Research Article

Trends in climatic and hydrological parameters in the Ajora-Woybo watershed, Omo-Gibe River basin, Ethiopia

Meseret Bekele Toma[1] · Mulugeta Dadi Belete[1] · Mihret Dananto Ulsido[1]

© The Author(s) 2022   OPEN

Abstract

Abstract The identification of hydro-meteorological trends is essential for analyzing climate change and river discharge at the watershed level. The Ajora-Woybo watershed in Ethiopia was studied for long-term trends in rainfall, temperature, and discharge at the annual, monthly, and seasonal time scales. The rainfall and temperature data extend 1990 to 2020, whereas the discharge data span from1990 to 2015. The Pettitt and Standard Normal Homogeneity Test (SNHT) tests were used to determine homogeneity. The Mann–Kendall and Sen's slope tests, as well as numerous variability measures, were then employed for trend analysis. The degree of relationship between climate variables and river discharge was determined using Pearson correlation coefficients (r). Inhomogeneity was discovered in annual rainfall data from the Angacha and Areka stations. Rainfall and discharge showed insignificant trends over time, with increasing and decreasing variability across stations. Monthly rainfall decreasing trends were observed to be significantly falling in February and March. Rainfall and runoff increase just insignificantly during the Kiremt season. On the other hand, minimum, maximum, and mean annual temperatures showed significant trends with annual increases of 0.01 °C, 0.04 °C, and 0.025 °C, respectively. In this study, the relationships between discharge and temperature and rainfall were found to be moderate and minimal, respectively. Generally, the results of the long-term examination of the hydrological and climate parameters in the watershed show that water resources vary throughout and over time. As a result, designing strategies require due attention.

Article highlights

- Hydrological and meteorological parameters are essential for analyzing trends in water resource and climate change at the watershed level.
- Mann-Kendall and Sen's slope tests, along with a number of variability measures, were utilized in conjunction with the time series analysis approach for trend analysis.
- The analysis of the rainfall, temperature, and discharge in the watershed's data generally demonstrates how the availability of water resource varies over time. Designing suitable plans for water resource management and sustainable development in the watershed is therefore essential.

Keywords Trend detection · Mann–Kendall · Sen's slope · Correlation · Ajora-Woybo watershed

---

✉ Meseret Bekele Toma, meseretbekelet@gmail.com | [1]Faculty of Biosystems and Water Resources Engineering, Institute of Technology, Hawassa University, Hawassa, Ethiopia.

1 Introduction

The global hydrological cycle is currently responding to the effects of global warming, which include increased atmospheric water vapor concentration and shifting precipitation patterns [1]. Hydro-meteorological characteristics have considerably improved the most common forms of natural disasters in Sub-Saharan Africa, particularly in drought and humidity [2, 3]. Climate change's impact on river basins is a serious problem for Ethiopia in terms of the sustainability of water supplies and agricultural productivity [4]. The country is also sensitive to climate variability, which increases the frequency and magnitude of disasters at the local and national levels [5]. These negative effects of climate change could compound the country's existing social and economic difficulties, especially if people rely on climate-sensitive resources such as rainwater agriculture [6]. As a result, understanding climate variability and change, as well as their relationship to local water resources, is critical for economic growth and the creation of adaptation strategies [7].

Surface water resources are impacted by climate change due to changes in spatial–temporal distribution and magnitude [4], which will therefore affect the water balance in the area and the ecological environment [4, 8]. Climate can fluctuate cyclically, monthly, seasonally, annually, and over decades, due to time-based variance (upward or downward trend) [9]. Concerns about the impact of climate change on the behavior of hydrological variables have prompted substantial research into climate and hydrological variable trends [10–12]. Furthermore, water management project design is dependent on observable meteorological and hydrological data [13]. This is because river basin integrated water resource management is critical to society's economic well-being and good ecological functioning, and robust analytical methodologies are also necessary to evaluate watershed hydrological behavior [14, 15]. The varied terrain of Ethiopia, seasonal fluctuations in the Intertropical Convergence Zone (ITCZ), and accompanying hydrological circulation all have a significant impact on the country's climatic system [2, 16]. This demonstrates that the country has a spatially diversified climate system, ranging from semi-arid (locally known as Bereha) in the lowlands to cool climate (Wurch) in mountainous regions with altitudes above 3350 masl. In this regard, three agro-ecologies are identified within the scope of this study: hot climate (kolla) in the lowlands, Midland (woinadega) at 2040 m above sea level in the middle portion of the watershed, and cold temperate climate (dega) in the watershed's highlands [17, 18].

Because the hydrological cycle is so closely linked to atmospheric precipitation and temperature, changes in those variables usually result in changes in the hydrological cycle [19]. Furthermore, the seasonality of river flow varies greatly from river to river and is mostly controlled by the local seasonal cycle of precipitation, evaporation demand, and water travel periods from runoff source [20]. As a result, climate change influences all of the processes involved in the water cycle and is one of the primary causes of hydrological changes [21]. Climate change and water resource management have sparked global, regional, and local interest [22]. Many research on the relationship between climate change and water resources have been conducted throughout the world, including Ethiopia. Climate variability and climate change in Ethiopia are mostly represented by variability, i.e. a drop in precipitation and a propensity to increase in temperature example. In addition, precipitation and temperature patterns vary greatly by region. Every ten years, the average annual minimum and maximum temperature rise by around 0.25 °C and 0.10 °C, respectively. Mengistu et al. [23] investigated the geographical and temporal variability, as well as changes in rainfall and maximum and minimum temperatures at seasonal and yearly time scales, in the Upper Blue Nile river basin, Ethiopia, from 1980 to 2011. They discovered that the minimum temperature increased significantly in the basin's northern, central, southern, and southeastern regions during all seasons. On an annual scale, maximum and minimum temperatures climbed dramatically throughout more than one-third of the basin; nevertheless, on an annual and seasonal timeline, the western section of the basin witnessed falling trends. They also found statistically insignificant increases in annual rainfall. Recently, [24], demonstrated annual precipitation variability in the Woleka sub-basin in northern Ethiopia. They discovered intra and inter-annual fluctuation in the basin's climatic parameters. Belihu et al. [25], indicated the annual rainfall pattern showed a considerable decline of around 12 mm each year upstream, which is mostly influenced by the significant decrease in rainfall during the high season. Temperature analyses also found that the catchment, particularly upstream, was warming. The minimum temperature trend indicated a considerable increase of approximately 0.08 °C every year. The stream flow generally shows a downhill trend. Reduced annual and seasonal rainfall, combined with rising temperatures, because increased evaporation and have a direct detrimental impact on stream flow [26]. Discovered that rainfall showed statistically declining tendencies on an annual time scale in the upper reaches of the Omo-Gibe River basin, but seasonal rainfall showed diverse findings in both directions. At the majority of locations, air temperature increased in a statistically significant way. The overall trend of river flow was downward. Woldesenbet

et al. [27] demonstrated that runoff has grown significantly at both the annual and seasonal scales at most monitoring stations in the upper Blue Nile basin. Stream flow trends in the region have increased dramatically on both an annual and seasonal basis at the majority of the gauging stations.

The Omo-Gibe basin is one of Ethiopia's most important surface water resources [28]. However, due to changing climatic circumstances and competition in resource demand from the downstream hydroelectric plant, irrigation, and the investment group, the basin's water resources are in high demand. The region's climatic characteristics cause great variability in the temporal and spatial distribution of precipitation over the basin, resulting in a correspondingly high variability in runoff rate. As a result, there is a need to measure and assess past climate change and its relationship with the basin's water resources in general, and the Ajora-Woybo watershed in particular. As a result, analyzing precipitation, temperature, and hydrological behavior is critical for planning and forecasting future climate conditions [29], despite the fact that this analysis only evaluates observable and historical climate conditions over the last three decades. Long-term studies on changes in climatic and hydrological variables in such watersheds can thus aid in our understanding of the watershed's response to climatic change. As a result, more research at the local level is required to assess the nature of the trend and its level of relevance. Consequently, the goal of this article was to look at the trends and changes in climatic and hydrological parameters in the Ajora-Woybo watershed from 1990 to 2020. The objectives of the present study was to examine temporal variations and trends in rainfall, temperature and discharge variables. Policymakers, investors, planners, and even communities (other end-users) require the findings of this study in order to prepare for the predicted trend and change in the area's climate and hydrology. This research will also aid in the development of watershed and water resource-based climate change solutions.

The rest of this study is organized below. In Sect. 2, materials as well as methodologies are presented. In Sect. 3, the results and discussion of the study are presented. In Sect. 4, the conclusions of this study are drawn.

2 Materials and methods

2.1 Description of the study area

The Omo-Gibe River basin covers 79,000 km^2, with a length of 550 km and an average width of 140 km, and includes areas of two national regional states, the Southern Nation Nationalities and Peoples Region (SNNPR) and the Oromia Region. The river basin's entire annual discharge is estimated to be around 16.6 billion cubic meters on average (BMC) [28]. The basin, accounting for 14% of the Ethiopias's yearly runoff. The Walga, Wabe, Derghe and Gilgel-Gibe and Gojeb Rivers in the northeast and the Gilgel-Gibe and Gojeb Rivers in the south-west are the Basin's primary tributaries. The main tributaries from the eastern side of the middle and lower Omo-Gibe watershed are the Ajancho, Soke, Shapa, Woybo, Sana, and Deme Rivers. The basin is a closed river basin with its southern boundary formed by Lake Turkana in Kenya.

