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Original Research Article

Homogeneity and change point detection of hydroclimatic variables: A case study of the Ghba River Subbasin, Ethiopia

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ABSTRACT

In most studies on hydroclimatic variability and trend, the notion of change point detection analysis of time series data has not been considered. Understanding the system is crucial for managing water resources sustainably in the future since it denotes a change in the status quo. If this happened, it is difficult to distinguish the time series data's rising or falling tendencies in various areas when we look at the trend analysis alone. This study's primary goal was to describe, quantify, and confirm the homogeneity and change point detection of hydroclimatic variables, including mean annual, seasonal, and monthly rainfall, air temperature, and streamflow. The method was employed using the four-homogeneity test, i.e., Pettitt's test, Buishand's test, standard normal homogeneity test, and von Neumann ratio test at 5% significance level. In order to choose the homogenous stations, the test outputs were divided into three categories: "useful", "doubtful", and "suspect". The results showed that most of the stations for annual rainfall and air temperature were homogenous. It is found that 68.8% and 56.2% of the air temperature and rainfall stations respectively, were classified as useful. Whereas, the streamflow stations were classified 100% as useful. Overall, the change point detection analyses timings were found at monthly, seasonal, and annual time scales. In the rainfall time series, no annual change points were detected. In the air temperature time series except at Edagahamus station, all stations experienced an increasing change point while the streamflow time series experienced a decreasing change point except at Agulai and Genfel hydro stations. While alterations in streamflow time series without a noticeable change in rainfall time series recommend the change is caused by variables besides rainfall. Most probably the observed abrupt alterations in streamflow could result from alterations in catchment characteristics like the subbasin's land use and cover. These research findings offered important details on the homogeneity and change point detection of the research area's air temperature, rainfall, and streamflow necessary for the planers, decision-makers, hydrologists, and engineers for a better water allocation strategy, impact assessment and trend analyses.

Keywords: Upper-Tekeza River basin; hydroclimate; change point; homogeneity

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1. Introduction

The world's climate is becoming warmer because of the environment and other considerations[1,2]. Different researches from Dobrowski[3], Stillman[4] and Harlan *et al*.[5] have demonstrated that more frequent hot air temperature extremes and fewer cold ones would occur in most landscapes if the global mean air temperature rises. According to the Intergovernmental Panel on Climate Change (IPCC) special report[6–9] on the effects of global warming of 1.5° cover pre-industrial levels and corresponding global greenhouse gas emission pathways, in the framework of strengthening the global response to climate change threat (warming up of atmosphere and oceans, reduction of snow and ice, the rise of sea level, and the incremental of concentrations of greenhouse gases). Climate change has thus raised concerns about the effects of changing streamflow and rainfall over a basin on the management of water resources on a daily and seasonal timeframe[10,11]. Researches from Cuo *et al*.[12], Nepal and Shrestha[13], Nepal[14] and Graham *et al*.[15] identify how climate change is reflected in changing patterns of precipitation and their impact on river basin hydrological regimes. Therefore, the public, governments, and academia are paying more attention to the evidence of global warming and how it affects human society. On a small geographical scale, it is also crucial to comprehend local and regional climates, even though the global air temperature is the main issue. Understanding how local and regional climate data sets have changed and behaved through time is so crucial. Numerous scholars have examined the variations in climate data series during the past few decades from a range of temporal and regional dimensions and climate change perspectives[16–21]. According to the studies, there is a far greater likelihood of an increase in air temperature than the current observed climate scenario, and it might even be more pronounced. Furthermore, other findings by Ren *et al*.[22] indicated that since 1961, the yearly mean air temperature in the northern China region has risen significantly as a result of urbanization. However, on the other side, a study by Philippart *et al*.[23] showed that climate warming was evident in northern than in southern European seas, and higher in enclosed than in open seas throughout all periods of observation (1980–2000). The average yearly temperature, mean maximum air temperature, and mean lowest air temperature have all grown at a rate of 0.42 °C, 0.92 °C and 0.09 °C $(100\ \text{year})^{-1}$, respectively in 125 stations distributed over the whole of India. Studies from the vast majority of stations show an increasing trend in the air temperature series and a declining trend in precipitation, such as Northern Ethiopia[24–27], East Africa[28–31], Saudi Arabia[32–35], and the China in most stations with an increase with air temperature[22,36–38]. The findings all support the idea that the global climate is warming. In recent decades, studies on both hydrology and climatology have focused heavily on the change point detection analysis of hydroclimatic data series. In climate change studies, the assumptions of stationarity, independence, and time-invariant features would no longer be valid and the outcomes of conventional frequency analysis would become doubtful because of the regular cyclical nature of the climate system[39]. Data from the time series are named stationary if they are free of trends, swings or changes. The changes could be either gradual (trend) or abrupt (jump) and, this indicates non-stationarity in hydroclimatic time series data[40,41]. Homogeneity test and identification of change points in hydroclimatic data series have been explored by many researchers around the globe[42–46]. In many hydroclimatic researches trend analysis was done before change point analysis. According to Villarini *et al*.[47] and Suhaila and Yusop[48], this method of analysis may lead to deceptive results since the critical knowledge derived from alteration point analysis not taken into account. When analysing trends Letzgus[49] suggested performing homogeneity and change point detection first followed by trend analysis, subsequently the results are more certain. According to their hypothesis, if homogeneity and change points are not considered while analysing a time series, the regime transition won't be apparent from a perceptible rising or decreasing trend across particular portions of the time sequence. Several scholars have successfully completed hydroclimatic trend analysis in the Ghba subbasin despite the fact that their homogeneity tests were disregarded[50–55]. Gebremicael *et al*.[56] carry out a trend analyses in the Upper Tekeze basin, where the present research subbasin is located, streamflow and rainfall data from nine and twenty-one chosen stations, spanning the periods of 32–63 and 21–43 years, respectively, were analysed. The results showed a stagnant rainfall data series across all stations and a declining streamflow trend, but no analysis of the air temperature have been done to date. In this study, the mean annual, seasonal and monthly air temperature, rainfall and streamflow homogeneity and change point detection is performed.

As a result, the purpose of this study is to carry out a homogeneity and changing point detection analysis with a focus on the alterations and patterns of rainfall, air temperature, and streamflow data series over time in the subbasin, which address these difficulties. Additionally, identifying potential causes of changes in streamflow, air temperature, and precipitation is another goal of our research. Moreover, these study's hydroclimatic parameters such as mean rainfall, air temperature, and streamflow were analysed monthly, yearly, and seasonally to offer information on the changes and influence of these climate variables on a changing climate in the Ghba river subbasin. The results of the current investigation are anticipated to be helpful for hydrologists, engineers, planners and policy makers in terms of future suitable management and distribution of water strategies due to the uncertainty in climate change.

2. Data and methods

2.1 Description of the study subbasin

The Ghba river subbasin is located in northern Ethiopia, spanning latitudes 13°14′ to 14°16′ north and longitudes 38°38′ to 39°48′ east (**Figure 1**). Mekelle, the capital of the Tigray regional state, is located inside the Ghba subbasin, which has a total size of around 5,125 km^2. It creates the Upper Tekeze River basin's headwaters, one of the principal tributaries of the Nile River[57,58]. There are hills and highlands in the north and north-eastern parts of the landscape, as well as highlands in the middle of the catchment[59]. Numerous rivers dividing the central highlands flow heading southwest portion of the subbasin where they join the major Tekeze River near Chemey[60]. The Mugulat Mountains, which are close to the town of Adigrat, are 3,300 m above sea level (m.a.s.l.), whereas the subbasin outlet is located at 930 m.a.s.l.[56]. The catchment's standard deviation is 361 m, which indicates that the topography is extremely rugged. The catchment's mean elevation is 2,144 m[60].

