Definition of drought

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 recognise 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 different ways of formulation of the Palmer Drought Severity Index (Sheffield et al. 2012; Dai 2011). Sheffield et al. (2012) argue that way of formulation of PDSI can have substantial effect on estimation of changes in severity of droughts over time. According to other studies, differences in formulation of the PDSI do not play a big role and it is more important to formulate the index such that the required data are available and reliable (Trenberth et al., 2014; van der Schrier et al., 2011; Wang and Dickinson, 2012). Trenberth et al. (2014) attribute the differences in results of Sheffield et al. (2012) and Trenberth et al. (2014) mostly to disparities among various rainfall datasets and different baseline periods rather than different formulations of the PDSI.

Drought can be measured in absolute terms (e.g. lake levels or amount of soil moisture) or in relative measures, which is for example the PDSI (Trenberth et al., 2014). Because drought is defined based on one tail of probability distribution function of a drought measure, small decrease in mean can appear as substantial 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).

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).

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, 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 (Baffes et al., 2017; 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. Another study, which finds positive correlation between precipitation and agricultural productivity is Vrieling et al. (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%

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

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.

Large literature apply Ricardian approach (which was originally developed by Mendelsohn et al., 1994) to estimate impacts of climate change, including change in precipitation on crop revenues in Africa (Bello and Maman, 2015; Kabubo-Mariara and Karanja, 2007; Kurukulasuriya et al., 2008; Seo et al., 2008). According to Seo et al. (2008) and Kurukulasuriya et al. (2008), if the warming will be mild and wet crop net revenue should increase. In case of more severe and dry scenario, the crop revenue is likely to decrease (Kurukulasuriya et al., 2008; Seo et al., 2008). Bello and Maman (2015) conclude that increase in temperature will affect net crop revenue negatively while increase in precipitation is likely to increase crop revenue. Kabubo-Mariara and Karanja (2007) argues that global warming will be harmful for crop production.

Deschenes and Greenstone (2007) use a production function approach to estimate economic impact of climate change, including impact of change in precipitation on agricultural profit in the United States. Production function method is an alternative to the Ricardian approach. Deschenes and Greenstone (2007) conclude that effect of global warming on agriculture should be positive in the US. In particular, agricultural yields should increase by 1.3 billion US dollars or 4%. However, the estimated 95% confidence interval is from -0.5 to 3.1 billion US dollars, hence, the estimated effect is not very large.

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).

Trends

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.

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