Trend and Change-Point Detection Analyses of Rainfall and Temperature Over the Awash River Basin of Ethiopia

Yitea Seneshaw Getahun (yiseneshaw@gmail.com)
Debre Berhan University

Ming-Hsu Li
National Central University

Iam-Fei Pun
National Central University

Research

Keywords: Climate index, Rainfall variability, Change-point detection, Trend

Posted Date: July 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-717348/v1

License: ☑️ This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Version of Record: A version of this preprint was published at Heliyon on September 1st, 2021. See the published version at https://doi.org/10.1016/j.heliyon.2021.e08024.
Abstract

**Background:** Awash River basin (ARB) as a system is in a state of continuous change that requires successive studies to discern the changes or trends of climatic elements through time due to climate change/variability, and other socio-economical developmental activities in the basin. The livelihood of communities in the ARB is primarily based on rainfall-dependent agriculture. Effects of rainfall anomalies such as reduction of agricultural productivity, water scarcity, and food insecurity are becoming more prevalent in this area. In recent years, ARB experienced more frequent and intense spatio-temporal rainfall anomalies, which make the shift and trend analyses of rainfall associated with sea surface temperature crucial in providing guidance to improve agricultural productivity.

**Method:** Change-point detection tests (Pettit’s, the von Neumann ratio (VNR), Buishand’s range (BR) and standard normal homogeneity (SNH)) and Mann-Kendall (MK) trend analysis of rainfall and temperature data from 29 meteorological stations in the ARB were carried out from 1986 to 2016.

**Results:** A significant increasing trend of annual and seasonal temperature was found. The temperature change-points for the annual and major rainy season (MRS) were detected in 2001, while for the minor rainy season (mRS) in 1997. A significant decreasing trend, shift, and high variability of rainfall were detected in the downstream part of the ARB. The BR and SNH results showed that the mRS rainfall change-point was in 1998, with a subsequent mean annual decrease of 52.5 mm. The increase (decrease) of rainfall in the annual and MRS was attributable to La Niña (El Niño) events.

**Conclusions:** The significant decreasing trend and change-point of rainfall in the mRS was attributable to the steady warming of the Indian and Atlantic Oceans, local warming, and La Niña events. With this knowledge of the current trends and change-point for rainfall and temperature in the ARB, it is therefore essential that appropriate integrated water management and water-harvesting technologies are established, especially in the downstream areas. Moreover, early detection of El Niño episodes would provide invaluable warning of impending rainfall anomalies in the ARB and would enable better preparations to mitigate its negative effects.

1. Introduction

In recent decades, several studies have reported the impacts of climate change and variability as manifested by the increasing rainfall anomalies and temperature (Ramli et al., 2019; Asfaw et al., 2018; Alemayehu and Bewket, 2017). The rising global temperature attributed to the greenhouse gases emission is unequivocal that in turn affects the rainfall anomalies (IPCC, 2014). Rainfall amount is expected to decrease while its anomaly is likely to increase in the Sub-Saharan Africa (IPCC, 2014). Recent studies of climate change and variability have been mainly focusing on basin scale, which provide more detail information for a better management and planning of local resources (Ramli et al., 2019; Elsanabary and Gan, 2015).
The economy of Awash River Basin (ARB) in Ethiopia is highly dependent on rainfed agriculture that is vastly sensitive to changes and variability of climate (Borgomeo et al., 2018). Rainfall anomalies tend to lower the agricultural productivity, livestock production, food security, and water availability of ARB (Tilahun et al., 2011). Thus, the expanding agricultural sector in the ARB is particularly vulnerable to rainfall anomalies and a decrease in the rainfall scenario could lead to a 5% decline in the basin's gross domestic product (GDP), with agricultural GDP possibly decreasing by as much as 10% (Borgomeo et al., 2018). In the future, climate variability is likely to worsen the water scarcity in the Sub-Saharan Africa (IPCC, 2014). The impacts of climate variability in the ARB is likely to be widespread due to ARB's high population, and is the most utilized river basin in Ethiopia that contributes greatly to the development of the national economy (Hailu et al., 2017; Bekele et al., 2017). Therefore, investigation of long-term trends and variation of rainfall and temperature in the ARB is of vital importance for managing of water resources and predicting weather-related disasters.

Furthermore, the predictive accuracy of climate, weather, and hydrological studies is depends on the quality of historical climate datasets (Javari, 2016; Ros et al., 2015). Pitifully, a number of non-climatic factors such as war, meteorological station relocation, failure of meteorological instruments, mishandling of data and abrupt environmental changes can affect the quality of historical climate data, leading to unrealistic trends, shifts, or jumps in the data record that can introduce errors into further analyses (Ros et al., 2015). Hence, understanding factors that affect the quality of historical climate data is vital for performing accurate climate change and variability studies. Trend analysis and change-point detection of rainfall and temperature would thus lead to better quality climate change and variability studies (Bisai et al., 2014; Jain et al., 2013).

Change-point detection of climate data have been performed using Buishand's range (BR), standard normal homogeneity (SNH), Pettit's and the von Neumann ratio (VNR) tests besides to the trend analysis based on Mann-Kendall (MK) test (Suhaila and Yusop., 2018; Javari, 2016; Ros et al, 2015; Jaiswal et al., 2015; Zarenistanan et al., 2014; Croitoru et al., 2012). Several studies conducted MK trend test on the temperature and rainfall for different parts of Ethiopia (Asfaw et al., 2018; Alemayehu and Bewket, 2017; Hayelom et al., 2017; Tamiru et al., 2015; Mengistu et al., 2014) and Awash river basin (Shawul and Chakma, 2020; Tadese, et al., 2019; Mulugeta et al., 2019; Gedefaw et al., 2018; Bekele et al., 2017). The findings from several recent studies in Ethiopia showed a significantly increasing trend in temperature and an inconsistent trend in rainfall. The above studies in ARB applied MK test for rainfall, and streamflow analyses but not for temperature, excluding Gedefaw et al. (2018) that used stations in the upper part of ARB, which were not adequate and representative of the entire ARB. Location information of all the stations in Gedefaw et al. (2018) were wrongly displayed and even with the correct location some of the station are quite far from ARB. Additionally, most of the previous studies were carried out in the upper part of the ARB, although the spatial distribution of rainfall and temperature over the basin is extremely uneven. In other words, the downstream part of ARB has not been well investigated. Furthermore, none of the previous studies has performed change-point detection tests. This means that there still exists lack of proper understanding of past temperature and rainfall in the ARB for different
time series. Thus, a comprehensive study that incorporates large-scale climate indexes is crucial in order to have a better picture on variation trends of temperature and rainfall in the ARB.

It has been shown that the rainfall in the major rainy season (MRS) in Ethiopia (June-September) declines during an El Niño event and increases during a La Niña event (Degefu et al., 2017; Gleixner et al., 2016; Fekadu, 2015; Elsanabary and Gan, 2015; Zaroug et al., 2014; Abtew et al., 2009). Moreover, the correlation strength of large-scale climate indexes with rainfall varies from season to season and region to region, and their complexity is not well understood. Thus, basin scale studies will enhance the predictability of seasonal rainfall. Assessments of large-scale climate indexes relating to rainfall pattern have been performed across the Ethiopia, but to date there has been no specific study on the ARB.

The main objective of this study was to examine trends and perform change-point detection tests on rainfall and temperature data of ARB. Accordingly, change-point detection and trend analyses of rainfall and temperature data were performed based on datasets collected from 29 meteorological stations across the Awash River basin. The change-point detection tests were carried out using Pettit’s, VNR, BR, and SNH tests, while a MK trend test was used for trend analysis.

The influence of elevation and large-scale climate indexes on the rainfall of the ARB were also examined, with the indexes used being the El Niño–Southern Oscillation (ENSO), the Dipole Moment of Indian Ocean (DMI), the Atlantic Multi-decadal Oscillation (AMO), and the North Atlantic Tropical Index (NTA).

An attempt was made in this study to provide a comprehensive interpretation of trends and shifts in annual and seasonal rainfall in the Awash River basin in relation to local and global climatic drivers. It was concluded that mRS rainfall has shifted and shows a significantly decreasing trend, particularly in the downstream area of the basin. It is therefore crucial that to improve water-resource management strategies and identify better adaptation options for the expanding agricultural activities in the ARB.