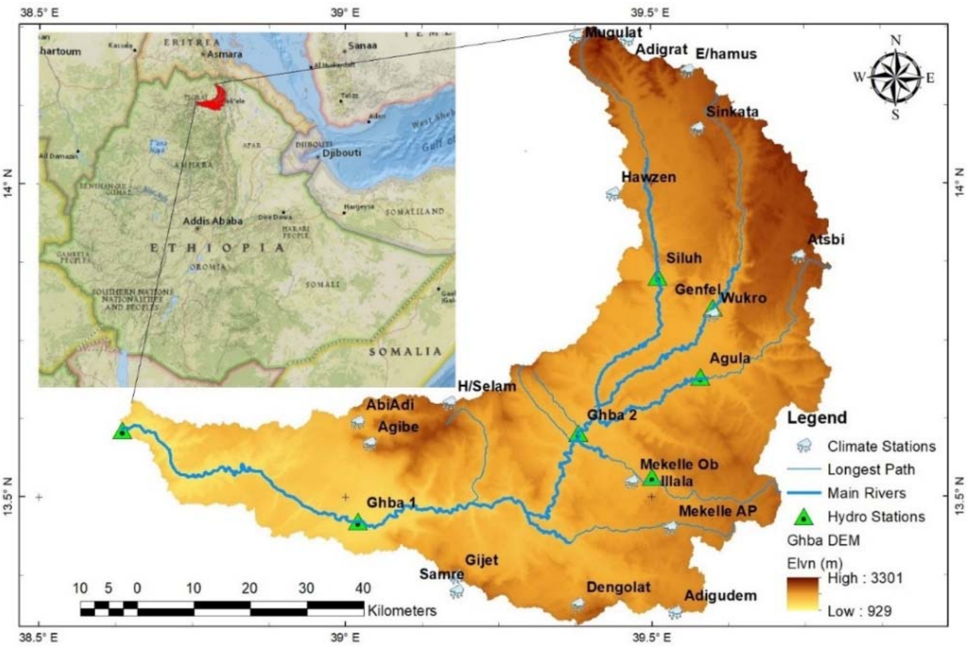

Figure 1. A study area's location.

2.2 Climate

The Ghba subbasin is classified as having a semi-arid climate, with rainfall typically occurring from July to September and a protracted dry season. The harsh weather is anticipated to occur from July through August[57]. The average annual precipitation in the subbasin varies from 450 mm in the east to 850 mm in some regions of the north and west[56]. The seasonal movement of the intertropical convergence zone (ITCZ) and the intricate topography of the subbasin are the main contributors to the significant variability of precipitation[56,61]. Because of this, the dry season, which may run between 10 months, and the rainy season, which lasts from June to September, both get above 85% of the total rainfall, with the maximum effective rainfall lasting no longer than 60 days[62]. Changes are frequently related to the Inter-tropical convergence zone's (ITCZ) seasonal migration. The yearly beginning and end of the ITCZ over Ethiopia's highlands change, which frequently results in interannual rainfall variations[63]. The Ghba's rainfall is quite erratic in both time and space[56]. The complicated terrain that favors the passage of air moisture that may be greatly intensified to develop rainfall regimes owing to orographic impact characterizes the general pattern of the subbasin's rainfall[64]. Rapid elevation changes can impede air mass flow and create a microclimate in the foothills that can lead to orographic rainfall[65,66]. As a result of the orographic effect, rainfall increases with elevation throughout the majority of the Tekeze basin[67,68], the Ghba subbasin differs from this. A research done by Gebrehiwot and van der Veen[69], and Mohammed *et al*.[70] showed that rainfall in the Tigray region increased with elevation to the south but decreased with elevation to the north and north-east. This demonstrates that because the subbasin is located in the north and north-eastern part of the region, the relationship between rainfall and elevation in the area varies. This was due to the complicated geography and seasonal motions of the ITCZ, which changes by the proximity from moist air sources[71,72]. This suggests that the relationship between elevation and rainfall is not constant.

2.3 Data pre-processing

In order to recognize, measure, and analyse the spatiotemporal datasets for hydrology and climate recent trends and alteration point analyses[73,74]. These statistical estimates mainly depend on the quality and the time series data's length[58,75]. Therefore, ample exertion was given to validate the accuracy of climate and flow data. The Ethiopian National Meteorology Services Agency provided the historical hydroclimatic data[76], the hydrological shape files were acquired from the Ministry of Water and Energy (MWE). The current investigation's main focus was on the streamflow and climate variables (air temperature and rainfall), which were gathered from 6 and 16 stations, respectively. These datasets were evaluated based on three criteria: long-term data availability, % of data missing and representativeness of the subbasin. The period of time chosen was more than 25 years, and the length of data recorded at each rainfall station is described in **Table 1** and demonstrates that this varies. Although the recording of flow data over the subbasin began in the late 1960s, it was stopped for the majority of the gauging stations during the civil war in the 1980s, and all of them are older than 30 years. The stations in the subbasin, however, have longer data periods of over 25 years, as indicated in **Table 2**, and they were employed in the analysis. **Figure 1** provides a summary of the location and general hydroclimatic data for the subbasin. For both the climate and streamflow stations in this study, stations with a long history of more than 25 years and fewer than 10% of the missing data were chosen. After choosing the timeframe for the analysis, missing gaps more than or equal to 5% were filled using methods for estimating missing data.

Time series plots were used for the first data visualization of rainfall and streamflow, and Excel's XLSTAT-time series analysis module, a Microsoft Excel add-in, was used for the normality, homogeneity, and outlier testing. With the help of Skewness, Kurtosis, and Z-value, the normalcy was examined. Critical Z-score values at 0.1, 0.05, and 0.01 percent significance levels, respectively, were 1.645, 1.96 and 2.576[55].

Data on daily streamflow and rainfall were grouped for the current study on an annual, monthly, and seasonal basis. Based on their locations and physical characteristics, the subbasin was separated into four catchments (**Figure 1**). As a result, the Siluh catchment covers the northern and northwestern section of the subbasin, while Genfel catchment includes the middle part, Agluai catchment covers the eastern part, and Tahtay Ghba catchment covers the southern and south western part. To assess the relationship between temporal and spatial variation over various regions, a time series data with comparable duration and length was needed[77]. The Ghba subbasin faced many difficulties, including a lack of data with comparable length and time (varying duration). As a result, the statistics for rainfall and streamflow span a different time period with a different beginning and ending date was set (**Table 1**) to omit data of years with many missing data. Thus, stations with a comparable era were grouped together in order to overcome this issue and obtain within typical stations of the subbasin. Datasets were divided into two groups; the first group included datasets spanning 35 years; the second group included datasets spanning 43 years and up to 65 years.

