Trend and Variability in Flood Discharge and Attribution to Climate Change in Wabi Shebele River Basin, Ethiopia

Fraol Abebe Wudineh[1](✉), Semu Ayalew Moges[2], and Belete Berhanu Kidanewold[1]

[1] School of Civil and Environmental Engineering,
Addis Ababa University, Addis Ababa, Ethiopia
`fraol.abebe@aait.edu.et`
[2] Department of Civil and Environmental Engineering,
University of Connecticut, Mansfield, USA

Abstract. This study tried to investigate trends and variabilities in mean and extreme hydro-climatic variables in Wabi Shebele River Basin using data based statistical approach. Linear trend investigation and Mann-kendall trend significance tests are performed as a preliminary analysis to see trends on mean discharges and climate variables, while Quantile Perturbation Method (QPM) analysis is conducted to detect clear oscillating patterns and trends in extremes. The result indicates that less increasing trend in mean annual discharge in the basin up to 0.58 Mm^3/year, 1.49 Mm^3/year, 0.94 Mm^3/year and 11.06 Mm^3/year in Maribo, Wabi at Dodola, Robe and Erer river respectively. Similarly, less increasing trend is observed in annual rainfall in western and eastern upper basin whereas decreasing trend in middle and lower part of the basin. Mean temperature shows significant increasing trend in upper and middle part of the basin, but decreasing trend in lower basin. The QPM analysis in flood and precipitation extremes indicates there is five/5/ year frequency of significant anomalies and general increasing trends in floods. In early 1980s, significant negative perturbation was observed in Maribo, Robe and Erer rivers. The precipitation extreme anomalies increase at Adaba station and decrease at Robe (Arsi) station. The correlation between discharges and precipitation decreases from West upper to lower basin part of the basin. Average correlation value (R^2) of 0.23%, 0.027%, 0.02% and 0.08% are observed in Maribo, Robe, Tebel and Erer watersheds respectively.

Keywords: Peak over threshold · Temporal variability · Quantile Perturbation Method (QPM)

1 Introduction

Both changes and variability in the water resources have severely threatened the sustainable water resources development, particularly in the downstream part of the watershed. Therefore, determining the variability of stream runoff is essential task in water resources

M. A. Delele et al. (Eds.): ICAST 2020, LNICST 385, pp. 98–120, 2021.
https://doi.org/10.1007/978-3-030-80618-7_7

management and ecosystem restoration [1, 2]. The mean annual discharge provides a measure of the potential supply; intra-annual and multi-annual variation provides information which can be used to determine the probability of experiencing deficiencies under natural conditions and the amount of storage required [2–4]. In current situations, the hydrology of the earth is shifting with the potential to make floods and droughts more extreme [5]. There is now highly need for decision- makers to better understand the ongoing change and variation in hydroclimatic extremes in order to make preparations for the possibility of changing conditions.

The studies of changes have both a scientific and practical significance. The need to understand the impact that man is having on the 'nature' also another importance. The Wabi Shebele River Basin is one of frequently affected basin by hydrological extremes in Horn of Africa [6, 7]. For instance, in 1996, 1999 unexpected floods destroying homes and crops specially in three districts i.e., Kelafo, Mustahil and Burkur [8]. According to the local authorities, 34 people and 750 livestock died, with 70,000 affected by the floods in these areas. The flood of April 2005 was considered as the worst flood in past 40 years by locals, when 30,000 persons surrounded by flood waters and 6000 live stocks were washed away [7]. Ethiopian Ministry of Water, Irrigation and Electricity (MoWIE) study of Wabi Shebele River Basin master plan shows that severe hydrologic extremes in the basin especially in 1973, 1979, 1984–85 is caused by natural atmospheric variability [28]. Previous studies have focused on water resources potential assessment than trends and variabilities of hydroclimatic elements in the basin [9–12]. A few studies conducted on climate characteristics shows significant declines of annual and summer (June-September) rainfall total since 1982 in south eastern of Ethiopia, using progressive Man-kendall test on annual rainfall of Jijiga and Negele climate gauging stations [13]. Upper Wabi shebele basin at upstream of Melka Wekana is located in high rainy area, which its discharge is affected by rainfall conditions more similar to those of the high Ethiopian plateaus than to those of the downstream of Wabi Shebelle basin [9].

To understand the driving factors of changes in extreme discharges, it is important to look back to historical records and assess how variable the extreme discharges were temporally in the river basin. Also, it is useful to understand whether extreme events become more frequent or intense in the recent years. The statistics most commonly used to describe variability of river runoff are the standard deviation, and the coefficient of variation. Mann-Kendall test and Spearman tests are the most non parametric trend tests used in hydro climatic variables. However, the results of these statistical tests are often influenced by serial correlation and increase the chance of incorrectly rejecting the null hypothesis of no trend or vice versa in most hydro climatological data. To overcome this problem a rather novel approach named quantile perturbation method (QPM) [14–18] which is not dependent on the above-mentioned assumptions is utilized for analyzing temporal trend and variabilities in extreme hydroclimatic variables in this study. The study of temporal changes in extreme events identifies anomalies which can be attributed to different phenomena.

This study aims to assess temporal changes in extreme high discharges in Wabi Shebele River Basin and attribute to climate variables. Specifically, the study aims at: 1) analyzing variabilities in extreme hydro-climatic variables and 2) investigating the correlation in between extreme discharge anomalies and precipitation extreme anomalies for better communicating the science to water resource practitioners.

2 Materials and Methods

2.1 Study Area

Wabi Shebele River Basin is a transboundary basin in between Ethiopia and Republic of Somalia in horn of Africa. It originates from Bale mountain ranges of the Galama and Ahmar of Ethiopia, about 4000 m above sea level and drains portion of Somalia before draining to Indian Ocean. About 72% of the catchment (202,220 km^2) is lying in Ethiopia. In this study, Wabi Shebele basin is used to represent the catchment that is lying in Ethiopia within 4^{o}45' N to 9^{o}45' N latitude and 38^{o}45' E to 45^{o}45' E longitude (Fig.1). The climate of the basin is dependent on the altitude and strong latitudinal movement of the intertropical convergence zone (ITCZ) [11, 19]. The highlands are cool and densely populated while the lowlands are arid and sparsely populated with recorded rainfall of 1487 mm and 220m respectively [2, 28]. While having the largest area coverage, the basin's annual runoff is estimated to 3.4 BCM which is the lowest among the major river basins exist in Ethiopia [19]. The spatial variability of temperature is significant with mean, maximum and minimum value of 19.9 °C, 27.1 °C and 12.6 °C respectively. The mean annual evaporation of the basin ranges from around 1,000 mm in the north-west to 2800–3000 mm in the south-east.