2. Study Area And Datasets

2.1. Study area

The Awash River basin is part of the Great Rift Valley and is located in the east-central part of Ethiopia. The length of the river is 1,200 km, and it has a drainage area of 116,374 km². The elevation of ARB varies from 215 m to 4185 m (Fig. 1). The Awash River originates from the central highlands, which lie west of Addis Ababa at an elevation of 3,000 m, and terminates in Lake Abbe at an elevation of 215 m, near the border with Djibouti (Dost et al., 2013). It is an endorheic basin with basin outlet ending in salty Lake Abbe. Approximately 18 million people and 6 million livestock are estimated to dwell within the ARB (Hailu et al., 2017; Dost, 2013), making it the most heavily exploited river basin in Ethiopia due to the existence of major industries, larger cities, and higher populations in the ARB than in other regions of the country (Adeba et al., 2015). The total mean annual volume of surface water available in the basin is estimated to be 4.64 billion m³ (Adeba et al., 2015). Water scarcity has increased due to rapid population
growth, urbanization, and climate variability that induces unreliable rainfall, which further results in recurring droughts (Hailu et al., 2017; Adeba et al., 2015). The water deficit has been severe in recent years, and it has affected development activities as well as the livelihoods of communities within the basin.

The climate of the ARB varies from humid subtropical in the upstream as well as southern and northwestern peripheries of the basin to an arid climate over the eastern lowlands of the basin (Murendo et al., 2010). The mean annual temperature varies from 10°C in the upstream as well as southern and northwestern peripheries of the basin to 30.5°C in the eastern lowlands of the basin (Adeba et al., 2015). Based on data from 1986–2016, the mean annual rainfall varies from 900–1300 mm in the upstream and northwestern peripheries of the basin to 192–500 mm in the eastern lowlands of the basin (Fig. 2). In general, there are three seasons in Ethiopia/ARB: (1) the major rainy season (MRS), locally called “Kiremt” during June, July, August, and September (JJAS), (2) the minor rainy season (mRS), locally called “Belg” during February, March, April and May (FMAM) and (3) the dry season, also known as “Bega” during October, November, December and January (ONDJ) (Degefu et al., 2017; Fekadu, 2015). The well-known mechanisms responsible for the three seasons are the Intertropical Convergence Zone (ITCZ), and the Indian monsoon system, which govern the atmospheric circulation. The surrounding land areas and the rugged terrain also play a considerable role in local rainfall variations (Viste, 2012; Endalew, 2007).

The prominent force driving rainfall during the MRS is the northward shift of the ITCZ from the equator (Viste, 2012), which initiate a low-pressure system development over the northern landmasses, while a subtropical high-pressure system develops in the south. As a result, the southwesterly trade winds bring a warm and moist tropical air mass to the ARB (Korecha and Barnston, 2007; Segele and Lamb, 2005).

The rainfall-producing mechanisms during the mRS have not been as well studied as those of the MRS. However, few studies stated that a thermal low development over the nearby landmasses and high-pressure zone over the Indian ocean induces a warm and moist air mass during the mRS (Souvereijns et al., 2016; Nicholson, 2011; Viste, 2012). The mRS rainfall is a significant contributor to the total annual rainfall in the northeast, eastern and southeastern portions of Ethiopia, where a large part of the ARB is located (Fekadu, 2015). Because of the orography the mRS rainfall is limited in the east, southeast and southern parts of the country (Degefu et al., 2017). During the dry season, the ITCZ shifts towards the south and a large high-pressure system develops over central Asia (Siberia), which enhances northeasterly airflow and brings the ARB under the influence of cool and dry air masses (Endalew, 2007; Seleshi and Zanke, 2004).

### 2.2. Datasets

The observed temperature and rainfall datasets from 1986–2016 for 31 years were obtained from 29 meteorological stations of the National Meteorological Agency, Ethiopia (Fig. 2). The sea surface temperature anomalies (SSTAs), namely the AMO (50°-60°N, 10–50°W), the NTA (5.5°-23.5°N, 15°-57.5°W), and Niño 3.4 (170°-120°W, 5°N-5°S) were downloaded from the National Oceanic and
Atmospheric Administration (NOAA) website (https://www.esrl.noaa.gov/psd/data/timeseries/AMO/). AMO is represented in two ways. The first comprises detrended SSTA averaged over the North Atlantic from 0°-70°N, to remove global warming signals and obtain a pure oscillatory signal of the Atlantic sea surface temperature (SST). The second comprises the North Atlantic SST data with the global mean SST data subtracted to remove global effect signals (Park and Li., 2018; Marullo et al., 2011; Trenberth and Shea, 2006). In this study, the first ways were used to remove the global warming signal from other SSTA series (Hong et al., 2008). The DMI is the difference in SSTA between the eastern (90° to 110ºE, 10ºS to 0ºN) and western (50° to 70ºE and 10°S to 10°N) tropical Indian Ocean, and was obtained from the Japan Agency for Marine Earth Science and Technology (http://www.jamstec.go.jp/frsgc/research/d1/iod/e/iod/dipole_mode_index.html).

3. Methodology

3.1. Tests for change-point detection

Non-parametric ranking tests, namely Pettit’s and the VNR, and parametric tests, namely the BR and the SNH were performed for change-point detection tests of rainfall and temperature on annual, seasonal, and monthly basis. A non-parametric approach is useful when assumptions are not made about the data distribution, and can better deal with data containing outliers. It is also less sensitive to sample size, but is not efficient (Whitley and Ball, 2002). The opposite is true for the parametric test. For all change-point detection tests if \( p \) value is smaller than the specific significance level, in this case 0.05, the null hypothesis i.e, that there is no change-point is rejected. Therefore, the alternative hypothesis i.e that a significant change-point exists in the time series at a particular year is accepted as true (Jaiswal et al., 2015).

The null hypothesis for the VNR test is that the data are independent and identically distributed random values, and the alternative hypothesis is that the values in the series are not randomly distributed. The VNR test statistic is defined as the ratio between the mean square successive (year-to-year) difference and the variance of the data. If the data are homogeneous, it is expected that the VRN test statistic = 2. Otherwise, the value must be < 2, implying that the sample mean rapidly varies. Thus, the critical values from the VRN test at 5% confidence levels can be used to identify change-points in a non-homogeneous series (for examples, see Table 2 of Jaiswal et al., 2015).

The null hypothesis of BR test is that the annual values of the testing variable are independent and identically distributed, and the alternative hypothesis is that a step-wise shift in the mean is present. In this test an adjusted partial sum is calculated, comprising the cumulative deviation of each sample from the mean. Then, the range of the adjusted partial sum for all of the samples is used to detect the change-point, based on the critical values given by Buishand (1982).

The same null and alternate hypotheses apply for the SNH test as for the BR test. In addition, in the SNH test the mean of a subset of the observations is combined with the mean of the remaining observations
to form the test statistic. Then, the sample at which the test statistic attains a maximum value can be a change-point, based on the total number of observations (see Table 2 of Jaiswal et al., 2015). In Pettit’s test, the same null hypothesis and alternative hypotheses are used as in the SNH and BR tests. However, Pettit’s test is based on the ranks of elements in a series, and thus the sums of the difference between observations on both sides of a chosen pivot are calculated. Then, the maximum value of this sum obtained for all pivots is used to identify the change-point, based on the number of observation and chosen confidence level (Javari, 2016).

The Pettit’s, BR, and SNH change-point detection tests reveal the exact year of the change-point, but the VNR test cannot do so: it only determines the existence of a change-point. Pettit’s and BR tests tend to detect a change-point years in the middle of the series, whereas the SNH test is more sensitive in detecting a change-point years near the beginning and end of the time-series because of its different hypothesis and method of critical value attainment (Ros et al., 2015). The details of these change-point detection tests, their statistical formulas, and the confidence level critical values are presented in Javari, (2016); Jaiswal et al., (2015) and Zarenistanak et al., (2014). A series is considered to have a change-point year if more than two tests reject the null hypothesis, or when two tests report the same change-point year (Jaiswal et al., 2015).