Table 1. General statistical information of hydrological flow monitoring stations

Station name	Lat.	Long.	Altitude (m.a.s.l.)	Catchment area (km^2)	Recording period	Analyses period	Missing data (%)
Siluh	13.85	39.51	2,230	967	1973–2018	1973–2018	5.9
Illala	13.53	39.5	2,004	341	1980–2018	1980–2018	4.1
Genfel	13.8	39.6	1,997	733	1992–2018	1992–2018	3.3
Agula	13.69	39.58	1,994	692	1992–2018	1992–2018	1.7
Geba 2	13.6	39.38	1,748	2,445	1967–2018	1990–2018	49.8
Geba 1	13.46	39.02	1,370	4,590	1994–2018	1994–2018	1.5

Table 2. Information on the overall air temperature and rainfall monitoring stations

Station name	Lat°	Long°	Alt. (m)	Recording period	Analyses period	Missing data (%)
Abi Adi	13.62	39.02	1,850	1961–2017	1983–2017	2.3
Adigrat	14	39.27	2,470	1970–2017	1970–2017	2.3
Agibe	13.39	39.6	1,800	1975–2017	1975–2017	4.5
Atsbi	13.79	39.6	2,200	1975–2017	1975–2017	8.5
Adigudem	13.16	39.13	2,100	1975–2017	1975–2017	2.4
Dengolat	13.19	39.21	1,950	1975–2017	1975–2017	2.6
E/hamus	14.18	39.56	2,700	1971–2017	1980–2017	2.5
Gijet	13.79	39.6	2,300	1975–2017	1980–2017	3.6
Hawzen	13.98	39.43	2,255	1971–2017	1980–2017	6.6
H/Selam	13.65	39.17	2,630	1973–2017	1980–2017	1.3
Mekelle AP	13.45	39.53	2,260	1952–2017	1983–2017	1.2
Mekelle Ob	13.52	39.5	2,000	1975–2017	1975–2017	4.9
Muglat	13.52	39.5	2,800	1975–2017	1975–2017	5.5
Samre	13.13	39.13	1,920	1967–2017	1980–2017	6.3
Sinkata	13.15	39.13	2,300	1975–2017	1975–2017	7.8
Wukro	13.79	39.6	1,995	1962–2017	1975–2017	9.7

2.4 Homogeneity and change point test

Data inhomogeneity is a constant problem when extreme hydroclimatic conditions and trend analysis are dealt with[73]. In this study, a shifting point or sudden change in the hydrologic regime was found using the homogeneity test, which was also utilized to select the useful stations for the impact analysis. Thus, the absolute homogeneity tests analyses of the seasonal and annual air temperature, rainfall, and discharge time series were carried out at every station for the entire subbasin. Consequently, the method of selecting three seasonal periods Dry (October–February), Short rainy (March–May), and Rainy (June–September) was employed to compare seasonal changes in the hydroclimatic variables. Thus, homogeneity tests for hydroclimatic data detects a changing point along with a time series data[78,79]. It is very important to understand the consistency of any interpretation, and is also vital for nay climate related studies[80]. Before, any climate change and impact assessments study performing different hydroclimatic homogeneity tests are crucial[55,73]. Homogeneity tests and data quality control before any climate studies is quite significant to reduce the level of uncertainty that might lead to wrong conclusions. Different studies use different techniques of Homogeneity test depending on the selected level of significance, test variables and procedure[81]. The current study employed four homogeneity tests to identify and eliminate the inhomogeneous stations from the trend analysis and to reduce uncertainty resulting from data inhomogeneity. These tests are discussed from Section 2.4.1 to Section 2.4.4.

2.4.1 Standard normal homogeneity test (SNHT)

The SNHT test was proposed from Alexandersson[82] to find a discrepancy in a time series of climate data by contrasting the average of the first *k* years of the record with the most recent *n*-*k* years, as shown in Equation (1). The test is one of the known likelihood ratio tests method of hydroclimatic studies used to distinguish inhomogeneities of hydroclimatic time series data as indicated researches from Latif *et al*.[83], and Khaliq and Ouarda[84]. With this approach, the null hypothesis is disregarded if T_0 is higher than a critical value, which depends on the sample size. The test finds breaks close to time-series' starts and endings[85,86]. A statistic $T(k)$ compares the mean of the first k years of the record with that of the last $(n-k)$ years[87]. Hence, statistic $T(k)$ is formulated as follows Equation (1).

$$\begin{cases} T(k) = kZ_1^2 + (n-k)Z_2^2, 1 \le k \le n \\ Z_1 = \frac{1}{k}\frac{\sum_{i=1}^{k}(Y_i - \bar{Y})}{S} \\ Z_2 = \frac{1}{n-k}\frac{\sum_{i=K+1}^{n}(Y_i - \bar{Y})}{S} \end{cases} \tag{1}$$

S is the estimated standard deviation. If a discontinuity is set at the year K, then $T(k)$ reaches a maximum near the year $k = K$. The test statistic T_0 is formulated as described in Equation (2).

$$T_0 = \min_{1\le k\le n} |T_k| \tag{2}$$

2.4.2 Buishand's range test (BRT)

The Buishand's range test is a parametric test that assumes independent test values and identically normally distributed[88]. The test dictates an abrupt change of the mean in unknown time of the hydroclimatic time series data[89]. Thus, this statistical method has been developed to verify the null hypothesis against alternative hypothesis[89]. It assumes that tested values are autonomous and normally distributed (null hypothesis), whereas the alternative hypothesis assumes that the series contains a jump like break or an abrupt change/shift as shown researches from Che Ros *et al*.[90], Kocsis *et al*.[91], Camuffo *et al*.[92] and Buishand[93]. The test statistics are the adjusted partial sum of the first year or cumulative deviations from the mean[93], and k until n years, which are defined as:

$$S_k^* = 0 \tag{3}$$

$$S_k^* = \sum_{i=1}^{k}(Y_i - \bar{Y}), k = 1, 2 \ldots \ldots \ldots n. \tag{4}$$

where, Y_i is a part of the time series and $\bar{Y}$ is the times-series' average value. In a homogeneous time series, the values of S_k^* due to the lack of consistent variations of the Y_i elements based on their average, it varies about zero. If a break/shift is present in year K, then S_k^* reaches a maximum (negative shift) or minimum (positive shift) near the year $k = K$. The $\frac{S_k^*/s}{\sqrt{n}}$ is portrayed in the graphs that show the test's outcomes. The rescaled adjusted range statistics (R) displayed in Equation (5) can be used to determine the significance of the change, which is the difference between the greatest and lowest value of the S_k^* values scaled by the standard deviation of the sample:

$$R = \frac{\left(\max_{0\le k\le n} S_k^* - \min_{0\le k\le n} S_k^*\right)}{s} \tag{5}$$

2.4.3 Pettitt's test

The rank-based Mann-Whitney test was modified to create the Pettitt's test, a nonparametric method for determining when a change in a time series happens without making any assumptions about the distribution of the data. Similar to the Buishand range test, the null hypothesis is the same[94]. The sudden transition breaks in the series' midsection are more apparent in Pettitt's test[95]. The ranks R_1, ..., R_n of the Y_1, ..., Y_n are used to compute the statistics Equation (6):

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1), 1,2 \ldots \ldots \ldots n. \tag{6}$$

If a discontinuity happens in year K, then the statistic (Equation (7)) is maximal or minimal near the year $k = K$i.

$$X_k = \max_{1\le k\le n} |X_k| \tag{7}$$

2.4.4 Von Neumann ratio test (VNRT)

The null hypothesis states that the data are independent and have a comparable distribution of random values, but the alternative theory claims that the values in the time series are not distributed randomly[96,97]. The test estimates the overall degree of inhomogeneity non the data series but offers no insight about where a discontinuity will occur. The von Neumann ratio N is defined as the ratio of the variance calculated using Equation (8) to the mean square difference from year to year.