2.2 Methods

Data. Meteorological data including precipitation and temperature were collected from the National Meteorological Agency (NMA). Daily rainfall and temperature (maximum and Minimum) records for 7 stations (Table 1), with a good spatial distribution, were used to see the characteristics of precipitation and temperatures in this study. These stations are selected based on quality of data, length of record, from different watersheds and rainfall regime. The distribution of rainfall between watersheds shows variations (Fig. 3). Significant variation occurs during the rainy season (i.e. June to September). Considerable variation is also observed from April to June and from September to October.

The discharge data in this study were collected from the Hydrology Department of the Ministry of Water, irrigation and Electricity (MoWIE). The measurements of river levels follow the guidelines of the World Metrological Organization (WMO) [20]. Five stations from upper, middle and lower part of the basin, relatively which have long record, one on main river and others on major tributaries of the basin were selected. The monthly database contains maximum and minimum discharges of each month in addition to the monthly average runoff, which assisted to construct the extremes time

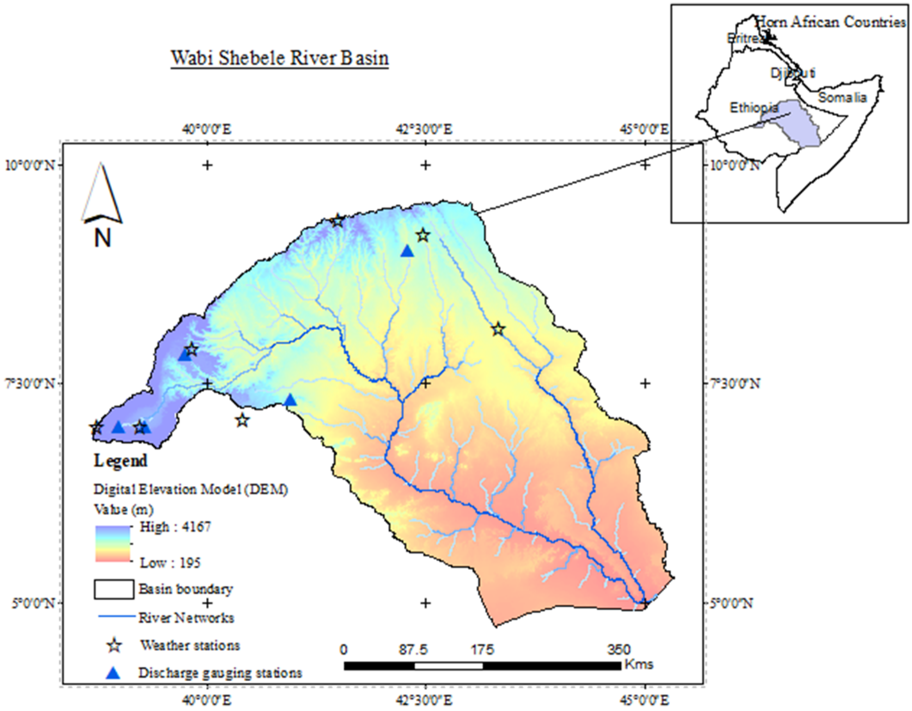

Fig. 1. Map of study area

series. Main characteristics of selected discharge gauging stations are described below (Table 1 and 2).

The number of missed data in discharge is maximum in dry season (October-January) in Wabi Shebele River Basin (Table 2). This may be due to inappropriate placing of discharge gauging station. Adane, [19] reported that some of gauging stations in Wabi Shebele River Basin are installed on raised structures anchored to bridges, while others are off setted in pockets of the main course of the stream. Due to these, most of the stations has shown that the stations are not reliable to capture the low discharge situation in the basin. Therefore, such type of gauging station placing problem may be the cause for missed data especially in dry season. For existing gaps in between data, multiple regression method with adjacent discharge data and rainfall data is used to fill.

Peak Over Threshold Selection (POT). In this study, three highest value for each year from wet season is used to see annual and monthly hydroclimatic variability. In case of daily precipitation analysis, at least 15 extreme measurements per year is selected. To see extreme variability in precipitation and discharge at weekly aggregation level, at least 5 POT values are selected. In case of extreme discharge, similar procedures in precipitation are followed to select monthly and annual extreme discharge.

Table 1. Annual summary of data used in the study.

Data source	Type of data	Period	Station name	Mean annual	Extreme mean	Missing data (%)	Remark
MoWIE	Discharge	1975–2008	Maribo	3.18	16.01	9.27	Catch. Area = 192 km^2
		1975–2015	Wabi at Dodola	7.32	36.14	4.45	Catch. Area = 1040 km^2
		1979–2006	Robe	5.91	24.3	19.97	Catch. Area = 169 km^2
		1983–2006	Tebel at Gindhir	1.2	2.07	11.75	Catch. Area = 79 km^2
		1984–1999	Erer (upper)	2.51	12.7	9.07	Catch. Area = 494 km^2
NMA	Rainfall	1980–2013	Adaba	892.3	182	21.1	Elev. = 2420 m
		2000–2018	Kofele	1107.5	165	6.4	Elev. = 2620 m
		1980–2013	Robe (Arsi)	1113.7	201.5	1.7	Elev. = 2400 m
		1980–2013	Gindhir	1090.7	201.5	11.51	Elev. = 1920 m
		1980–2013	Diredawa	665.4	130.4	1.92	Elev. = 1260 m
		1980–2011	Jijiga	585.5	112.6	2.87	Elev. = 1775 m
		1980–2011	Degahabour	349.6	91.9	5.64	Elev. = 1070 m

Q = Discharge in m^3s^{-1}, RF = Rainfall in mm.

Trend Analysis. Trends and variabilities in hydroclimatic data from year to year were determined by linear regressions and standard deviations. The statistical significancy of trends in the data was determined by the Mann-Kendall test. Both “ZMK” and “p” values were obtained to characterize trends and statistical significance. “ZMK” is the standardized Mann-Kendall (MK) statistic which follows the standard normal distribution with a mean of zero and a variance of one, and “p” is the probability value of the MK statistic also referred to the statistical significance (%). The value of near to zero

Table 2. Seasonal summary of data used in the study.

Type of data	Station/River	Season	Extreme mean	Font size and style
Discharge	Maribo	Dry	10.47	11.43
		Wet	16.01	4.9
	Wabi at Dodola Bridge	Dry	24.73	6.14
		Wet	36.14	2.99
	Robe	Dry	6.52	18.3
		Wet	20.98	22.4
	Erer	Dry	3.9	11.7
		Wet	12.25	6.4
Rainfall	Adaba	Dry	56.86	23.2
		Wet	178.88	21.3
	Kofele	Dry	96.86	10.5
		Wet	155.14	4.6
	Robe (Arsi)	Dry	77.83	2.4
		Wet	195.5	0.6
	Diredawa	Dry	56.9	1.8
		Wet	178.9	1.3
	Jijiga	Dry	46.7	2.6
		Wet	104	3.1
	Degehabour	Dry	33.9	4.8
		Wet	78.2	6.5

Dry = October–March, Wet = April–September.

regression gradient means no trend (the null hypothesis), whereas the value of regression gradient very different from zero means large trend in data (the alternative hypothesis).