3.2. Trend analyses and coefficients of variation (CV)

Non-parametric Mann-Kendall (MK) test was used for trend analysis of both rainfall and temperature. The test statistic of the MK test is calculated in the same way as it is in Pettit’s test, and it assumed to have a normal distribution thus allowing the z-value to be calculated. This z-value is used to determine whether there is a significant trend (Suhaila and Yusop, 2018; Kendall, 1975). In the MK test, the negative value of slope indicates a decreasing trend, while the positive value of slope illustrates an increasing trend. The MK test does not provide an estimate of the magnitude of the trend. To overcome this, Sen’s slope estimation test is used, which computes the linear rate of change (Suhaila and Yusop, 2018). The Sen’s slope is the median of the slopes calculated using all possible data point pairs in a data series (Asfaw et al., 2018). The rainfall CV that is the measure of how much the rainfall amount deviated from the mean was computed as the standard deviation divided by the long-term mean of a rainfall time series and multiplying it by one hundred percent (Asfaw et al., 2018). The degree of variability of rainfall was classified as low when CV < 20%, moderate when 20% < CV < 30%, high when 30% < CV < 40%, very high when 40% < CV < %70, and extremely high when CV > 70.

4. Results And Discussion

4.1. Trend analysis and coefficients of variation (CV)

Trend and change-point analysis of average temperature and rainfall were carried out for the entire ARB, using the entire basin as one series and using each station in the basin individually, on annual and seasonal basis from 1986–2016. Additionally, change-point analysis and trends of monthly temperature and rainfall were examined for the entire basin as one series. CV was applied for rainfall only.
4.1.1. The entire ARB average temperature and rainfall

The MK trend test was applied on average temperature and rainfall of the entire ARB. The MK test indicated a significant increasing trend in temperature on annual, seasonal and monthly basis, except for December, which is the coldest month in Ethiopia (Table 1). The annual rainfall decreased insignificantly, whereas the converse was true for the MRS. At the same time, the mRS rainfall decreased significantly. The Sen's slope rate of mean annual rainfall decrease was \(-1.29\) mm/y, while the rate of MRS rainfall increase was \(0.004\) mm/y (Table 1). On a monthly basis, February showed a significant decreasing trend in rainfall. An insignificant decreasing trend in rainfall was observed in March, April, June, and September, whereas May, July, and August showed an insignificant increasing trend in rainfall.

The annually and MRS rainfall CV were 22.5% and 32.1%, implying moderate and high variability of rainfall, respectively (Table 1). Likewise, the CV of the mRS was 57.2%, implying that there was a very high variability in rainfall. At the same time, the monthly CV showed less variability in August (10.4%), while it showed moderate variability in June (24.6%). During the mRS, there was extremely high variability in February, with a CV of 98.8%. The remaining months of the mRS showed very high variability, indicating the high uncertainty of mRS rainfall in a given year.
### Table 1
MK test and CV analysis of entire ARB average rainfall and temperature plus AMO SST

| Months, Season | Rainfall (mm) | Mean Temp (°C) | AMO SST (°C) |
|----------------|---------------|----------------|--------------|
|                | CV %          | p-value        | Sen's slope  | p-value      | Sen's slope  | p-value      | Sen's slope  |
| Jan            | 76.8          | 0.919          | -0.003       | 0.001        | 0.035        | 0.00001      | 0.016        |
| Feb            | 98.8          | **0.013**      | -1.140       | 0.001        | 0.046        | 0.00001      | 0.014        |
| Mar            | 46.5          | 0.518          | -0.531       | **0.003**    | 0.045        | **0.001**    | 0.012        |
| Apr            | 38.4          | 0.062          | -1.203       | 0.001        | 0.061        | 0.001        | 0.012        |
| May            | 44.0          | 0.185          | 0.906        | 0.001        | 0.051        | 0.001        | 0.013        |
| Jun            | 24.6          | 0.415          | -0.320       | **0.0001**   | 0.037        | **0.011**    | 0.012        |
| Jul            | 16.2          | 0.153          | 0.993        | **0.0001**   | 0.034        | **0.002**    | 0.016        |
| Aug            | 10.4          | 0.518          | 0.352        | **0.002**    | 0.022        | 0.000        | 0.018        |
| Sep            | 21.3          | 0.352          | -0.285       | **0.0001**   | 0.038        | **0.0001**   | 0.019        |
| Oct            | 74.9          | 0.415          | 0.403        | **0.0001**   | 0.036        | **0.0001**   | 0.021        |
| Nov            | 99.3          | **0.025**      | 0.155        | 0.001        | 0.053        | **0.0001**   | 0.017        |
| Dec            | 98.8          | 0.066          | -0.049       | 0.324        | 0.012        | **0.0002**   | 0.015        |
| MRS            | 32.1          | 0.919          | 0.004        | **0.0001**   | 0.032        | **0.0003**   | 0.016        |
| mRS            | 57.2          | **0.049**      | -0.56        | **0.0001**   | 0.051        | **0.000**    | 0.013        |
| Annual         | 22.5          | 0.659          | -1.29        | **0.0001**   | 0.040        | **0.0001**   | 0.015        |

#### 4.1.2. Average temperature and rainfall of each station in the ARB

Trend analysis of average temperature and rainfall were performed not only for the entire basin, but also for each of the meteorological stations in the basin. A significant increasing trend in annual and seasonal temperature were found at all of the meteorological stations, but Mojo, Debre Zeit, Kulumsa and Harbu stations were outliers, showing insignificant temperature increases. A significant decreasing trend in annual rainfall was detected at Asgori, Gewane, Merssa, and Assaita meteorological stations, but most of the meteorological stations indicated an insignificant decreasing trend (Fig. 3). Rainfall during the MRS showed a significant decreasing trend at the Gewane and Asgori meteorological stations. The other ten meteorological stations showed an insignificant decreasing trend in rainfall, whereas the remaining 17 stations showed an insignificant increasing trend in rainfall (Fig. 3). In the mRS, a significant decreasing trend of rainfall was observed at eight meteorological stations (Dubity, Gewane, Erer, Bati, Merssa, Asgori, Awash 7 Kilo and Assaita), which are all located in the downstream part of the ARB. The remaining...
meteorological stations indicated an insignificant decreasing trend, with the exception of Lefessa and Mojo meteorological stations.

The mean annual and seasonal spatial variability of rainfall from each station was interpolated over the basin as indicated in (Fig. 4). In the annual and MRS, high and very high variabilities of rainfall were noticed in the downstream part of the ARB, while less variability was observed in the upstream part of ARB. Similarly, extremely high variability of rainfall was noticed in the downstream area of the ARB during the mRS, whereas moderate variability was observed in the upstream part of the ARB. High rainfall variability was observed in the mRS than in the annual and MRS. Circular features technically known as “bully-eye effects” generated on the rainfall spatial variability map were due to the station data sparsity used for the interpolation (Goovaerts, 2010). It is the effect of the surrounding area that data point weighting in the interpolation.

A significant increase in temperature and rainfall of variability has been reported in different parts of Ethiopia, which is in line with our results, but the significant decline of rainfall in the mRS and especially in the lowland part of the basin was a novel finding (Hayelom et al., 2017; Tamiru et al., 2015). A similar finding that mRS rainfall is more variable than the MRS rainfall has been reported in the northern part of Ethiopia (Hayelom et al., 2017).

Based on gridded reanalysis rainfall data, Mulugeta et al. (2019) detected a significant decreasing trend of MRS rainfall, whereas the annual, mRS and dry rainy season rainfall showed no trend in the entire ARB in which most of the findings were not similar with our result. The gridded data uncertainty relating with topography, resolution and different periods used for the MK test might cause the disagreement. On the other hand, an insignificant increasing trend of MRS rainfall was detected in the entire ARB based on 12 stations, whereas the annual and mRS rainfall indicated the contrary (Bekele et al., 2017). This finding in line with our result, except that the mRS rainfall decreased significantly in our case. Because of the less number of stations (i.e. 3) that Bekele et al. (2017) used from the downstream part of the basin, it was difficult to compare the significant decreasing trend of mRS rainfall that it was occurred in the downstream part of the basin in our finding. Over the entire ARB, a significant decreasing trend of annual rainfall was detected in 5 out of 28 stations, whereas two stations indicated the contrary and the remaining non-significant trend (Tadese, et al., 2019). Commonly used stations with our study were 11 out of 28, but the periods used for the MK test were different. Tadese, et al. (2019) also used less number of station from the downstream part of the basin. Four station were used from the downstream part of the basin such as Mersa, Kombolcha, Adaiytu and Mile, 2 of them showed significant decreasing trend of mRS rainfall, while the remaining 2 depicted insignificant decreasing trend that resembles with our finding.