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \tag{8}$$

From this point forward, n represents the length of the dataset, Y_i represents the i-th element, and Y is the dataset's mean value for each of the test descriptions. The anticipated value, $N = 2$, occurs when the sample is homogenous. The value of N tends to be lower than the critical number if the inquiry time series has a break. N values may exceed two if there are rapid changes in the sample's mean[98,99]. Although this test is quite effective at all times, it cannot determine the year of the shift or break.

2.5 Homogeneity test classification

The time series datasets in this investigation were found to be inhomogeneous using absolute homogeneity tests for air temperature, rainfall, and streamflow. Based on the test methods proposed and applied by Daba *et al.*[73] and Wijngaard *et al.*[100], the statistical test results were classified into three classes, which are "useful", "doubtful", and "suspect". Each hydroclimatic variable was examined independently, and then its classifications ("useful", "doubtful", and "suspect") were merged for a final assessment of the significance of time series data. This might be described as the series that rejects one or none under the four tests at the 5% significance level classed as "useful", the series that rejects two under the four tests categorized as "doubtful", and the series that rejects three or all under the four tests categorized as "suspect". As shown researches from Wijngaard *et al.*[100], Tan *et al.*[101], Lin *et al.*[102], and Khalil[103], according to the alpha value of 0.05 (95% confidence level), if the P value exceeds the alpha value, the series is homogenous. The alternative hypothesis states that the series is not evenly dispersed, which prevents VNR from determining the year of the break, although the BR test, SNHT, and Pettitt's test presume the series had a break as shown researches from Kang and Yusof[78], and AL-Lami *et al.*[104]. The discrete evaluation of four homogeneity tests led to an estimating the use of time series for air temperature, rainfall, and streamflow.

3. Results and discussion

Four homogeneity SNHT, tests Pettitt's, VNR, and BRT were applied to assess the homogeneity and change point of seasonal, monthly, and annual streamflow and climate time series data. Thus, the homogeneity test and identification of change points analyses were performed as discussed from Section 3.1 to Section 3.4.

3.1 Monthly air temperature, rainfall and streamflow homogeneity and change point tests

The four-homogeny test (SNHT, Pettitt's, VNR, and BRT) at monthly level were applied for hydroclimatic datasets of air temperature, rainfall, and streamflow, the critical value of T_0 was with a 95% level of confidence for the specified sample size. The test was evaluated against a user-defined significance level (5%) and p values less than 5% were considered as a statistically significant change in the data set. The 5% significance level was chosen as it is usually used in the hydroclimatic trend analyses as shown researches from Fathian *et al.*[81], Hamlaoui-Moulai *et al.*[105], and Wang *et al.*[106]. This Pettitt technique has frequently been used to detect time alteration points in the hydroclimatic data as shown researches from Wu *et al.*[40], Gebremicael *et al.*[56], Ryberg *et al.*[107], Wang *et al.*[108], and Slater *et al.*[109]. Thus, estimated statistical analysis for the sequence of monthly data lower than the significant value (5%) was thought to be homogeneous. As described in **Tables 3** and **4**, the symbols D: doubtful; S: suspect; and U: useful was used to categorize homogeneity tests. Accordingly, in **Table 3** eleven rainfall and nine air temperature stations were levelled as “useful” for all months and, thus indicates the stations are homogenous. In addition to this, **Table 4** also indicates the test for six hydro stations were useful and thus revealed homogeneity. Furthermore, **Figures 2**, **3** and **4** are sample examples of monthly abrupt point changes by Pettitt’s test for homogeneity tests of air temperature, rainfall and streamflow, respectively. In this example, the test for selected stations is detected by Pettitt’s test. These are the date (H_a) at which the series of data has changed as the computed *p*-value for all tests were bigger than the significance level alpha = 0.05, in other words, it detects the regime distributions change.

3.2 Annual and seasonal rainfall homogeneity and change point tests

The overview of the four homogeneity test results (SNHT, Pettitt’s test, VNR, and BRT) for the annual climatic data time series of rainfall at various stations is presented in **Table 5**. The series of annual rainfall data was examined for homogeneity using the alpha value of 0.05 (95% confidence

Table 3. Summery result of monthly rainfall and air temperature homogeneity test

S/N	Station	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
		R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
1	Abi Adi	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	Adigrat	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
3	Agibe	U	S	U	D	D	S	U	U	S	S	S	S	D	S	S	S	S	U	S	S	S	S	S	S
4	Atsbi	U	D	U	D	S	S	U	U	U	U	D	D	D	D	D	S	S	D	D	D	D	D	D	D
5	Adigudem	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
6	Dengolat	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
7	E/hamus	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
8	Gijet	S	S	D	D	D	D	U	S	U	U	D	D	D	D	D	D	S	S	D	D	D	D	D	S
9	Hawzen	U	U	U	U	U	S	U	U	U	S	U	S	U	S	U	S	U	S	U	S	U	S	U	S
10	H/Selam	U	U	U	U	U	S	U	U	U	U	U	U	U	D	U	S	U	D	U	D	U	D	U	D
11	Mekelle AP	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
12	Mekelle Ob	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
13	Muglat	S	S	S	S	D	D	U	U	S	D	S	S	S	S	S	S	S	U	S	S	S	S	S	S
14	Samre	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
15	Sinkata	S	S	S	D	S	S	D	U	S	U	S	S	S	S	S	S	S	U	S	S	S	S	S	S
16	Wukro	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

R: rainfall; T: temperature; U: useful; D: doubtful; S: suspect

Table 4. Summery result of monthly flow homogeneity test

S/N	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
1	Siluh	U	U	U	U	U	U	U	U	U	U	U	U
2	Illala	U	U	U	U	U	U	U	U	U	U	U	U
3	Genfel	U	U	U	U	U	U	U	U	U	U	U	U
4	Agula	U	U	U	U	U	U	U	U	U	U	U	U
5	Ghba 2	U	U	U	U	U	U	U	U	U	U	U	U
6	Ghba 1	U	U	U	U	U	U	U	U	U	U	U	U

Q: flow; U: useful; D: doubtful; S: suspect

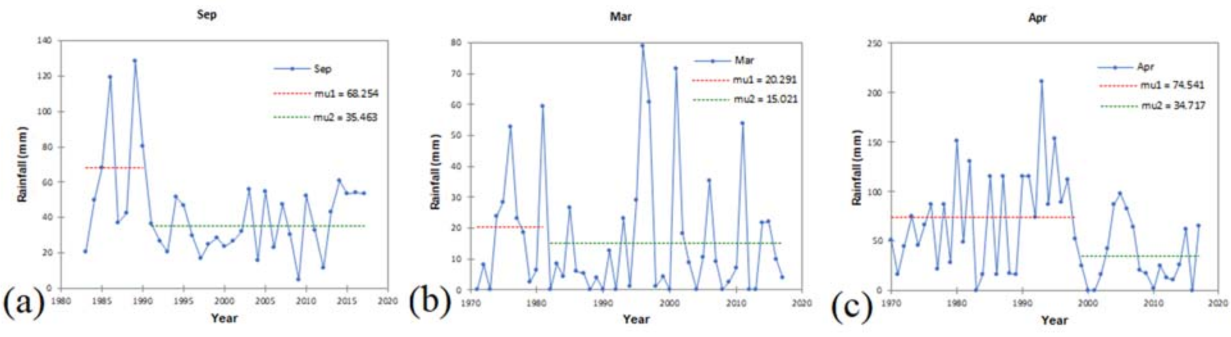

Figure 2. Monthly rainfall abrupt changes as determined by Pettitt’s test at **(a)** Mekelle AP; **(b)** Hawzen; **(c)** Adigrat.

