs without a known rhythm and is not necessarily linked to the annual alternation of dry and rainy seasons. According to forecasts by the Intergovernmental Panel on Climate Change (IPCC), soil moisture will decrease in the coming decades, which will double the area at risk and three times more frequent droughts. Therefore, it's important to get a fundamental and integrated view to the problematical topic 'drought'.

Methodology and relevant literature

We have conducted a literature search. This was based on the given topic in the first step. In addition, we looked at further literature.

Definition of objective and tasks

Important is to have a common understanding of what we understand by drought. There are different definitions, depending on if they are categorized as conceptual (definitions formulated in general terms) and operational (Hisdal and Tallaksena 2003). In this paper we use the definition by Dai A (2010): "Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas."

Table 1 Drought: A selection of definitions (based on Belal et.al. 2014)

Citation	Definition
WMO (1986)	Drought means a sustained, extended deficiency in precipitation.
FAO (1983)	FAO defines a drought hazard as "the percentage of years when crops fail from the lack of moisture."
MWD (2007)	Drought is a normal, recurrent feature of climate, although often erroneously considered an unexpected and an extraordinary event. It is a temporary aberration within the natural variability and can be considered an insidious hazard of nature; it differs from aridity which is a long-term, average feature of climate.
UNa Secretariat General (1994)	Drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

Dai (2010)	Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas.
Mastrangelo et al. (2012)	Drought is by far the most important environmental stress in agriculture, causing important crop losses every year.

Four droughts exist not only different definitions like in Table 1, they were also classified into 4 categories (Hennessyetal. 2008), which include:

1. **Meteorological drought** is defined as a lack of precipitation over a region for a period of time. Amount of precipitation is used for meteorological drought analysis. Drought is a deficit of precipitation with respect to average values. Different studies use monthly precipitation to analyze droughts.

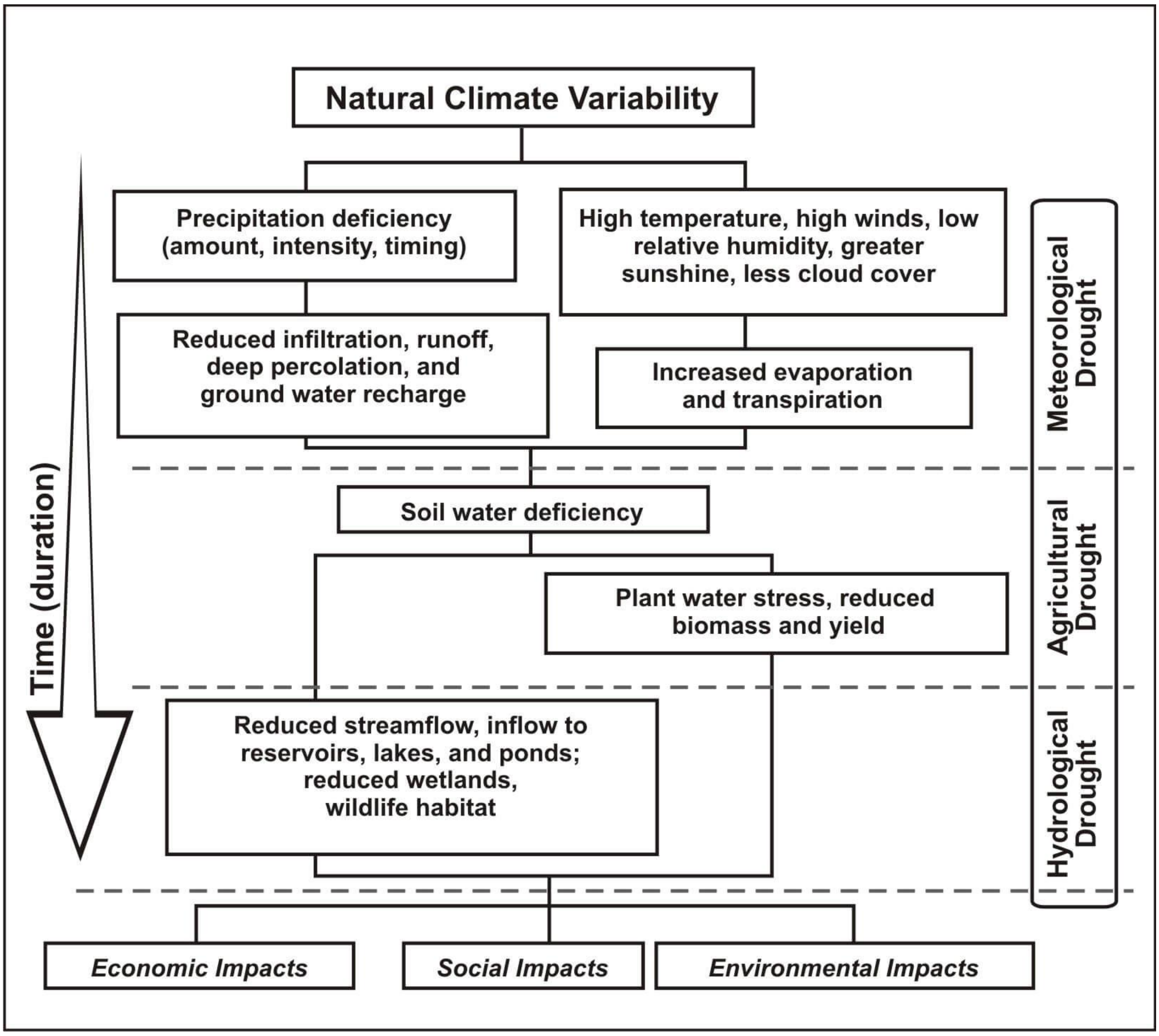
2. **Hydrological drought** is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system.