The Ajora-Woybo watershed, located on the eastern side of the middle Omo-Gibe River basin, is one of the major watersheds in the Omo-Gibe Basin. It was selected as the case study for this research. The study regions, the Ajora-Woybo watershed, contains four perennial rivers (Ajancho, Soke, Shapa and Woybo Rivers) that are flowing downstream to the lower valley eventually forms two rivers i.e. Ajora and Woybo (from which the name of watershed is given) finally joining into Gibe III dam reservoir (Fig. 1). In addition, many small intermittent tributaries drain into the rivers. The watershed covers an area of some 1723.7 km^2 with a perimeter of 336.8 km. The watershed lies between 7°2'0"N and 7°50'0"N latitude and 37°30'0"E and 38°0'0"E longitude. The enormous irrigation dam project, which includes the proposed dam currently under construction in the watershed, is intended to result in 10,000 hectares of cultivated land, with the Ajancho and Woybo Rivers serving as the primary water sources.

The topography of the watershed, which includes the Omo, Ajancho-Soke, and Gilgel-Gibe Rivers, is exceedingly diversified, with mountainous to hilly terrain cut by sharply incised gorges. The lowest and highest of the watershed lies at an altitude greater than 731 masl and 3036 masl maximum elevation respectively. A gauging site is located at each part of the rivers (i.e. for Ajancho, Soke, Shapa and Woybo) with in the watershed. The climate of the Ajora-Woybo watershed varies in its nature from a hot arid climate in the southern part of the floodplain to a tropical humid one in the highlands that include the extreme north and northeastern part of the watershed. Between these extremes, and for most of the watershed, the climate is tropical sub humid. Each zone has its own weather patterns and agricultural production methods. The annual rainfall varies greatly from the north to the south, ranging from around 1900 mm in the north to less than 300 mm in the south. Furthermore, the rainfall regime in the watershed is bimodal. The mean annual temperature in the watershed varies from 16 °C in the highlands of the north to over 29 °C in the lowlands of the south [18].
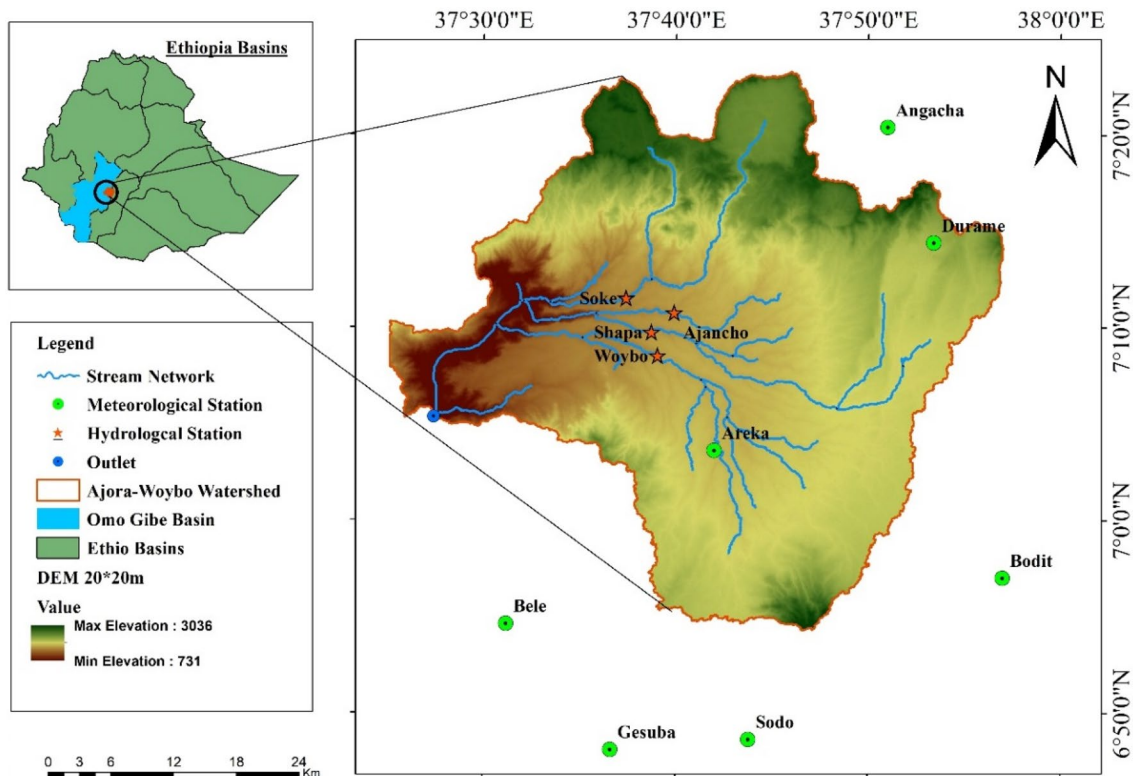
Fig. 1 Location map of the study area

2.2 Data

2.2.1 Data pre-processing

The daily meteorological (rainfall and temperature) data from 1990 to 2020 and the hydrological data from 1990 to 2015 are collected from the National Meteorological Agency (NMA) and the Ministry of Water and Energy (MWE) office of Ethiopia (Table 1).

2.3 Methods

2.3.1 Filling of the missed data using multiple imputations (MI)

Multiple imputations are a filling method that provides valid statistical inferences under missing at random condition. The MD (missing data elimination techniques) rates using standard regression procedures and then combine the results of these analyses to obtain the final result, as shown in Eq. (1) [30, 31]. MI using chained equations produces m imputations based on sequential imputation regression models of each variable conditioned by

Table 1 General characteristics of meteorological stations

No	Stations	Latitude	Longitude	Elevation (m)	RF	Temp	Missing (%)
1	Angacha	7.34	37.85	2317	A	A	2.56
2	Areka	7.06	37.70	1752	A	NA	3.74
3	Bele	6.91	37.52	1240	A	NA	1.29
4	Bodit	6.95	37.95	2043	A	A	0.2
5	Durame	7.24	37.89	2116	A	A	2.4
6	Gesuba	6.66	37.63	1650	A	A	1.2
7	Sodo	6.81	37.73	1854	A	A	0.1

A = available NA = not available

all other variables [30, 32]. The multiple imputations have been implemented in software such as XLSTAT [32]. MI is a widely used method in hydrology and its advantages were does not overestimate error, simulate missing data multiple times [30, 32] and leads to best estimation of missing values [33]. To apply this method, we can proceed as follows: (i) Find k similar databases for each missing value; then the observed values are used to impute MD. (ii) For each MD (Px), we use data imputations Pi by applying single variable regression methods to obtain k different estimate results Ii (Px, Pi). (iii) The result Px will be obtained by combining all imputations results Ii using the average of all the k complete data values, that is:

$$P_x = \frac{\sum_{i=1}^{k} I_i\left(P_x, P_i\right)}{K} \tag{1}$$

where, k observed values of the respective variable.

2.3.2 Homogeneity test using Pettitt test and standard normal homogeneity test (SNHT)

2.3.2.1 Pettitt test
To investigate the existence of the change points or break-point detection in the rainfall and temperature characteristics in time series data different methods can be applied. The Pettittt test was used to identify whether or not there is a point change or jump in the data series [34, 35]. It is based on the Mann–Whitney two-sample test, which allows the detection of a single shift at an unknown time and independent of the distribution of data [34]. In addition, many researchers also applied Pettitt test in climatic and hydrological time series (e.g. [24–26, 34]).

It considers a sequence of random variables $x_1, x_2, \ldots, x_T$, with a change point at τ (x_t for t = 1,2,…, τ), and a common distribution function F1(x) and x_t for t = τ + 1, … T has a common distribution function and F2(x), and F1(x) ≠ F2(x). The null hypothesis H0: no change or $\tau = T$ is tested against the alternative hypothesis Ha: change or $1 \leq \tau \leq T$ using the non-parametric statistic KT = Max|Ut, T|, $1 \leq \tau \leq T$. To achieve the identification of change point, a statistical index $U_{t,T}$ is defined as follows

$$U_{t,T} = \sum_{t-1} \sum_{j=t-1} D_{ij} \tag{2}$$

$$\text{Sgn}\left(x_i - x_j\right) = \begin{cases} 1 & \text{if } x_i - x_j > 0 \\ 0 & \text{if } x_i - x_j = 0 \\ -1 & \text{if } x_i - x_j < 0 \end{cases} \tag{3}$$

$D_{ij} = sgn\left(x_i - x_j\right)$, the $sgn\left(x_i - x_j\right)$ computed using equation 3, (4)

Then, the approximate significance probability, p (t), of a change point is calculated from an Eq. 3 and the time series changing points of the rainfall and river discharge was checked.

$$P \cong 2*\exp\left[\frac{-6K_T 2}{T^3 + T^2}\right] \tag{5}$$

2.3.2.2 Standard normal homogeneity test (SNHT)
The SNHT was developed by [36] to detect a change in a set of precipitation data. The test is applied to a set of ratios comparing observations from one monitoring station to the average of several stations. The ratios are then standardized. Here, the series of Xi corresponds to the standardized ratios. The null and alternative hypotheses are determined as follows:

Ho: The T variables Xi follow an N (0, 1) distribution.

Ha: Between times 1 and v, the variables follow an N (μ_1, 1) distribution, and between v + 1 and T, they follow an N(μ_2, 1) distribution. The Alex-Anderson statistic defined by:

$$T_o = \max_{1 \leq t < T}\left[v \, \bar{z}_1^2 + (n-v) \, \bar{z}_2^2\right] \tag{6}$$

$$\text{With } \bar{z}_1 = \frac{1}{v}\sum_{t=1}^{v} x_1 \text{ and } \bar{z}_2 = \frac{1}{n-v}\sum_{t=v+1}^{T} x_i \tag{7}$$

The statistic T_o derives from a calculation comparing the likelihood of the two alternative models. The model corresponding to Ha implies that μ_1 and μ_2 are estimated while determining the v parameter maximizing the likelihood.

