Trend Analysis of Climatic and Hydrological Parameters in Ajora-Woybo Watershed, Omo-Gibe River Basin, Ethiopia

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Abstract

Background: Identifying hydro-meteorological trends is basic for assessing change in climate and river discharge at watershed level. This study examined the long-term trends of rainfall, temperature, and discharge in the annual, monthly and seasonal time scale of Ajora-Woybo watershed in Ethiopia. The data span of rainfall and temperature is between 1990 and 2020 and that of discharge is between 1990 and 2015. Homogeneity test was performed by using Pettit and SNHT tests. Then Mann-Kendall and Sen's slope test for trend analysis and different variability measures were used.

Results: Results indicate that inhomogeneity was detected in annual rainfall data of Angacha and Areka stations. On annual basis, rainfall and discharge exhibited insignificant trends over time while showing a general decreasing pattern. On monthly basis, February and March were found to have significantly decreasing trend for rainfall. During the Kiremt season, rainfall increases and discharge decreases insignificantly. In contrast, maximum, minimum and mean annual temperatures exhibited significant trends with annual increment of 0.04°C, 0.01°C, and 0.025 °C per year respectively. Correlations of discharge with both temperature and rainfall have found to be weak in this study.

Conclusions: This trend, combined with population growth and increasing demand of water for agricultural activities exacerbates competing demands for water resources. Caution is therefore required when it comes to developing appropriate measures for the planning and sustainable development of the water resources in the watershed.

Key words: climatic parameters, River discharge, trend detection, Ajora-Woybo watershed

Background

Nowadays, the global hydrological cycle has been responding to the observed effects of global warming (IPCC, 2014), which include an increasing atmospheric water vapor content and changing precipitation patterns (Belay et al., 2021). In Sub-Saharan Africa, hydro-meteorological variables experienced significant warming, especially droughts and floods, are the most common forms of natural disasters (Serdeczny et al., 2016). For Ethiopia, climate change impacts on river basins are of major concern in view of the sustainability of water resources and agricultural production (Belay et al., 2021). Ethiopia is vulnerable to climate variability, and climate change is likely to increase the frequency and magnitude of disasters (Fazzini et al., 2015). Adverse impacts of climate change may worsen existing social and economic challenges of the whole country (Conway, 2011; Gizachew and Shimelis, 2014), particularly where people are dependent on resources that are sensitive to climate change and rain-fed agriculture (Addisu et al., 2015). Thus, understanding climate variability and change and its relation with water resource at a local scale is very important for economic growth and formulation of adaptation strategies that will increase the resilient of the local community (Adeba, 2015; Philip, 2019). It is therefore important for society to be prepared to reduce the vulnerability level of the community at local scale (Araya-Osses et al., 2020).

Climate change is altering surface water resources through changes in spatiotemporal distribution and magnitude (Chen et al., 2020), which will affect regional water balance and ecological environment (Asfaw et al., 2018; Witte et al., 2012). The change is based on time (real upward or downward tendency), namely the climate can change in the form of cycles, both daily, seasonal, annual, and decades (Fazzini et al., 2015; Bodian et al., 2020). According Twisa and Buchroithner (2019), the change in precipitation alters the hydrological systems, affecting water resources in both spatially and temporally. Concerns about climate change impacts on the behavior of hydrologic variables tend to extensive studies to specify trends of climatic and hydrological variables (Belihu et al., 2018; Emmanuel et al. 2019; Mubialiwo et al., 2020). Therefore, planning for water resources management projects depends on observational and historical climatic and hydrologic data (Chen et al. 2014). Integrated water resources management in a river watershed described in this case studies is essential for the economic welfare of the society and healthy environmental function as well as powerful analysis techniques necessary to identify hydrological behavior of watersheds. Because according to Adeba (2015) water resources development is essential to bring about sustainable development and overall economic growth.

The climate system of Ethiopia is strongly influenced by complex topography of the country, seasonal migration of the InterTropical Convergence Zone (ITCZ) and associated atmospheric circulations (Fazzini et al., 2015). Spatially, Ethiopia has a diverse climate system, ranging from the semi-arid desert type (bereha) in the lowlands to the cool type (wurch) in the mountainous regions > 3300 amsl: which traditionally classified in to five agro-ecological zones. Particularly, the study area entertains in three agro-ecologies: Lowland (kolla) with elevation less than 1500m a.s.l. in the lower part of the watershed; midland (woinadega) with elevation 1500m-2300m a.s.l. in the middle half of

the watershed; and cool temperate climate (dega) in the mountainous areas of the watershed. These diversified climate state have significant social, economic and environmental opportunities. However, empirical evidences have been warning that present global climate changes have knocking the ecological and livelihoods systems of the country, and the study area is not exceptional.