3. **Agricultural drought**, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. A decline of soil moisture depends on several factors which are affected by meteorological and hydrological droughts along with differences between actual evapotranspiration and potential evapotranspiration. Several drought indices, based on a combination of precipitation, temperature, and soil moisture, have been derived to study agricultural droughts.

4. **Socio-economic drough**t is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water). Socio-economic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. Otherwise, it is the effect of elements of the above droughts on supply and demand of economic goods and human well-being.

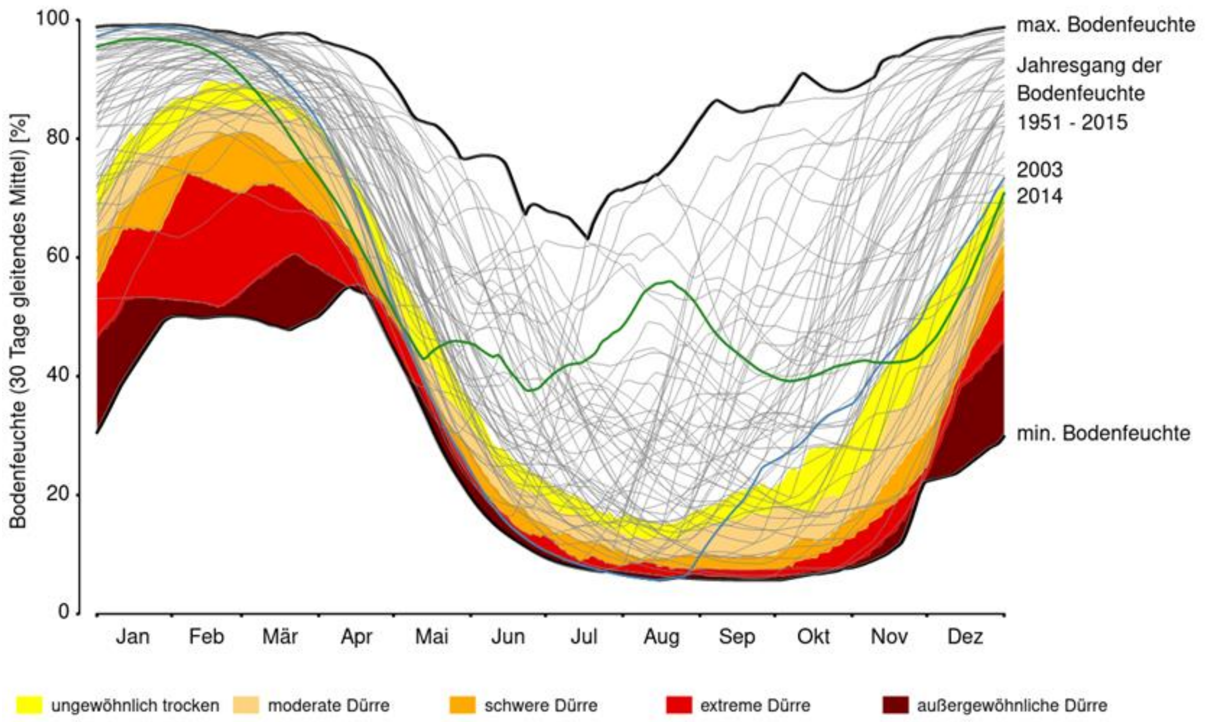
Figure 1 shows an analysis of the relationships between the Meteorological drought, the Hydrological drought and the Agricultural drought.

Fig. 1 The sequence of drought impacts associated with meteorological, agricultural, and hydrological drought (Source: National Drought Mitigation Centre, https://drought.unl.edu/Education/DroughtIn-depth/TypesofDrought.aspx)



In Figure 2 you can see an example of a presentation of a hydrological drought curve. It's the soil moisture at a location in Brandenburg, 30-day moving average over the course of the year and drought areas.

Fig. 2. Daily soil moisture map (from August 15, 2010) derived from ASCAT, AMSR-E, and SMOS Satellite measurements for ascending (left) and descending (right) satellite orbits. https://www.grundwasser-online.de/messwerte/bodenfeuchte



Like figure 1 shows, the impacts of a drought can categorised according to MWD (2007) and (Belal et.al. 2014) as economic, environmental or social:

Economic impacts

Many economic impacts occur in agriculture and related sectors, including forestry and fisheries, because of the reliance of these sectors on surface and subsurface water supplies. In addition to obvious losses in yields in crop and livestock production, drought is associated to increase of insect infestations, plant diseases and wind erosion. The incidence of forest and range fires substantially augments during extended droughts, which in turn places both human and wildlife populations at higher levels of risk. Income loss is another indicator used in assessing the impacts of drought because a lot of sectors are affected. Reduced income for farmers has a ripple effect. Retailers and others who provide goods and services to farmers face reduced business, leading to unemployment, increased credit risk for financial institutions, capital shortfalls and loss of tax revenue for government. Less discretionary income affects recreation and tourism industries. Prices of food, energy and other products increase as supplies are reduced. In some cases, local shortages of certain goods result in the need to import these goods from outside the stricken affected region. Reduced river discharge impairs the navigation on rivers and causes an increase of transportation costs, because products must be transported by rail or road. Hydropower production may also be curtailed significantly.