2.3.3 Testing for serial correlation

The statistical tests presume that the succeeding data in the series are independent in order to identify a trend in a time series. The presence of serial correlation in the data has a significant impact on the strength of trend tests [37]. When there is a trend, a positive serial correlation causes the null hypothesis of no trend to be incorrectly rejected (type I error). Similar to this, when there is a negative serial correlation, the null hypothesis of no trend is accepted, even when it is wrong (type II error) [37, 38]. Lag-1 serial correlation coefficients are computed to examine the data for serial correlation. By determining the lag-1 serial correlation coefficient 1, the time series is examined for serial correlation in a number of trend investigations. The lag-1 serial correlation coefficient (ρ_1) is determined as follows for every time series $X_i = x_1, x_2 \ldots x_n$.

$$\rho_1 = \frac{\frac{1}{n-1} \sum_{i=1}^{n-1} (x_i - E(x_i)) \cdot (x_{i+1} - E(x_i))}{\frac{1}{n} \sum_{i=1}^{n} (x_i - E(x_i))^2} \quad (8)$$

where $E(x_i)$ is the mean of the sample and n is the sample size

$$E(x_i) = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (9)$$

The probability limits for ρ_1 on the correlogram of an independent series is given by Anderson (1941) as

$$\rho_1 = \begin{cases} \frac{-1 + 1.645\sqrt{n-2}}{n-1} & \text{, for the one } - \text{ tailed test} \\ \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} & \text{, for the two } - \text{ tailed test} \end{cases} \quad (10)$$

By contrasting the ρ_1 value with the essential Student's t-distribution values, the significance of serial correlation was assessed.

Each station contains 16 series (12 monthly, one annual and three seasonal series), and a total of 112 time series generated from seven rain gauge locations (7×16) were subjected to serial correlation tests. Two series out of 112 series were determined to be serially associated at a 99% confidence level, according to the study's findings, thus no need of pre-whitening test before applying the MK test.

2.3.4 Mann–Kendall trend detection (MK)

The non-parametric Mann–Kendall [39, 40] statistics was chosen to detect the historical trends for rainfall, temperature and stream flow time series data, as it is widely used for water resource planning and management studies (e.g. [25, 41–44]). It is also used to determine whether a set of data values is increasing or decreasing over time, and whether the trend is statistically significant in either direction. Outliers are well treated by the Seasonal Kendall methods because it uses the rank of the values and the method is usually less affected by the presence of outlier's value and this makes the test not sensitive to outlier's values [25, 44]. The observed rainfall, temperature and the discharge trends were analyzed in time series analysis. This is to discern how the historical rainfall and temperature varied over the time 1990 to 2020 with relation to discharge. The daily rainfall, temperature and the discharge data were first calculated as monthly rainfall and temperature (maximum, minimum, and mean) and discharge. Then monthly values were averaged and summed to obtain the seasonal and annual values. In Ethiopia, seasons are classified on the basis of its rainfall patterns. NMA (National Meteorological Agency) [18] states that there are three main seasons:

Kiremt (the main rainy season from June to September), Belg (a small rainy season from February to May) and Bega (a dry season from October to January). Trend analyses were carried out on monthly, seasonal and annual basis with reference to other researchers (e.g. [25, 26, 32]). Yue and Wang [45] pointed out that the significance of the trend depends on the pre-specified significance level, the size of the trend, the sample size, and the amount of variation within a time series. That is, the larger the absolute size of the trend, the more meaningful the tests; the larger the sample size, the more meaningful the tests become.

The test is based on S statistics and each paired observed values x_j ($j > k$) of the random variable will be inspected to find out whether $x_j > x_k$ or $x_j < x_k$

$$S = \sum_{k-1}^{n-1} \sum_{j=k-1}^{n} \text{sgn}(x_j - x_k) \quad (11)$$

where x_j and x_k are the annual data values in years j and k, $j > k$ respectively and n is number of observation.

$$\text{Sgn}(x_j - x_k) = \begin{cases} 1 \text{ if } x_j - x_k > 0 \\ 0 \text{ if } x_j - x_k = 0 \\ -1 \text{ if } x_j - x_k < 0 \end{cases} \quad (12)$$

S is normally distributed with mean zero, and Variance,

$$\text{var}(S) = \frac{n(n-1)(2n+5)}{18} \quad (13)$$

Computation for Z score is obtained as:

$$z = \begin{cases} \frac{s-1}{\sqrt{v}} \text{ if } s < 0 \\ 0 \text{ if } s = 0 \\ \frac{s+1}{\sqrt{v}} \text{ if } s > 0 \end{cases} \quad (14)$$

For a given level of significance α, if $Z < \frac{Z_\alpha}{2}$ or $Z > \frac{Z_1}{2}$, the null hypothesis that trend is absent can be rejected at α% significance level. Where, var(S) is the variance of Mann–Kendall statistic, S. The standardized MK test statistic (Z-score) follows the standard normal distribution with a mean of zero and a standard deviation of one. A positive value of Z indicates an increasing trend (upward trend) while a negative Z value signifies a decreasing trend (downward trend). When the p-value is less than the level of significance (α), the null hypothesis (Ho) is rejected and a statistically significant trend exists in the rainfall, temperature and river discharge time series. If the p-value is greater than (α), the null hypothesis (H$_o$) is accepted. Failing to reject the null hypothesis does not mean that there is no trend. Rather, it is a statement that the available evidence is not sufficient to conclude that there is a trend.

2.3.5 Sen's slope estimator test

It was used for estimating the magnitude of a trend by putting the linear rate of change and the intercept. The slope estimation is given by

$$\beta = \text{Median}\left[\frac{x_j - x_k}{j - k}\right] \text{ for all } k < j \text{ and } i = 1, 2 \dots N$$

(15)

The median of N values of β_i gives the Sen's slope of β, using following Eq. 16:

$$\beta = \begin{cases} \frac{\beta N+1}{2}, & \text{if } N \text{ is odd} \\ \frac{\frac{\beta N}{2} + \frac{\beta N+2}{2}}{2}, & \text{if } N \text{ is even} \end{cases}$$

(16)

where, xj and xk are the sequential data values, and n is the number of the recorded data. A positive value of β indicates an upward (increasing) trend, and a negative value indicates a downward (decreasing) trend in the time series.

2.3.6 Coefficient of variation

The coefficient of variation measures the overall variability of the rainfall, temperature and river discharge in the area of interest from the mean value. It is calculated as the ratio between the standard deviation and the long-term data mean as expressed in Eq. 17.

$$CV(\%) = \left(\frac{\sigma}{\overline{X}}\right)$$

(17)

where CV is the coefficient of variation, σ is the standard deviation over the period and $\overline{x}$ is the mean hydro-climatic parameters. Generally, CV is used to classify the degree of variability of events into three: low (CV < 20), moderate (20 < CV < 30), and high (CV > 30). Higher CV shows more variation in parameters and vice versa [42, 46].

2.3.7 Correlation analysis between climate and river discharge

Pearson correlation coefficients (r) was calculated for the degree of the linear relation between climate variables (rainfall and temperature) with river discharge. Moreover, the correlation between climate variables and runoff helps us to estimate their relationships. Because it is based on the method of covariance, it is known as the best approach of quantifying the relationship between variables of interest. It indicates the size of the association, or correlation, as well as the direction of the relationship.

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

(18)

where r is the correlation coefficient, n is the length of the time series, and i is the number of years during the analyzed periods 1990–2020. Xi and Yi are the rainfall, temperature and discharge in the year i, respectively, and X and Y are the mean rainfall and, temperature and discharge, respectively during the studied periods. The obtained value was ranked into a weak correlation (0 < |r| ≤ 0.3), a low correlation (0.3 < |r| ≤ 0.5), a moderate correlation (0.5 < |r| ≤ 0.8), and a strong correlation (0.8 < |r| ≤ 1) [43, 46].

All MK trend tests, Sen's slope, Pettitt change-point detections and variability analyses were conducted using the XLSTAT (https://www.xlstat.com) software [24, 34, 47] (Fig. 2).

3 Results and discussions

3.1 Pettitt test and standard normal homogeneity test (SNHT)

Homogeneity tests are used to assess the effects of non-climatic factors such as changes in instrumentation, observing practices, station relocations, and station environments on climate time series data [48]. For this study, two types of homogeneity test (i.e., Pettitt's test and the SNHT test) were performed at 5% level of significance.