The rainfall in mRS showed higher variability than in the MRS and annual that matches with our result (Tadese, et al., 2019). Similarly, the MRS and mRS rainfalls were showed insignificant trend. Gedefaw et al. (2018) also carried out MK trend analysis of rainfall and temperature in the ARB. However, the location information of all the stations in this study is wrong. Even if we use the correct locations of these stations
According to the Ethiopian Meteorological Agency website, some of them are still far from the ARB (see http://www.ethiomet.gov.et/stations/regional_information for more information). Therefore, we only used their results from Gewane and Bui stations for comparison with our study. Gedefaw et al. (2018) detected a significant increasing trend of mean annual temperature in Gewane and Bui stations of ARB that is similar with our finding. Gewane station found to have a significant increasing trend of annual rainfall, whereas Bui station demonstrated an insignificant decreasing trend. We commonly used Gewane station only but our finding was contrary to Gedefaw et al. (2018) that might be due to the different period data used for the MK test that they used from 1993–2006, while we used from 1986–2016. Likewise, Shawul and Chakma, (2020) found a significant increasing trend of maximum temperature and an insignificant trend of annual rainfall in the upper ARB that was parallel with our finding. Generally, except the study based on the gridded data, most of the previous studies based on the observed data showed a good agreement with our finding.

4.2. Change-point detection tests of temperature and rainfall

4.2.1. The entire ARB average temperature and rainfall

The Pettit and VNR, BR, and SNH change-point detection tests were performed to detect the presence of shifts in the annual, seasonal and monthly series of temperature and rainfall data during the period 1986–2016 (Table 2 and Table 3). Analysis of the annual and MRS temperature indicated that there was a change-point in 2001. In this case, the mean annual temperature increased from 20.6°C to 21.2°C, with an increase of 0.6°C after the change-point. Similarly, the MRS temperature increased by 0.52°C after the change-point (Fig. 5). According to the BR and SNH tests, the change-point of the mRS temperature was detected in 1997, whereas Pettit's test indicated that the change-point in 2001 (Table 3 and Fig. 5). The mRS temperature shifted three years earlier than annual and MRS indicating that mRS months are highly sensitive to global warming. The change-point of average monthly temperature was detected in all months except for December, yet the change-point year varied based on the type of test. The highest average temperature increase after the change-point was 1.1°C in April, May, and November, while the lowest increase was 0.5°C in July, August, and September (Table 3). The MK trend test was applied to the temperature data before and after the change-point, and was found to significantly increase both before and after the change-point.

Table 2. Entire basin changing point detection of average annual, seasonal and monthly temperature (1986-2016)
| Months, Seasons | Pettit's test | VNR | BR test | SNH test |
|----------------|--------------|-----|---------|---------|
|                | Year of shift | Temp | P-value | Year of shift | Temp | Year of shift | Temp |
|                | Pre | Post |       | Pre | Post | Pre | Post |
| Jan | 2002 | 18.72 | 19.44 | Yes | 2002 | 18.72 | 19.44 | 2002 | 18.72 | 19.44 |
| Feb | 2002 | 19.84 | 20.68 | Yes | 2002 | 19.84 | 20.68 | 2002 | 19.84 | 20.68 |
| Mar | 1997 | 20.97 | 21.64 | Yes | 2001 | 21.13 | 21.74 | 2001 | 21.13 | 21.74 |
| Apr | 1997 | 21.36 | 22.42 | Yes | 1997 | 21.36 | 22.42 | 1997 | 21.36 | 22.42 |
| May | 1998 | 22.09 | 23.13 | Yes | 1997 | 22.04 | 23.11 | 1997 | 22.04 | 23.11 |
| Jun | 1997 | 22.61 | 23.25 | Yes | 1999 | 22.66 | 23.28 | 1997 | 22.61 | 23.25 |
| Jul | 2000 | 21.46 | 22.01 | No | 2000 | 21.46 | 22.01 | 2000 | 21.46 | 22.01 |
| Aug | 2000 | 20.99 | 21.39 | Yes | 2000 | 20.99 | 21.39 | 2000 | 20.99 | 21.39 |
| Sep | 2001 | 20.97 | 21.52 | Yes | 1997 | 20.78 | 21.45 | 1997 | 20.78 | 21.45 |
| Oct | 2000 | 19.98 | 20.57 | Yes | 2000 | 19.98 | 20.57 | 2000 | 19.98 | 20.57 |
| Nov | 2001 | 18.89 | 19.96 | Yes | 2001 | 18.89 | 19.96 | 2001 | 18.89 | 19.96 |
| Dec | No | 18.54 | 0.86 | No | 18.54 | No | 18.54 |
| Major | 2001 | 21.54 | 22.06 | Yes | 2001 | 21.54 | 22.06 | 2001 | 21.54 | 22.06 |
| Minor | 2001 | 21.20 | 22.00 | Yes | 1997 | 21.07 | 21.92 | 1997 | 21.07 | 21.92 |
| Annual | 2001 | 20.58 | 21.24 | Yes | 2001 | 20.58 | 21.24 | 2001 | 20.58 | 21.24 |

There was no significant trend and change-point of temperature in the coldest month December, which indicted that it is relative insensitive to global warming. The mean temperature of April, May, and June shifted three years earlier than others did indicting that these three months were highly sensitive to global warming. This in turn could potentially affect the agricultural productivity in the ARB.

There were no change-points detected for rainfall either annually or during the MRS. However, the mRS change-point for rainfall was detected in 1998 based on the BR and SNH tests, with a mean rainfall decrease from 267.6 mm to 215.1 mm (Fig. 5 and Table 2). Furthermore, the Awash River basin's average monthly rainfall change-point was detected in February 2000 using the Pettit and VNR and BR tests. The VNR and BR tests showed a change-point in April 2000, but as the VNR test does not identify a change-point year, it could not be inferred that April was the rainfall change-point month (Table 2). Pettit’s test detected comparatively fewer change-points for rainfall, while the BR and VNR tests detected more
change-points. The rainfall trend before and after the change-points were assessed, and revealed that the annual and seasonal rainfall trends were insignificant. Analysis of annual and MRS temperature indicated that there was a change-point in 2001, whereas the annual and MRS rainfall showed no change-point existed. The mRS change-point of rainfall was one year later than the change-point of temperature (Fig. 5).

Table 3. Entire basin changing point detection of average annual, seasonal and monthly rainfall (1986-2016)

| Months, Seasons | Year of shift | Year of shift | Year of shift | Year of shift | Mean rainfall | Mean rainfall | Mean rainfall |
|-----------------|--------------|--------------|--------------|--------------|---------------|---------------|---------------|
|                 | Pettit's test | VNR BR test  | SNH test     |              |               |               |               |
|                 | Pre Post     | P-value      | Pre Post     |              |               |               |               |
| Jan             | No 2.37      | No 2.37      | No 2.37      |              |               |               |               |
| Feb             | 2000 54.53 15.9 Yes 2000 54.53 15.9 No 25.94 |              |               |               |               |               |               |
| Mar             | No 62.24 | No 62.24 | No 62.24 |              |               |               |               |
| Apr             | No 79.36 | Yes 1998 79.36 72.17 No 79.36 |              |               |               |               |               |
| May             | No 69.8 | No 69.8 | No 69.8 |              |               |               |               |
| Jun             | No 78.83 | No 78.83 | No 78.83 |              |               |               |               |
| Jul             | No 198.74 | No 198.74 | 2001 195.74 189.2 |              |               |               |               |
| Aug             | No 204.98 | No 204.98 | No 204.98 |              |               |               |               |
| Sep             | No 101.95 | No 101.95 | No 101.95 |              |               |               |               |
| Oct             | No 36.52 | Yes 36.52 | No 36.52 |              |               |               |               |
| Nov             | No 7.89 | No 7.89 | No 7.89 |              |               |               |               |
| Dec             | No 2.18 | No 2.18 | No 2.18 |              |               |               |               |
| Major           | No 582.74 | No 582.74 | No 582.74 |              |               |               |               |
| Minor           | No 235.41 | No 1998 267.6 215.1 1998 267.6 215.1 |              |               |               |               |               |
| Annual          | No 866.83 | No 866.83 | No 866.83 |              |               |               |               |

