DROUGHT AND WATER SCARCITY IN EUROPE: PAST AND FUTURE

SECHERESSE ET DÉFICIT D'EAU EN EUROPE: PASSÉ ET PERSPECTIVES

Henny A.J. Van Lanen, *Assoc. Prof., Hydrology and Quantitative Water Management Group, Wageningen University, Wageningen, The Netherlands, henny.vanlanen@wur.nl*

ABSTRACT: Low river flows and droughts are increasingly being observed over the last decades in Europe. Moreover, in vast areas drought will likely increase due to climate change? The increasing trends to more severe drought are explained in the context of growing water scarcity that also is reported in many European regions. Water scarcity often enhances drought impacts. First, trends in historic European drought events are discussed. Then understanding of transformation of meteorological drought into soil moisture and hydrological drought (groundwater, streamflow), which is called drought propagation, is described. Knowledge on drought propagation is essential for water resources management. Water scarcity in Europe and its spatial distribution is touched upon, incl. an observational-modelling framework that is being proposed to distinguish between water scarcity and drought. We conclude with an assessment of future drought and water scarcity due to global change and implication of the use of modeling chain approaches, incl. uncertainty.

Keywords: trends, drought propagation, observation, modeling approach, water management.

RÉSUMÉ : Au cours des dernières décennies, on a observé de plus en plus d'étiages et de sécheresses en Europe. On s'attend en outre à l'accroissement de sécheresses de grande ampleur en raison du changement climatique. On expliquera les tendances à des sécheresses plus sévères dans un contexte de raréfaction de l'eau qui se manifeste dans de nombreuses régions européennes. La rareté de l'eau aggrave souvent les impacts des sécheresses. En premier lieu, nous discuterons des tendances dans l'historique des sécheresses en Europe. On décrira ensuite la transformation de la sécheresse météorologique en sécheresse pédologique puis hydrologique (eaux souterraines, cours d'eau), appelée propagation de la sécheresse. La connaissance de la propagation de la sécheresse est essentielle pour la gestion des ressources en eau. Nous aborderons le problème de la rareté de l'eau en Europe et de sa distribution spatiale, y compris un cadre d'observation et de modélisation proposé pour distinguer rareté de l'eau et sécheresse. Nous conclurons par une estimation de la sécheresse et de la rareté de l'eau futures en raison du changement climatique et ce qu'elle implique sur l'utilisation de chaînes de modèles en particulier en ce qui concerne l'incertitude.

Mots clés: tendances, propagation de la sécheresse, approche d'observation et de modélisation, gestion de l'eau

INTRODUCTION

Low river flows and droughts are increasingly being observed over the last decades in several European countries. Moreover, in vast areas drought will likely increase due to climate change (Seneviratne [HvL1]et al, 2012). The increasing trend to more severe drought goes along with growing water scarcity that also is reported in many European regions (EEA, 2012). First, trends in historic European drought are dealt with and to what extend these were captured by large-scale models, which is paramount knowledge for drought projection for the near and far future. Understanding of transformation of meteorological drought into soil moisture and hydrological drought (groundwater, streamflow), which is called drought propagation, is essential for adequate water resources management. Water scarcity in Europe is discussed, incl. an observational-modelling framework to distinguish between water scarcity and drought. The paper concludes with an assessment of future drought and water scarcity due to global change and implication of the use of modeling chain approaches, incl. uncertainty.

PAST DROUGHTS AND WATER SCARCITY

Trends in historic hydrological droughts in Europe

Low river flows and droughts are increasingly being observed, for instance, France (Renard and al, 2008), Switzerland (Birsan et al, 2005), Slovakia (Demeterova and Skoda, 2009) and Spain (Morán-Tejeda et al., 2010). These national trend studies hamper consistency in the changes detected in streamflow, because of the trend detection method and the time period chosen. As a response to this Stahl et al. (2011), carried out a consistent pan-European trend study to determine change in observed streamflow. They used a consolidated dataset of near-natural streamflow records from 441 small catchments in 15 countries across Europe. Their study showed a coherent picture of changes in annual streamflow with drying trends in southern and eastern regions, and generally wetting trends elsewhere. These results were confirmed by a recent study for the EU-FP7 DROUGHT-R&SPI project[1] (Alderlieste and Van Lanen, 2012)(Fig. 1, left). Trends in monthly streamflow for the summer period are, however, negative, implying drying trends, for large parts of Europe. The maximum extent of drying was found for August (Stahl et al., 2011). Alderlieste and Van Lanen (2012)(Fig. 1, right) obtained a similar regional picture for drought intensity (deficit volume / duration).