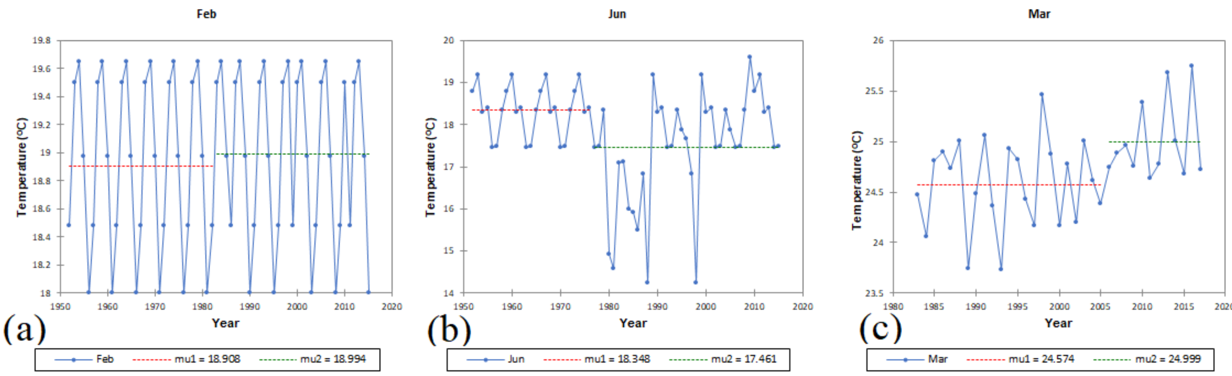

Figure 3. Monthly air temperature abrupt changes as based on the Pettitt's test at **(a)** Mekelle AP; **(b)** Adigrat; **(c)** Abi Adi.

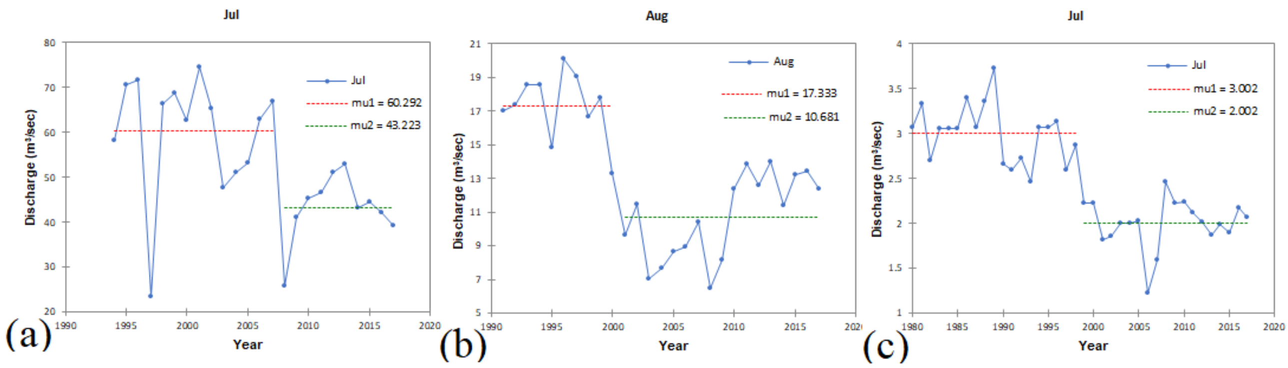

Figure 4. Monthly streamflow abrupt changes as determined by Pettitt's test at **(a)** Ghba 1; **(b)** Ghba 2; **(c)** Ilala.

Table 5. Results of homogeneity tests on rainfall with a 95% confidence level

-	-	***p*-value of test statistics**				-
S/N	**Station**	**Pettitt's test**	**SHNT**	**BRT**	**VNR test**	**Remark**
1	Abi Adi	0.745	0.478	0.433	0.056	Useful
2	Adigrat	0.818	0.537	0.291	0.052	Useful
3	Agibe	**0.049**	**0.026**	**0.032**	**0.001**	Suspect
4	Atsbi	0.31	0.41	**0.003**	**0.001**	Doubtful
5	Adigudem	0.335	0.246	0.12	0.38	Useful
6	Dengolat	0.063	0.134	0.054	0.051	Useful
7	E/hamus	0.86	0.591	0.434	0.06	Useful
8	Gijet	0.63	0.51	**0.032**	**0.001**	Doubtful
9	Hawzen	0.788	0.344	0.52	0.42	Useful
10	H/Selam	0.972	0.584	0.313	0.038	Useful
11	Mekelle AP	0.093	0.068	0.056	0.162	Useful
12	Mekelle Ob	0.141	0.143	0.112	0.195	Useful
13	Muglat	**0.048**	**0.032**	**0.041**	**0.002**	Suspect
14	Samre	0.91	0.71	0.561	0.111	Useful
15	Sinkata	**0.049**	**0.038**	**0.044**	**0.006**	Suspect
16	Wukro	0.09	0.056	0.09	0.056	Useful

*The bold numbers represent inhomogeneity in the corresponding stations and test statistics.

level). The seasonal and yearly rainfall data series' estimated test statistics superior to the alpha values were thought to be homogeneous, the opposite was true where *p* values were less than a 5% significance threshold, and data series were thought to be inhomogeneous.

As summarized in **Table 5**, the yearly rainfall data series was proven to be inhomogeneous according to the results of the BR and VNR tests for five stations, whereas the SNH and Pettitt's tests exhibited the inhomogeneity of the data series for three stations. **Table 5**'s analysis of all test outcomes also revealed eleven rainfall stations' yearly data series were discovered homogeneous and deemed