There exists a dearth of empirical evidences regarding the relationship between global climate change and water resource at local and household levels in Ethiopia. For example, Temesgen et al. (2008) conducted quantitative assessment of vulnerability due to climate change in Ethiopia based on the Ricardian approach. The study found that both the decrease in rainfall and the increase in temperature were detrimental to Ethiopian agriculture. According to the NMA (2007; 2014) revealed that in Ethiopia climate variability and change in the country is mainly manifested through the variability and decreasing trend in rainfall and increasing trend in temperature. Besides, rainfall and temperature patterns show large regional differences. In addition, Ethiopian climate is also characterized by a history of climatic extremes such as droughts and floods. The average annual minimum temperature in the country has increased by about 0.250°C every 10 years, while the average annual maximum temperature has increased by about 0.10°C per decade. The average annual rainfall of the country showed a very high level of variability over the past 50 years even though the trend remained more or less constant. Studies also indicate that mean temperature and precipitation have been changing over time. Rainfall is historically highly variable and there is no clear trend in the amount of rainfall over time (Serdeczny et al., 2016; Woldesenbet and Elagib, 2021). Recently, Woldesenbet and Elagib (2021) showed stream flow trends increased significantly on annual and seasonal scales at most of the gauging stations in the upper Blue Nile River basin. Asfaw et al. (2018), showed intra- and inter-annual variability of rainfall in northern Ethiopia of Woleka sub basin. Jaweso et al. (2019), in Upper Omo-Gibe River revealed rainfall exhibited statistically decreasing trends at a mean annual time scale, while seasonal rainfall depicted heterogeneous results in both directions. For the majority of the stations, air temperature showed statistically significant increasing trends. There is generally a decreasing trend in stream flow.

This continuous change in climate and hydrological pattern requires continuous investigation and analysis of trends with change point detection in climatic variables in all the regions of the world specifically at the local level to understand hydrological behavior of the watershed. The trend of climate and hydrological changes are detected through change in the average pattern of the climate parameters such as rainfall, temperature and River discharge. Analysis of temperature and precipitation variability is the very important side influencing on climate variability and extremes (Bhuyan et al., 2018; Tesfaye et al., 2019). Therefore, an examination on rainfall, temperature and hydrological behavior is important for planning and the prediction of future climate conditions (Bhuyan et al., 2018), although this study consider only observed and historical climate condition for the last three decades. Studies conducted on the analysis of climate and hydrological parameters across the Omo-Gibe Basin are lacking particularly in Ajora-Woybo watershed. Thus, long-term studies on changes in climatic and hydrological variables in such watersheds can help to improve

our understanding of the watershed response to climatic changes. Therefore, more research in this respect needed at a local scale in order to determine the nature of trend and level of significance. Therefore, the aim of this paper was to investigate the trends and changes of climatic and hydrological parameters over Ajora-Woybo watershed from 1990 to 2020. The objectives of the study are (1) to analyze rainfall, temperature and discharge trends, (2) to examine temporal variations in rainfall, temperature and discharge, and (3) to evaluate the relationship between climatic parameters and river discharge. The policymakers, investors, planners and even communities (other end-users) need this study findings on the future climate and hydrology characteristics of the area and, so that they can prepare for the expected trend and change. This study will also support decision making in watershed and water resource-based climate change strategies.

Materials and methods

Description of the study area

The Omo-Gibe River basin has an area of 79,000 km² with a length of 550 km and an average width of 140 km and covers parts of two national regional states, the SNNPR and the Oromia Region. The average total annual discharge from the River basin is estimated to be about 16.6 billion cubic meters (BMC). The Basin is Ethiopian's second largest river system after that of the Blue Nile, accounting for 14% of Ethiopian's annual runoff. The main tributaries of the Basin are from northeast Walga, Wabe, Wariness, Derghe, and south-west Gilgel-Gibe and Gojeb Rivers. From the eastern side of the middle and lower Omo-Gibe catchment the Ajancho, Soke, Shapa, Woybo, Sana, Deme and Zage Rivers are the main tributaries. Closed River basin flows into Lake Turkana in Kenya that forms its southern boundary.