Quantile Perturbation Method (QPM). QPM is an empirical statistical analysis used to study trends and multi decadal oscillations in extremes [17]. It uses ranks of time series to detect frequency and perturbation of extreme discharge series in this paper. The perturbation is the ratio of similarly ranked data from the two series i.e. series in block length and refence series. The reference series is the long-term expected series while the other series is taken as the actual series within a particular block (sub-period). Then, for each block of years a single perturbation is calculated as the average of all perturbations above a particular threshold. Repeating the averaging over the different blocks assigns one factor to each block which eventually leads to a temporal variation of the perturbation factor. To identify periods of significant perturbations, the confidence interval is calculated and superimposed on the same plot. To calculate the confidence intervals, the values in the full time series at each site are randomly resampled to make a new series with different sequence, and the anomalies are recalculated for the resampled series based on the QPM method. The anomaly calculations are repeated 1000 times, leading to 1000 anomaly values for each block period. After ranking of the 1000 anomaly factors, the 25th and 975th values define the 95% confidence intervals for each block period. It is then graphically possible to identify periods of significant variations that the perturbation factors between the upper and lower limits of the confidence interval (the region of acceptance of the null hypothesis) are considered insignificant, whereas those outside the region of acceptance of the null hypothesis are defined as statistically significant.

Based on Tabbari et al., [21] recommendations, QPM is applied on different block length (5, 7 and 10-years) to select appropriate value of sub-period (block length) in between 5- and 15-years as preliminary analysis in the study. From preliminary analysis the block length which shows better oscillation patterns (high and low) of extreme value is selected for the whole time series variability analysis.

Pearson's Correlation Coefficient. Pearson's correlation coefficient is used to see the strength of linear relationship between two variables. If the two variables are linearly related, the correlation coefficient will be near 1 or -1. The sign depends on whether the variables are positively or negatively related. The correlation coefficient related to zero (0) if there is poor relationship between the variables. Between rainfall in the Wabi Shebele basin and runoff in main and tributary rivers were determined at daily and annual time scales. The effect of seasonality in precipitation on river discharge was investigated separately by using data from the wet period from April - September (6 months).

3 Results and Discussion

The spatial and temporal variabilities in hydro-climate of Wabi Shebele River Basin is observed using data based statistical approach. Linear regression test, Mann-Kendall trend test and quantile perturbation method (QPM) are used to investigate possible trends and oscillation patterns in river discharge and climate variables. The linear trend test and Mann-Kendall trend test are performed to see trends on mean discharges, total rainfall and mean temperatures and then compare with previous results, while the QPM analysis was used to see trends and variabilities in hydroclimatic extremes due to its capacity to detect clear oscillating patterns and trends in extremes.

As observed on Figs. 2 and 3, the Wabi Shebele basin rainfall is bimodal type taking place from February-May and June – September on high land area and from March-May and September – November in lowland. In western - eastern upper and middle basin, the months from June-September (Summer) is the periods in which largest precipitation record exist, the months from march -may (Spring) is the period in which significant precipitation record exist. But in lowland around Gindhir, Gode and Degehabour, the months from March-May (Spring) and September-November (Autumn) are periods in which largest and significant rainfall records exist respectively (Fig. 2). Therefore, in highland and lowland of Wabi Shebele River Basin has two regimes of wet and dry season categories are exist. The months in which less precipitation is record exist collectively categorized as dry season in both regions. Accordingly, the highland part of the basin around Adaba, Merero, Robe (Arsi), Seru, Deder, Harar and Jijiga have dry season in between October and March, and wet season in between April and September. Whereas the lowland area of the basin around Gindhir, Degehabour, Gode have wet season (March to May; September to November) and dry season (December to February; June to August). The low-lying areas of Wabi Shebelle Basin around Degehabour, Gode, Kebridehar, and Kelafo rains from March to May is caused by moisture from the Indian Ocean, while the October to November rains is associated with the retreat of the ITCZ in a southward direction [11]. The temperature situation of sub basins shows that wet season is the season in which maximum temperature record exist specially February up to May, and the dry is the season in which minimum temperature record exist (Fig. 2).

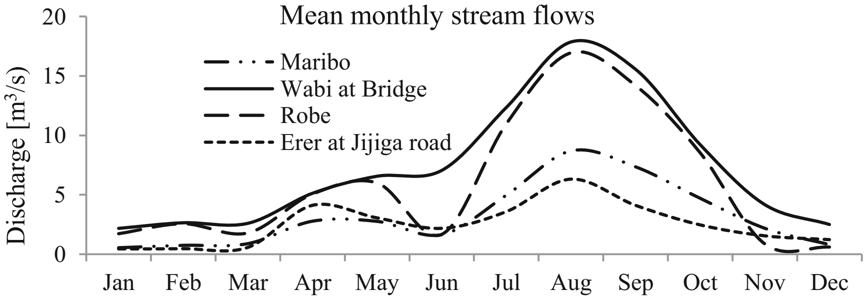

Fig. 2. Mean monthly discharge distributions at selected gauging stations in record length.

In all rivers, the discharge is recorded as maximum in wet season (July to September) season and minimum in dry season (October–March). Around 60% of the annual discharge in all rivers is from the heavy summer (June–September) rains, whereas around 19% of the annual discharge is from spring (February–May) rains.

3.1 The Trend Analysis

In this study linear regression test and Mann-Kendall trend test are performed to see trends and verify its significance on mean discharge, total rainfall and mean temperatures and then compare with previous results. A linear trend analysis to the annual mean runoff at all stations revealed an increasing trend at values of 1.45 Mm^3, 0.58 Mm^3 and 0.94 Mm^3 on Wabi at Dodola bridege, Maribo and Robe respectively. The verification analysis on trend using Mann-Kendall trend test (Table 3) shows insignificant trends for the selected stations at annual and seasonal discharge levels (Table 3). In some stations significant increasing trend in discharge are observed in wet season, for example, in Wabi river at Dodola bridge and Erer river at western and eastern upper basin.

Trends in mean river discharge follows similar trends with rainfall exist in western and eastern upper basin sample gauging stations (Table 3 and 4). The spatial and temporal distribution of rainfall governs amount and intra and inter annual variability of discharges. This indicates that, Wabi Shebele River flow exhibits typical characteristics of tropical rainfall-dependent discharge regimes. Similar result in discharges was obtained from trend analysis on mean river discharge in between 1975 and 2015 in Wabi Shebele River Basin shows less or insignificant trends (Table 3).