4.2.2 Average temperature and rainfall of each station in the ARB
In addition to the entire ARB’s average rainfall analysis, station-wise change-point detection tests of annual and seasonal average temperature and rainfall were performed. The annual temperature change-point were confirmed in 19 meteorological stations out of the 29 as indicated in Fig. 6, a. The highest mean annual temperature shift occurred in Assaita station in 1997 that increased from 29.2 °C to 31.7 °C, with an increase of 2.5 °C after the change-point. Following Assaita station, the highest mean annual temperature shift detected in Gewane (2001), Combolecha (1997), Tulu Bolo (1997), and Asebe Teferi (2001) with the corresponding mean annual temperature increase of 2.3 °C, 2.2 °C, 1.4 °C, and 1.3 °C after the change-point. On the other hand, the lowest mean annual temperature shift occurred at Bokeksa station in 2001 that it increased from 21.6 °C to 21.9 °C. Excluding Bokeksa station, all the meteorological stations that is 18 out of 29 confirmed the mean temperature change-point of MRS like that of the annual (Fig. 6, b). The highest MRS mean temperature shift occurred in Assaita and Combolecha in 1997 that the mean increased from 31.4 °C to 34.0 °C and 17.8 °C to 20.4 °C, respectively, with an increase of 2.6 °C after the change-point. Whereas, the lowest mean MRS temperature increase after the change-point were 0.4 °C in Metehara, and 0.5 °C in Awash 7 kilo, A.A Obs, and Debre Berhan stations. After the change-point, the mean MRS temperature increase in Gewane, Tulu Bolo, and Asebe Teferi were 2 °C, 1.8 °C and 1.3 °C, respectively.

Meteorological stations of 20 out of 29 confirmed the mRS mean temperature change-point as shown in Fig. 7 that includes stations of Kokadam and Merssa but not Debre Berhan. In most of the stations the mRS temperature change-point were detected in 1997/98, while the annual and MRS change-point were in 2000/2001. The highest mean mRS temperature shift detected in Gewane station that it increased from 27.9 °C to 30.8 °C with the mean increase of 2.9 °C after the change in point. After the change-point, the mRS mean temperature of Assaita, Combolecha, Tulu Bolo, increased by 2.7 °C, 2.6 °C, 2.4 °C, respectively.

In general, 10 out of the 29 meteorological stations indicated that a change-point of rainfall occurred in the annual and/or seasonal series (Fig. 8). At the remaining meteorological stations there was either a change-point in only one or two types of tests in different years, or no change-point at all. Most of the change-points were detected in the downstream part of the ARB.

In most of the observations the major change-point years were 1997/98 and 2001/02, though there were variations from one test to another. The change-point of rainfall for the mRS occurred in 1997/98, whereas for the MRS and annual rainfall the change-point was typically in 2001/2002. At Gunna station, the highest MRS average rainfall shift was detected in 2002, using all change-point detection tests. Before the change-point in 2002, the average JJAS rainfall value was 884 mm, whereas after the change-point the mean JJAS rainfall decreased to 669 mm. The next highest average-rainfall shift was detected at Erer station in 1998, using all change-point detection tests for the mRS. The mean rainfall before the change-point was 401 mm and 240 mm after (Fig. 8). Station-wise trend analysis was performed before and after the change-points, and there were no significant trends detected.
Similar to our result a study in Malaysia showed the change-point of rainfall and temperature in 1997/98 and 2001/02. The change-point in Malaysia were related to ENSO and La Niña events, or to urbanization (Suhaila and Yusop, 2018). The change-point of rainfall and temperature caused by ENSO was also detected in 2001/02 in India and Nigeria (Dibal et al., 2017; Bisai et al., 2014). Drastic changes in land use-land cover, from forest/grassland to agricultural land, have occurred in the ARB in association with increasing population and may have contributed to the shifts of rainfall and temperature (Getahun and Van Lanen, 2015). The change-point of rainfall and temperature in a given region may also be due to topographical variation, relocation of meteorological stations, and urbanization (Sahin and Cigizoglu, 2010).

4.3 The influence of elevation on the Awash River basin’s rainfall

The elevation of ARB meteorological stations was correlated with their rainfall datasets. The correlations of station elevation to station rainfall for the annual, MRS (JJAS) and mRS (FMAM) were 0.79, 0.81 and 0.52, respectively (Fig.9). The meteorological stations at high elevations showed higher rainfall relative to those at low elevations, and the rainfall variation among meteorological stations was strongly related to the differences in elevation. As a result, it was found that the rainfall magnitude decreased from the upstream to the downstream (lowland) region of the ARB.

To examine the influence of elevation on the change-point, the correlation of annual and seasonal rainfalls to elevation were independently examined for 1986-2001 and 2002-2016. The correlations between annual and JJAS rainfall with elevation before and after the change-point (2002) were almost identical. The correlation of FMAM rainfall with elevation after the change-point in 2002 was much higher than before the change-point (Fig. 9, b). This indicated that the shift of rainfall might also be influenced by topography.

The correlations of temperature with JJAS and FMAM rainfall were -0.26 and -0.45, respectively. The increase in temperature implies that there was a decrease in rainfall in the basin, and thus that local warming could be another cause of the significant decline of rainfall, particularly during FMAM. The contribution of JJAS and FMAM rainfalls to the annual rainfall of the basin were 58% and 42%, respectively.

4.4 The influence of climate variability on ARB’s rainfall

4.4.1 SSTAs association with Awash River basin’s rainfall

The influences of SST indexes such as the ENSO, DMI, AMO, and NTA on the change-point of ARB rainfall were also evaluated. El Niño was classified as a super, major, moderate or minor event if the Nino
3.4 index region SSAs was respectively >2, between 1 and 2, between 0.7 and 1, and between 0.5 and 0.7, respectively. The same scales were applied to La Niña: with super, major, moderate and minor La Niña events corresponding to respective Niño3.4 index region SSAs of >-2, between -1 and -2, between -0.7 and -1, and between -0.5 and -0.7, respectively (Wang et al, 2017; Santoso et al, 2017). Generally, the annual and MRS rainfall were lower than normal during the warming phase of El Niño with a correlation of -0.50 and -0.68, respectively, while an increase in rainfall was observed for the mRS with a correlation of 0.43 (Fig.10, a). This showed that during La Niña the annual and MRS rainfall increases from normal, while the mRS rainfall decrease. In this case, all of the twelve major, moderate and minor La Niña events showed an increase in rainfall during the annual and MRS, but the super La Niña events in 1989, 1995 and 2011 were an exception. However, the influence of La Niña events on the mRS rainfall was highly inconsistent that only five out of 12 La Niña events showed a decrease in the mRS rainfall.

The exceptions in a few of the years, for example the increase of MRS rainfall during the minor El Niño event in 1994, may be due to the cold SST that was present in the eastern equatorial Atlantic at this time, which enhanced the northward movement of the ITCZ and monsoon troughs (Korecha and Barnston, 2007). During the MRS, most of the negative rainfall anomalies were attributable to El Niño, and the positive rainfall anomalies to La Niña. For the mRS, the opposite was true. However, the rainfall anomalies can vary substantially based on the maturity of El Niño or La Niña events. The positive anomaly of rainfall in the mRS might be partly related to the early-matured, strong El Niño events (Korecha and Barnston, 2007). Korecha and Barnston, (2007) pointed out that ENSO is the most important factor governing the MRS rainfall, and that the rain-bearing mechanisms like ITCZ become weak if the El Niño event begins maturing during the late northern summer, while the contrary could occur in the case of La Niña. Thus, El Niño maturity may account for the fact that we observed that the MRS rainfall was significantly reduced in the super and major El Niño events as compared to moderate and minor events.

During El Niño (warm SSTA), the horizontal wind-fields weaken the entire Indian monsoon system with a weaker tropical easterly jet and weaker East African low-level jet, which leads to the suppression of low-level moisture flux to the ARB. This causes a deficit in rainfall during the MRS (Segele and Lamb, 2005; Gleixner et al., 2016; Degefu et al., 2017). The increase of mRS rainfall with El Niño and the warming phase of the west (tropical) Indian Ocean is associated with an easterly wind anomaly, which results in enhanced moisture flux and produces wet conditions (Degefu et al., 2017; Diro et al., 2008; Marchant et al., 2007). Conversely, the cooling phase is associated with a westerly wind anomaly, which result in suppression of moisture flux and produces dry conditions. This is similar to what Diro et al, (2008) stated, i.e., that in the southwest Indian Ocean a low frequency of tropical cyclones is associated with excess rainfall in the mRS and that the opposite is also true.