Ajora-Woybo watershed elected as case study for this research is one of the major watersheds in Omo-Gibe Basin and is situated in the eastern side of the middle Omo-Gibe Basin. The study regions i.e. Ajora-Woybo watershed contain four perennial Rivers (Ajancho, Soke, Shapa and Woybo Rivers) that are flowing downstream lower valley eventually forms two rivers i.e. Ajora and Woybo (from where the name of watershed is given) finally joining into Gibe III dam reservoir. In addition, many small intermittent tributaries drain into the Rivers. The watershed covers an area of some 1723.5 km² with a perimeter of 336.8 km. The watershed lies between 7°2'0''N and 7°26'0''N latitude and between 37°32'0''E and 37°58'0''E longitude. The big irrigation dam project including the proposed dam under construction in the watershed was planned to have 10,000 hectares of land cultivated for which Ajancho and Woybo Rivers are the main source.

The topography of the watershed varies considerably (Worku et al. 2014). The northern two-thirds of the watershed have mountainous to hilly terrain cut by deeply incised gorges of the Omo, Ajancho-Soke, and Gilgel-Gibe Rivers. The lowest and highest of the watershed lies at an altitude greater than 731 masl with 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.

Climate of Ethiopia is classified into five climate zones based on the altitude and temperature. Each zone has its own rainfall pattern and agricultural production system. The climate of the Ajora-Woybo watershed varies 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. Rainfall varies from over 1900 mm per year in the northern areas to less than 300 mm per year in the south. In addition, the rainfall regime is bimodal in the watershed. The mean annual temperature in the watershed varies from 16⁰c in the highlands of the north to over 29⁰c in the lowlands of the south.

Figure 1. Location map of the study area

Materials

Data pre-processing

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

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

Methods

Filling of 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 equation (1) (Rubin, 1987; Schafer, 1997). The multiple imputations have been implemented in software such as XLSTAT (Armanous et al., 2020; Ekeu-Wei et al., 2018). MI is widely used method in hydrology and its advantages were does not overestimate error, simulate missing data multiple times (Ekeu-Wei et al., 2018) and leads to best estimation of missing values (Sattari et al., 2017). 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 (P_x), we use data imputations P_i by applying regression methods to obtain k different estimate results I_i (P_x, P_i). (iii) The result P_x will be obtained by combining all imputations results I_i using average of all the k complete data values, that is:

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

Homogeneity test using Pettit test and Standard Normal Homogeneity Test (SNHT)

Pettit test: To investigate the existence of the change points/break-point detection in the rainfall and temperature characteristics in time series data different methods can be applied. The Pettit test was used to identify whether or not there is a point change or jump in the data series (Pettit, 1979; Bodian et al., 2020). It is based on the Mann-Whitney two-sample test, allows the detection of a single shift at an unknown time and independent of the distribution of data (Bodian et al., 2020). In addition, many researchers also applied Pettit test in climatic and hydrological time series (e.g. Asfawu et al., 2018; Belihu et al., 2018; Jaweso et al., 2019; Bodian et al., 2020).

It considers a sequence of random variables $x_1, x_2, \dots, x_T$, with a change point at τ (x_t for $t = 1, 2, \dots, \tau$), and a common distribution function $F_1(x)$ and x_t for $t = \tau + 1, \dots, T$ have a common distribution

function and $F_2(x)$, and $F_1(x) \neq F_2(x)$. The null hypothesis H_0 : no change or $\tau = T$ is tested against the alternative hypothesis H_a : change or $1 \leq \tau \leq T$ using the non-parametric statistic $KT = \text{Max}|U_t, T|$, $1 \leq \tau \leq T$.

$$U_{t,T} = \sum_{t=1}^T \sum_{j=t+1}^T D_{ij} \quad (2)$$

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

$$\text{sgn}(x_i - x_j) = \begin{cases} 1 & \text{if } x_i - x_j > 0 \\ 0 & \text{if } x_i - x_j = 0 \\ -1 & \text{if } x_i - x_j < 0 \end{cases} \quad (3)$$

Then, the approximate significance probability, $p(t)$, of a change point then calculated from equation 3 and time series changing points of rainfall and River discharge was checked.

$$P \cong 2 * \exp \left[\frac{-6KT^2}{T^3 + T^2} \right] \quad (4)$$

Standard Normal Homogeneity Test (SNHT):

The SNHT was developed by Alex-Anderson (1986) 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 X_i corresponds to the standardized ratios. The null and alternative hypotheses are determined as follows:

H_0 : The T variables X_i follow an $N(0, 1)$ distribution.