Environmental impacts

Environmental losses are the result of damages to plant and animal species, wildlife habitat, air and water quality, forest and range fires, degradation of landscape quality, loss of biodiversity and soil erosion. Some of the effects are short-term and conditions quickly return to normal situation after the end of the drought. Other environmental effects linger for some time or may even become permanent. These effects are enhanced, if the management of water resources is permanently not sustainable at all, as often true for wetlands (Zacharias et al., 2003). Wildlife habitat, for example, may be degraded through the loss of wetlands, lakes and vegetation. This habitat change can have negative impacts on species and, even more, their individuals. However, some species may recover from this temporary aberration. The degradation of landscape quality, including increased soil erosion, may lead to a more permanent loss of biological diversity and productivity of the landscape. Although environmental losses are difficult to quantify, growing public awareness and concern for environmental quality has forced public officials to focus greater attention and resources on these effects.

Often drought stress on plants and ecosystems is enhanced by a combination of stress factors; e.g. Matyssek et al. (2006) reviewed the interactions between drought and ozone stress in forest trees, finding a strongly reduced tolerance under exposure of the combined stress as well as a consequent reduced carbon fixation of forests. As for the 2003 summer drought in Europe, Ciais et al. (2005) found a reduction of up to 30 % in gross primary productivity over Europe, resulting in a strong anomalous net source of carbon dioxide to the atmosphere and hence a reversion of the carbon sequestration by European ecosystems of the previous years.

Environmental impacts from irrigation can be of different types: aquifer exhaustion from over abstraction, salinization of groundwater, increased erosion of cultivated soils on slopes and water pollution by nutrients and pesticides. These impacts are not well documented in many EU member states but different case studies show that over-abstraction and salinization of aquifers occur in many parts of the Mediterranean coastline (Portugal, Spain, Italy and Greece) and some localized areas in northern Europe (the Netherlands) (Digital Atlas of Global Water Quality, UN GEMS/Water Programme). Soil erosion is particularly severe in Spain, Portugal and Greece. The desiccation of former wetlands and the destruction of former high nature value habitats are significant in different regions of both southern and northern Europe (west France, inland Spain, Hungary and southeast England).

Social impacts

The social dimensions of drought are wide-ranging and typically compound problems that may have already existed within the community. For example, if a community is experiencing a shortage of health, education, housing, or employment resources, then the effects of drought will place further strain on those limited resources and affect the ability of providers to deliver effective services (Kenny 2008).

Research indicates that social impacts as a result of drought on individuals, families, and communities may include:

- People being reluctant to get involved in community activities,
- A decline in traditional industries,

- Volunteer stress or burnout, or an inability to even have volunteering effort,
- The need to and or ability to seek off-farm work,
- Increased financial pressures,
- A decline in the health (both physical and mental health)of individuals and their families,
- Dealing with questions of whether to leave the farm and/or problems associated with succession planning,
- A loss of local farm labor,
- An inability to leave the property because of the demands of feeding and water regimes,
- The local economy impact from a postponement of capital purchases as a result of drought, and
- A general increase of working hours with little opportunity for recreation and family time.

Quantifying the Impacts of Droughts

Droughts have different Impacts and like other natural hazards in most cases the goal is to quantify these impacts in form of a monetary valuation. Not every sector is equally affected by droughts. Table 2 presents sectors that might be adversely affected by droughts.

4 categories of costs are used to assess and estimate the impact of droughts (Meyer et al., 2013):

Direct costs
Including damages to assets such as buildings, contents and infrastructure; production interruption because of destroyed machinery; shortages of productive inputs or reduction of labour or its productivity.

Indirect costs
Indirect costs are induced production losses of suppliers and customers of economic agents directly affected by a hazard (Przyluski and Hallegatte, 2011).

Intangible costs
Damages to goods and services which are not measurable (or at least not easily measurable) in monetary terms because they are not traded on a market.

Risk mitigation costs
These can be directly incurred costs and indirect costs which are induced costs in other sectors.

Table 2. Description of the main sectors affected by droughts (Vogt et al., 2016)

Sector	Description
Economic impacts	A water deficit induced by droughts affects production, sales and business in a variety of sectors.
Socio-economic impacts	Welfare changes experienced by human beings should be accounted for in the measures of the socioeconomic impacts of drought. The social impacts of drought can affect people's health and safety, cause conflicts between people when water restrictions are required, and may result in changes in lifestyle.
Impacts on environment, forestry, wildfires, and biodiversity	Drought affects the environment in many different ways. Plants and animals depend on water, and under drought conditions their food supply can shrink and their habitat can be damaged. Sometimes the damage is only temporary and their habitat and food supply return to normal when the drought is over. But sometimes drought impacts on the environment can last a long time, or may lead to permanent land and ecosystem degradation.
Impacts on farming and livestock	Farmers might be adversely affected if a drought damages their crops. They may spend more money due to increasing irrigation costs, drilling new wells or feeding and providing water to their animals. Industries linked with farming activities, such as companies that make tractors and food, may lose business when drought damages crops or livestock.
Impacts on public water supply	Drought conditions impact water supplies by decreasing supply and increasing demand for various usages (industrial, agriculture or residential use).
Impacts on surface and groundwater	Direct impacts of droughts on surface waters include reduced river flows and reservoir levels. Significant decreases in aquifer levels are the main expression of drought impacts on groundwater.
Impacts on power generation: hydropower, thermal, and nuclear	Hydroelectricity production is related to the amount of water stored in the upper reservoirs, the production level can be lower during a drought. Peak demands for electricity then need to be satisfied by other means available in the short term (e.g. gas turbines). The amount of losses depends on hydroelectricity infrastructures and drought severity. Reduced availability of cooling water can force the reduction of power generation and even shutdown of thermal or nuclear power plants during droughts.
Impacts on commercial shipping	During low-flow conditions, barges and ships may have difficulty in navigating streams, rivers, and canals because of low water levels, affecting businesses that depend on water transportation for receiving or delivering goods and materials. People might have to pay more for food or fuel as a result.
Impacts on tourism and recreation	Since many activities in the tourism sector are water-related, droughts can bring critical losses. Droughts have impacts on both summer and winter activities.

