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Research Article

Watershed-Based Rainfall variability and trends of extreme rainfall events in South East Awash Basin, Ethiopia

Yonas Tadesse Alemu

Department of Geography and Environmental Studies, Dire Dawa University, Ethiopia, P.O.Box 1362

Abstract: This study presents analysis of Rainfall variability and trends of extreme rainfall events. The study employed the coefficient of variation and the Precipitation Concentration Index (PCI) as statistical descriptors of rainfall variability. The indices at the five stations were subjected to non-parametric Mann-Kendall test to detect the trend over the period between 1985 to 2014. The study results reveals, the watershed experienced moderate inter-annual rainfall variability. The *Belg* rainfall shows high variability than *Kiremt* rainfall. Highest *Belg* & *Kiremt* rainfall variability is observed in *Dire Dawa* with coefficient of variation of 46% and 40% respectively. The PCI analysis showed that 100% of the years for annual PCI and *Belg* rainy season was fell within the irregular precipitation distribution. The annual rainfall has showed a negative trend in most of the stations. The Mann–Kendall trend test during the *Kiremt* season shows a positive trend in *Dengego*, *Dire Dawa*, *Combolcha* and *Haramaya* at significant p<0.1 in *Degego*, p<0.05 in *Dire Dawa*, p <0.05 in *Combolcha* and p <0.01 in *Haramaya*. The heavy rainfall events, the 90th & 95th percentiles, in all the five stations showed an increasing pattern. This implies that the watershed has been vulnerable for extreme hydro-meteorological events.

Key Words: Rainfall variability; extreme rainfall; trends of rainfall, south East Awash Basin; Ethiopia.

Introduction

The rainfall pattern in Ethiopia was highly variable during the 20th century, and the geological record of changes of lake-levels, for example, confirms high rainfall variability (Gissila *et al*. 2004; Nicholson 2000 in Rosell and Holmer, 2007).

Ethiopian agriculture is heavily dependent on natural rainfall, with irrigation agriculture accounting for only around 1.1% of the total cultivated land in the country. The amount and temporal distribution of rainfall is thus the single most important determinant of national crop production levels from year to year, and rainfall in much of the country is often erratic and unreliable. Rainfall variability and associated droughts have historically been major causes of food shortages and famine in the country ((Wood, 1977; RRC, 1985; Pankhurst and Johnson, 1988 in Woldeamlak & Conway, 2007). Apart from drought as such, seasonal and annual rainfall variability is a significant economic burden to Ethiopia. According to the World Bank, current rainfall variability costs the Ethiopian economy 38% of its growth potential (Woldeamlak, 2012).

Extreme weather events in Ethiopia significantly affect the agro-socio-economic environment. Droughts in northern, southern and eastern Ethiopia cause great human sufferings and losses of life. Such consequences not only result from insufficient total rainfall amount, but also from long dry spells within the rainy season (Sileshi and Camberlin, 2006).

Ethiopia already suffers from climate variability and extreme events, which have had immense social, economic, environmental and infrastructural costs (Woldeamlak, 2012). For instance, interannual variation in the performance of the national economy is largely controlled by rainfall variability (World Bank in Woldeamlak, 2012). According to Roy and Balling (2004), one of the most significant consequences of global warming would be an increase in the magnitude and frequency of extreme precipitation events brought about by increased atmospheric moisture levels, thunderstorm activity, and/or large-scale storm activity. As noted in the latest assessment of the IPCC (2014), climate models generally predict an increase in extreme precipitation events given a build-up of greenhouse gases, and in many parts of the world an increase in these large precipitation events has been observed during the period of historical records.

The spatial and temporal variability of rainfall is high in Ethiopia and the rainfall variability represent an important component of gaining knowledge of the water balance dynamics on different scales for water resources management and planning (De-Luis et al., 2011; Ezemonye & Emeribe, 2011 in Adegun, 2012; Oromia National Regional State, 2011). Information derived through a good understanding of the spatial and temporal characteristics of rainfall is very important for agricultural planning, flood frequency analysis, hydrological modeling, water resources assessments, assessing and understanding climate change impacts and other environmental assessments (Adegun et al., 2012).

Seleshi and Camberlin (2006**)**, reported absence of trends in many indices of extreme rainfall events for the *kiremt* and *belg* rainfall seasons in much of Ethiopia and absence of trend in the length of maximum dry spells (days with <1 mm rainfall) in *kiremt* and *belg* seasons.

The temporal distribution of rainfall during the growing season is an important influence on crop yields and can induce food shortages and famine (Bewket & Conway, 2007).

National Meteorological Services (2007) in Temesgen et al. (2010) showed that there was a very high variability of rainfall over the past 50 years. The country's average annual rainfall has recently shown a very high level of variability, even though the trend has remained more or less constant (National Meteorological Services, 2007 in Temesgen et al., 2010).