H_a : Between times 1 and v , the variables follow an $N(\mu_1, 1)$ distribution, and between $v + 1$ and T , they follow an $N(\mu_2, 1)$ distribution. The Alex-Anderson statistic defined by:

$$T_o = \max_{1 \leq t < T} [v\bar{z}_1^2 + (n-v)\bar{z}_2^2] \quad (5)$$

$$\text{With } \bar{z}_1 = \frac{1}{v} \sum_{t=1}^v x_t \text{ and } \bar{z}_2 = \frac{1}{n-v} \sum_{t=v+1}^T x_t \quad (6)$$

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

Mann–Kendall trend detection

Observed rainfall, temperature and 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. Daily rainfall, temperature and discharge data were first calculated as monthly rainfall, temperature (maximum, minimum, and mean) and discharge. Monthly values were averaged and summed to obtain seasonal and annual values. In Ethiopia, seasons are classified based on rainfall

pattern. NMA (2014) states that there are three main seasons: Kiremt (main rainy season from June to September), Belg (small rainy season from February to May) and Bega (dry season from October to January). Trend analyses were carried out on monthly, seasonal and annual basis with reference to other researchers (e.g. Emmanuel et al. 2019; Philip, 2019; Tesfaye et al., 2019). Yue and Wang (2004) 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. 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 (Belihu et al., 2018; Mubialiwo et al. 2020). This makes the test not sensitive to outlier's values.

The non-parametric Mann-Kendall (MK; Kendall, 1975; Mann, 1945) statistics was chosen to detect 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. Belihu et al., 2018; Emmanuel et al. 2019; Philip, 2019; Mubialiwo et al., 2020). The test 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 $x_j < x_k$.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (7)$$

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.

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \quad (8)$$

S is normally distributed with mean zero, and Variance,

$$\text{var}(S) = \frac{n(n-1)(2n+5)}{18} \quad (9)$$

Computation for Z score is obtained as:

$$z = \begin{cases} \frac{s-1}{\sqrt{v}} & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \frac{s+1}{\sqrt{v}} & \text{if } s < 0 \end{cases} \quad (10)$$

For a given level of significance α , the null hypothesis of no trend in the time series will be rejected if $Z_z > 1-\alpha$. More specifically, $Z > z_{1-\alpha}$ indicates existence of an increasing trend and $Z < z_\alpha$ implies a decreasing trend.

Where, $\text{var}(S)$ 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 (H_0) 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_0) 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 (Mubialiwo et al., 2020).

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 (Sen, 1968). The slope estimation is given by

$$\beta = \text{Median} \left[\frac{x_j - x_k}{j - k} \right] \text{ for all } k < j \text{ and } i = 1, 2, \dots, N \quad (11)$$

The median of N values of β_i gives the Sen's slope of β , using following equation 12:

$$\beta = \begin{cases} \frac{\beta_{N+1}}{2}, & \text{if } N \text{ is odd} \\ \frac{\beta_N + \beta_{N+2}}{2}, & \text{if } N \text{ is even} \end{cases} \quad (12)$$

Where, x_j and x_k 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.

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 equation 13.

$$CV(\%) = \left(\frac{\sigma}{\bar{x}} \right) \quad (13)$$

Where CV is the coefficient of variation, σ is the standard deviation over the period and $\bar{x}$ 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 (Asfaw et al. 2018; Philip, 2019).

Correlation analysis between climate and river discharge

The relationship between climate variables and changes in river discharge is the subject of ongoing debate (Gedefaw et al., 2018). Moreover, the correlation between climate variables and runoff helps us to estimate their relationships. Pearson correlation coefficients (r) was calculated for the degree of the linear relation between climate variables (rainfall and temperature) with river discharge.

$$r = \frac{\sum_{i=1}^n (xi - \bar{x})(yi - \bar{y})}{\sqrt{\sum_{i=1}^n (xi - \bar{x})^2 \sum_{i=1}^n (yi - \bar{y})^2}} \quad (14)$$

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. X_i and Y_i are the rainfall, temperature and discharge in the year i , respectively, and $\bar{X}$ and $\bar{Y}$ are the mean rainfall and, temperature and discharge, respectively during the studied periods (Bhuyan et al., 2018; Philip, 2019). The obtained value was ranked into a weak correlation ($0 < |r| \leq 0.3$), a low correlation ($0.3 < |r| \leq 0.5$), a moderate correlation ($0.5 < |r| \leq 0.8$), and a strong correlation ($0.8 < |r| \leq 1$) (Bayable et al., 2021).