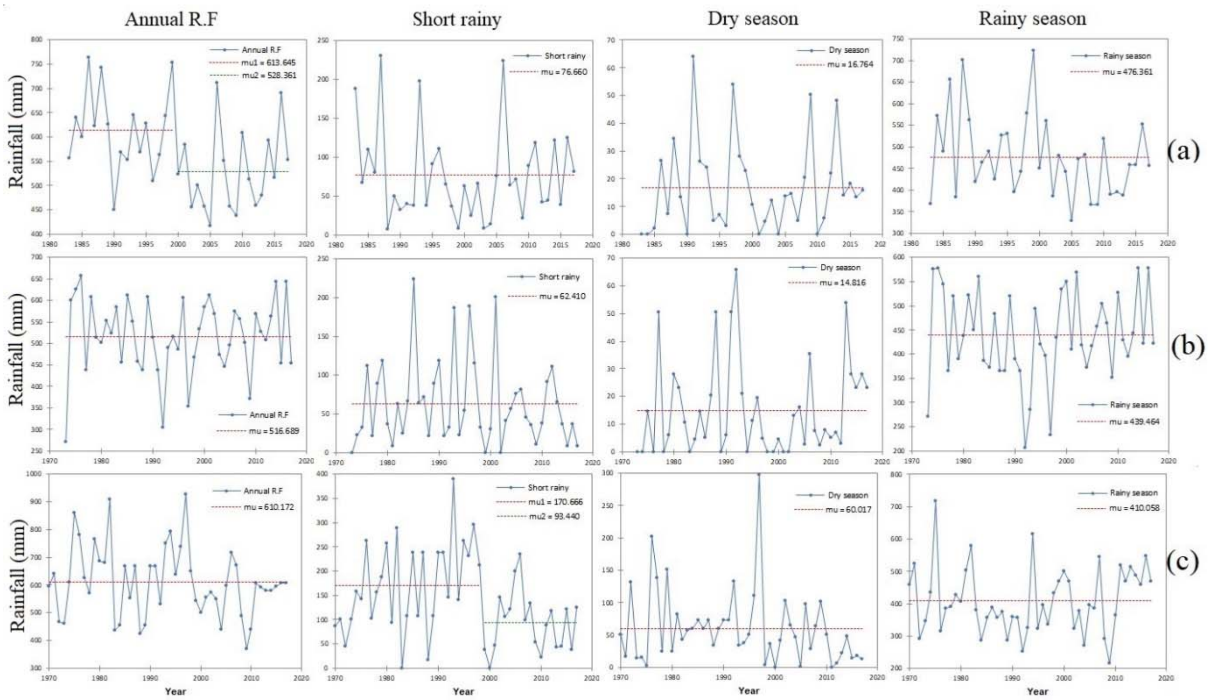

Figure 5. Seasonal and annual rainfall homogeny test determined by Pettitt's test **(a)** Mekelle Ap; **(b)** Wukro; **(c)** Adigrat.

useful while three stations were found to be inhomogeneous in all tests, while two stations were deemed doubtful in two tests because they were partially inhomogeneous. Accordingly, 68.75% of the rain gauges were divided into group as "useful", only 12.5% among the stations classified as "doubtful", and 18.75% grouped the rainfall stations as "suspect".

As illustrated in **Figure 5**, sample results of rainfall characteristics for the selected stations of seasonal and annual rainfall, homogeneity test showed a change point at Mekelle station annually and Adigrat station at short rainy season.

3.3 Seasonal and annual air temperature homogeneity and change point tests

The four-homogeneity test summary (SNHT, Pettitt's test, VNR, and BRT) is a set of outcomes for the annual climate data time series of air temperature at different stations is depicted in **Table 6**. The seasonal and annual data sets were examined for homogeneity using the alpha value 0.05 (95% confidence level). Test statistics that are anticipated for the seasonal and annual rainfall data set higher than alpha values were regarded as being homogeneous, however, where *p* values were below than the 5% criterion of significance, data series were regarded as being inhomogeneous.

The findings of the SNHT and Pettitt's test, which are summarized in **Table 6**, revealed that the yearly air temperature data series for seven stations were determined to be inhomogeneous, whereas, the VNR and BRT tests shown that the data series was inhomogeneous for four stations. The annual data set from nine rainfall sites was determined to be homogeneous and deemed useful based on the outcomes of all tests, four stations were found to be inhomogeneous throughout all tests, while three stations were partially inhomogeneous over two dubious tests labelled as "doubtful". Accordingly, 56.25% of the air temperature stations were labelled as "useful", only 18.75% stations were classified as "doubtful", and 25% the air temperature monitoring stations were classified as "suspect".

As illustrated in **Figure 6**, sample results of air temperature characteristics for the selected stations for seasonal and annual rainfall homogeneity test were detected a change point at Mekelle AP and Abi Adi stations both at annual and seasonal. Whereas, at Edagahamus only at short rainy season, a change point was detected.

Table 6. Results of homogeneity tests on air temperature at a 95% level of significance

-	-	*p*-value of test statistics				-
S/N	**Station**	**Pettitt's test**	**SHNT**	**BRT**	**VNR test**	**Remark**
1	Abi Adi	0.451	0.371	0.332	0.096	Useful
2	Adigrat	0.918	0.847	0.581	0.192	Useful
3	Agibe	**0.001**	**0.015**	**0.012**	**0.002**	Suspect
4	Atsbi	0.021	0.001	**0.131**	**0.211**	Doubtful
5	Adigudem	0.415	0.446	0.322	0.581	Useful
6	Dengolat	0.213	0.311	0.114	0.156	Useful
7	E/hamus	0.911	0.851	0.514	0.114	Useful
8	Gijet	0.001	0.002	**0.12**	**0.11**	Doubtful
9	Hawzen	0.041	0.032	0.021	0.014	Suspect
10	H/Selam	0.031	0.001	0.241	0.171	Doubtful
11	Mekelle AP	0.131	0.211	0.125	0.133	Useful
12	Mekelle Ob	0.211	0.312	0.242	0.187	Useful
13	Muglat	**0.003**	**0.011**	**0.021**	**0.011**	Suspect
14	Samre	0.562	0.871	0.491	0.321	Useful
15	Sinkata	**0.031**	**0.021**	**0.034**	**0.003**	Suspect
16	Wukro	0.211	0.124	0.151	0.211	Useful

*The bold numbers represent inhomogeneity in the corresponding stations and test statistics.