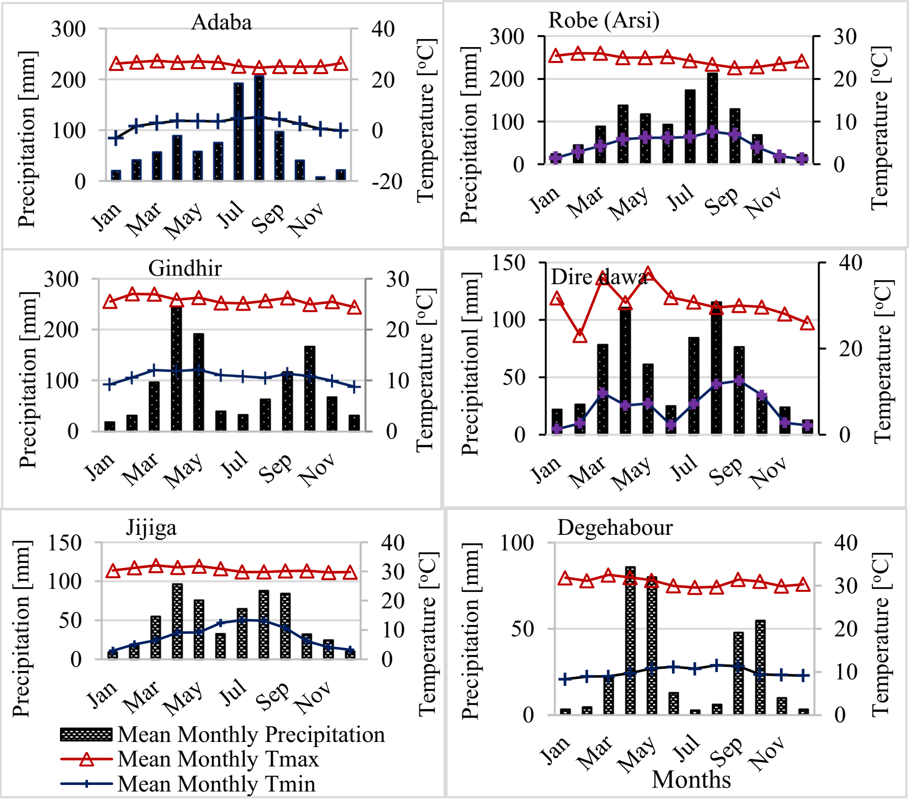

Fig. 3. Mean monthly precipitation and temperatures distributions at selected gauging stations.

Table 3. Statistical summary of trend test in mean annual discharge.

Stations	Data type	Period	Average (Mm^3)	St. dev. (Mm^3)	Slope (Mm^3/year)	S	α	Z_{mk}	p-value
Maribo	Discharge	1975–2008	100.2	24.32	0.581	587	0.05	1.48	0.092
Wabi at Dodola Bridge	Discharge	1975–2015	230.9	64.44	1.485	164	0.05	1.83	0.619
Robe	Discharge	1979–2006	48.5	28.19	0.944	74	0.05	1.44	0.086
Tebel	Discharge	1983–2006	3.00	1.66	0.179	192	0.05	4.73	0.001
Erer	Discharge	1984–1999	87.5	78.29	11.07	48	0.05	2.03	0.018

Trend analysis on annual, seasonal and monthly rainfall indicates less or insignificant increasing trends in record length (1980–2013) at western and eastern upper Wabi Shebele Basin on Bale, Arsi and Harar highlands. But, significant decreasing trends in rainfalls is observed at middle and lowland area of the basin around Arsi robe, Gindhir and Degehabour in Wabi Sheble basin (Table 4). The wet season (April to September) rainfall has shown insignificant increasing trend in the basin. The study conducted by EPCC [22] also indicates insignificant trend of summer rainfall which range from +4 up to −5 mm/decade and substantial decreasing trends in spring rainfall during the last three decades from 1975–2007 in the basin.

Temperature trend analysis shows significant increasing trends in most of gauging stations located in upper and middle part of the basin except lower part of the basin around Degahabour which shows significant decreasing trend (Table 5). The south-eastern part of the low-lying areas of the basin around Degehabur, Gode, Kebridehare, and Kelafo receives no rainfall in July and August and has two rainy seasons [11]. The first is from March to May, and the second is from October to November. As tried to explained under Sect. 2.2, max temperature in the basin is recorded in wet season and minimum temperature is in dry season. The temperature trend difference from other part of the basin probably tied to rainfall distribution difference from others.

Table 4. Statistics summary of trend in annual rainfall.

Stations	Data type	Period	Average (mm)	St. dev. (mm)	Slope	S	α	Z_{mk}	p-value
Adaba	Rainfall	1980–2013	892.3	303.2	0.8	99	0.05	1.48	0.44
Kofele	Rainfall	2000–2018	1097.6	107.6	−7.62	−55	0.05	−1.97	0.17
Robe (Arsi)	Rainfall	1980–2013	1113.7	339.8	−19.3	−169	0.05	−2.52	0.04
Gindhir	Rainfall	1980–2013	1090.7	455.4	−10.9	−1	0.05	−0.03	0.39
Diredawa	Rainfall	1980–2013	665.4	151.0	2.38	39	0.05	0.56	0.64
Jijiga	Rainfall	1980–2013	585.5	108.8	1.6	57	0.05	0.91	0.33
Degehabour	Rainfall	1980–2011	349.6	155.3	−3.8	−85	0.05	−1.39	0.304

3.2 Trends and Variabilities in Annual Extremes

Quantile perturbation method (QPM) is used to see possible trends and variabilities in extreme discharge and climatic variables. The method has a capacity to explore clear oscillating patterns and trends in hydroclimatic extremes. The method also has also the option of identifying the statistical significance of the variability observed and thus the statistical significance of the variability identified. The mean perturbation is assigned to a year which is approximately in the middle of the block. The value of confidence interval is superimposed on the same plot of extreme perturbations to identify the periods of significant variations.

From preliminary analysis conducted, 5 (five) year block of periods shows better oscillation patterns (high and low) of extreme discharges and precipitation in comparison

Table 5. Statistics summary of trend in mean temperature.

Stations	Data type	Period	Average (°C)	St. dev. (°C)	Slope	S	α	Z_{mk}	p-value
Adaba	Temperature	1980–2013	14.66	0.714	0.05	239	0.05	3.5	0.001
Kofele	Temperature	2000–2018	19.56	0.527	0.01	55	0.05	1.9	0.397
Robe (Arsi)	Temperature	1980–2013	14.85	0.689	0.06	339	0.05	5.0	0.001
Gindhir	Temperature	1980–2013	18.32	0.70	0.02	115	0.05	1.7	0.139
Diredawa	Temperature	1980–2013	25.54	0.40	0.03	330	0.05	4.9	0.002
Jijiga	Temperature	1980–2013	19.50	0.654	0.04	194	0.05	3.1	0.002
Degehabour	Temperature	1980–2011	19.30	6.333	−0.3	−161	0.05	2.8	0.005

to 7- and 10-years block lengths as shown on Fig. 4. Hence a 5-year block was used as block length of variability analysis in this study.

