Definition of drought

How we define drought is very important. Based on specification of drought, we can measure changes in aridity over time. According to international meteorological community, drought can be defined as *'prolonged absence or marked deficiency of precipitation'*, a *'deficiency of precipitation that results in water shortage for some activity or for some group'* or a *'period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance'* (Trenberth et al., 2007; Heim, 2002). The International Panel for Climate Change discuss three types of droughts: *(i)* 'Agricultural drought' which is defined in terms of moister deficits in upper layer of soil up to about one meter depth *(ii)* 'meteorological drought' which refers to prolonged deficit of precipitation and *(iii)* 'hydrological drought' which relates to low streamflow, lake and levels of groundwater (IPCC; Trenberth et al., 2007; Heim, 2002). Trenberth et al. (2014) discuss definitions and measures of drought and their relation to contradictory results of two recent studies, in particular Sheffield et al. (2012) and Dai (2011). Sheffield et al. (2012) argue that drought has not increased much since 1960 althought incorrect versions of Palmer Drought Severity Index (PDSI) give substantially different results. On the other hand, Dai (2011) conclude that results differ only slightly for different forms of PDSI and all its forms indicates widespread drying. Besides difference in way of calculating the drought index, Trenberth et al. (2014) attribute the contradicting results to disparities among various rainfall datasets and different baseline periods.

As discussed by Trenberth et al. (2014), drought can be measured in absolute terms (e.g. lake levels or amount of soil moisture) or using relative measures, such as PDSI. Because drought is defined based on one tail of probability distribution function of a drought measure, small decrease in mean can appear as very big increase in frequency of droughts. This has caused confusions and therefore usage of percentiles of soil moisture or streamflow is recommended as a better measure than mean (Trenberth et al., 2014).

Specifying a reliable index which could be used as a basis for definition of drought seems to problematic. The degree of drought does not only depend on precipitation, but also on whether and how fast the moisture is carried away (so the index should also incorporate evapotranspiration, which PDSI does. It also accounts for balance of precipitation.) Thus, besides precipitation, the index should incorporate humidity, wind, solar and long-wave radiation data (van der Schrier et al., 2011). However, availability of reliable data for solar radiation is a real problem (Wang and Dickinson, 2012).

How do authors define drought in terms of distribution of index?

quantile..

- Trenberth et al. (2014):

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Extreme events, disaster and hazards

Lavell et al. (2012) define extreme events as 'the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable'. Some authors define extreme events only in terms of meteorological phenomena (Easterling et al., 2000; Jentsch et al., 2007), others include also consequential physiological impacts or other effects on humans and ecosystems (Lavell et al., 2012; Young, 2002).

According to Lavell et al. (2012), disasters are defined as 'severe alternations in the normal functioning of community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may acquire external support for recovery.' The hazardous physical events may be of natural, socio-natural, or purely anthropogenic origin (Lavell et al., 2012; Wisner et al., 2004).

Hazard can be defined as 'the potential occurrence of a natural or human induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources' Lavell et al. (2012).

Changes and trends in drought

Strong downwards trend in precipitation has been observed in the tropics from 10°N to 10°S, especially after 1976/1977 (Trenberth et al., 2007). During the period $1900-2005$, the climate has become wetter in many parts of the world (eastern parts of America, northern Europe, northern and central Asia) but it has became much drier in Mediterranean, Sahel, southern Africa and parts of Southern Asia. Furthermore, increased frequency of heavy rain events has been observed also in the areas with decline in total rainfall (Trenberth et al., 2007). Trenberth et al. (2014) argue that as a consequence of global warming, dry areas have strong tendency to get drier while wet areas are getting wetter.

Economic Effects of Droughts

Shifts in staple food demand curve are usually not very large; hence, when staple food becomes scarce, its price is usually subject to a massive increase (Brown and Kshirsagar, 2015; Brown, 2014). For low income groups, this often leads to reduction in calorie intake and often to malnutrition and increased risk of related health problems (Golden et al., 2011; Handa and Mlay, 2006). Local food prices are therefore a good indicator of food scarcity and insecurity (Brown and Kshirsagar, 2015). Brown and Kshirsagar (2015) investigate effects of weather disturbances and international price changes on local food prices which serve as a proxy for food scarcity. They use Kalman Filter approach (see Durbin and Koopman (2012) for more details) and they focus on regions which contain large segments of low income population including locations in Africa, South Asia and Latin America. They conclude that almost 20% of local market prices are affected by domestic weather disturbances, 9% of them are affected by international price change and 4%by both of them. Based on whether or not international food price and weather shocks are significant in explaining local food prices, Brown (2014) groups food markets in selected developing countries into four categories as follows: significantly affected by both international food prices and weather, significantly affected by weather but not international food prices, significantly affected by international food prices but not by weather and not significantly affected by either of them. Brown (2014) then discus common characteristics of markets in each of these groups.

Ochieng et al. (2016) estimate effects of climate variability and change on agricultural production [1] using panel data in Kenya. According to their results the effects are significant, yet different for different crops. Temperature has positive effect on tea and negative effect on production of maize and crop. Further, rainfall affects production of tea negatively.

look at many references in Brown and Kshirsagar (2015) and Ochieng et al. (2016) !!!maybe also look if good references in Willenbockel (2011)??

Lesk et al. (2016) estimate national production losses per disaster worldwide during $1964 - 2007$ using a statistical method called superposed epoch analysis. Besides drought, they focus on extreme heat, cold and flood events. They conclude that on average 10.1% reduction of cereal production can be linked to droughts and 9.1% reduction is attributable to extreme heat. They did not find any significant effect of extreme cold and floods on production. Mehrabi and Ramankutty (2017) estimate cumulative crop production losses resulting from heat and drought disasters over the same time period $(1964 - 2007)$. Their estimates are almost half of those of Lesk et al. (2016). The biggest losses are in Botswana, Paraguay, Nigeria, Angola and USA.

Willenbockel (2011) uses the GLOBE Computable General Equilibrium model of the global economy to estimate food prices for various 2030 scenarios. According to his results, climate change will lead to substantial increase in both domestic and world market crop prices in comparison to baseline scenario in the absence of climate change. However, the increase in prices can be substantially mitigated if appropriate adaptation measures will be taken in sub-Saharan Africa (Willenbockel, 2011).

[1] Mesured as value of yields per acre in farm household

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