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Analyses of rainfall trends in the Nile River Basin

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Abstract

Trends in rainfall at 39 locations of the Nile River Basin (NRB) in Africa were analyzed. Comparison was made between rainfall trend results from the long-term data and those of short-term series selected over different time periods. The bias on trend results from series of short-term records was quantified. Homogeneity test was conducted to assess the coherence of the trend directions on a regional basis. Based on an assumed population (for simplicity) of rainfall data time periods in the range 75–100 years, bias in the short-term trend analysis was noted to reduce by about 10% for every 10% increase in record length. Under some conditions if respected, it was possible to derive trends at stations with short records based on those at nearby stations with longer term records but in the same region. Using the same data record length and uniform time period at all the selected stations, an improved regional coherence of rainfall trend results was obtained. In the equatorial region, trend in annual rainfall was found mainly positive and significant at level $\alpha = 5\%$ in 4 of the 7 stations. Collectively for Sudan, Ethiopia and Egypt, trends in the annual rainfall were mostly negative and significant at $\alpha = 5\%$ in 69% of the 32 stations. Heterogeneity in the trend directions for the entire NRB was confirmed at $\alpha = 1\%$ in 13% of the 39 stations. These findings are vital for water and agricultural management practices.

Keywords: Trend analysis; Trend homogeneity; Sub-trend identification; Mann–Kendall test; Rainfall; Nile River Basin

1. Introduction

The warming and changes in all components of the climate system can be hypothetically ascribed to the continued increase in greenhouse gas emissions (Intergovernmental Panel on Climate Change, IPCC, 2013). Changes in rainfall can be used to assess the influence of the climate system on hydrology. Some studies conducted recently to determine changes in hydrological variables include Mphale et al. (2014), Onyutha (2015a, 2015b), Shiau and Huang (2015), Stojković et al. (2014), and Syafrina et al. (2014). To detect trends, nonparametric tests are more often used than the parametric ones due to their suitability for data with specific distribution properties (e.g. non Gaussian). Nonparametric trend detection can be carried out using the Spearman's rho (SMR) (Lehmann, 1975; Sneyers, 1990; Spearman, 1904), the Mann–Kendall (MK) (Kendall, 1975; Mann, 1945), and the Cumulative Rank Difference (CRD) (Onyutha, 2015a) test. Close agreement with respect to the performance of these methods was found between MK and SMR (Yue et al., 2002a) and MK and CRD (Onyutha, 2015a). Thus, the MK test was deemed to be representative and thus adopted for this study. To eliminate autocorrelation which influence trend analysis, von Storch (1995) suggested a pre-whitening. Because the von Storch's approach eliminates a portion of the trend if present, Yue et al. (2002a) proposed a Trend-Free Pre-Whitening (TFPW) for the case when both trend and lag-1 autoregressive process AR(1) exist in a time series.

Some important factors to be considered in trend analysis include data quality, data record length and selected time periods, etc (World Meteorological Organization, WMO, 2000). Although the trend from the full time series may be insignificant, separate analyses done over short time periods may reveal significant sub-trends which are vital to ascertain the influence of short-durational climate fluctuations (Onyutha, 2015a). The influence of short-term data on trend analysis may exist in the form of bias in the trend results. To partly solve this problem of trend bias due to short-term data at a given station, long-term rainfall series from another nearby station can be used. This solution can be adequately implemented if the region in which the stations are selected are homogeneous.

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In this study area, a number of previous change analyses based on short-term annual rainfall from few meteorological stations have been mostly limited to sub-basins. Moreover, the form of changes analyzed in the rainfall of the study area seem to have mostly been rather decadal or multi-decadal variability than long-term trend; see among others Onyutha (2015b), Onyutha and Willems (2015a, 2015b), and Taye and Willems (2012). Both trend and variability have also occasionally been analyzed, for instance, by Nyeko-Ogiramoi et al. (2013). The study by Taye and Willems (2012) on temporal variability of hydro-climatic extremes using the Quantile Perturbation Method (QPM) was limited to the upper Blue Nile basin. Onyutha and Willems (2015b) used the QPM to compute variability in the annual maxima rainfall at some few locations in the Lake Victoria basin. Based on observed hydro-meteorological extremes, the study by Nyeko-Ogiramoi et al. (2013) which was also limited to the Lake Victoria basin analyzed trend and variability using the MK test and QPM respectively. In the study by Onyutha and Willems (2015a), station-based data were used to analyze spatiotemporal variability of seasonal and annual rainfall totals using the QPM. The limitations of the studies by Nyeko-Ogiramoi et al. (2013), Onyutha and Willems (2015a, 2015b), and Taye and Willems (2012) were that they: (1) did not cover sufficient locations of all the riparian countries of the Nile River Basin (NRB), (2) analyzed variability using the QPM which considers rainfall intensity directly (without rescaling), thereby rendering the method susceptible to possible anomaly exaggeration in case an outlier exists, (3) did not quantify the uncertainty due to short-data record lengths on the trend or variability results. To take into consideration (1)–(2), using country-wide gridded (instead of station-based) monthly rainfall data, Onyutha (2015b) analyzed variability in all the riparian countries of the NRB using the Nonparametric Anomaly Indicator Method (NAIM). The difference between the QPM and NAIM is that the QPM analyzes variability in terms of the frequency of extreme events and perturbation of rainfall extremes, while the NAIM computes anomalies in the series after applying temporal convolution to the nonparametrically rescaled data set.