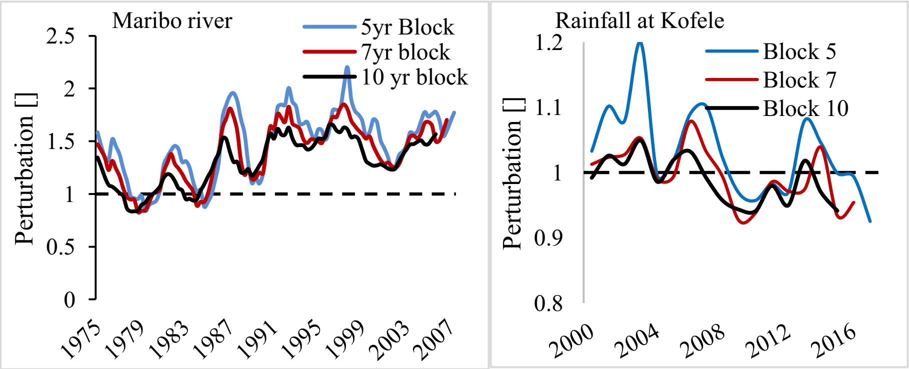

Fig. 4. Extreme perturbations at different block lengths on both discharge and precipitation.

Extreme Discharge. When considering extreme high discharges in annual time steps, most of perturbation values varies within confidence interval (Fig. 5). Among gauging stations increasing trend is observed on Maribo river. In early 1980s, significant negative perturbation up to −26.5%, −17.8%, −25% and −20% was observed in Maribo, Robe, Tebel and Erer watersheds respectively. Whereas, maximum significant perturbations up to 88.3%, 95.6%, 610% and 482% are observed respectively in watersheds in between 1986–1989. High oscillation pattern in annual extreme high discharges were observed in upper basin watersheds. Generally, extreme high discharge quantile perturbation shows increasing trend in Wabi Shebele River Basin from 1975 to 2015. The estimated confidence intervals are wide enough excluding the possibility of statistically significant change. Therefore, significant anomalies of extreme discharges can be due major driving factors like climate variables or catchment characteristics.

The oscillation pattern of extreme discharge quantiles changes within half a decade in both directions negatively and positively, which shows existence of external factors effects with in a given interval of years. For instance, the sea surface temperature change (SST) occurrence over the globe will occur within two to seven year interval in the form of El-Nino and La-Nino [23]. The effect this climate change indices is high over the world including our country. There is a consequence of flood and drought in Ethiopia during the occurrence year of these indices [24]. Most of positive significant anomalies of extreme discharge quantiles in Wabi Shebele River Basin occurred in moderate to very strong El-Nino years (Table 6). Contrary most of negative significant anomalies in the basin occurred in week to strong La Nino years. This indicates global climate change indices are a probable cause for changes of extreme discharge quantiles in Wabi Shebele River Basin. The impact of El Niño and La Niña are surprisingly increasing over the globe especially in developing countries like Ethiopia which their economies are dependent on regularly occurring seasonal weather conditions.

Table 6. Summary of QPM analysis in annual extreme discharge.

Sub basin	Magnitude of highest anomaly (%)	Time of highest anomaly	Remark
Maribo	−10.7 −11.9 +95.6 100.5 120.5	1979 1984 1987 1992 1997	WE WL SE SE VSE
Wabi at Dodola Bridge	−26.5 +61.5 +85.3 −15.5 −20.1	1979 1982 1987 1990 2002	WE VSE SE SL ME
Robe	+610.5 +655.7	1989 1999	SL SL
Tebel	−53.2 +846.9 +1071.3	1983 1997 2002	VSE VSE ME
Erer	−31.1 +482.5 +501.1	1985 1988 1996	WL SE ML

WE = Weak El Niño, SE = Strong El Niño, VSE = Very strong El Niño, WL = Weak La-Niña, SL = Strong La-Niña years.

The effects of El Niño southern oscillation had a variable impact on Horn African countries, ranging from drought to floods in history [25]. El Niño refers to the large-scale ocean-atmosphere climate interaction linked to a periodic warming in sea surface temperatures across the central and east-central Equatorial Pacific and La Niña represent periods of below-average sea surface temperatures across the east-central Equatorial Pacific [26]. The humanitarian impact of La-Niña is greater when it immediately follows an El-Niño. In 1988 El Niño year's floods affected 2.5 Million peoples, whereas the 1999 and 2011 drought years occurred following La-Niña events affected 31.5 Million and 14 Million peoples respectively in the region including Wabi Shebele basin [24].

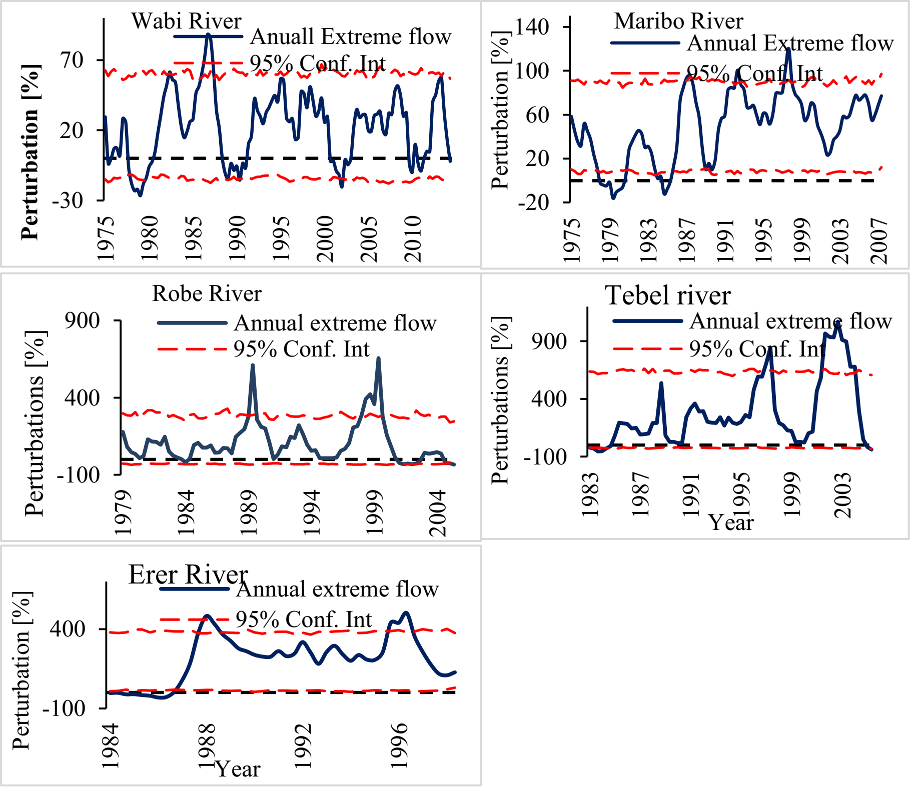

Fig. 5. Extreme discharge variability with confidence interval in Wabi Shebele River Basin.