The results of the p-values for the Pettitt test are shown in Table 2. Any p-value less than the significance level of $\alpha = 0.05$ indicates inhomogeneity in the corresponding time series. For five stations (Bele, Bodit, Durame, Gesuba and Sodo), the null hypothesis was satisfied for all months. Two stations (Angacha and Areka) were found to be inhomogeneous as the p values were less than 0.05. The p values obtained from SNHT in the Table 2 show null hypothesis of homogeneous data was rejected for p values less than 0.05. Five stations have showed homogeneous data for all months. The data of two stations were inhomogeneous in the months. The change point detection may be related to occurrence of
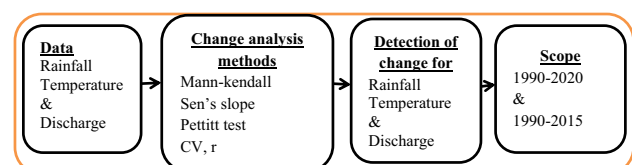

Fig. 2 Flow diagram to analyze changes of rainfall, temperature and discharge

Table 2 The p values obtained from the homogeneity tests for the annual rainfall

Stations	Pettitt test (p–value)	SNHT test (p–value)	alpha (α)
Angacha	**0.024**	**0.013**	0.05
Areka	**0.041**	**0.001**	0.05
Bele	0.53	0.1	0.05
Bodit	0.67	0.89	0.05
Durame	0.1	0.21	0.05
Gesuba	0.49	0.6	0.05
Sodo	0.71	0.79	0.05

El-Niño (2009–2010) and La-Nina (2010–2011) effect in Ethiopia as reported by [49]. Durame station is nearby Angacha but there has not been any significant rainfall-pattern-shift been observed. This could be connected to the highest elevation area experienced the highest annual rainfall values, and the lowest elevation area saw the lowest annual rainfall values. This discovery is confirmed by the findings of [26, 46], who discovered that mean annual rainfall and heights are closely associated in Ethiopia's west Hararge watershed and upper Omo-Gibe basin.

3.2 Detection of change points for annual rainfall

The Pettitt test analysis revealed that the rainfall in the upper and central watershed area shows a break point change with a different time series in Angacha and Areka stations (Fig. 3). The change point analysis in the annual rainfall showed that about 28.5% of the stations is inhomogeneous. The year of 2009 was the year of change and the mean annual rainfall was estimated about 1630 mm before shift and 1300 mm after shift at Angacha station. The year of 2013 was year of change and the mean annual rainfall was estimated to be about 1432 mm before shift and 1776 mm after shift at Areka station. Which clearly indicates inconsistency of rainfall data and this may be related to the topography and the high vegetation coverage of the area. The move of the rain gauge to a new location, significant changes in the station's neighborhood, changes in the ecosystem brought on by natural disasters like forest fires and landslides, and errors in observation starting on a specific date could all be contributing factors to the inconsistent rainfall pattern at the Angacha and Areka stations. Generally, except the northern highlands, where a major shift of rainfall was exhibited, the remaining parts, the central and southern parts revealed that there was no significant shift/change point/ of annual rainfall.

3.3 Detection of change points in stream flow time series

The change point analysis has shown that there is no change point in river discharge of the watershed at four gauging stations (Fig. 4).

3.4 Analysis of rainfall

3.4.1 Annual rainfall

The rainfall analysis from the inside and its nearby meteorological stations of Ajora-Woybo watershed was made based on the availability and reliability of the observed gauge stations. The meteorological stations such as Angacha, Areka, Bele, Bodit, Durame, Gesuba and Sodo stations were selected due to the long time availability of data. Accordingly, Angacha and Durame meteorological stations from the upper, Gesuba and Sodo stations from the lower and the remaining from central part of sub-watershed have recorded reliable rainfall data for the last 31 years (Table 3 and Fig. 5).

The mean annual rainfall of the watershed during the study period was 1271.8 mm with 140.5 mm standard deviation and CV of 11%. The minimum and maximum ever-recorded rainfalls were 318 mm (in 2017 the driest year) in Gesuba station and 2161.8 mm (in 2019-the wettest year) in Bele station per year. Moreover, June to September is the major rainy season (Kiremt), during this period 48–62% of the annual rainfall has received. As indicated below (Fig. 5) in mean annual rainfall trend, the rainfall is generally homogenous and decreasing but it was insignificant rate. This result agreed with the work done by [26] in southern Ethiopia and [24] in north central Ethiopia. Their finding shows that there is a decreasing RF pattern since about 1981. Viste et al. [50] also showed that the decline in precipitation in the southern part of the country is large enough to produce trends on the national level. CV was used to classify the degree of variability of rainfall events. Based on this, the watershed rainfall is variable in the last two decades, particularly in the Angacha, Bele and Gesuba stations while the remaining stations become less variable.

3.4.2 Mann–Kendall test result of annual rainfall

MK test on annual rainfall data of watershed, the results are obtained in the following manner in Table 4. The MK is based on the calculation of Kendall's tau (measures of connection between two successive annual rainfall years). The analysis results shows that five of the stations successive annual rainfall years are negatively related and decreasing trend (i.e. Angacha, Bele, Bodit,
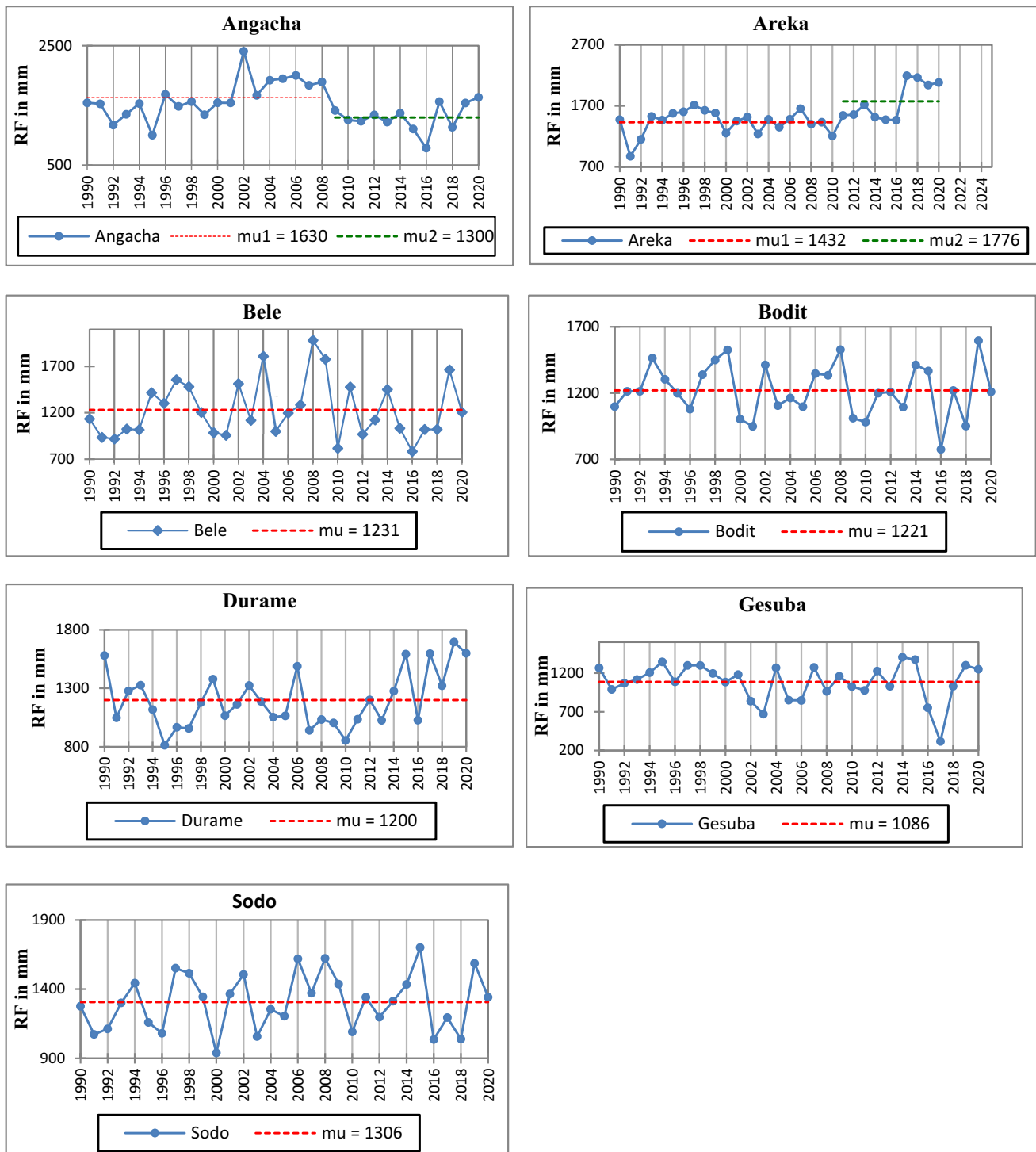
Fig. 3 Homogeneity test of the annual mean rainfall at seven stations, where mu is the annual mean rainfall (mm), mu^1 is the annual mean rainfall (mm) before the change point and mu2 is the annual mean rainfall (mm) after the change point