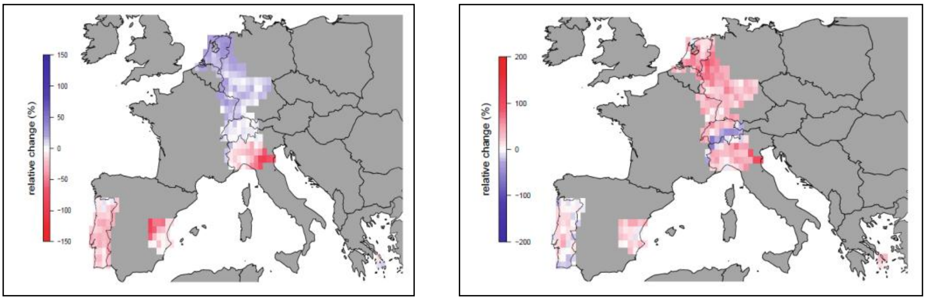

Fig. 1. Trends in mean annual flow (left) and drought intensity (right) over the period 1963-2001, derived from the simulated multi-model mean daily total runoff simulated by nine large-scale hydrological models[2]. Red indicates dryer conditions, blue indicates wetter conditions.

Both Stahl et al. (2012) and Alderlieste and Van Lanen (2012) investigated the uncertainty in the trends using runoff simulated by a suite of large-scale models. They studied the spread among the models and the modeled runoff against observed streamflow. They concluded that the use of simulated runoff to determine trends in low flows and drought should be viewed with caution due to the substantial uncertainty. This need to be considered when these models are used for the assessment of future drought.

Drought propagation

When trends in droughts are studied, it is relevant to distinguish

[1] DROUGHT-R&SPI (Fostering European Drought Research and Science-Policy Interfacing, www.eu-drought.org/).

[2] Model outcome is available through the EU-FP6 project WATCH (WATer and global CHange, www.eu-watch.org/).

between the different types of drought, i.e. meteorological drought (e.g. precipitation), soil moisture drought and hydrological drought (groundwater, streamflow). Although meteorological drought (e.g. Standard Precipitation Index, SPI) and soil moisture drought (e.g. Palmer Drought Severity Index, PDSI) trigger hydrological drought, these are not good metrics for hydrological drought, the latter is of paramount importance for water resources management.

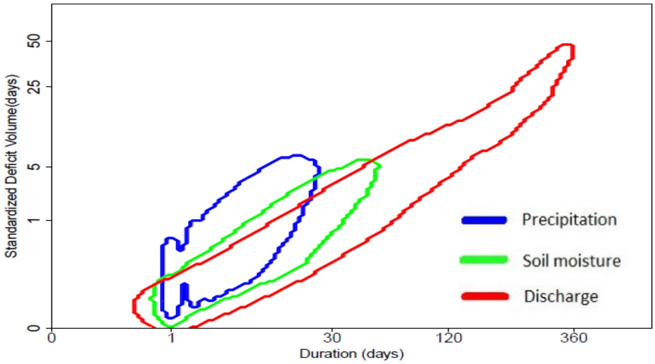

Fig. 2. Probability field of drought duration and deficit volume in precipitation, soil moisture and discharge for the temperate climate (C-climate) reflecting drought propagation.

Tijdeman et al. (2012) show for the temperate climate (C-climate, Koeppen-Geiger) that the bivariate probability field of drought duration and deficit volume in discharge (hydrological drought) clearly differs from those of precipitation and soil moisture (Fig. 2). This difference is caused by drought propagation, which leads to lengthening, lagging, attenuating and pooling of meteorological drought. Tijdeman et al. (2012) demonstrate that the propagation depends on climate characteristics and Van Lanen et al. (2013) discuss the role of soils and aquifers.

Current water scarcity

Water scarcity usually is characterized through a relatively straightforward indicator, i.e. the water exploitation index (WEI), which is calculated annually as the ratio of total freshwater abstraction to the total renewable resource. A WEI > 20 % means that a water resource is under stress and values >40 % indicate severe water stress, which reflects unsustainable use of the water resource (EEA, 2009). The EEA study shows that Cyprus (45%) and Bulgaria (38%) have the highest WEI scores in Europe, with high values also apparent for Italy and Spain. National estimates, however, do not reflect the extent and severity of water scarcity at the river basin scale. For example, while Spain's national WEI is approximately 34%, the southern river basins of Andalusia and Segura have extremely high WEIs that exceed 100%. Some river basins in Portugal also suffer from severe water stress.