Precipitation Extremes. The perturbation in precipitation extreme varies within confidence interval in most of stations of the basin taken in consideration. But unique result is observed on Adaba and Robe (Arsi) stations record (Fig. 6). An increasing and decreasing trend of precipitation extremes is observed in Adaba and Robe (Arsi) stations respectively. In early 1980s significant negative anomaly up to −10.4% is observed at Adaba station, but maximum positive perturbation of +38.2% is observed at Robe station. In 2000s significant positive anomaly of +137.8% is observed at Adaba and significant negative anomaly of −39.2% at Robe (Arsi) rainfall stations are observed. In the other side most rainfall stations indicate significant positive precipitation anomalies in early 1980s specially between 1982–1983 and immediate decreasing trend in between 1984 and 1985 (Table 7 and Fig. 6). Generally, most of rainfall perturbation analysis indicates decreasing trends in middle Wabi Shebele basin.

In Ethiopia, droughts and floods are occurred frequently at every 3–5 years for last 50-years [27]. The actual power generated from Melka Wakena Dam, the hydropower plant exist in this sub basin, shows power decrement in 1991, 1996 and 2000 by 32%, 21% and 38% relative to their Preceded years [20].

In other side western and eastern upper Wabi Shebele basin indicates significant positive anomaly in precipitation extremes in 2000s. This also coincided with the resent study result [7, 19, 24, 28, 29] which indicates several devastating floods in Wabi Shebele River Basin in recent years. The destructive flood in August 2005 on the basin affected 100,000, 154 deaths and the flood occurred starting November 2008, in basin caused around 52,000 human displacement from 14 kebeles (small admirative unit), 185 villages and 164-hectare farm lands washed away [29].

Table 7. Characteristics of highest anomaly in precipitation extremes.

Station name	Magnitude of highest anomaly (%)	Time of highest anomaly
Adaba	−14.4 +76.8 −18.3 137.8	1983 1990 2000 2009
Kofele	+42.2 +47.9 −9.7	2006 2007 2017
Robe (Arsi)	+38.2 +34.5 −47.1 −36.9	1982 1987 1993 2001
Gindhir	+170.7 −33.5 −42.5 −38.6	1980 1994 2000 2003
Diredawa	−20.06	1984
Jijiga	+47.3 −19	1986 2008
Degehabour	+210.4 +215.5 −20.8 +201.2	1982 1986 1990 2000

Temperature Extremes. There are a few limitations in the application of the frequency perturbation method for temperature compared to rainfall. First, the independence criterion is difficult to ascertain as there are correlation in daily value similar to river

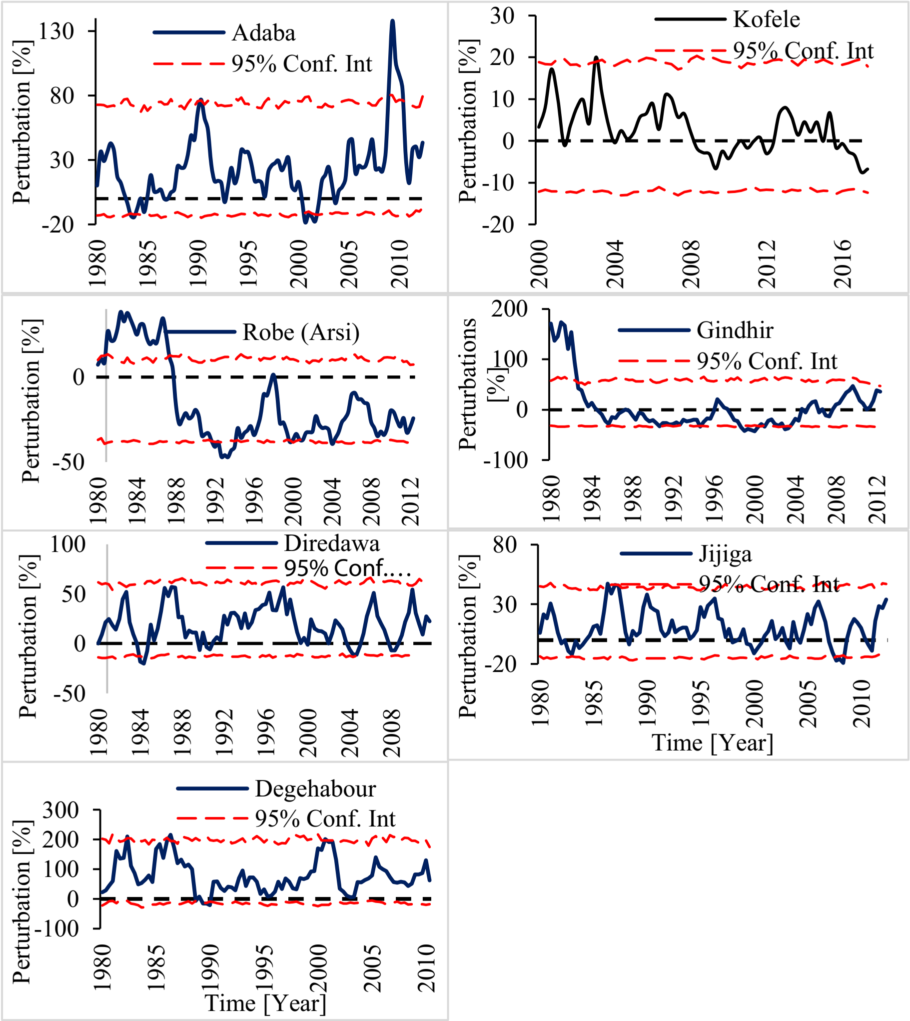

Fig. 6. Annual precipitation extreme perturbations using 5-year block length with 95% Confidence interval at seven /7/ gauging station of Wabi Shebele River Basin.

discharge. For this study, the independence criterion was ignored. Instead, only a threshold for the peaks was selected. Second, temperature significance periods were not based on 95% confidence intervals because there was no reasonable distribution valid for all the periods in temperatures [17]. Therefore, temperature anomalies were then analyzed based on the long-term average perturbation.

Extreme high temperatures in Wabi Shebele River Basin perturbation analysis shows general increasing trends in the basin particularly in upper and middle of the basin but less decreasing trend in lower part of the basin (Fig. 7). Starting 1990 significant increasing trends are observed in Adaba, Kofele, Robe gauging stations record.