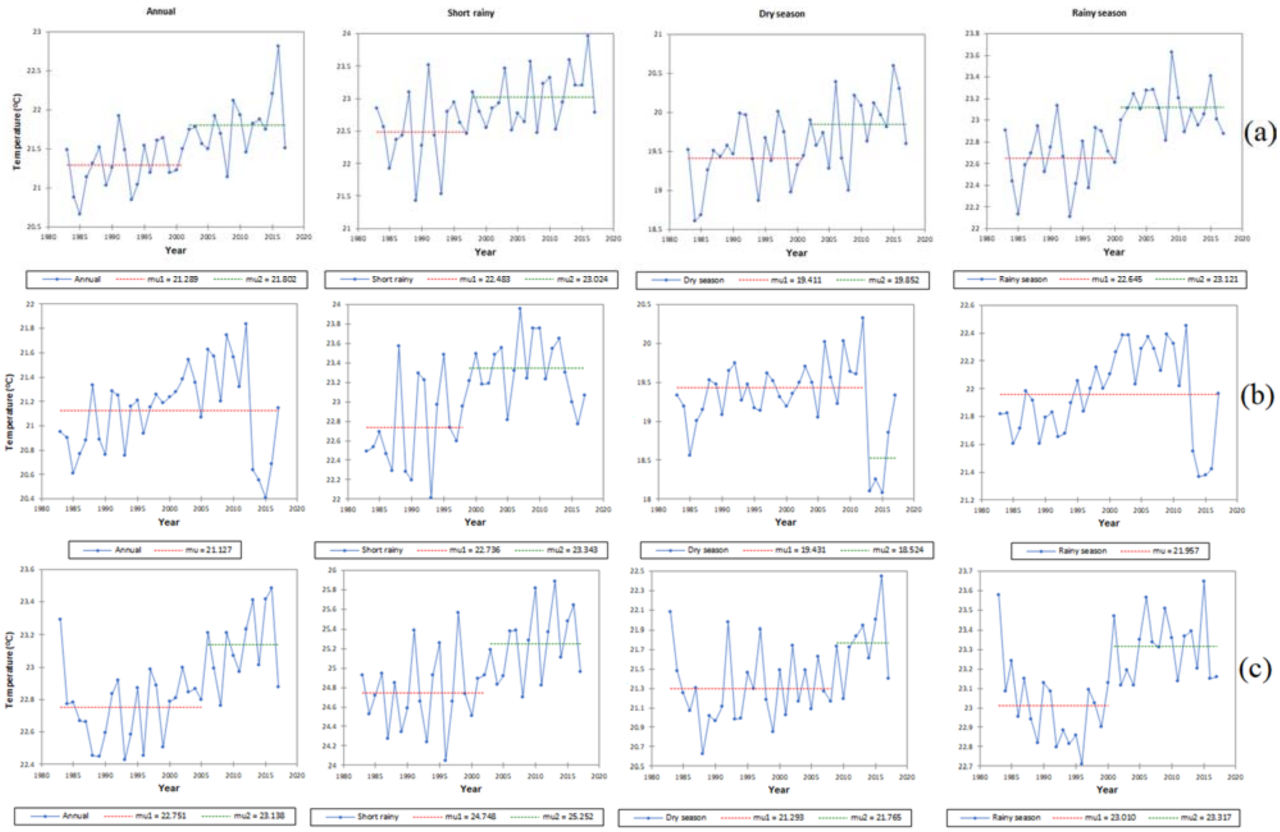

Figure 6. Seasonal and annual air temperature homogeny test determined by Pettitt's test **(a)** Mekelle Ap; **(b)** Edagahamus; **(c)** Abi Adi.

3.4 Seasonal and annual discharge homogeneity and change point tests

The selected homogeneity test results from the seasonal and yearly discharge data series examined by the four tests for homogeneity at each station are shown in **Table 7**. **Figure 7** describes the Pettitt's and SNHT tests that detected the occurrence of an abrupt change/change point of data series on discharges annually at all hydro station and also stations of Ghba 1 and Ghba 2, a change point was detected at all seasons. Whereas, as described in **Figures 7** and **8**, a change point at different seasons was seen in all station. And, in general, all the taste

Table 7. Results of homogeneity tests on streamflow with a 95% level of significance

		p-value of test statistics				
S/N	Station	Pettitt's test	SHNT	BRT	VNR test	Remark
1	Siluh	0.531	0.328	0.231	0.12	Useful
2	Illala	0.621	0.645	0.381	0.086	Useful
3	Genfe l	0.151	0.097	0.112	0.091	Useful
4	Agula	0.351	0.512	0.131	0.079	Useful
5	Ghba 2	0.41	0.231	0.102	0.432	Useful
6	Ghba 1	0.62	0.098	0.099	0.191	Useful

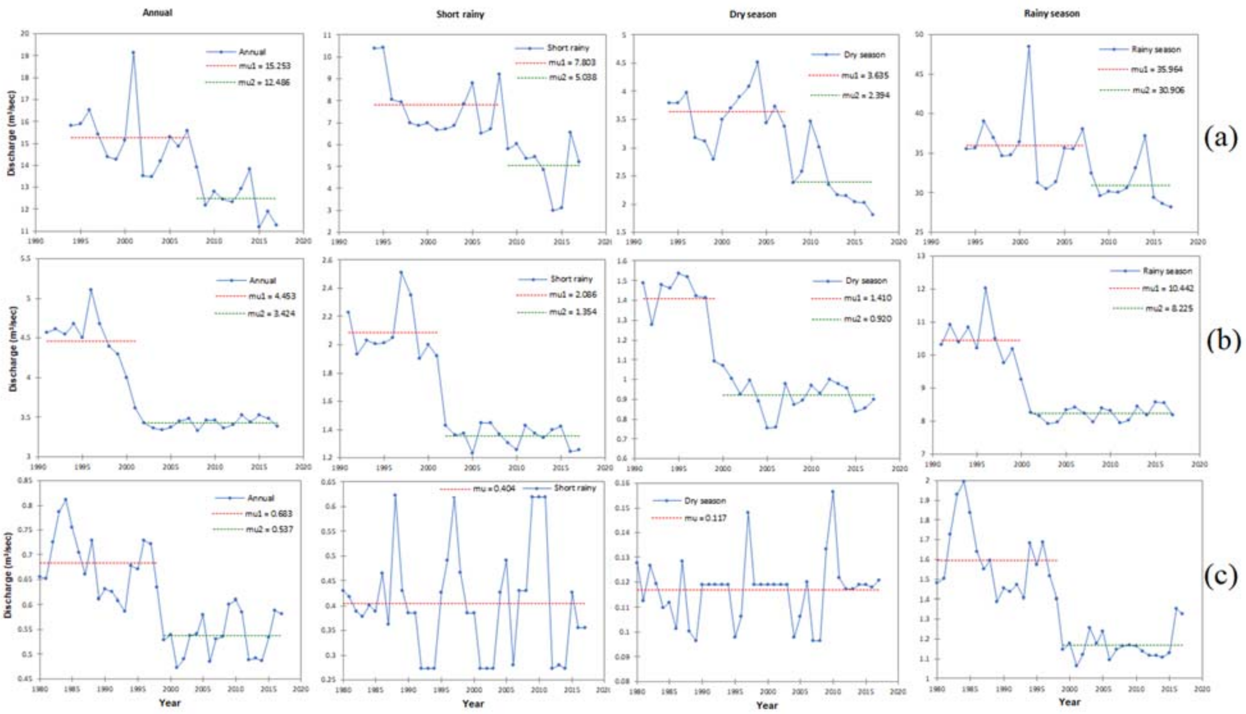

Figure 7. Seasonal and annual streamflow homogeny test determined by Pettitt's test at **(a)** Ghba 1; **(b)** Ghba 2; **(c)** Illala.