Durame and Gesuba stations). The remaining two stations show an increasing trend but significant only in Areka (0.032) station. Annually, Z-score result was found to be in upward trend in two stations (Areka and Sodo) whereas the remaining five stations has downward trend (Table 4). This study revealed a combination of upward and downward trends and also [26] reported similar results in upper Omo-Gibe Basin.
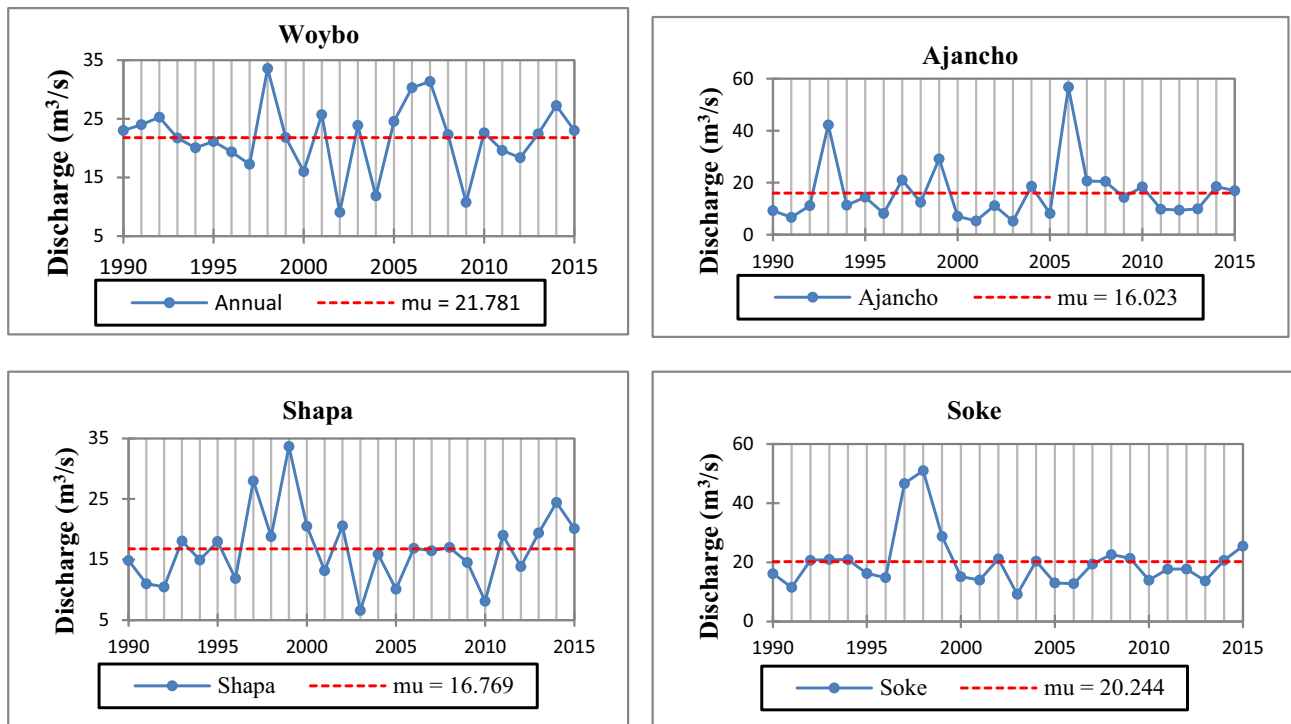
Fig. 4 Homogeneity test of the annual mean discharge at four stations, where mu is the annual mean discharge

Table 3 Mean annual rainfall of the watershed

Stations	Min (mm)	Obs year	Max (mm)	Obs year	Mean	SD	CV (%)
Angacha	786.5	2016	2107.6	2002	1489.4	305.7	20.5
Areka	875.6	1991	1712.5	1997	1399.5	168.8	12.1
Bele	784.3	2016	2161.8	2019	1243.9	343.3	27.6
Bodit	774.3	2016	1527.8	2008	1210.9	185.1	15.3
Durame	812.8	1995	1596.0	2017	1183.5	215.5	18.2
Gesuba	318.0	2017	1404.6	2014	1081.8	232.7	21.5
Sodo	938.2	2000	1700.3	2015	1293.5	195.8	15.1
Mean RF	918.4		1488.5		1271.8	140.5	11.0

Fig. 5 Linear trend of mean annual RF of the watershed
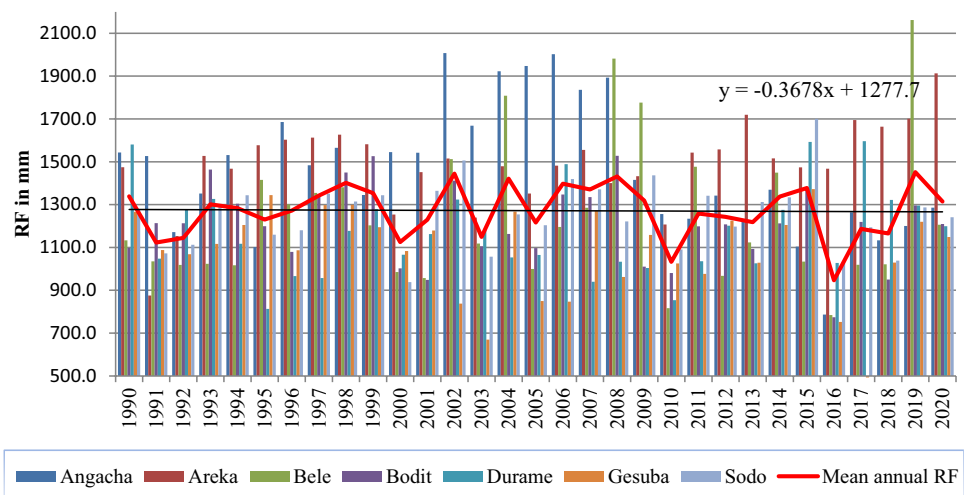
Table 4 MK test result of annual RF

Stations	MK (S)	Kendall tau	P value	Sen's slope	Z–score
Angacha	−43	−0.092	0.48	−6.354	−1.21
Areka	127	0.273	**0.032**	13.9	1.45
Bele	−31	−0.067	0.61	−2.24	−0.24
Bodit	−21	−0.045	0.74	−0.73	−0.50
Durame	−65	−0.14	0.28	−6.42	−0.63
Gesuba	−21	−0.045	0.73	−2.12	−1.31
Sodo	37	0.08	0.54	3.45	0.02

3.4.3 Analysis of monthly and seasonal RF

The monthly RF is highest in August and lowest in December in all of the stations. The rainfall trend was increased from February to April and June to August at all stations but its rate is insignificant. Monthly, the RF trend is significantly decreasing in February and March whereas November, December, January, February, March and April months show decreasing trend however it was insignificant. July, August, September and October months show increasing trend but it was insignificant rate (Fig. 6a).

Seasons are classified based on the rainfall pattern in Ethiopia (Fig. 6b). Seasonally, the precipitation was found to be Z = 2.78 in Kiremt, Z = −1.74 in Belg, Z = −0.26 in Bega (Table 5). All the three seasons show there is no change of rainfall in the watershed at 95% confidence level and increasing for Kiremt and decreasing for Belg and Bega trend in the watershed. The seasonal rainfall trend has varies from Kiremt to Bega season 571.3 mm/season in Angacha station and 270.3 mm/season in Gesuba station. This insignificant rainfall trends may be due to high inter–annual variability [25]. Because rainfall in the studied area is seasonal and primarily falls during the Kiremt and Belg months, such statistical significance have a significant impact on the overall observed annual rainfall. However, if the downward trend in rainfall can last during the dry season months, it could lead to a lengthening of the dry

Table 5 MK test result for monthly and seasonal RF

| Time	Parameters				
	Man–Kendall (S)	Kendall tau	P value	Sen's slope	Z–score
Jan	−9	−0.4	0.24	−1.6	−0.85
Feb	−13	−0.6	**0.05**	−3.4	−0.78
Mar	−21	−1	**0.00**	−5.5	−0.52
Apr	−7	−0.3	0.38	−8.5	−0.11
May	−3	−0.1	0.77	−3.1	−0.05
Jun	−11	−0.5	0.14	−10.6	−0.20
Jul	−9	−0.4	0.24	−8.4	−0.03
Aug	9	0.4	0.24	11.3	0.01
Sep	13	0.6	0.07	16.5	0.19
Oct	1.0	0.05	1.0	0.6	0.47
Nov	−3	−0.1	0.7	−2.4	−0.73
Dec	11	0.5	0.14	0.9	0.87
Kiremt	11	0.5	0.14	43.3	2.78
Belg	−13	−0.6	0.06	−22	−1.74
Bega	−3	−0.1	0.77	−3.3	−0.26

season and a decrease in soil moisture at that time. In addition, the variation of monthly and seasonal RF and declining trend of moisture in time may have a significant impact on different rain–fed agricultural activities. A drought in the agricultural sector can also result from a drop in rainfall during the dry season, which will reduce crop production. As a result, it is crucial to keep an eye on these falling patterns since they may have both direct and indirect effects on the watershed's overall water budget.

3.5 Analysis of temperature

3.5.1 Annual temperature

The annual temperature of the maximum (Tmax), minimum (Tmin) and mean (Tmean) along with their standard

Fig. 6 **a** Monthly mean of each stations and **b** Seasonal mean RF trend of the watershed
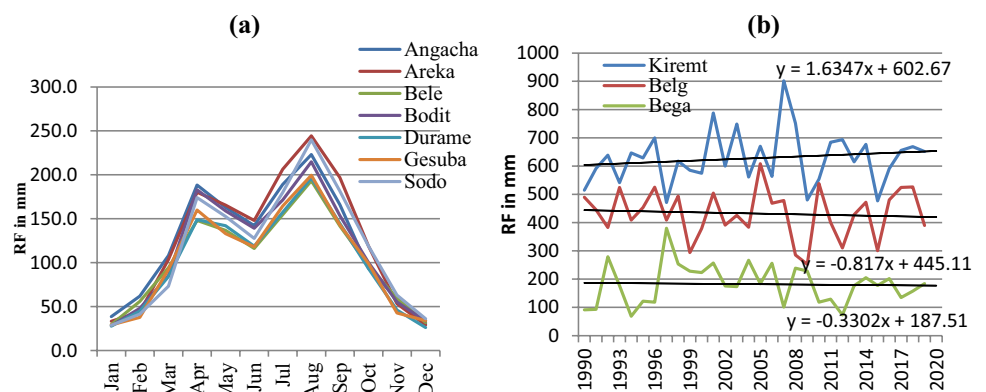
deviation (SD) and coefficient of variation (CV) have been statistically computed for each stations (Fig. 7). The temperature variability between the different years and the average annual temperature is 20.1 °C, while the annual mean maximum temperature reached 25.7 °C and the annual mean minimum temperature was 14 °C. The maximum temperature trend was significantly increasing at all station except at Angacha station. The minimum temperature trend was significantly increasing at all station except at Gesuba station. The mean temperature trend was significantly increasing at all station except at Angacha and Gesuba station.