In addition to ENSO, the influence of Indian and Atlantic Ocean warming and cooling on the Awash River basin’s rainfall were examined. The correlation of DMI with basin rainfall was negative for the annual and seasonal series, indicating that the warming in the Indian Ocean resulted in a reduction of
rainfall in the ARB. Notable, there was constant warming in the Indian Ocean during 1999-2015, which could have reduced the Awash River basin's rainfall (Fig. 10).

The other large-scale climatic variability considered in this study were the AMO and the NTA from the Atlantic Ocean. The warming of a large part of the North Atlantic Ocean and the cooling of the south is the positive phase of the AMO, and the converse is true for the negative phase of the AMO. In the case of the AMO and the NTA, a one-year lag of correlation results fitted better than a zero-year lag. As a result, the one-year lag of AMO and NTA were correlated with annual and seasonal rainfall of the ARB.

The one-year lag correlations of annual rainfall with NTA and AMO were -0.46 and -0.44, respectively (Fig. 11). The correlation result of AMO to the annual and seasonal rainfall was negative, which implies that a warming (positive) AMO reduces the rainfall in the ARB. Similarly, the warming of the NTA may reduce rainfall in the ARB. However, the association of AMO and NTA warming with reduction of rainfall in the ARB was not true for some years, such as 1996, 1998, 2006, 2010 and 2016. This may be due to the dynamic relationship between large-scale climatic indexes and other drivers of rainfall in the ARB.

4.4.2 The overall influence of SSTAs on the mRS rainfall changing-point

The change-point of rainfall for the entire ARB during the mRS was detected in 1997/98. The number of El Niño or La Niña events before and after 1997/98 was examined, and the number of El Niño events was almost the same, with four events both before and after the change-point. There were four La Niña events before the change-point and eight events after the change-point (Table 4). It is generally considered that La Niña increases the annual and MRS rainfalls, but decreases the mRS rainfall. Therefore, the higher number of La Niña events after the change-point could decrease the mRS rainfall, and partially affect the change-point. A high correlation of mRS rainfall with Nino3.4 was indeed detected after the change-point, which could be another indication of La Niña's influence on the mRS rainfall change-point. The mRS rainfall correlation with Nino3.4 was higher after the change-point, while the Nino3.4 correlation with the MRS was low (Table 4).

Table 4. Rainfall correlation with SST before and after change-point 1997/98 and number of El Niño/ La Niña events
### SST indices

| SST indices | Before the changing point | No. of El Niño/ La Niña | After the changing point | No. of El Niño/ La Niña |
|-------------|----------------------------|------------------------|--------------------------|------------------------|
|             | MRS | mRS | Annual | El Ni | La Ni | MRS | mRS | Annual | El Ni | La Ni |
| Nino3.4     | -0.71 | 0.29 | -0.27  | 4     | 4     | -0.63 | 0.57 | -0.34  | 4     | 8     |
| DMI         | -0.42 | -0.17 | -0.62  | 0.26  | -0.13 | -0.26 |
| AMO         | -0.57 | 0.16  | -0.31  | 0.42  | 0.63  | 0.71  |
| NTA         | -0.35 | 0.38  | -0.24  | 0.24  | 0.70  | -0.32 |

AMO and NTA correlations after the change-point were higher, especially in the mRS, but there was inconsistency for the annual and the MRS rainfall. The AMO correlations with the annual rainfall and MRS rainfall before the change-point were negative, but became positive after the change-point. A significant increasing trend of AMO SST in parallel with the ARB average temperature was observed. The change-point year of AMO SST was the same as the ARB mRS rainfall change-point. Therefore, AMO SST variability could be the main player in the ARB that reduces the mRS rainfall and generates a change-point. Moreover, after the mRS change-point, the temperature in both the AMO SST and ARB were significantly increased. Analogously with ENSO, the mRS rainfall correlation with AMO SST was also increased more after the change-point than before it. Overall, these findings show that the basin rainfall was more highly influenced by SST large-scale climate variability after the change-points than before them.

### 5. Conclusions

Variability, trend and mean shift assessments of long-term temperature and rainfall at local basin scale are important for water resources planning and management. In this study the variability, trend and change-point of temperature and rainfall were analyzed in Awash River basin (ARB) during 1986-2016 using different parametric and non-parametric statistical tests. In view of trend, the basin temperature showed a significant increasing trend on both an annual and seasonal basis. The ARB annual rainfall is insignificantly decreased. The entire ARB rainfall indicated an insignificant increasing trend during the major rainy season (MRS), while the minor rainy season (mRS) rainfall showed a significant decreasing trend. Furthermore, most of the stations that showed a significant decreasing trend in rainfall were from the downstream parts of ARB. The mRS was revealed to have very high rainfall variability, especially in the downstream parts of ARB.

Change-point detection was also undertaken in this study, and in most of the times the annual and the MRS change-point in temperature was detected in 2001, whereas the mRS temperature change-point was found in 1997. There was no change-point found in the annual and MRS rainfalls. However, based on the
BR and SNH tests, the mRS rainfall change-point was detected as having occurred in 1997/98, with an average rainfall of 267.6 mm before and 215.1 mm afterwards with a subsequent average rainfall decrease of 52.5 mm. Like the significant decreasing trend of rainfall, most of the stations that showed a significant change-point in rainfall were from the downstream lowland part of ARB. Similarly, all test types detected the annual and seasonal AMO SST change-point in 1997/98, which is the same year that the ARB rainfall change-point occurred for the mRS.

The correlation of DMI/IOD with rainfall was negative for the annual and seasonal series, implying that the warming phase of DMI leads to a decrease in rainfall in the ARB. Moreover, a major El Niño year (1997) was followed by three La Niña years in 1998, 1999 and 2000 that resulted in four consecutive years of rainfall reduction in the downstream parts of the ARB where the mRS is the main contributor. Therefore, the change-point and decreasing trends in the mRS rainfall since 1997 could be attributed to the La Niña events. Additionally, the correlation of AMO with the mRS rainfall was negative, implying that a positive AMO reduced the mRS rainfall. Similarly, the correlation of NTA with the mRS was negative, implying that warming in the NTA could reduce the mRS rainfall. Overall, the mRS rainfall in the basin tended to decline with the increase in Indian and Atlantic Ocean SST, and there has been a constant SST increase since 2000.

For the most part, the average shift and a significant decreasing trend in rainfall, particularly in the mRS, could be attributed to the steady warming of the Indian and Atlantic Oceans, local warming, and La Niña events. More detailed studies of rainfall variability and climate change assessments would be very helpful, as rainfall variability has been a huge social and economic problem in the ARB. The mRS average rainfall shift, as well as a significant decreasing rainfall trend, could affect pre-agricultural land preparation, agricultural planning, and other related agricultural activities. Therefore, it is highly recommended to develop an early warning system for El Niño/ La Niña events, to develop an appropriate water-management strategic plan, and to provide adaptation options for the local population.

**Abbreviations**

NMA: National Meteorological Agency; BR: Buishand’s range test; SNH: standard normal homogeneity test; VNR: von Neumann ratio tests; MK: Mann-Kendall; NOAA: National Oceanic and Atmospheric Administration; ENSO: El Niño–Southern Oscillation; DMI: Dipole Moment of Indian Ocean; AMO: Atlantic Multi-decadal Oscillation; NTA: North Atlantic Tropical Index; MRS: major rainy season; mRS: minor rainy season; ARB: Awash River Basin; SST: Sea Surface Temperature; CV: coefficients of variation; SSTAs: sea surface temperature anomalies; ITCZ: Intertropical Convergence Zone.

**Declarations**

**Ethics approval and consent to participate**

Not applicable
Consent for publication

Not applicable

Availability of data and materials

The datasets used in the study are available in the National Meteorological Agency (NMA) of Ethiopia repository. Access to NMA data can be allowed based on justifiable request. However, the datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. The sea surface temperature anomalies (SSTAs) data were downloaded from NOAA as described in dataset section of this paper.

Competing interests

The authors have no competing interest to declare.

Funding

This study received no external funding.

Authors' contributions

YS carried out data analysis, data interpretation, and drafted the manuscript. LH advised how to analysis the data, edited the paper and shaped the manuscript. PF revised and edited the manuscript.