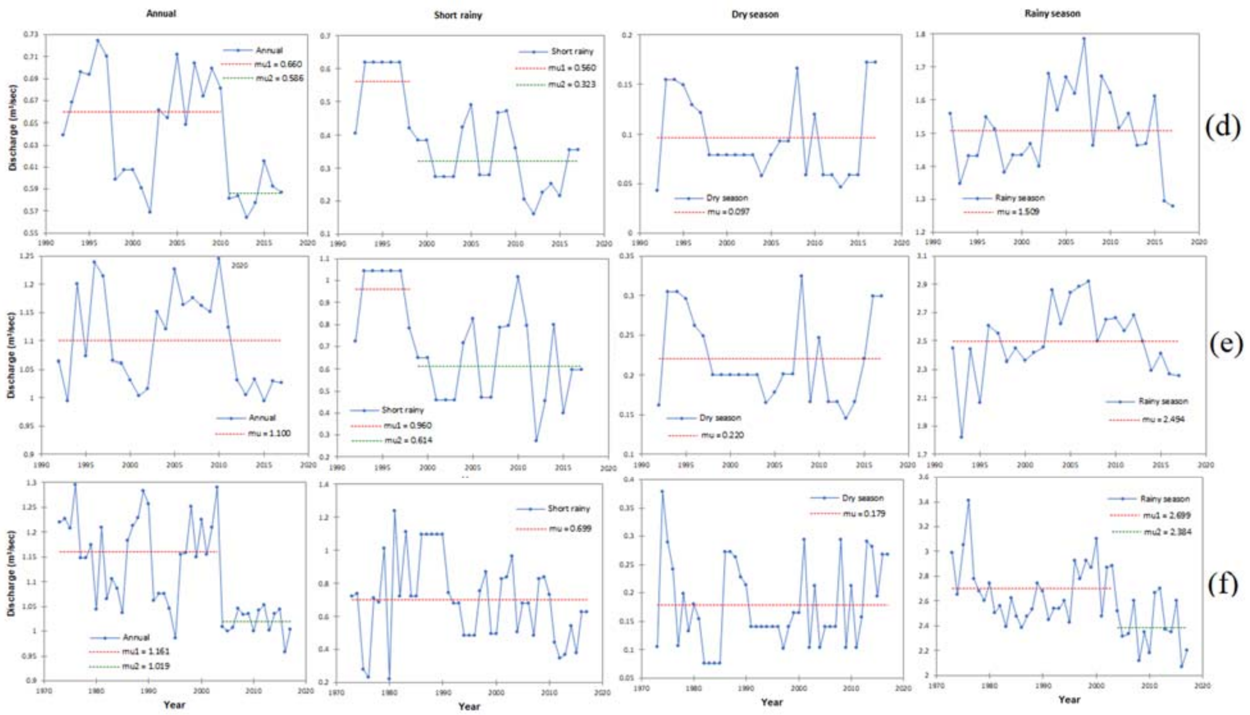

Figure 8. Seasonal and annual streamflow homogeny test determined by Pettitt's test at **(d)** Genfel; **(e)** Agulai; **(f)** Siluh.

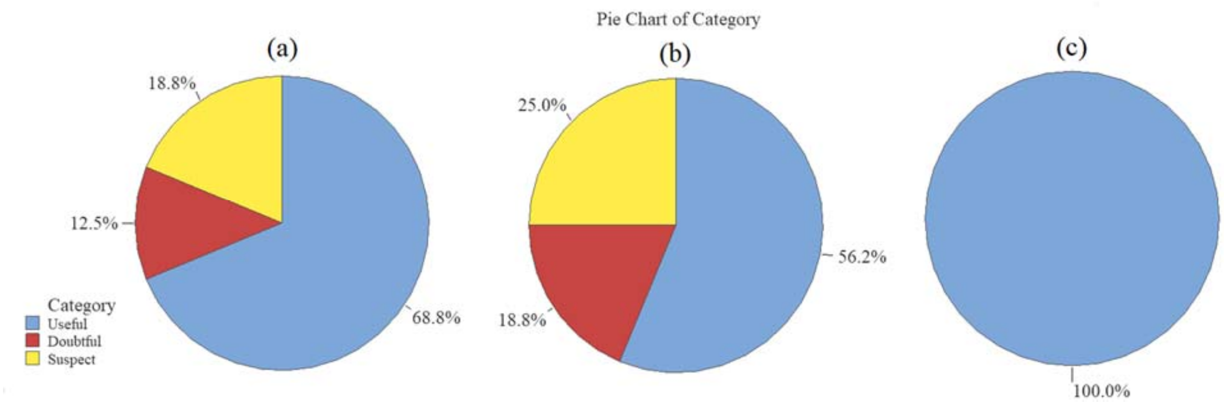

Figure 9. Categories of yearly rainfall **(a)** air temperature; **(b)** discharge; **(c)** stations distribution (%).

results for the six stations were evaluated at a defined significance level (5%) and *p* values less than 5% were considered as a statistically significant change in the data set or a regime change in hydrology. Thus, **Table 7** describes the results found for all seasonal and annual discharge data sets were grouped into useful stations.

The homogeneity tests showed that the NVR had the highest sensitivity for detecting inhomogeneity non-yearly and seasonal data series, whereas, Pettitt's test had the lowest sensitivity. In comparison to other tests, it was shown that the SNHT and Pettitt's tests were the most sensitive to detecting inhomogeneity in the case of the monthly data series.

An overview of the aforementioned Sections 3.2 to 3.4 by percentage category for all the available hydroclimatic datasets in the area of study whether they are reliable, dubious, or suspect is shown in **Figure 9**, which is the final and most significant illustration.

4. Conclusion and recommendations

Homogeneity test analysis and change point detections of the mean annual, seasonal and monthly rainfall, air temperature and streamflow series were executed for sixteen and six meteorological and hydro stations respectively, located in the subbasin. Change point analysis via the non-parametric Pettitt's tests showed that the majority of the detection points at the stations in both seasonal and annual analyses occurred in the years 1992–2007. These change points are suspected of being related to the occurrence of human-induced environmental change[110]. The findings of this study indicate that substantial trends are more often connected with change points that occur across the series[56]. In the current study, the subbasin showed a general trend of raising air temperatures from 2000 to 2017. It was also shown that there was larger decrease in streamflow while no change point was detected in rainfall stations. In comparison to the increase in the mean global air temperature for the past 30 years as reported by Change[7] of the IPCC (2018), and the study by Araya *et al*.[111] shows the increasing point change in air temperature series in Ghba subbasin is due to climate change, and other main driving force is the rapid growth of urbanization in the subbasin[112].

Data accessibility and correctness are the most crucial elements in hydroclimatic researches. One technique of evaluating consistency of a hydroclimatic data series are being compared to neighbouring gauged stations, this continues to be the motivation behind all tests for relative homogeneity. Different statistical tests being used was applied in order to examine homogeneity and changing points in air temperature, rainfall, and discharge in the Ghba subbasin for a varying period of nearly three to five decades. The Ghba subbasin's monthly, seasonal, and annual air temperature, rainfall, and discharge data sets were analysed for homogeneity making use of four statistical tests, SNHT, Pettitt's test, BRT, and VNR. For each unique homogeneity test, all data series were analysed at a significance level of 0.05. Homogeneity tests, as well as point change detection analysis were used to carry out the study's stated goal. For the purpose of providing seasonal comparisons of variations in hydro climatological factors, the evaluations were completed for three seasons, dry, short rainy, and rainy. According to the homogeneity tests, the majority of the annual and monthly (air temperature and rainfall) stations were rated as useful (homogeneous) the discharge stations, however, were categorized as homogeneous at all stations. In contrast, compared to the monthly time series, the yearly discharge and rainfall time series are comparatively more useful (homogeneous). The homogeneous hydroclimatic time series data can therefore be used for all hydroclimatic investigations in any hydrological impact assessment. Although there had never been a homogeneity test study for the stations in the research region, our analysis of change points and station future trends has revealed results that are comparable to those studies by Gebremicael *et al*.[54], Gebremicael *et al*.[56], and Walraevens *et al*.[53] trend analyses, despite the absence of air temperature trend studies in the study area. As a result, our study strongly suggests that several further studies should be conducted, particularly those that focus on the homogeneity of air temperature and generally on the hydroclimatic variables.

Adding other air temperature indices, such as the frequency of hot days, warm nights, chilly days, and cold nights, and exploring their anomalies throughout the complicated terrain of the Ghba subbasin, would be necessary in future studies to analyse the variations in air temperature extremes. Additionally, anthropopressure studies are quite significant because of the human-induced environmental change, one of the possible causes of the regime distribution change.

Author contributions

Conceptualization, MGH and AGA; methodology, MGH; software, MGH; validation, MGH, AGA and AAA; formal analysis, MGH; investigation, AGA; resources, AAA; data curation, MGH; writing—original draft preparation, MGH; writing—review & editing, AAA; visualization, AAA; supervision, AGA; project administration, AGA; funding acquisition, MGH.

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Conflict of interest

The authors declare no conflict of interest.

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