The Mann–Kendall test statistics of the Tmax, Tmin, and Tmean are shown in Table 6. Analysis of temperature using the MK test shows that the climate in the watershed has generally warmed over the past three decades. Based on the trend of minimum and maximum temperatures, the magnitude of change was found to be about 0.01 °C/year to 0.04 °C/year and the mean values also proved that the watershed has warmed by about 0.025 °C/year. In addition, the minimum temperature analysis in southern part of the watershed (Gesuba station) has showed an

Fig. 7 Annual max, min and mean temperature trend of the watershed

increasing trend particularly in extremes. The reason for Gesuba station displaying a rising tendency in extremes when compared to the other stations could be attributed to the area's low elevation of 1650 m. This finding is consistent with [25], who found that Ethiopia's climate shifts from its hot and dry lowlands to its cool plateau mostly as a function of elevation. Similar results were also reported by [18] that revealed the mean minimum temperature has been increasing throughout the country even in the cool months by 0.37 °C per decade even though our finding less than the country report. The increasing trend of temperature in the area has significant impact on agricultural activities particularly in soil water demand and it has also led to the loss of more water from the watershed due to evapotranspiration. CV of Tmin highly observed in Bodit station (7.5%) among others.

3.5.2 Monthly and seasonal temperature

From the basic temperature data, the monthly and seasonal, of the maximum, minimum and mean temperatures along with their trend have been statistically computed for each month and for the three seasons: Kiremt, Belg and Bega (Table 7 and Fig. 8).

The monthly maximum temperature trend was increasing at all stations but with insignificant change. In addition, the minimum temperature trend showed increasing trend in most stations but decreasing trend throughout at Bodit station. The maximum monthly temperature is highest in March 31.2 °C at Gesuba station and lowest in July 21.2 °C at Bodit station. On the average, August is the coldest month of the year and March is the warmest (only slightly warmer than February). The lowest mean monthly temperature occurred in July (19.28 °C) and the warmest
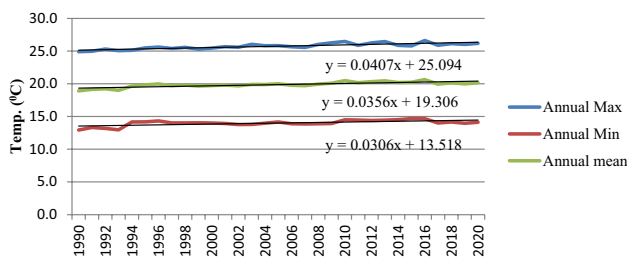
Table 6 Annual temperature characteristics in Ajora–Woybo watershed

Stations	Parameters	Min	Max	Mean	SD	CV	P value	slope
Angacha	Tmax	23	25.7	24.1	0.78	3.2	0.07	−0.032
	Tmin	12.12	15.98	13.7	0.98	7.2	0.001	0.072
	Tmean	18.1	20.8	18.9	0.8	4.2	0.12	−0.043
Bodit	Tmax	23	25.9	24.67	0.64	2.6	0.08	0.037
	Tmin	6.8	14.26	12.76	2	7.5	0.001	0.052
	Tmean	15.2	19.9	18.7	1.2	6.4	0.00	0.042
Durame	Tmax	23	27.37	25.34	1.39	5.5	0.001	0.134
	Tmin	12.12	16.34	14.39	0.94	6.5	0.001	0.085
	Tmean	17.7	21.5	19.8	1.12	5.7	0.001	0.112
Gesuba	Tmax	27.7	30.27	29.17	0.725	2.5	0.01	0.051
	Tmin	12.34	15.63	14.5	0.81	5.6	0.072	0.026
	Tmean	20.4	22.8	21.84	0.51	2.3	0.29	0.014
Sodo	Tmax	24.63	26.37	25.43	0.42	1.7	0.002	0.028
	Tmin	13.37	15.6	14.6	0.52	3.6	0.001	0.044
	Tmean	19	20.9	20	0.42	2.1	0.001	0.35

month was March (21.88 °C). In the case of seasonal trend analysis, increasing trend of minimum and maximum temperature was detected at all station (Fig. 9). The Mann–Kendall test statistics of the Tmax, Tmin and Tmean are given in Table 7. Towards the north, the temperature was cooler, but to the south, the temperature was warmer. The result of MK test in monthly temperature (maximum and minimum) revealed that the watershed had experienced warming. Mean temperature of Kiremt show decreasing

trend which it was insignificant. The slope of the whole months shows that there is a positive value implying an increase in the mean monthly and seasonal temperature. Belay et al. [1] revealed similar result in southern Ethiopia. These results are consistent with regional studies that revealed an upward trend in Ethiopia's yearly maximum and lowest temperatures as well as the country's average annual temperature. Due to the impact of warming on water availability and various agricultural activities, such

Table 7 MK test result of monthly and seasonal Temperature

Time	Mean	Tmax			Tmin			Tmean		
		Z−score	P	Slope	Z−score	P	Slope	Z−score	P	Slope
Jan	21.12	0.86	0.2	0.7	0.65	0.6	0.48	0.63	0.13	0.4
Feb	21.76	0.35	0.2	1.0	1.09	0.48	0.7	1.43	0.13	0.72
Mar	21.88	0.29	0.2	1.0	2.13	0.23	0.54	1.58	0.08	0.7
Apr	21.04	0.36	0.2	0.7	1.09	0.08	0.41	0.54	0.08	0.53
May	20.56	0.21	0.2	0.5	0.63	0.2	0.45	0.06	0.08	0.39
Jun	19.98	0.82	0.8	0.4	0.18	0.48	0.68	0.78	0.48	0.56
Jul	19.28	0.60	1	0.1	0.88	0.48	0.82	1.65	0.81	0.47
Aug	19.38	0.45	0.8	0.2	1.05	0.48	0.8	1.52	0.48	0.51
Sep	19.98	0.79	0.5	0.4	0.36	0.48	0.72	0.78	0.48	0.58
Oct	20.46	−0.07	0.2	0.56	0.53	0.2	0.4	0.18	0.48	0.44
Nov	20.86	0.43	0.08	0.56	0.41	0.4	0.6	0.31	0.23	0.4
Dec	20.94	0.65	0.2	0.53	0.88	0.6	0.45	0.41	0.23	0.37
Kiremt	19.68	1.15	0.8	0.35	0.63	0.48	0.77	−1.15	0.48	−0.55
Belg	21.34	0.68	0.2	0.81	1.15	0.23	0.53	0.91	0.08	0.54
Bega	20.86	0.47	0.1	0.52	0.52	0.48	0.5	0.31	0.23	0.4

Fig. 8 **a** Mean monthly maximum and **b** Mean monthly minimum temperature of the watershed
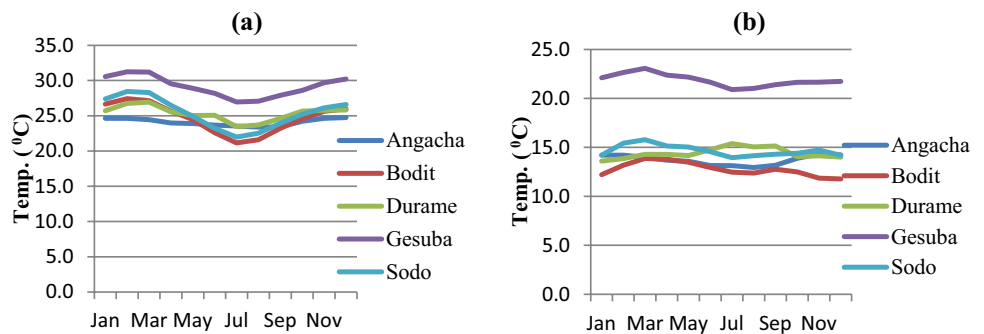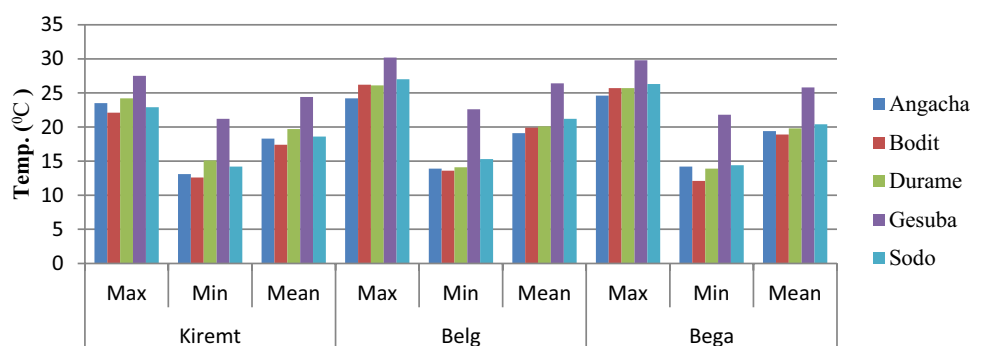

Fig. 9 Seasonal maximum, minimum and mean temperature of the watershed

temperature changes, like those in other regions of the world, require significant attention.