Remote sensing and GIS:Quantifying the Impacts of Droughts

Remote sensing and GIS is an unconventional method for the detection, the monitoring and the mitigation of droughts. Tools allow us to obtain and distribute continuous information rapidly over large areas by sensors. The spectral bands used by these sensors cover the whole range between visible and microwaves (Hadish 2010). Satellites today are able to explore the whole earth surface in some days and to repeat this in regular intervals.
Frequent and sustained information are available from the surface characteristics of planar with full information of ground surface spectrum of time, space, and direction. It can provide macro, dynamic, and real-time monitor data sources for real-time and dynamic monitoring of drought (Zhang et al. 2011a, b). Natural hazards are multi-dimensional so without GIS it would be impossible to make a useful drought risk assessment. A big advantage is that GIS allows not only a picture of a present drought but also creates information for potential future events and damages due to drought hazard. The remotely sensed images from satellites and aircrafts are often the only source that can provide up-to-date and accurate information on the terrain topography and the use of the land for large areas at acceptable costs (Wipulanusat et al. 2009). GIS transforms the model to its language and analyzes the data by powerful analysis function, and then adds drought assessment early warning function into the drought assessment system (Tao et al. 2011).

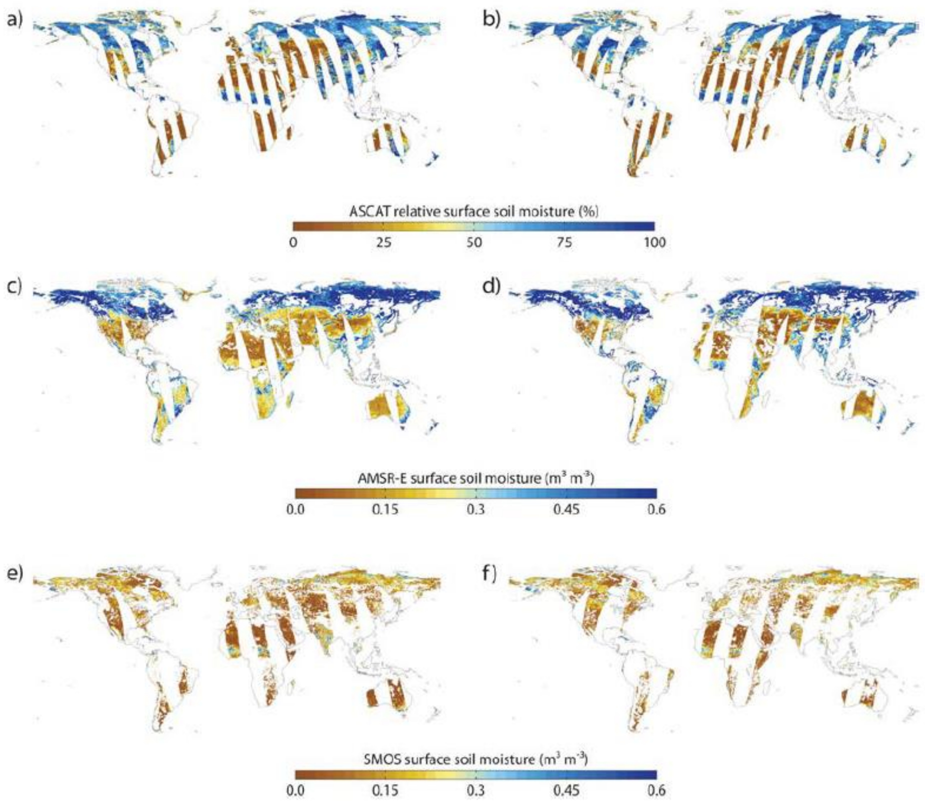


Fig. 1. Daily soil moisture map (from August 15, 2010) derived from ASCAT, AMSR-E, and SMOS Satellite measurements for ascending (left) and descending (right) satellite orbits (Wagner, 2012).

In this context, continuous precipitation, runoff models, which represent the components of the water balance, are most often used for the catchment area as a function of soil moisture. The simulated soil moisture is internal to the model state variable, an example for this can look like as you can see in fig. 2. Remote sensing offers several options for observing soil moisture from the satellite. Microwave sensors in particular are due to the the wavelengths used are suitable for providing information for the top layers of the soil (Hasenauer, 2019).