All MK trend tests, Sen's slope, Pettit change-point detections and variability analyses were conducted using the XLSTAT (<https://www.xlstat.com>) software (Alhaji et al., 2018; Asfawu et al., 2018; Bodian et al., 2020; Abegaz and Mekoya, 2020).

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

Results and discussion

Pettit 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 (Toreti et al, 2011). For this study, two types of homogeneity test (i.e., Pettit's test and the SNHT test) were performed at 5% level of significance.

The results of the p-values for the Pettit 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 showed homogeneous data for all months. The data of two stations were inhomogeneous in the months. The change point detection is may be related to occurrence of El-Niño (2009-2010) and La-Nina (2010-2011) effect in Ethiopia as reported by UNCHA (2016).

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

Stations	Pettit 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

Detection of change points for annual rainfall

The Pettit test analysis revealed that rainfall in the upper and central watershed area shown a break point change with different time series in Angacha and Areka station. The change point analysis in annual rainfall showed about 28.5 % of the stations is inhomogeneous. The year of 2009 was 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 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 step topography and high vegetation coverage of the area. 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.

Figure 3. Homogeneity test of the annual mean rainfall at seven stations, where μ is the annual mean rainfall (mm), μ_1 is the annual mean rainfall (mm) before the change point and μ_2 is the annual mean rainfall (mm) after the change point

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 watershed at four gauging stations.

Figure 4. Homogeneity test of the annual mean discharge at four stations, where mu is the annual mean discharge.

Analysis of annual rainfall

The rainfall analysis from the meteorological stations of in and around 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 based on the long time availability of data. Accordingly, Angacha and Durame meteorological station 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.

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 (figure 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 Jaweso et al. (2019) in southern Ethiopia and Asfawu et al. (2018) in north central Ethiopia. Their finding showed that decreasing RF pattern since about 1981. Viste et al. (2013) and Jaweso et al. (2019) 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, watershed rainfall is highly variable in the last two decades, particularly in the Angacha, Bele and Gesuba stations while the remaining stations become less variable.

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

Figure 5. Linear trend of mean annual RF of watershed

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 MT 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, Durame and Gesuba stations). The remaining two stations show 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 remaining five stations has downward trend. This study revealed a combination of upward and downward trends and Jaweso et al. (2019) reported similar results in upper Omo-Gibe Basin.

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

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 April to August at all station but it was insignificant rate. Monthly, the RF trend is significantly decreasing in February and March whereas September, November, January, April,

June and July months show decreasing trend but it was insignificant. December, October and August months show increasing trend but it was insignificant rate.

Seasons are classified based on rainfall pattern in Ethiopia. Seasonally, the precipitation was found to be in Kiremt ($Z = 2.78$), Belg ($Z = -1.74$), Bega ($Z = -0.26$), as shown in 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 was varies from Kiremt to Bega season 571.3 mm/season in Angacha station and 270.3 mm/season in Gesuba station. Insignificant rainfall trends may be due to high inter-annual variability (Belihu et al., 2018). 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.

Figure 6. (a) Monthly mean of each stations and (b) Seasonal mean RF trend of the watershed

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

Analysis of annual temperature

The annual temperature of the maximum (Tmax), minimum (Tmin) and mean (Tmean) along with their standard deviation (SD) and coefficient of variation (CV) have been statistically computed for each stations. 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. Temperature, next to rainfall plays a significant role in loss of water over a watershed (Belihu et al., 2018).

The Mann–Kendall test statistics of the Tmax, Tmin, and Tmean are shown in Table 6. Analysis of temperature using the MK test showed 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 (Bele station) showed an increasing trend particularly in extremes. Similar results were reported by NMA (2007) 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 lead to lose of more water from the watershed due to evapotranspiration. CV of Tmin highly observed in Bodit station (15.7%) among others.