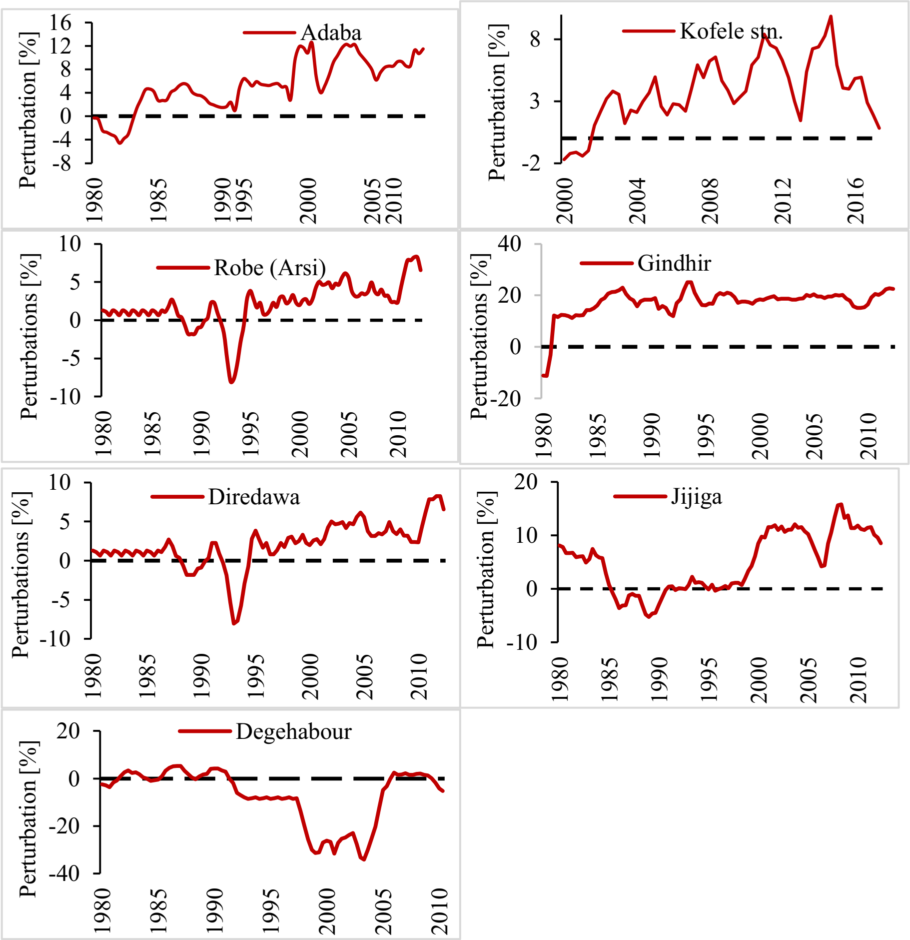

Fig. 7. Extreme high Temperature average perturbations using 5-year block length at selected gauging stations in Wabi Shebele Basin.

3.3 Trends and Variabilities in Seasonal Extremes

The QPM approach is applied to extreme value at seasonal aggregation level. Three maximum events are selected from each season to see temporal variability in extreme seasonal flood events. Two seasons, i.e. dry (October–March) and Wet (April– September), are used to see extreme quantiles in this study.

Extreme Discharge. QPM analysis conducted on seasonal extreme discharges indicates significant positive anomalies in dry season streamflow of upper Wabi shabele basin at five years interval in average i.e., 1977, 1982, 1987, 1997 and 2008. These years are directly coincided with weak to very strong El-Nino years.

Table 8. Characteristics of highest anomaly in seasonal discharges.

Station/River name	Magnitude of highest anomaly (%)	Season of occurrence	Year
Maribo	+370	Dry	1997
Wabi at Dodola Bridge	+265.1	Dry	1997
Robe	+967.3	Dry	1989
Tebel	+1029.7	Wet	2001
Erer	+1318.9	Dry	1998

For Wet season quantile perturbation analysis also shows similar dry season perturbation oscillation patterns. There are both negative and positive significant anomalies occurred in upper Wabi shebele river discharge extremes at half a decade interval. Accordingly, the years 1976, 1982, 1986, 1995 and 2010 are the yeas in which positive significant anomalies observed in wet season. Whereas the years like 1978–80, 1984–85, 1990 and 2001–02 are the years in which significant decrement of extreme discharge observed in upper Wabi Shebele River Basin. Similar to dry season, wet season positive significant anomalies are separately observed in moderate to very strong scale El-Nino years. Whereas negatively significant anomalies are observed in La-Nina years.

Precipitation Extremes. Except the years like 1988 and 1997, most of the precipitation extreme over Wabi Shebele River Basin changes within confidence interval. The 1988 the rainfall across the basin shows significant positive anomalies in the basin during dry season. It is also evident that, there is increasing trend in extreme precipitation on Adaba station rainfall. The 1988 was the year in which high flood disasters occurred in the horn of Africa as a whole [24]. Similar results are reported by MoWR [20] on upper Wabi Shebele basin around Adaba. In early 1990s and late 2000s significant increasing trend is observed in dry season.

In wet season (April- September), the extreme precipitation anomalies obeyed two phases in Wabi Shebele River Basin, decreasing trend in between 1980–1990 and less increasing trend in between 1990 to 2013. Early 1980s and 1990s are years in which significant positive and negative anomalies are observed respectively in most of stations (Table 9).

Temperature Extremes. *Q*PM analysis on seasonal extreme high temperatures indicates increasing trend in both dry and wet season (Table 10). The size of positive trends decreases from western to eastern upper basin and indicates general decreasing trend in downstream of Wabi Shebele River Basin around Degehabour and Gode area. There is strong arguments in literatures that, with more water vapor and heat in the atmosphere, results for high storms [30–32].

Table 9. Characteristics of highest anomaly in seasonal extreme precipitation

Station name	Magnitude of highest anomaly (%)	Season of occurrence	Year
Adaba	+666.6	Dry	1990
Kofele	+32.9	Wet	2004
Robe (Arsi)	+5948.9	Dry	1982
Gindhir	+777.1	Dry	1992
Diredawa	+1493	Dry	1997
Jijiga	−23.7	Wet	1999
Degehabour	+251.7	Wet	1985

Table 10. Characteristics of highest anomaly in seasonal extreme high temperatures.

Station name	Magnitude of highest anomaly (%)	Season of occurrence	Year
Adaba	+15.8	Wet	2004
Kofele	+11.9	Wet	2014
Robe (Arsi)	+12.8	Dry	2002
Gindhir	+18.9	Dry	1990
Diredawa	+12.9	Dry	2012
Jijiga	+17.9	Wet	2008
Degehabour	−35.6	Dry	2003

3.4 Effect of Aggregation Level on Detected Anomalies

The effects of time aggregation on variability analysis is investigated based on QPM analysis on daily, monthly and annual anomalies in the study area. In extreme discharge perturbation analysis, anomalies at daily aggregation level is less than both monthly and annual perturbation (Fig. 8). Whereas, the precipitation extreme perturbation at daily aggregation level are higher than both monthly and annual aggregation level (Fig. 9) which coincided with the study result of Ntegeka and Willems [17]. This indicates that, the extreme discharge perturbation conducted by QPM at different aggregation level gives completely opposite result with the study result of Ntegeka and Willems [17] in which the perturbations of smaller aggregation level are greater than larger level. It is known that the first day discharge has significant effect on the next day or lack of independency in daily discharge may be the cause for less anomaly in small time aggregation level.