Drought and water scarcity are fundamentally different (natural versus human-induced causes), nevertheless water management should realize that they are closely linked and careful attention needs to be paid to the complex interrelationships, incl. the feedbacks between these two phenomena. Van Loon and Van Lanen (2013) propose an observation-modeling framework to separate drought and water scarcity effects on the hydrological system. The basis of the framework is simulation of the situation that would have occurred without human influence, the `naturalized' situation, using a hydrological model, which is complemented with analysis of anomalies. Application of the framework illustrates that the impact of groundwater abstraction on the hydrological system was, on average, four times as high as the impact of drought for the Upper-Guadiana basin, Spain.

FUTURE DROUGHTS AND WATER SCARCITY

Future hydrological droughts

Most assessments of 21st century droughts address meteorological or soil moisture droughts (e.g. Sheffield and Wood, 2008; Dai, 2012), which are a first step for hydrological drought projections. Feyen and Dankers (2009) investigated the impact of climate change (A2 scenario) on streamflow drought in Europe. They used a large-scale hydrological model driven by high-resolution regional climate model. They project for the nonfrost season that hydrological drought in 2071-2100 will become more severe and persistent in most parts of Europe. Corzo-Perez et al. (2011) analysed future hydrological drought on a global scale for two time domains (2021-2050 and 2071-2100), two emission scenarios (A2 and B1), three downscaled and bias-corrected GCMs, and 5 large-scale hydrological models. The number and spatial distribution of drought events did not clearly show a consistent change. Similar to Corzo-Perez et al. (2011), Alderlieste and Van Lanen (2013) explored future hydrological drought in selected case study areas in Europe (Fig. 3).

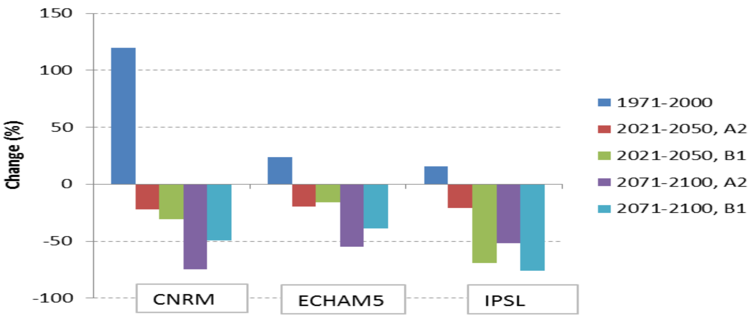

Fig. 3. Median annual 7-day minimum flow MA(7) as simulated with 3 GCMs (CNRM, ECHAM5, IPSL). Model performance: difference in the AM(7) of the 3 GCMs forcing against a re-analysis dataset forcing (1971-2000), and change in AM(7) relative to the control period (1971-2000) in the near future (2021-2050) and far future (2071-2100) for two emission scenarios (A2 and B1).

The future annual minimum flow (AM(7)) will decrease (15-75%) according to a conceptual hydrological model that was forced with the climate output from three GCMs and two emission scenarios. However, differences between the models are substantial. Moreover, performance of some models is limited. For example, the AM(7) derived from the discharge simulated with the conceptual hydrological model forced with CNRM deviates more than 100% with the AM(7) obtained with the same model forced with a re-analysis dataset (WATCH Forcing Data). The limited number of global studies on future hydrological drought and the differences in model outcome still make projections uncertain.

WATER SCARCITY PROJECTIONS

Impacts of water scarcity are expected to increase in the next decades. The likely future occurrence of water scarcity, however, largely depends on meteorological conditions, and socio-economic and environmental developments. Given the results of different scenarios, social systems and future policies will alter the natural impacts projected by the climate scenarios. Outcome suggests that water abstractions are expected to increase in Europe by 2050 under the Economy First scenario, except for river basins in Denmark, the Iberian Peninsula, Italy, Greece, Cyprus, and Turkey, while for the Sustainability Eventually scenario simulated total water abstractions will decrease by over 25% for the whole of Europe, because of more efficient water use and conservation (Flörke et al., 2011; Kossida et al., 2012).

ACKNOWLEDGEMENTS:
The reported research was supported by a series of European Union funded drought projects: e.g. WATCH and the on-going DROUGHT-R&SPI (grant 282769). I am also grateful to discussions with many colleagues, in particular from the European Drought Centre (EDC, www.geo.uio.no/edc/) and the UNESCO IHP-VII programme Flow Regimes from International Experimental and Network (FRIEND http://undine.bafg.de/servlet/is/7398/). The reported research is part of the programme of the Wageningen Institute for Environment and Climate Research (WIMEK-SENSE).