Acknowledgments

The authors gratefully appreciate groups producing SST datasets such as Australian Bureau of Meteorology, Japan Agency for Marine-Earth Science and Technology (JAM- STEC), NOAA/NWS/CPC, NOAA/OAR/ESRL PSD and the Ethiopian National Meteorology Agency for providing observed meteorological datasets.

References

1. Abtew, W., Melesse, A. M., Dessalegne, T., 2009. El Niño Niño Southern Oscillation link to the Blue Nile River Basin hydrology. Process, 23, 3653–3660. https://doi.org/10.1002/hyp.7367

2. Addisu, S., Selassie, Y. G., Fissha, G., Gedif, B., 2015. Time series trend analysis of temperature and rainfall in lake Tana Sub-basin, Ethiopia. Environmental Systems Research, 4(1), 25. https://doi.org/10.1186/s40068-015-0051-0
3. Adeba, D., Kansal, M. L., Sen, S., 2015. Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia. Sustainable Water Resources Management, 1(1), 71–87. https://doi.org/10.1007/s40899-015-0006-7

4. Asfaw, A., Simane, B., Hassen, A., Bantider, A., 2018. Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes, 19, 29–41. https://doi.org/10.1016/J.WACE.2017.12.002

5. Alemayehu, A., Bewket, W., 2017. Local spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia. Geografiska Annaler: Series A, Physical Geography, 99(2), 85–101. https://doi.org/10.1080/04353676.2017.1289460

6. Bekele, D., Alamirew, T., Kebede, A., Zeleke, G., Melese, A. M., 2017. Analysis of rainfall trend and variability for agricultural water management in Awash River Basin, Ethiopia. Journal of Water and Climate Change, 8(1), 127-141. https://doi.org/10.2166/wcc.2016.044

7. Bisai, D., Chatterjee, S., Khan, A., B. N., 2014. Statistical Analysis of Trend and Change-point in Surface Air Temperature Time Series for Midnapore Weather Observatory, West Bengal, India. Journal of Waste Water Treatment Analysis, 05(02). https://doi.org/10.4172/2157-7587.1000169

8. Buishand, T. A., 1982. Some methods for testing the homogeneity of rainfall records. Journal of Hydrology, 58(1-2), 11-27. https://doi.org/10.1016/0022-1694(82)90066-X

9. Borgomeo, E., Vadheim, B., Woldeyes, F. B., Alamirew, T., Tamru, S., Charles, K. J., Walker, O., 2018. The Distributional and Multi-Sectoral Impacts of Rainfall Shocks: Evidence From Computable General Equilibrium Modelling for the Awash Basin, Ethiopia. Ecological Economics, 146, 621–632. https://doi.org/10.1016/J.ECOLECON.2017.11.038

10. Croitoru, A.E., Holobaca, I.H., Lazar, C., Moldovan, F., Imbroane, A., 2012. Air temperature trend and the impact on winter wheat phenology in Romania. Climatic Change, 111(2), 393–410. https://doi.org/10.1007/s10584-011-0133-6

11. Degefu, M. A., Rowell, D. P., Bewket, W., 2017. Teleconnections between Ethiopian rainfall variability and global SSTs: observations and methods for model evaluation. Meteorology and Atmospheric Physics, 129(2), 173–186. https://doi.org/10.1007/s00703-016-0466-9

12. Dibal, N.P, Mustapha, M., A. T., Yahaya, A. M., 2017. Statistical Change-point Analysis in Air Temperature and Rainfall Time Series for Cocoa Research Institute of Nigeria, Ibadan, Oyo State, Nigeria. International Journal of Applied Mathematics and Theoretical Physics, 3(4), 92. https://doi.org/10.11648/j.ijamtp.20170304.13

13. Diro, G. T., Black, E., Grimes, D. I. F., 2008. Seasonal forecasting of Ethiopian spring rains. Meteorological Applications, 15(1), 73–83. https://doi.org/10.1002/met.63

14. Dost, R., Obando, E. B., Hoogeveen, W., 2013. Water Accounting Plus (WA+) in the Awash River Basin Coping with Water Scarcity-Developing National Water Audits Africa Client: FAO, Land and Water Division. http://www.wateraccounting.org/files/projects/awash_basin.pdf. (Accessed July 14, 2019)

15. Elsanabary, M. H., Gan, T. Y., 2015. Evaluation of climate anomalies impacts on the Upper Blue Nile Basin in Ethiopia using a distributed and a lumped hydrologic model. Journal of Hydrology, 530, 225-
240. https://doi.org/10.1016/J.JHYDROL.2015.09.052

16. Endalew, G. J., 2007. Scientific report; Changes in the frequency and intensity of extremes over Northeast Africa. http://bibliotheek.knmi.nl/knmi/pubWR/WR2007-02.pdf. (Accessed June 14, 2019)

17. Fekadu, K., 2015. Ethiopian Seasonal Rainfall Variability and Prediction Using Canonical Correlation Analysis (CCA). Earth Sciences, 4(3), 112. https://doi.org/10.11648/j.earth.20150403.14

18. Gedefaw, M., Wang, H., Yan, D., Song, X., Yan, D., Dong, G. Qin, T., 2018. Trend Analysis of Climatic and Hydrological Variables in the Awash River Basin, Ethiopia. Water, 10(11), 1554. https://doi.org/10.3390/w10111554

19. Getahun, Y. S., HAJ, V. L., 2015. Assessing the Impacts of Land Use-Cover Change on Hydrology of Melka Kuntrie Subbasin in Ethiopia, Using a Conceptual Hydrological Model. Hydrol Current Res 2015, Vol 6(3): 210. https://doi.org/10.4172/2157-7587.1000210

20. Goovaerts, P., 2010. Combining Areal and Point Data in Geostatistical Interpolation: Applications to Soil Science and Medical Geography. Math Geosci 42, 535–554. https://doi.org/10.1007/s11004-010-9286-5

21. Gleixner, S., Keenlyside, N., Viste, E., Korecha, D., 2016. The El Niño effect on Ethiopian summer rainfall. Climate Dynamics, 49(5–6), 1865–1883. https://doi.org/10.1007/s00382-016-3421-z

22. Hailu, R., Tolossa, D., Alemu, G., 2017. Water security: stakeholders’ arena in the Awash River Basin of Ethiopia. Sustainable Water Resources Management, 1–19. https://doi.org/10.1007/s40899-017-0208-2

23. Hayelom, B., Chen, Y., Marsie, Z., Negash, M., 2017. Temperature and Precipitation Trend Analysis over the Last 30 Years in Southern Tigray Regional State, Ethiopia. https://doi.org/10.20944/PREPRINTS201702.0014.V1. (Accessed April 25, 2020)

24. Hong, C.C., Li, T., Ho, T., Kug, J.C., 2008. Asymmetry of the Indian Ocean Dipole. Part I: Observational Analysis. Journal of climate 21, no. 18 (2008): 4834-4848. https://doi.org/10.1175/2008JCLI2222.1

25. IPCC., 2014. synthesis report summary for policy makers. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). IPCC, Geneva, Switzerland, 151 pp. https://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf. (Accessed August 11, 2019)

26. Jain, S. K., Kumar, V., Saharia, M., 2013. Analysis of rainfall and temperature trends in northeast India. International Journal of Climatology, 33(4), 968–978. https://doi.org/10.1002/joc.3483

27. Jaiswal, R. K., Lohani, A. K., Tiwari, H. L., 2015. Statistical Analysis for Change Detection and Trend Assessment in Climatological Parameters. Environmental Processes, 2(4), 729–749. https://doi.org/10.1007/s40710-015-0105-3

28. Javari, M., 2016. Trend and Homogeneity Analysis of Precipitation in Iran. Climate, 4(3), 44. https://doi.org/10.3390/cli4030044

29. Kendall, M., 1975. Rank correlation methods. London: Charles Griffin. http://www.worldcat.org/title/rank-correlation-methods/oclc/489980698. (Accessed May 11, 2019)
30. Korecha, D., Barnston, A. G., 2007. Predictability of June–September Rainfall in Ethiopia. Monthly Weather Review, 135(2), 628–650. [https://doi.org/10.1175/MWR3304.1]