3.6 Analysis of river discharge

3.6.1 Annual discharge

In the watershed, a long period record has been observed at Woybo, Ajancho, Shapa and Soke hydrometric stations. The analysis was done based on the record of four−gauging stations. The mean annual flow computed over the period 1990 to 2015 was 22.2 m^3/s (Woybo), 16.2 m^3/s (Ajancho), 16.7 m^3/s (Shapa) and 20.2 m^3/s (Soke), respectively (Table 8). Sen's slope showed that Woybo station have upward magnitude of trend whereas the remaining stations (Ajancho, Shapa and Soke) show a downward magnitude of trends. According to the study maximum and minimum flow have varied between 33.67 m^3/s in 1999 to 56.72 m^3/s in 2006 and 5.1m^3/s in 2002 to 9.2 m^3/s in 2003, respectively. The discharge trends for the four gauging stations in the watershed area have showed different directions of trends. However, these trends were statistically not significant. These heterogeneous results may suggest human interventions [51] and natural causes [9, 26].

Based on CV analysis, the watershed annual river flow is highly variable, especially in the Ajancho station (72.5%). The annual trend of the discharge showed a varied trend across stations, which is insignificant. There have been numerous authors, who have reported increasing and decreasing trends in southern and central Ethiopia. Belihu et al. [25] reported increasing and decreasing trend across stations in the Gidabo River basin annually. Gedefaw et al. [43] informed that there was a decrease trend in the Awash River flow. Similarly [26, 51] has found an increasing and decreasing trend in stream flow of rivers in upper Omo−Gibe basins from year to year.

3.6.2 Monthly and seasonal discharge

The average monthly and seasonal discharge of the Ajora−Woybo watershed from 1990 to 2015 is depicted in Table 9. The highest monthly discharge was seen in August, which is slightly greater than July and September, and the three months lie in Kiremt season. In January and February, the watershed gets poor amount of discharge. The mean monthly average discharge was low from December to March, and started to increase in the month of April. MK results reveal that no significant trend was found in the monthly discharge of the watershed. Sen's slope shows the months of July, August, September and October have an upward magnitude whereas the remaining months show a downward magnitude of trend. This indicates that monthly discharge generally show an upward and downward trend over several months.

Seasonal trend over time at the watershed is shown in Fig. 10. As can be seen from figure, Kiremt season drains the highest amount of water, while Belg and Bega season drains the lowest amount of water with insignificant trend in both cases. The result of trend analysis in discharge across stations indicates that there is an insignificant increasing and decreasing trend and inter seasonal variability of discharge. A similar study conducted at the upper Omo−Gibe River basin has indicated that there is increasing and decreasing trend for seasonal stream flow at Gibe and Abelti gauging station [26]. Generally, the amount of surface water resources of the watershed is decreasing from time to time and this means there will exist shortage of water for irrigation and for the operation of the hydropower dam (Gibe III) which is typically dependent on Woybo, Ajancho, Soke and Shapa rivers. This increasing and decreasing trend of the discharge in this study may be attributed to a decreasing trend in rainfall at some stations and an increasing trend in temperature along with other factors. Different authors suggested the seasonal

Table 8 Annual discharge of the watershed

Stations	Min	Max	Mean	SD	CV	*P* value	Slope
Woybo	5.08	46.26	22.2	7.9	35.7	0.57	0.9
Ajancho	5.19	56.72	16.2	11.6	72.5	0.54	−0.13
Shapa	6.58	33.67	16.7	5.94	35.4	0.33	−0.15
Soke	9.2	51.03	20.2	9.55	47.2	0.9	−0.03

Table 9 MK test result of monthly and Seasonal discharge

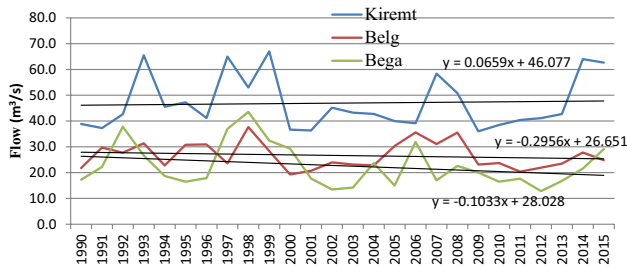|	Time															
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Kiremt	Belg	Bega
Z−score	−0.8	−0.8	−0.8	−0.7	−0.5	−0.5	0.16	0.4	0.45	0.16	−0.4	−0.6	−1.3	2.9	−1.2	−0.01
Slope	−1.9	−2.4	−1.1	−0.8	−2.4	−2.3	0.04	6.8	0.92	2.44	−3.8	−2.2	−0.04	0.1	−0.1	−0.12

Fig. 10 mean seasonal discharge of the watershed

stream flow reduction might be related to the catchment dynamics especially land cover and climate changes over the River basins [25, 43, 51].

3.7 Correlation analysis between climate and River discharge

The correlation between precipitation and river discharge was found to be positive and existence of good relation ($R^2 = 0.68$) in this study. In addition, the correlation between temperature and runoff was found to be negative and very weak ($R^2 = -0.04$). The decreasing trend of runoff is probably related to the other factors [52]. Therefore, the cause of this change needs further investigation (Fig. 11).

4 Conclusion

The purpose of this paper was to examine he historical trends and changes in meteorological and hydrological characteristics in the Ajora−Woybo watershed between 1990 and 2020. At each site, the annual, monthly, and seasonal variability of the parameters was investigated. At all locations, inter−annual fluctuation in rainfall, temperature, and discharge was recorded. Mann–Kendall and Sen's slope tests revealed that decreasing and increasing trends in rainfall, temperature, and discharge were seen at the observed stations.

The results show that inhomogeneity was observed in the annual rainfall data of Angacha and Areka stations, while majority of the stations were homogeneous. The rainfall decreases annually but the rate was insignificant trend. Monthly RF is highest in August and lowest in December in all stations. The temperature variability among different years and the average annual temperature is 20.1 °C, while the average annual maximum temperature is 25.7 °C and the average annual minimum temperature is 14 °C. The trend of maximum, minimum and average temperatures was significantly increasing at the watershed level. Based on the trend of minimum and maximum temperatures, the magnitude of change was found to be between 0.01 °C/year and 0.04 °C/year, and the mean values also demonstrate that the watershed is warming by about 0.025 °C/year. The annual trend of the discharge showed an increasing and decreasing tendency from time to time across stations. Seasonally, during kiremt season increasing trend of discharge was observed
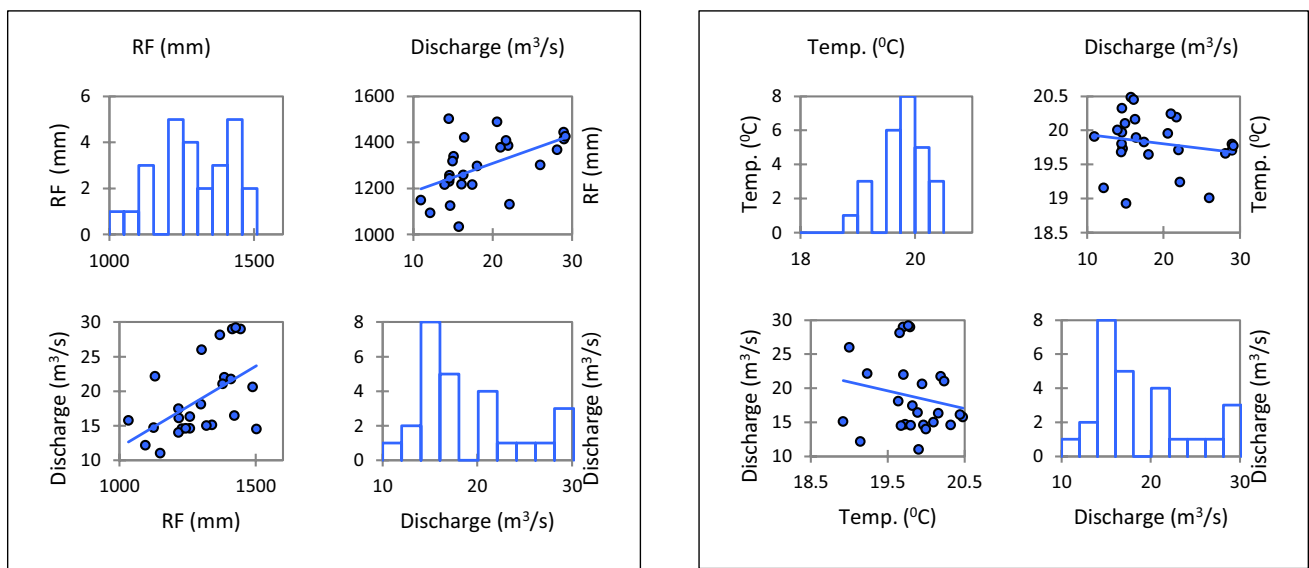

Fig. 11 Correlation coefficient between rainfall with discharge and temperature with discharge

with insignificant rate. The slope of Sen's discharge shows an upward trend for the months of July, August, September and October, while the remaining months show a downward trend. In the Kiremt and Bega season the highest and lowest amount of water flows in the watershed, respectively. The correlation of runoff with rainfall and temperature was found to be moderate and very weak in this study, respectively.

Overall, the findings of the long–term investigation of hydro–meteorological parameters in the Ajora–Woybo watershed show that water resources vary over time. It is conceivable to assume that a decrease in water supplies in this watershed might related to climate change or changes in land use. They are, however, outside the scope of this study; as a result, further study needed in the future.

Data availability Data are available from the corresponding authors upon reasonable request.