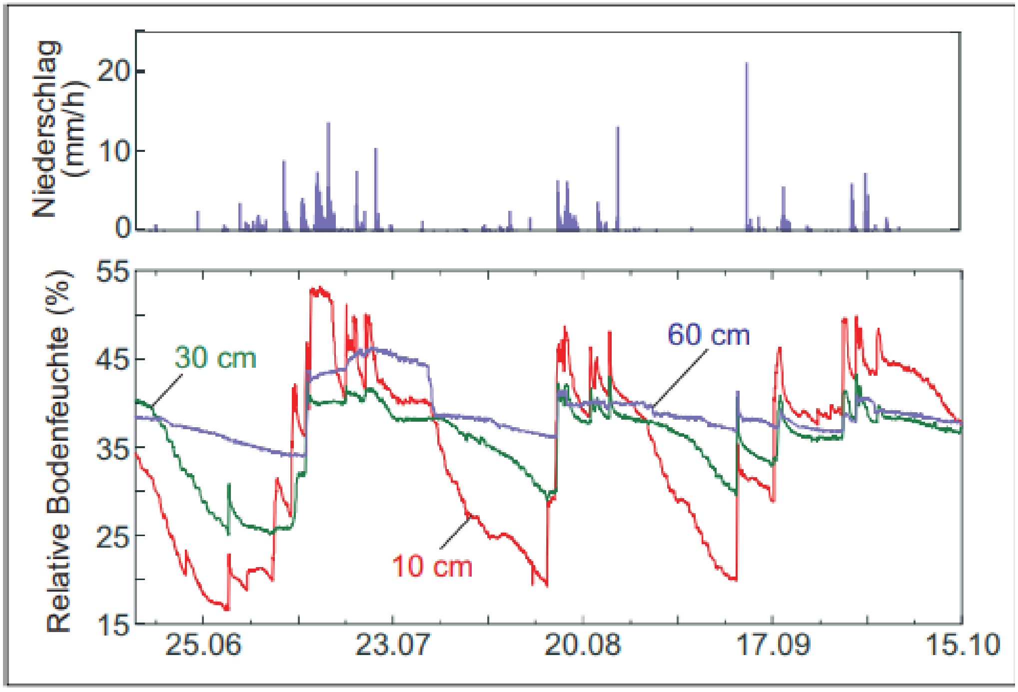


Fig. 2. The course of the soil moisture measured at different depths and the observed precipitation at a meadow location in Lower Austria (Wolfsbach) for the period from June to October 2006 (Hasenauer et al. 2009).

Meteorological drought indices

Drought indices like in the attachment below are commonly used to detect the potential risk of occurrence and severity of drought, and to study spatial–temporal reasoning. Many of these indices have been developed for detecting temporal variability and magnitude of the drought actions in interesting regions. We will describe the following three indices more accurately.

1. Standardized Precipitation Index (SPI)

This Index is one of the most common climatological precipitation indices to identify and calculate precipitation surpluses and droughts, which are precipitation deficits. The precipitation conditions which are occuring over a month, quarter or six months in relation to the respective normal values were evaluated. As a transformed result is a standard normal distribution (bell curve) shown the distribution function of the precipitation values. If the precipitation value is less than -1 standard deviation it shows drought circumstances. A positive SPI value indicates a period of time that was more humid than normal values (Mc Kee et al., 1993).

2. Crop Moisture Index (CMI)

The CMI indicates general conditions and not local variations. The calculations consisting of the weekly total precipitation amount and average temperature and previous history of the indices. Therefore the status of dryness or wetness is calculated and shows the affecting potential to crops and field activities. The CMI gives the short-term or current status of agricultural drought or moisture surplus (Botyanszka et al., 2020).

3. Aridity Index (AI)

An aridity index can be used to classify the climates of various regions. Monthly calculation can be used to determine the onset of drought. It’s a numerical value to quantify the degree of climatic dryness at a given location and thus to define arid climatic zones. It’s mainly used to determine the development of drought over shorter timescales, which is helpful for identifying and monitoring agricultural and meteorological impacts and can be used to track the effects which are affecting local water resources because of the climate change.

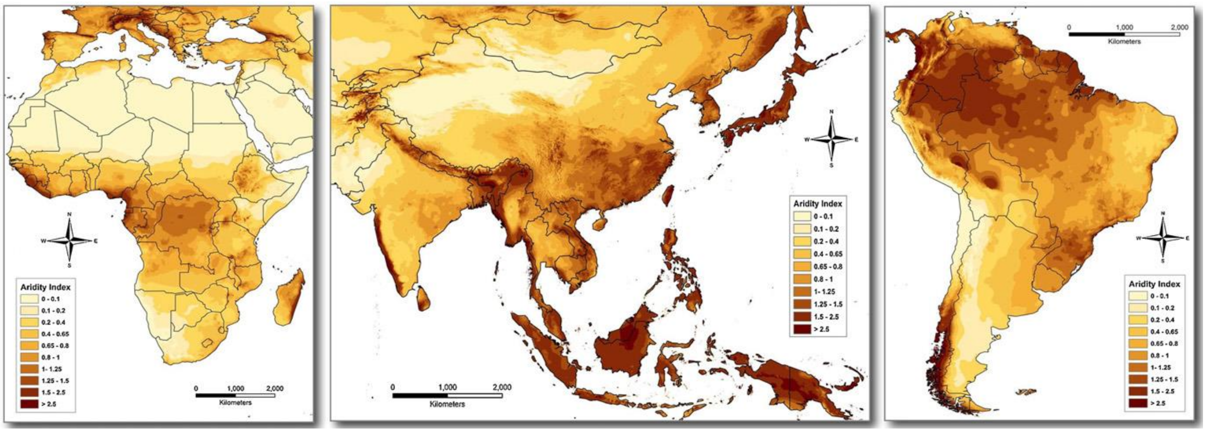


Fig. 2. Aridity Index (AI) was calculated for the entire globe. Note that higher AI and darker color represents more humid conditions, with low AI and lighter colors representing higher aridity (data source: Hijmans et al., 2004)