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	15.7	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

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

Monthly and seasonal temperature

From the basic temperature data, the monthly and seasonal temperature of the maximum, minimum and mean along with their trend have been statistically computed for each month and the three seasons; Kiremt, Belg and Bega.

The monthly maximum temperature trend was increasing at all station but insignificant change. In addition, the minimum temperature trend showed increasing trend in most stations but decreasing 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 month was March (21.88°C). In case of seasonal trend analysis, increasing trend of minimum and maximum temperature was detected at all station (figure 9). The Mann–Kendall test statistics of the Tmax, Tmin and Tmean are given in Table 7. The nonparametric estimate for the magnitude of the sen's slope was computed for the significant trends, which certify all the trends in °C/year. Towards the north, the temperature was cooler and 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 but it was insignificant. The slope of the whole months shows that a positive value implying an increase in the mean monthly and seasonal temperature. Belay et al. (2021) revealed similar result in southern Ethiopia.

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

Figure 8. (a) Mean monthly maximum and (b) Mean monthly minimum temperature of the watershed

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

Analysis of annual river discharge

In the watershed, long period record was observed at Woybo, Ajancho, Shapa and Soke hydrometric stations. The analysis was done based on the record at four-gauging station. The mean annual flow computed over the period 1990 to 2015 was 22.15 m³/s (Woybo), 16 m³/s (Ajancho), 16.77 m³/s (Shapa) and 20.24 m³/s (Soke). Sen's slope showed Ajancho and Shapa stations are upward magnitude whereas the remaining stations show downward magnitude of trend. Maximum flow varies between 33.67 m³/s in 1999 to 56.72 m³/s in 2006 and minimum has occurred 5.1m³/s in 2002 to 9.2 m³/s in 2003. Discharge trends for four gauging stations in the watershed area showed different directions of trends. However, these trends were statistically not significant. These heterogeneous results suggest human interventions (Degefu and Bewket, 2017) and natural causes (Jaweso et al., 2019).

Based on CV analysis, watershed annual River flow is highly variable, especially in the Ajancho station (72.5%). The annual trend of discharge showed a decreasing trend which is insignificant with coefficient of determination ($R^2 = 0.0069$). There are numerous authors have reported decreasing trends in the streamflow of Rivers in southern and central Ethiopia. Belihu et al. (2018) reported decreasing trend in Gidabo River basin annually. Gedefaw et al. (2018) informed that there was a decrease in Awash River stream flow. Jaweso et al. (2019) found decreasing trend in stream flow of rivers in Gibe Rivers from year to year.

Table 8. Annual discharge of the watershed

Stations	Min	Max	Mean	SD	CV	P value	Slope
Woybo	5.08	46.26	22.15	7.9	35.7	0.57	-0.9
Ajancho	5.19	56.72	16	11.6	72.5	0.54	0.13
Shapa	6.58	33.67	16.77	5.94	35.4	0.33	0.15
Soke	9.2	51.03	20.24	9.55	47.2	0.9	-0.03
Discharge of Watershed	43.8	116.6	75.2	22.2	29.5	0.61	-0.16

Figure 10. (a) Linear trend and (b) Pettit homogeneity tests of mean annual discharge

Monthly and seasonal Discharge

The average monthly and seasonal discharge of the Ajora-Woybo watershed from 1990 to 2015 are depicted in figure 11. The highest monthly discharge was seen in September, which is slightly greater than August, and both months lies in Kiremt season. In February, the watershed gets the poor amount of discharge. The mean monthly average discharge was low from January to March, and started to increase in the month of April. MK results reveal that no trend was found in monthly discharge of the watershed. Sen's slope show the month of September and October is upward magnitude whereas the remaining months show downward magnitude of trend. Monthly discharge generally shows decreasing trend except September and October.

Seasonal trend over time at the watershed is shown in figure 11(b). Kiremt season drains the highest amount of water and Belg season drains the lowest amount of waters. The result of trend analysis in discharge at watershed indicates that there is a decreasing trend of seasonal discharge but it was insignificant for three seasons. Similar study conducted at upper Omo-Gibe River Basin indicated that decreasing trend for seasonal stream flow at Gibe at Abelti station gauging station (Jaweso et al., 2019). Generally, the amount of surface water resources of the watershed is decreasing from time to time and this means there will exist a shortage of water for irrigation and operation of hydropower dam (Gibe III) which is mostly dependent on Woybo, Ajancho, Soke and Shapa Rivers. The decreasing trend of 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 factor. Belihu et al. (2018) and Jaweso et al. (2019) suggested the stream flow reduction might be related to the catchment dynamics especially land cover change and climate changes over the River basins.