31. Marchant, R., Mumbi, C., Behera, S., Yamagata, T., 2007. The Indian Ocean dipole? the unsung driver of climatic variability in East Africa. African Journal of Ecology, 45(1), 4–16. [https://doi.org/10.1111/j.1365-2028.2006.00707.x]

32. Marullo, S., Artale, V., Santoleri, R., 2011. The SST Multidecadal Variability in the Atlantic-Mediterranean Region and Its Relation to AMO. Journal of Climate, 24(16), 4385-4401. [https://doi.org/10.1175/2011JCLI3884.1]

33. Mengistu, D., Bewket, W., Lal, R., 2014. Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. International Journal of Climatology, 34(7), 2278–2292. [https://doi.org/10.1002/joc.3837]

34. Murendo, C., Keil, A., Zeller, M., 2010. Drought impacts and related risk management by smallholder farmers in developing countries: evidence from Awash River Basin, Ethiopia. Research in Development Economics and Policy (Discussion Paper Series). [https://ideas.repec.org/p/ags/uhohdp/114750.html]. (Accessed May 14, 2018)

35. Mulugeta, S., Fedler, C., Ayana, M., 2019. Analysis of Long-Term Trends of Annual and Seasonal Rainfall in the Awash River Basin, Ethiopia. Water, 11(7), 1498. [https://doi.org/10.3390/w11071498]

36. Nicholson, S. E., 2011. Dryland Climatology. Arid regions climate. Cambridge: Cambridge University Press. [https://doi.org/10.1017/CBO9780511973840]

37. Park, J.-H., Li, T., 2018. Interdecadal modulation of El Niño–tropical North Atlantic teleconnection by the Atlantic multi-decadal oscillation. Clim. Dyn. 1–16. [https://doi.org/10.1007/s00382-018-4452-4]

38. Ros, F. C., Tosaka, H., Sasaki, K., Sidek, L. M., Basri, H., 2015. Absolute homogeneity test of Kelantan catchment precipitation series. In AIP Conference Proceedings (Vol. 1660, p. 050028). AIP Publishing LLC. [https://doi.org/10.1063/1.4915661]. (Accessed March 24, 2019)

39. Ramli, M. F., Aris, A. Z., Jamil, N. R., Aderemi, A. A. 2019. Evidence of climate variability from rainfall and temperature fluctuations in semi-arid region of the tropics. Atmospheric research, 224, 52-64. [https://doi.org/10.1016/j.atmosres.2019.03.023]

40. Santosso, A., Mcphaden, M.J., Cai, W., 2017. The Defining Characteristics of ENSO Extremes and the Strong 2015/2016 El Niño. Reviews of Geophysics, 55(4), 1079-1129. [https://doi.org/10.1002/2017RG000560]

41. Segele, Z. T., Lamb, P. J., 2005. Characterization and variability of Kiremt rainy season over Ethiopia. Meteorology and Atmospheric Physics, 89(1–4), 153–180. [https://doi.org/10.1007/s00703-005-0127-x]

42. Seleshi, Y., Zanke, U., 2004. Recent changes in rainfall and rainy days in Ethiopia. International Journal of Climatology, 24(8), 973–983. [https://doi.org/10.1002/joc.1052]

43. Sahin, S., Cigizoglu, H. K., 2010. Homogeneity analysis of Turkish meteorological data set. Hydrological Processes, 24(8), 981–992. [https://doi.org/10.1002/hyp.7534]
44. Souverijns, N., Thiery, W., Demuzere, M., Lipzig, N. P. M.Van., 2016. Drivers of future changes in East African precipitation. Environmental Research Letters, 11(11), 114011. https://doi.org/10.1088/1748-9326/11/11/114011

45. Suhaila, J., Yusop, Z., 2018. Trend analysis and change-point detection of annual and seasonal temperature series in Peninsular Malaysia. Meteorology and Atmospheric Physics, 130(5), 565-581. https://doi.org/10.1007/s00703-017-0537-6

46. Shawul, A., Chakma, S., 2020. Trend of extreme precipitation indices and analysis of long-term climate variability in the Upper Awash basin, Ethiopia. Theoretical and Applied Climatology, 140(1-2), 635-652. https://doi.org/10.1007/s00704-020-03112-8

47. Tadese, M. T., Kumar, L., Koech, R., Zemadim, B. 2019. Hydro-Climatic Variability: A Characterisation and Trend Study of the Awash River Basin, Ethiopia. Hydrology, 6(2), 35. https://doi.org/10.3390/hydrology6020035

48. Tamiru, S., Tesfaye, K., Mamo, G., 2015. Analysis of Rainfall and Temperature Variability to Guide Sorghum (Sorghum Bicolor) Production in Miesso Areas, Eastern Ethiopia. International Journal of Sustainable Agricultural Research, 2(1), 1–11. https://doi.org/10.18488/journal.70/2015.2.1/70.1.1.11

49. Trenberth, K.E., Shea, D.J., 2006. Atlantic hurricanes and natural variability in 2005. Geophys. Res. Lett. 33, L12704. https://doi.org/10.1029/2006GL026894

50. Tilahun, H.; Erkossa, Teklu; Michael, M.; Hagos, Fitsum; Awulachew, S. B., 2011. Comparative Performance of Irrigated and Rainfed Agriculture in Ethiopia. World Applied Sciences Journal. https://cgspace.cgiar.org/handle/10568/41794

51. Viste, E., 2012. Moisture Transport and Precipitation in Ethiopia. https://folk.uib.no/evi003/Publications/Viste_PhDthesis2012.pdf. (Accessed April 18, 2019)

52. Wang, B., Li, J., He, Q., 2017. Variable and robust East Asian monsoon rainfall response to El Niño over the past 60 years (1957–2016). Adv. Atmos. Sci. 34, 1235-1248. https://doi.org/10.1007/s00376-017-7016-3

53. Whitley, E., Ball, J., 2002. Statistics review 6: Nonparametric methods. Critical Care, 6(6), 509. https://doi.org/10.1186/cc1820. (Accessed May 10, 2020)

54. Zarenistanak , M., Dhorde, A.G., Kripalani, R. H., 2014. Trend analysis and change-point detection of annual and seasonal precipitation and temperature series over southwest Iran. Journal of Earth System Science, 123(2), 281-295. https://doi.org/10.1007/s12040-013-0395-7

55. Zaroug, M. A. H., Giorgi, F., Coppola, E., Abdo, G. M., Eltahir, E. A. B., 2014. Simulating the connections of ENSO and the rainfall regime of East Africa and the upper Blue Nile region using a climate model of the Tropics. Hydrology and Earth System Sciences, 18(11), 4311–4323. https://doi.org/10.5194/hess-18-4311-2014

Figures
Figure 1

Map of the study area: a) Africa, Ethiopia (Awash river basin), b) meteorological stations used for this study, DEM, Lakes and major rivers of Awash River basin. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Spatial average annual and seasonal rainfall distribution of Awash river basin from (1986-2016): a) annual rainfall, b) average monthly rainfall, c) major rainy season rainfall, d) minor rainy season rainfall. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 3

Station-wise annual and seasonal trends of rainfall in Awash river basin from (1986-2016): a) annual, b) major rainy season, c) minor rainy season. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 4

Spatial variability of annual and seasonal rainfall in Awash river basin from (1986-2016): a) annual, b) major rainy season c) minor rainy season. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 5

Awash River basin average rainfall and temperature change-point using BR, SNH and Pettit’s tests, T1 is the average temperature or rainfall value before the changing point and T2 is average value after the changing point: a) annual temperature, b) MRS temperature, c) mRS temperature, and d) mRS rainfall.
Figure 6

Station based average temperature change-point using (BR, SNH and Pettit) tests and the temperature shift plot before and after the change-point: a) annual, b) major rainy season.
Figure 7

Station based average temperature change-point using (BR, SNH and Pettit) tests and the temperature shift plot before and after the change-point in minor rainy season.
Figure 8

Station based average rainfall change-point using (BR, SNH and Pettit) tests and the rainfall shift plot before and after the change in point: a) annual, b) major rainy season, c) minor rainy season.
Figure 9

Awash river basin average rainfall with elevation: a) annual and seasonal rainfall correlation with elevation (1986-2016), b) annual and seasonal rainfall correlation with elevation before and after the changing point.
Figure 10

Basin average normalized annual and seasonal rainfall with SSTA: a) basin average rainfall correlation with Nino3.4; b) basin average rainfall correlation with DMI.