Therefore, to differ from other previous studies such as Nyeko-Ogiramoi et al. (2013), Onyutha (2015b), Onyutha and Willems (2015a, 2015b), and Taye and Willems (2012) by focusing on trend analyses while investigating the possible bias due to short-term data record lengths, this study was aimed at: (1) determining how data record length and selected time period influence trend results, (2) assessing the bias in trend results due to short-term data length, (3) investigating the homogeneity of the rainfall trend directions, and (4) determining rainfall trends at 39 locations across the entire NRB.

2. Study area and rainfall data

The NRB, which stretches over 35° of latitude in north–south direction (31°N to 4°S) and over 16° of longitude in west–east direction (24 to 40°E), has a total catchment area of about 3 400 000 km^2 (see Fig. 1). The River Nile which has 11

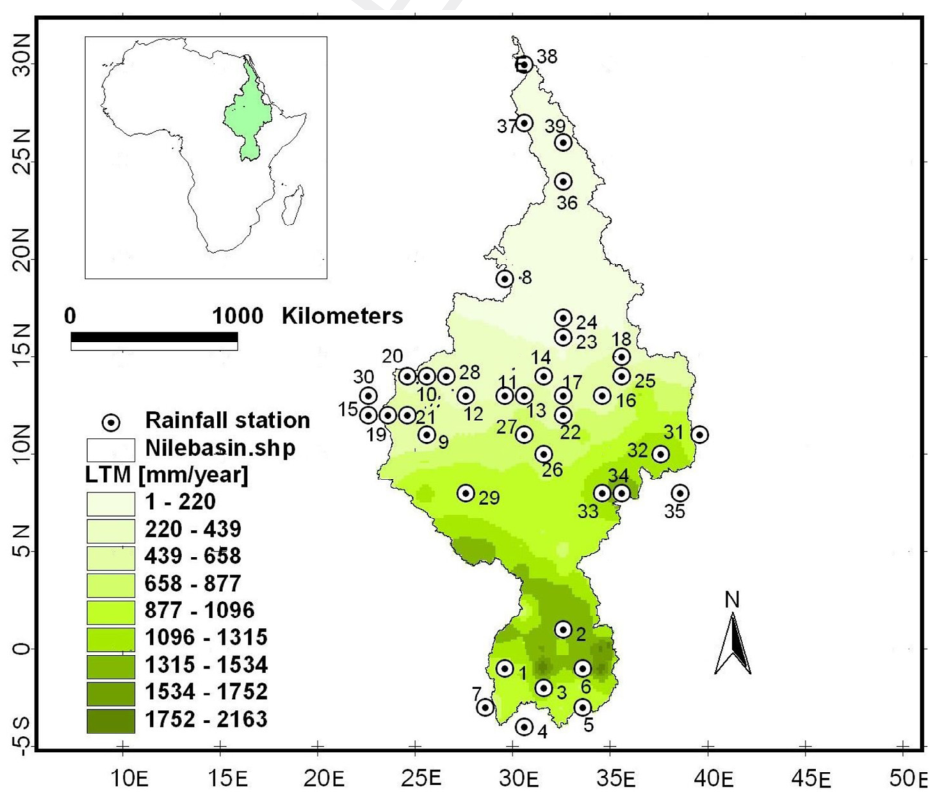

Fig. 1. Locations of the selected meteorological stations (see Table 1 for details) in the Nile basin; the background was obtained by surface interpolation (kriging method) of the Long Term Mean (LTM) of annual rainfall.

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