REFERENCES

Alderlieste MAA & Van Lanen HAJ., 2012. *Trends in low flow and drought in selected European areas derived from WATCH forcing data and simulated multi-model mean runoff*. DROUGHT-R&SPI Technical Report No. 1, 110 pg. [available at: http://www.eu-drought.org/].

Birsan M-V, Molnar P, Burlando P & Pfaundler M., 2005. *Streamflow trends in Switzerland*. J. Hydrol., 314, 312–329.

Corzo Perez, GA, Van Lanen HAJ, Bertrand N, Chen C, Clark D, Folwell S, Gosling S, Hanasaki N, Heinke J, Voβ F., 2011. *Drought at the global scale in the 21st Century*. WATCH Technical Report No. 43,117pg.[availableat: http://www.eu-atch.org/publications/technical-reports/2].

Dai A., 2012. *Increasing drought under global warming in observations and models*. Nature Clim. Change, doi:10.1038/nclimate1633.

Demeterova B & Skoda P., 2009. *Low flows in selected streams of Slovakia*. J. Hydrol. Hydromech., 57, 55–69.

EEA., 2009. *Water resources across Europe — confronting water scarcity and drought*. European Environmental Agency, EEA Report No 2/2009, Copenhagen.

EEA., 2012. *European waters — assessment of status and pressures*. European Environmental Agency, EEA Report No 8/2012, Copenhagen.

Feyen L & Dankers R., 2009. *Impact of global warming on streamflow drought in Europe*. Journal of Geophysical Research, 114 (D17), doi:10.1029/2008JD011438.

Flörke M, Wimmer F, Laaser C, Vidaurre R, Tröltzsch J, Dworak T, Stein U, Marinova N, Jaspers F, Ludwig F, Swart R, Long H-P, Giupponi C, Bosello F & Mysiak J., 2011. *Climate Adaptation? Modelling water scenarios and sectoral impacts*. Final Report, European Commission, Directorate General Environment.

Kossida M, Kakava A, Tekidou A, Iglesias A & Mimikou M., 2012. *Vulnerability to Water Scarcity and Drought in Europe.* European Topic Centre on Inland, Coastal and Marine Waters [available at: water.eionet.europa.eu].

Morán-Tejeda E, Ceballos-Barbancho A & Llorente-Pinto JM., 2010. *Hydrological response of Mediterranean headwaters to climate* *oscillations and land-cover changes: The mountains of Duero River basin (Central Spain)*. Global Planet. Change, 72, 39-49.

Renard B, Lang M, Bois P, Dupeyrat A, Mestre O, Niel H, Sauquet E, Prudhomme C, Parey S, Paquet E, Neppel L & Gailhard J., 2008. *Regional methods for trend detection: assessing field significance and regional consistency*. Water Resour. Res., 44, W08419, doi:10.1029/2007WR006268.

Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, Luo Y, Marengo J, McInnes K, Rahimi M, Reichstein M, Sorteberg A, Vera C & Zhang X., 2012. *Changes in climate extremes and their impacts on the natural physical environment.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sheffield J & Wood EF., 2008. *Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations*. Clim Dyn (2008) 31:79–105, DOI 10.1007/s00382-007-0340-z.

Stahl K, Hisdal H, Hannaford J, Tallaksen LM, Van Lanen HAJ, Sauquet E, Demuth S, Fendeková M & Jódar J., 2010. *Streamflow trends in Europe: evidence from a dataset of near-natural catchments*. Hydrol. Earth Syst. Sci. 14: 2376-2382, doi:10.5194/hess-14-2367-2010.

Stahl K, Tallaksen LM, Hannaford J & Van Lanen HAJ. 2012. *Filling the white space on maps of European runoff trends: estimates from a multi-model ensemble*. Hydrol. Earth Syst. Sci., 16: 2035-2047, doi:10.5194/hess-16-2035-2012.

Tijdeman E, Van Loon AF, Wanders N & Van Lanen HAJ., 2012. *The effect of climate on droughts and their propagation in different parts of the hydrological cycle*. DROUGHT-R&SPI Technical Report No. 2, 70 pg. [available at: http://www.eu-drought.org/].

Van Lanen HAJ, Wanders N, Tallaksen LM &Van Loon AF., 2013. *Hydrological drought across the world: impact of climate and physical catchment structure*. Hydrol. Earth Syst. Sci. 17: 1715–1732, doi:10.5194/hess-17-1715-2013 .

Van Loon AF & Van Lanen HAJ., 2013. *Making the distinction between water scarcity and drought using an observation-modeling framework*. Water Resources Research 49: 1483–1502, doi:10.1002/wrcr.20147.

&&&&&