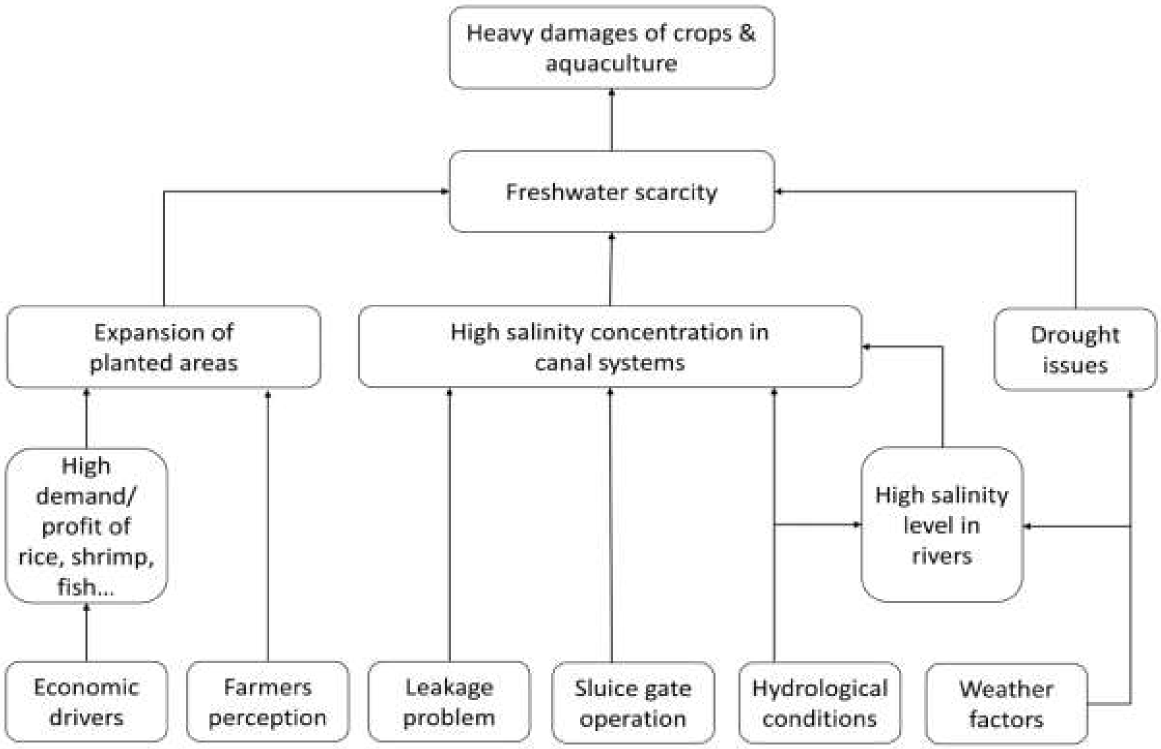
Application to an environmental case study

The Mekong Delta

The effects of climate change are nowadays manifested in the Mekong Delta Area – the sea level rises in lower areas at the mouth of the delta, increased rainfall, increased number of extreme weather events, rising average temperatures and increased salinity intrusion. The number of typhoons and tropical depressions has continually increased from seven to eight per year.

An Assessment-Team was built to look at the origins of the problems. The whole Management work programme was based on a review of literature informations from field observations and collaboration with Commune People’s Committees.

Table 3. Causal diagram of serious damages in the Mekong Delta (Nguyen Thanh Binh, 2015)



One of the problems was that the capacity of the Vietnamese agencies to provide accurate information for drought forecasting and early warning systems was very limited.
In future management programs it's important to use advanced modeling and GIS techniques in addition. Therefore to discover areas at risk for salinity and drought with high spatial and temporal resolution maps. In Integrated Drought Management Programs it's also important to handle the problems with applications of several short-, medium- and long-term solutions (Tre et al., 2016).

Another study has focused on drought monitoring in this region. They use Station data (CHIRPS) with a long-term record and high resolution to establish a great potential for drought monitoring. CHIRPS, Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 35+ year quasi-global rainfall data set. The assessment of CHIRPS captures precipitation and monitores drought by using satellite-based CHIRPS. It can capture various drought characteristics at various time scales. Also used is the SPI at various time scales (1–12-month) to identify and describe the drought events at the Lower Mekong Basin.