Declarations

Competing of interest The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Belay A, Demissie T, Recha JW, Oludhe C, Osano PM, Olaka LA et al (2021) Analysis of climate variability and trends in Southern Ethiopia. Climate 9(6):96

2. Serdeczny O, Adams S, Baarsch F, Coumou D, Robinson A, Hare W et al (2017) Climate change impacts in Sub–Saharan Africa: from physical changes to their social repercussions. Reg Environ Chang 17(6):1585–1600

3. Teshome A, Zhang J (2019) Increase of extreme drought over Ethiopia under climate warming. Adv Meteorol 2019:1–18

4. Emiru NC, Recha JW, Thompson JR, Belay A, Aynekulu E, Manyevere A et al (2021) Impact of climate change on the hydrology of the upper Awash River basin Ethiopia. Hydrology 9(1):3

5. Getahun AB, Ayal DY, Ture K, Zeleke TT (2021) Determinants of climate variability adaptation strategies: a case of Itang special District, Gambella Region Ethiopia. Clim Serv 23:100245

6. Gezie M (2019) Farmer's response to climate change and variability in Ethiopia: a review. Cogent Food Agric 5(1):1613770

7. Iglesias A, Garrote L (2015) Adaptation strategies for agricultural water management under climate change in Europe. Agric Water Manag 155:113–124

8. Thoma DP, Tercek MT, Schweiger EW, Munson SM, Gross JE, Olliff ST (2020) Water balance as an indicator of natural resource condition: case studies from great sand Dunes National Park and preserve. Glob Ecol Conserv 24:e01300

9. Mahmood R, Jia S, Zhu W (2019) Analysis of climate variability, trends, and prediction in the most active parts of the Lake Chad basin. Afr Sci Rep 9(1):6317

10. Belihu M, Tekleab S, Abate B, Bewket W (2020) Hydrologic response to land use land cover change in the upper Gidabo Watershed, Rift Valley Lakes basin Ethiopia. Hydro Res 3:85–94

11. Fang G, Yang J, Chen Y, Zhang S, Deng H, Liu H et al (2015) Climate change impact on the hydrology of a typical watershed in the Tianshan Mountains. Adv Meteorol 2015:1–10

12. Salami AW, Ikpee OD, Ibitoye AB, Oritola SF (2016) Trend analysis of hydro–meteorological variables in the coastal area of Lagos using Mann–Kendall trend and standard anomaly index methods. J Appl Sci Environ Manag 20(3):797

13. Sharma KD, Gosain AK (2010) Application of climate information and predictions in Water sector: capabilities. Procedia Environ Sci 1:120–129

14. Wang G, Mang S, Cai H, Liu S, Zhang Z, Wang L et al (2016) Integrated watershed management: evolution, development and emerging trends. J For Res 27(5):967–994

15. Weng SQ, Huang GH, Li YP (2010) An integrated scenario–based multi–criteria decision support system for water resources management and planning – a case study in the Haihe River basin. Expert Syst Appl 37(12):8242–8254

16. Fazzini M, Bisci C, Billi P (2015) The climate of Ethiopia. In: Billi P (ed) Landscapes landforms of Ethiopia. Springer, Dordrecht, pp 65–87

17. NMA (National Meteorological Agency) (2007) National meteorological agency. In: Annual report, Addia Ababa, Ethiopia

18. NMA (National Meteorological Agency) (2014) National meteorological agency. In: Annual report, Addis Ababa, Ethiopia

19. Allan RP, Barlow M, Byrne MP, Cherchi A, Douville H, Fowler HJ et al (2020) Advances in understanding large–scale responses of the water cycle to climate change. Ann N Y Acad Sci 1472(1):49–75

20. Dettinger MD, Diaz HF (2000) Global characteristics of stream flow seasonality and variability. J Hydrometeorol 1(4):289–310

21. Yang D, Yang Y, Xia J (2021) Hydrological cycle and water resources in a changing world: a review. Geogr Sustain 2(2):115–122

22. Cosgrove WJ, Loucks DP (2015) Water management: current and future challenges and research directions. Water Resour Res 51(6):4823–4839

23. Mengistu D, Bewket W, Lal R (2014) Recent spatiotemporal temperature and rainfall variability and trends over the upper Blue

Nile River basin, Ethiopia: climate variability, trends, upper blue Nile basin Ethiopia. Int J Climatol 34(7):2278–2292

24. Asfaw A, Simane B, Hassen A, Bantider A (2018) Variability and time series trend analysis of rainfall and temperature in north-central Ethiopia: a case study in Woleka sub-basin. Weather Clim Extrem 19:29–41

25. Belihu M, Abate B, Tekleab S, Bewket W (2018) Hydro-meteorological trends in the Gidabo catchment of the Rift Valley Lakes basin of Ethiopia. Phys Chem Earth Part A/B/C 104:84–101

26. Jaweso D, Abate B, Bauwe A, Lennartz B (2019) Hydro-meteorological trends in the upper Omo-Ghibe River basin Ethiopia. Water 11(9):1951

27. Woldesenbet TA, Elagib N (2021) Analysis of climatic trends in the upper Blue Nile basin based on homogenized data. Theoret Appl Climatol 146:1–14

28. Berhanu B, Seleshi Y, Melesse AM (2014) Surface water and groundwater resources of ethiopia: potentials and challenges of water resources development. In: Melesse AM, Abtew W, Setegn SG (eds) Nile River basin. Springer, Cham, pp 97–117

29. Al-Safi HIJ, Sarukkalige PR (2017) Assessment of future climate change impacts on hydrological behavior of Richmond River catchment. Water Sci Eng 10(3):197–208

30. Aieb A, Madani K, Scarpa M, Bonaccorso B, Lefsih K (2019) A new approach for processing climate missing databases applied to daily rainfall data in Soummam watershed Algeria. Heliyon 5(2):e01247

31. Baddoo TD, Li Z, Odai SN, Boni KRC, Nooni IK, Andam-Akorful SA (2021) Comparison of missing data infilling mechanisms for recovering a real-world single station streamflow observation. Int J Environ Res Public Health 18(16):8375

32. Banda VD, Dzwairo RB, Singh SK, Kanyerere T (2021) Trend analysis of selected hydro-meteorological variables for the Rietspruit sub-basin, South Africa. J Water Clim Chang 12(7):3099–3123

33. Sattari M-T, Rezazadeh-Joudi A, Kusiak A (2017) Assessment of different methods for estimation of missing data in precipitation studies. Hydrol Res 48(4):1032–1044

34. Bodian A, Diop L, Panthou G, Dacosta H, Deme A, Dezetter A et al (2020) Recent trend in Hydroclimatic conditions in the Senegal River basin. Water 12(2):436

35. Pettitt AN (1979) A non-parametric approach to the change-point problem. J R Stat Soc Ser C 28(2):126–135

36. Alexandersson H (1986) A homogeneity test applied to precipitation data. J Climatol 6(6):661–675

37. Patakamuri SK, Muthiah K, Sridhar V (2020) Long-term homogeneity, trend, and change-point analysis of rainfall in the Arid District of Ananthapuramu, Andhra Pradesh State India. Water 12(1):211

38. Gao F, Wang Y, Chen X, Yang W (2020) Trend analysis of rainfall time series in Shanxi province, Northern China (1957–2019). Water 12(9):2335

39. Kendall MG (1975) Rank correlation methods. Griffin, London

40. Mann HB (1945) Nonparametric tests against trend. Econometrica 13(3):245

41. Abegaz WB (2020) Temperature and Rainfall Trends in North Eastern Ethiopia. Int J Environ Sci Nat Resour. https://doi.org/10.19080/IJESNR.2020.25.556163

42. Alemu ZA, Dioha MO (2020) Climate change and trend analysis of temperature: the case of Addis Ababa Ethiopia. Environ Syst Res 9(1):27

43. Gedefaw M, Yan D, Wang H, Qin T, Wang K (2019) Analysis of the recent trends of two climate parameters over two Eco-Regions of Ethiopia. Water 11(1):161

44. Mubialiwo A, Onyutha C, Abebe A (2020) Historical rainfall and evapotranspiration changes over Mpologoma catchment in Uganda. Adv Meteorol 2020:1–19

45. Yue S, Wang C (2004) The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. Water Resour Manage 18:201–218

46. Bayable G, Amare G, Alemu G, Gashaw T (2021) Spatiotemporal variability and trends of rainfall and its association with Pacific Ocean Sea surface temperature in West Harerge Zone Eastern Ethiopia. Environ Syst Res 10(1):7

47. Alhaji UU, Yusuf AS, Edet CO, Oche CO, Agbo EP (2018) Trend analysis of temperature in Gombe State using mann kendall trend test. J Sci Res Rep 20(3):1–9

48. Toreti A, Kuglitsch FG, Xoplaki E, Della-Marta PM, Aguilar E, Prohom M et al (2011) A note on the use of the standard normal homogeneity test to detect inhomogeneities in climatic time series: standard normal homogeneity test. Int J Climatol 31(4):630–632

49. UNCHA (United Nations Office for the Coordination of Humanitarian Affairs (2016) Ethiopia: learning from the impact of past LA NIÑA events, Humanitarian response

50. Viste E, Korecha D, Sorteberg A (2013) Recent drought and precipitation tendencies in Ethiopia. Theor Appl Climatol 112(3–4):535–551

51. Degefu MA, Bewket W (2017) Variability, trends, and teleconnections of stream flows with large-scale climate signals in the Omo-Ghibe River basin Ethiopia. Environ Monit Assess 189(4):142

52. Xu J, Gao X, Yang Z, Xu T (2021) Trend and attribution analysis of runoff changes in the Weihe River basin in the last 50 years. Water 14(1):47