On the other hand, as reported in Bewket & Conway (2007), rainfall has recently exhibited a downward trend in parts of Ethiopia. Seleshi and Demar´ee (1995) identified a declining trend in the main June–September (*kiremt*) rains. Seleshi and Zanke (2004); Verdin *et al*. (2005) in Cheung et al. (2008), did also find significant declines in the annual and *Kiremt* rainfall totals in the eastern, southern and southwestern parts of Ethiopia.

The warm and drier lowlands, particularly extensive in the south east, eastern and north eastern parts of the country, are inherently areas of low and erratic precipitation not suitable for reliable crop production and are used for extensive pastoral livestock production (Coppock, 1994 in Aklilu et al., 2013). Rainfall in semi-arid zones shows high year-to-year variability, a fact which is particularly valid for the study region as well as for other parts of Ethiopia (Elisabeth, 2004).

This paper is intended to analyze rainfall variability at annual and seasonal time scales and examine trends of extreme rainfall events in the Oda Gunufeta -Cherecha -Dechatu watershed, Awash Drainage Basin in Eastern Ethiopia.

The study area

The Oda Gunufta- Chercha - Dechatu sub-watershed (figure 1) is located within Awash River Basin. About 30% of the watershed is found within the East Harerge zone, Oromiya National Regional State and the remaining 70% lies in Dire Dawa Administrative council. Due to its tropical location the area experiences high temperature throughout the year with minor seasonal variations. Temperature progressively increases northward from a temperate type along the mountain side to its southern most point. The mean annual average air temperature is $29^{0}{}_{C.}$

The seasonal rainfall has a bimodal distribution with peaks in April and August. The two rainy seasons are spring and summer locally called '*Belg*' and '*Kiremt*' respectively, separated by a short dry spell in June. The average annual rainfall is 600 mm. Average evapo-transpiration is much more than precipitation, i.e. 3255 mm, with low relative humidity of 36% and 40% at elevations 1200 and 1800 m.a.s.l. respectively (DDAC Water, Mines & Energy Resources Development Office, 2002).

The area is one of the drought affected region of the country with varied farming and pastoral systems. In these areas, rainfall is inadequate, erratic in distribution with a short growing season. Agriculture in the rural part is rudimentary and low in productivity. Food insecurity is the most important human deprivation in the region, and is related to lack of access to adequate food, that manifests itself in its extreme form as hunger and famine (DDAC Water, Mines & Energy Resources development Office, 2002).

With regard to River System and Hydrology almost all the streams originate from mountain ranges located immediately south of the watershed and flows North wards, finally end up into Awash River. The streams originate from the escarpments and rush down the steep slopes creating high peak of short span flood. This is aggravated by depletion of vegetation cover due to land use change. The geologic set up of the area could also be a driving force for higher runoff coefficient.

There are no perennial rivers in the area except some streams that have connection to springs. Even these streams are no more on the river course due to upstream abstraction for irrigation. From the nature of the river courses wide and sandy and gravelly bed it could easily be deduced that the amount of flood during rainy seasons is enormous. Almost all the river courses in the regional have got the same characteristics. The secondary information and data collected proved also that the torrential rainfall in the catchment area produces high but short-lived flood. The sediment yield from the catchment is also quite significant (DDAC Water, Mines & Energy Resources Development Office, 2002).

According to DDAC Water, Mines & Energy Resources development Office (2002), the agro-pastoralist & pastoralist Agro-ecological Zones are the major categories of the watershed. Rain fed crop farming is the major important activity for the households of agro-pastoral areas. In these areas, rainfall is inadequate, erratic in distribution with a short growing season. The pastoral community's livelihood is based on keeping of livestock, which is highly affected by the harsh climatic condition of the area.

