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Bayesian trend analysis in annual rainfall total, duration and maximum in the Kara River basin (West Africa)

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ABSTRACT

Study region: The Kara River basin, northern Togo and Benin, West Africa.
Study focus: This study investigated long-term trends in annual rainfall (annRAIN), annual rainfall duration (DURATION) and annual maximum rainfall (MAXAN) for seven stations between 1950 and 2010. A Bayesian trend analysis was performed by fitting the Lognormal, Normal and Generalized Extreme Value (GEV) distributions to annRAIN, DURATION and MAXAN, respectively, with a time covariate for both the location and scale parameters. Spatio-temporal variation of the mean decadal rainfall and the seasonality of the mean monthly rainfall were also analyzed.
New hydrological insights for the region: The results indicate that the interannual variability of annRAIN is decreasing over time at all stations, and the average annRAIN is also markedly decreasing at several stations. However, DURATION is increasing at most stations suggesting that in those parts of the basin where annRAIN is decreasing, rainfall occurs more frequently but with less intensity. For MAXAN, evidence for decreasing trend is found in two stations, and for increasing trend in one station. It is also shown that the peak of the rainy season shifted from September to August since the 1980s. Furthermore, changes in the spatio-temporal distribution of the mean decadal rainfall are also observed. This study provides valuable new insights into trends affecting rainfall variables in the Kara River basin.

1. Introduction

1.1. The importance of rainfall trends

Historical trends in climatic variables are of interest in a variety of academic disciplines, such as ecology, agriculture and water

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resources management, but also from an economic perspective (MacKellar et al., 2014). In fact climate change is expected to have significant impacts on rainfall variables such as rainfall extremes, annual rainfall, rainy events and rainy days etc. (Trenberth et al., 2007). For instance climate-induced modifications of the frequency and intensity of extreme rainfall as well as periods with low rainfall totals can potentially enhance floods and droughts (Boukhris, 2008) and result in significant impacts on human livelihood and socio-economic development. Furthermore, these changes also affect water availability, the vegetative period, crop productivity and rainfall-runoff dynamics. Within this context, Miranda et al. (2011) showed that changes in rainfall quantity, frequency and seasonality affect the productivity and physiology of plant communities in the semi-arid southeast region of the Iberian Peninsula. The authors could also assess the resilience of the community to high variability in rainfall regime. Pielke and Downton (2000) found that the trend in flood damage in Unites States between 1932 and 1997 was related not only to societal factors (increasing population and wealth) but also to trends in climate variables as shown for increasing precipitation. Further studies indicated that the observed increase in precipitation has masked a tendency for increasing drought related to increasing temperature (Easterling et al., 2007).

1.2. Rainfall trends in West Africa

Several studies attempted to understand rainfall variability and trends in West Africa (Collins, 2011; Fink et al., 2010; Le Barbé et al., 2002; Le Lay and Galle, 2005; Riede et al., 2016; Sylla et al., 2015, 2013). While there is a strong evidence of increasing temperature, there are still higher uncertainties in precipitation trends which exhibit higher spatial and seasonal variabilities (Collins, 2011; Riede et al., 2016). Nevertheless, it is very likely that precipitation has decreased between 1950 and 2010 with a recovery over the last 20 years (Riede et al., 2016). Le Barbé et al. (2002) analyzed rainfall variability in West Africa during 1950-90, and showed that a severe drought occurred during the period 1970-90 due to decreasing frequency of rainy events in July-August, leading to decreasing totals. Le Lay and Galle (2005) investigated the oceanic and continental West African monsoon regimes which control rainfall variability in the region, and showed that the majority of rainfall changes occur in the continental regime. The rainfall peak associated with this regime has occurred increasingly earlier in the season (July-August) between 1950 and 2002. Also the annual rainfall deficit is mainly linked to the decrease in the number of large events during the continental part of the season (Le Lay and Galle, 2005). Mouhamed et al. (2013) analyzed climate extremes in the West African Sahel between 1960 and 2010 and concluded that trends in rainfall indices are not uniform in time. There is a general decreasing tendency in annual total rainfall and maximum number of consecutive wet days while an increasing trend is observed in the cumulated rainfall of extremely wet days. The authors also found that while the maximum number of consecutive wet days is decreasing in general, there has been an upward recovery from the late 1980s to 2010 after an important decrease from 1960 to mid 1980s.

1.3. Probabilistic assessment of trends

The use of statistical and probabilistic methods has been widely recognized to play an important role in characterizing hydrologic and meteorological phenomena (Gamage et al., 2013; Markovic, 1965; Yue and Hashino, 2007). In particular, the estimation of probability distributions, and hence of quantiles, is a key component of such characterization, with many engineering applications (design and planning of hydraulic and water resources systems, hazard mapping, etc.) (Ouarda and El-Adlouni, 2011).

Many studies used an assumption of independence and identical distribution of the target variable. However, the latter assumption is questionable in the contexts of climate change or low-frequency climate variability which imply long-term fluctuations of the distribution of the target variable, and hence of its parameters. According to Milly et al. (2008), "*stationarity is dead*" and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Some authors argued the contrary (e.g. Montanari and Koutsoyiannis, 2014) and suggested that the word "stationarity" is sometimes misused. In any case, there is a need to derive probabilistic models that go beyond the independence and identical distribution assumptions and to use those models to manage water systems (Milly et al., 2008).

Non-stationary (or at least non-identically-distributed) analysis of hydro-meteorological phenomena has gained particular interest during recent decades. The most common approach is to introduce covariate(s) through the parameters of a target distribution and to assess whether the parameters are changing with the covariate(s). For instance, covariate-based extreme value analysis has been widely used (Cheng et al., 2014; Katz et al., 2002; Ouarda and El-Adlouni, 2011; Renard et al., 2006; Renard et al., 2013; Strupczewski and Kaczmarek, 2001; Strupczewski et al., 2001a,b; Sugahara et al., 2009).

Fitting probability distributions with covariates in the parameters requires good estimation methods that are in general computationally intensive and complex. Bayesian inference in combination with Markov Chain Monte Carlo methods offer a consistent framework to estimate complex statistical models and, importantly, to quantify estimation and predictive uncertainties (Renard et al., 2013).

1.4. Objectives and outline

The primary objective of this paper is to estimate time-varying distributions for the annual rainfall, the annual rainfall duration and the annual maximum daily rainfall within the Kara River basin. Located in West Africa, the Kara River basin is a semi-arid hydrology catchment of the Volta basin covering Togo and Benin which is poorly investigated in terms of climate research. The majority of studies on climate trends were carried out at larger scales such as the great Volta basin, at country level or in West Africa in general (Le Barbé and Lebel, 1997; Le Barbé et al., 2002; Le Lay and Galle, 2005; Mouhamed et al., 2013; Panthou, 2013). In addition, the methods applied for the statistical trend analyses varied among the studies. Although some of these studies provide