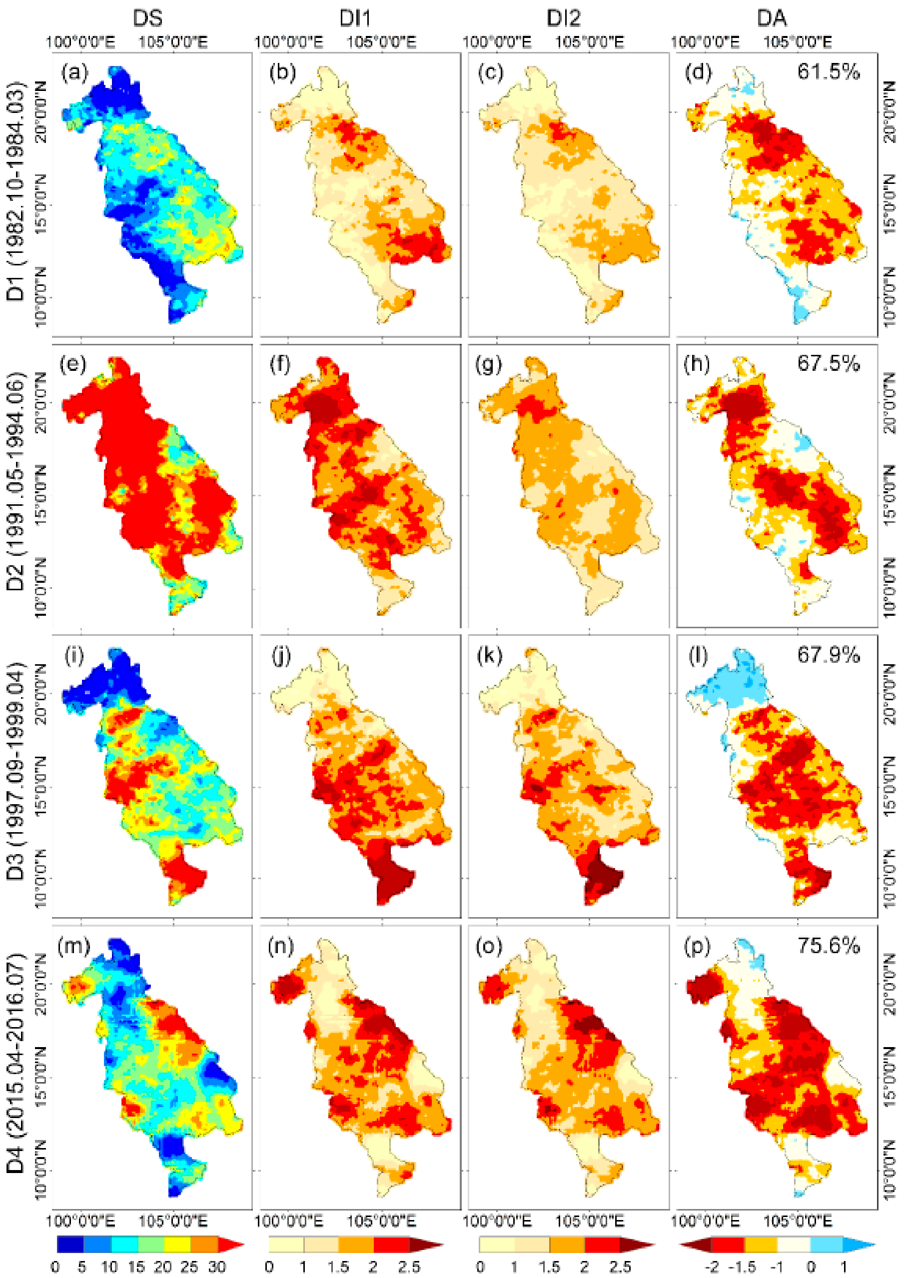


Fig. 2. Spatial distribution of drought severity (DS), drought intensity (DI1 and DI2) and SPI value for the month with maximum drought area (DA) for four most severe drought events over LMB from 1981 to 2016: (a–d) D1, (e–h) D2, (i–l) D3 and (m–p) D4. All the statistics are based on SPI12 (Guo et al., 2017)

Discussion and Conclusion

The Challenges of drought monitoring and forecasting

Effective drought forecasting systems must integrate precipitation and all other climatic parameters such as stream flow, groundwater levels, reservoir levels and soil moisture into a connected assessment of current and future drought and water balance conditions. It’s important to have fundamental data sets, which are consistent and have preferably no data lacks. Another problem is that drought indices are sometimes inadequate for detecting the early onset and end of drought. Drought monitoring systems should be integrated, have to handle with multiple climate, water and soil parameters and socio-economic indicators.In summary it’s important to have a comprehensive and integrated approach which is required to monitor drought effectively and to provide early warning.

Summary

Drought affects more people than we actually imagine. Drought has a enormous effect, more than any other natural disaster and the impact causes very high costs in economic, social and environmental areas. A consistant and reliable development of effective drought monitoring and early warning systems is a big challenge to deal with. The aim is to manufacture an effectively system. An improved drought monitoring, an integrated drought monitoring management is a key component and very important to apply in drought preparedness plans and in national drought policy.

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Indicators and indices (WMO, 2016)

Meteorology	*Page*	*Ease of use*	*Input parameters*	*Additional information*
Aridity Anomaly Index (AAI)	11	Green	P, T, PET, ET	Operationally available for India
Deciles	11	Green	P	Easy to calculate; examples from Australia are useful
Keetch–Byram Drought Index (KBDI)	12	Green	P, T	Calculations are based upon the climate of the area of interest
Percent of Normal Precipitation	12	Green	P	Simple calculations
Standardized Precipitation Index (SPI)	13	Green	P	Highlighted by the World Meteorological Organization as a starting point for meteorological drought monitoring
Weighted Anomaly Standardized Precipitation (WASP)	15	Green	P, T	Uses gridded data for monitoring drought in tropical regions
Aridity Index (AI)	15	Yellow	P, T	Can also be used in climate classifications
China Z Index (CZI)	16	Yellow	P	Intended to improve upon SPI data
Crop Moisture Index (CMI)	16	Yellow	P, T	Weekly values are required
Drought Area Index (DAI)	17	Yellow	P	Gives an indication of monsoon season performance
Drought Reconnaissance Index (DRI)	17	Yellow	P, T	Monthly temperature and precipitation are required
Effective Drought Index (EDI)	18	Yellow	P	Program available through direct contact with originator
Hydro-thermal Coefficient of Selyaninov (HTC)	19	Yellow	P, T	Easy calculations and several examples in the Russian Federation
NOAA Drought Index (NDI)	19	Yellow	P	Best used in agricultural applications
Palmer Drought Severity Index (PDSI)	20	Yellow	P, T, AWC	Not green due to complexity of calculations and the need for serially complete data
Palmer Z Index	20	Yellow	P, T, AWC	One of the many outputs of PDSI calculations
Rainfall Anomaly Index (RAI)	21	Yellow	P	Serially complete data required
Self-Calibrated Palmer Drought Severity Index (sc-PDSI)	22	Yellow	P, T, AWC	Not green due to complexity of calculations and serially complete data required
Standardized Anomaly Index (SAI)	22	Yellow	P	Point data used to describe regional conditions
Standardized Precipitation Evapotranspiration Index (SPEI)	23	Yellow	P, T	Serially complete data required; output similar to SPI but with a temperature component
Agricultural Reference Index for Drought (ARID)	23	Red	P, T, Mod	Produced in south-eastern United States of America and not tested widely outside the region
Crop-specific Drought Index (CSDI)	24	Red	P, T, Td, W, Rad, AWC, Mod, CD	Quality data of many variables needed, making it challenging to use
Reclamation Drought Index (RDI)	25	Red	P, T, S, RD, SF	Similar to the Surface Water Supply Index, but contains a temperature component