Figure 11. (a) Mean monthly discharge and (b) mean seasonal discharge of the watershed

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	-0.78	-0.8	-0.79	-0.69	-0.48	-0.48	-0.16	-0.4	0.45	0.16	-0.36	-0.62	-1.32	-2.98	-1.16	-0.01
slope	-1.96	-2.39	-1.06	-0.82	-2.36	-2.31	-0.04	-6.84	0.92	12.44	-3.82	-2.18	-0.04	-0.11	-0.07	-0.12

Correlation analysis between climate and River discharge

Correlation between climate (rainfall and temperature) parameters and their impact in river discharge is a subject of ongoing debate (Jurgelenaite and Jakimavicius, 2014; Gedefaw et al., 2018). Therefore, the correlation between the climate variables and discharge help us to estimate their relations. The correlation between precipitation and river discharge ($R^2 = 0.28$) was found to be very weak in this study. Moreover, the correlation between temperature and runoff was also very weak ($R^2 = 0.04$). This shows that temperature plays a minor role in the increase and decrease of discharge. The decreasing trend in river discharge is likely related to the reduction of a long-term precipitation cycle (Chen and Grasby, 2014). The influence of rainfall on stream flow is weak and this reveals that other factors like evapotranspiration, soil infiltration and land use change may contribute (Gedefaw et al., 2018) and needed to be considered which does not the scope of this study. Therefore, the cause for this change needs further investigation.

Figure 12. Correlation coefficient between rainfall with discharge and temperature with discharge

Conclusion

This study investigated the trends of rainfall, temperature, and discharge in the Ajora-Woybo watershed during the period of 1990-2020. The annual time series were homogeneous from the majority of the stations. The annual, monthly and seasonal variability of parameters was investigated in all stations. There was inter-annual variability of rainfall, temperature, and discharge observed across the stations. The Mann–Kendall test and Sen's slope test analyses showed that decreasing and increasing trends of rainfall, temperature, and discharge were observed across the stations.

Results indicate that inhomogeneity was detected in annual rainfall data of Angacha and Areka stations. The rainfall is generally homogenous and declining annually but it was insignificant rate. The monthly RF is highest in august and lowest in December in all of the stations. Seasonally, the rainfall was found to be in Kiremt ($Z = 2.78$), Belg ($Z = -1.74$) and Bega ($Z = -0.26$). The temperature variability between the different years and the average annual temperature is $20.1\text{ }^{\circ}\text{C}$, while the annual mean maximum temperature reached $25.7\text{ }^{\circ}\text{C}$ and the annual mean minimum temperature was $14\text{ }^{\circ}\text{C}$. The maximum, minimum and mean temperature trend was significantly increasing at the watershed level. From the minimum and maximum temperature trend, it was observed that the magnitude of change reaches about $0.01\text{ }^{\circ}\text{C/yr}$ to $0.04\text{ }^{\circ}\text{C/yr}$ and the mean values also proved that the watershed was warming at about $0.025\text{ }^{\circ}\text{C/yr}$. The annual trend of discharge showed a decreasing trend from time to time. Mean annual flow of watershed was $75.2\text{ m}^3/\text{s}$. Sen's slope of discharge show the month of September and October is upward magnitude whereas the remaining months show downward magnitude of trend. Generally monthly discharge shows decreasing trend except September and October. Kiremt season drains the highest amount of water and Belg season drains the lowest amount of waters in the watershed. The correlation of discharge with both rainfall ann temperature was found to be very weak in this study.

Overall, the results from the long-term analysis of hydro-meteorological variables in the Ajora-Woybo watershed indicate a decrease in water resources. From the results, decrease in water resource due to climate change or land-use change may be detected in such a watershed. However, they are beyond the focus of this. For this purpose, additional driving factors should be investigated in the future study.

Declarations

Ethics approval and consent to participate: Not applicable for this section

Consent for publication: Not applicable for this section

Availability of data and materials: The data that support the findings of this study are available from Ministry of Water and Irrigation and National Meteorological Agency of Ethiopia but restrictions apply to the availability of these data, which were used under license for the current

study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Ministry of Water and Irrigation and National Meteorological Agency of Ethiopia.

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