3.5 Correlation Analysis

Intergovernmental Panel on Climate Change (IPCC) [26] indicate that climate change “has detectably influenced” several of the water-related variables that contribute to

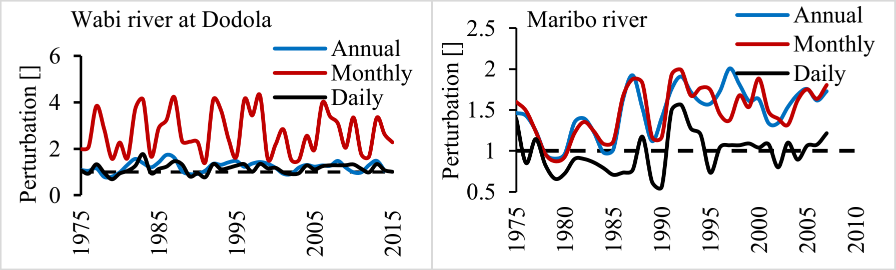

Fig. 8. Comparison between extreme discharge perturbations at different aggregation levels

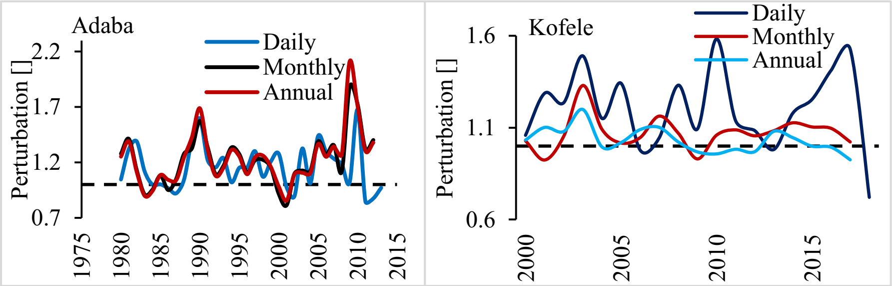

Fig. 9. Comparison between precipitation perturbations at different aggregation levels.

floods, such as rainfall and snowmelt [26]. In this study the rainfall variability in Wabi shebele basin was taken as one of the major driving factors for flood change in the basin. To confirm this hypothesis, Pearson's correlation analysis is conducted on extreme anomalies of discharge and precipitation in different watersheds of the basin (Table 11). The statistical significance of correlation value is checked using student test at 5% significance error.

The result indicates that oscillation pattern of both variables, i.e. extreme discharge and precipitation anomalies are similar even though the statistical correlation value shows a little bit small. From Table 8, it is evident that in dry season a better positive correlation value in between extreme discharge and precipitation up to 62%, 20%, 30%, 53% and 65% are observed at Maribo, Wabi at Dodola, Robe, Tebel and Erer watersheds respectively. Further in Wet season, low negative correlation value up to −42%, −42% and −9% are in Maribo, Wabi at Dodola and Robe watersheds respectively. Whereas positive wet season correlation value up to 31% was observed in Erer watershed. In general, statistical correlation using Pearson's correlation coefficient method shows, less than 50% correlation value in average in between extreme discharge and precipitation correlation. This implies that for change in extreme discharge in Wabi Shebele River Basin, there is other driving factors in addition to climate elements. There was study result by MoWR, [20], in upper Wabi Shebele River Basin (upstream of Melka wakena) strong flood only occurs when soil has been previously saturated with water after the first rainy phase. This is because of not very intense rainfall conditions and considerable perviousness of soil in sub basin.

Table 11. Annual and seasonal correlation coefficient between discharges and rainfall.

Station name	Annual	Dry season (October–March)	Wet season (April–September)
Maribo	0.03	**0.62***	0.004
Wabi at Dodola Bridge	−0.20	0.20	-0.18
Robe river	−0.09	0.3	-0.13
Tebel river	−0.18	**0.53***	-0.29
Erer river	−0.14	**0.65***	-0.27

* = Statistically significant at 5% significant error

4 Conclusions

Temporal variabilities in hydro climate variables were examined for Wabi Shebele River Basin in between 1975–2015. The preliminary trend detection done on discharges at five sample rivers using linear trend regression test which is verified by Mann-Kendall significance test indicates less/insignificant increasing trends on mean annual discharge. Rain fall trend analysis conducted on total rainfall of different stations in the basin indicates significant decreasing trend in middle and lower part of the basin. The western and eastern highland area of the basin indicates less increasing trends in rainfall. The trend analysis conducted on mean temperatures indicates significant increasing trend in Wabi Shebele River Basin.

The temporal trend and variability analysis done on extreme high discharge using QPM approach indicates significant increasing trend in Maribo river from western upper basin and Erer river discharge from eastern upper basin. The other most extreme discharge anomalies vary within confidence interval. The dry and wet seasons anomalies mostly follow similar oscillation pattern with annual extreme discharge anomaly. Most of positive significant anomalies of extreme discharge quantiles in Wabi Shebele River Basin occurred in moderate to very strong El-Nino years. Contrary most of negative significant anomalies in this sub basin occurred in week to strong La Nino years. Therefore, we can conclude that global climate change indices may be the other influential factors for increments and decrements of extreme discharge quantiles in Wabi Shebele River Basin in addition to other driving factors in the sub basin. The precipitation extreme perturbations analysis shows increasing trend at all aggregation levels in western and eastern upper basin and decreasing trend in middle in between 1980 and 2018. QPM analysis on extreme high temperature indicates significant increasing trend with high oscillation pattern. The study conducted by EPCC [22] reveals similar result that substantial increasing trend in rainfall over south eastern highlands of Ethiopia and warming trend of about 0.4 °C/decade in the region which strengthen the current study.

The QPM analysis conducted to explore the effect of time aggregation level on extreme quantile perturbations indicates that, the perturbations for the annual aggregation level are generally greater than both monthly and daily perturbations in case of extreme discharge, which completely contradict to the result obtained in case of precipitation, in which extreme perturbation at daily aggregation level is greater than both monthly and annual perturbation. This indicates, the extreme discharge perturbation conducted by QPM at different aggregation level on extreme discharge gives completely opposite result with the study result of Ntegeka and Willems [17] done on precipitation extreme, which is the perturbations of smaller aggregation level are greater than larger level. The correlation analysis done between extreme discharge and precipitation indicates strong correlation of dry season extreme discharge and precipitation anomaly up to 65% in some watersheds, even though it falls below 50% in other sample watersheds.

Wabi Shebele River Basin is largest basin in Ethiopia with ungagged hydrologic characteristics. It is hard to characterize the whole basin extreme hydroclimatic variabilities with only five sub basins which most of it confined at upper highland area of the basin, while the basin has more than 11 sub basins with larger than 500 km^2 catchment area. Therefore, extension of river discharges and precipitations in ungagged sub basin using robust model and analysis can explore better information on trends, temporal variabilities, correlations and periodicities in extreme hydroclimate variabilities of the basin.

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