Soil moisture	Page	Ease of use	Input parameters	Additional information
Soil Moisture Anomaly (SMA)	25	Yellow	P, T, AWC	Intended to improve upon the water balance of PDSI
Evapotranspiration Deficit Index (ETDI)	26	Red	Mod	Complex calculations with multiple inputs required
Soil Moisture Deficit Index (SMDI)	26	Red	Mod	Weekly calculations at different soil depths; complicated to calculate
Soil Water Storage (SWS)	27	Red	AWC, RD, ST, SWD	Owing to variations in both soil and crop types, interpolation over large areas is challenging

Hydrology	Page	Ease of use	Input parameters	Additional information
Palmer Hydrological Drought Severity Index (PHDI)	27	Yellow	P, T, AWC	Serially complete data required
Standardized Reservoir Supply Index (SRSI)	28	Yellow	RD	Similar calculations to SPI using reservoir data
Standardized Streamflow Index (SSFI)	29	Yellow	SF	Uses the SPI program along with streamflow data
Standardized Water-level Index (SWI)	29	Yellow	GW	Similar calculations to SPI, but using groundwater or well-level data instead of precipitation
Streamflow Drought Index (SDI)	30	Yellow	SF	Similar calculations to SPI, but using streamflow data instead of precipitation
Surface Water Supply Index (SWSI)	30	Yellow	P, RD, SF, S	Many methodologies and derivative products are available, but comparisons between basins are subject to the method chosen
Aggregate Dryness Index (ADI)	31	Red	P, ET, SF, RD, AWC, S	No code, but mathematics explained in the literature
Standardized Snowmelt and Rain Index (SMRI)	32	Red	P, T, SF, Mod	Can be used with or without snowpack information

Remote sensing	Page	Ease of use	Input parameters	Additional information
Enhanced Vegetation Index (EVI)	32	Green	Sat	Does not separate drought stress from other stress
Evaporative Stress Index (ESI)	33	Green	Sat, PET	Does not have a long history as an operational product
Normalized Difference Vegetation Index (NDVI)	33	Green	Sat	Calculated for most locations
Temperature Condition Index (TCI)	34	Green	Sat	Usually found along with NDVI calculations
Vegetation Condition Index (VCI)	34	Green	Sat	Usually found along with NDVI calculations
Vegetation Drought Response Index (VegDRI)	35	Green	Sat, P, T, AWC, LC, ER	Takes into account many variables to separate drought stress from other vegetation stress
Vegetation Health Index (VHI)	35	Green	Sat	One of the first attempts to monitor drought using remotely sensed data

Water Requirement Satisfaction Index (WRSI and Geo-spatial WRSI)	36	Green	Sat, Mod, CC	Operational for many locations
Normalized Difference Water Index (NDWI) and Land Surface Water Index (LSWI)	37	Green	Sat	Produced operationally using Moderate Resolution Imaging Spectroradiometer data
Soil Adjusted Vegetation Index (SAVI)	37	Red	Sat	Not produced operationally

Composite or modelled	*Page*	*Ease of use*	*Input parameters*	*Additional information*
Combined Drought Indicator (CDI)	38	Green	Mod, P, Sat	Uses both surface and remotely sensed data
Global Integrated Drought Monitoring and Prediction System (GIDMaPS)	38	Green	Multiple, Mod	An operational product with global output for three drought indices: Standardized Soil Moisture Index, SPI and Multivariate Standardized Drought Index
Global Land Data Assimilation System (GLDAS)	39	Green	Multiple, Mod, Sat	Useful in data-poor regions due to global extent
Multivariate Standardized Drought Index (MSDI)	40	Green	Multiple, Mod	Available but interpretation is needed
United States Drought Monitor (USDM)	41	Green	Multiple	Available but interpretation is needed

Note: Indicators and indices are sorted by 'ease of use' and then alphabetically within each 'ease of use' category.

Key to variables:
AWC = available water content,
CC = crop coefficient,
CD = crop data,
ER = ecoregion,
ET = evapotranspiration,
GW = groundwater,
LC = land cover,
Mod = modelled,
Multiple = multiple indicators used,
P = precipitation,
PET = potential evapotranspiration,
Rad = solar radiation,
RD = reservoir,
S = snowpack,
Sat = satellite,
SF = streamflow,
ST = soil type,
SWD = soil water deficit,
T = temperature,
Td = dewpoint temperature,
W = wind data.