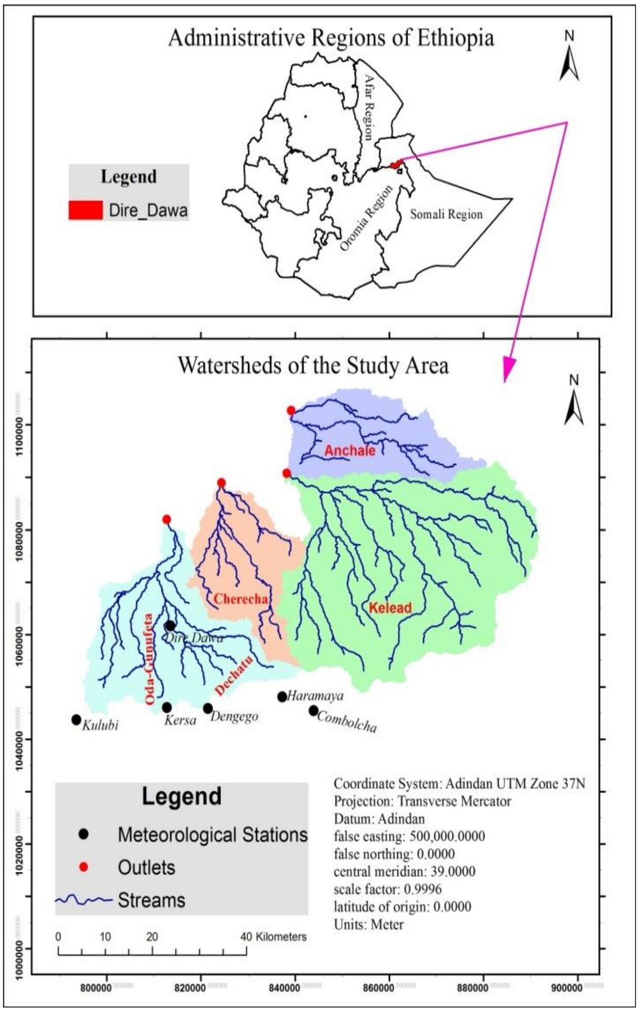

Fig. 1 the study watershed

Source: Ethiopian National Meteorological Agency (2015)

Data and methods

To analyze the historical climate dynamics, rainfall data were arranged at monthly, seasonal and annual time scales. The rainfall data were collected from the Ethiopian National Meteorological Services Agency. Relatively long rainfall records were obtained for 5 stations; Kulubi; Haramaya; Dire Dawa; Dengego and Combolcha. Missing daily rainfall values were filled using correlation of daily data with neighboring stations. This procedure was mainly applied to one station (Dengego) whose data showed discontinuities in 1991. Similar strategy was used by Bewket & Conway, (2007) in the analysis of temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. Kersa station was omitted from the analysis because it has relatively lesser record periods. All the 5 stations records are analyzed at monthly and daily time steps. The monthly records were used to analyze the rainfall variability while daily records were used to examine the extreme events. The period 1985-2014 is taken the common period having best data for all the 5 stations. The extreme rainfall conditions were assessed by arranging the daily rainfall data at 5 percentile, 10 percentile, 90 percentile and 95 percentile manners and trends of extreme events were calculated. In this study, a daily total for each station was selected based on the frequency distribution of precipitation for the entire 1985 to 2014 periods.

Extreme frequency is a count of high rainfall events per *kiremt* or *Belg* season. An 'extreme' rainfall is defined here as being equal to or above the 1985-2013 mean 95^{th} percentiles. Extreme proportion measure how much of the total rain comes from extreme events: it is the proportion of seasonal rainfall that comes from the highest six rainfalls each season (Sileshi and Camberlin, 2006). Then, the long-term mean, and coefficient of variation were computed for all the annual and seasonal rainfall. As it has been noted by Sileshi and Camberlin (2006), changes in extreme seasonal rainfall could be measured by extreme rainfall indices with daily rainfall data. One of the indices was extreme intensity, defined as the average intensity of events greater than or equal to the 95th percentile.

Table 1: Rainfall stations in the study watershed

Stations	Altitude(m)	latitude	Longitude	Series length	No. years with missing data
Dengego	2078	9^0 21'N	41^0 52'	1985-2014	1
Dire Dawa	1180	$9^0$49'N	$42^0$19'E	1985-2014	-
Haramaya	2020	9^0 22' N	42^0 01' E	1985-2014	-
Combolcha	2122	9^0 26' N	42^0 6' E	1985-2014	-
Kulubi	2436	9^0 26' N	41^0 40' E	1985-2014	-

To calculate the rainfall variability that causes extreme meteorological events, the coefficient of variation and the Precipitation Concentration Index (PCI) was applied as statistical descriptors of rainfall variability. The PCI value was calculated as given by Oliver (1980);

The PCI was estimated on an annual and rainy seasons, based on the division of the rainy seasons into two categories. The number 100 in the formula for the annual PCI (Equation 1) represents 12 months of the year signifying 100% while 25 represents 3 months for each rainy season and 50 represents 6 months of the year. According to Oliver (1980), PCI values of less than 10 represent a uniform precipitation distribution or low precipitation concentration, values between 11 and 20 represent irregular distribution of rainfall or high concentration of precipitation, while values above 20 represent a strong irregularity of precipitation distribution or very high precipitation concentration. The Precipitation Concentration Index for the annual, short rainy season (SRS), main rainy season (MRS) and long dry season (LDS) was computed according to equations 1, 2, 3 and 4, respectively.

$$PCIanual=100*[\Sigma P_t^2/ (\Sigma P_t)^2] \quad (1)$$

$$PCI\ SRS=25*[\Sigma P_t^2/ (\Sigma P_t)^2] \quad (2)$$

$$PCI\ MRS=25*[\Sigma P_t^2/ (\Sigma P_t)^2] \quad (3)$$

$$PCI\ LDS=50*[\Sigma P_t^2/ (\Sigma P_t)^2] \quad (4)$$

Where P_t is rainfall amount of the i^{th} month; and Σ= summation over the 12 months.

The indices at the five stations were subjected to non-parametric Mann-Kendall test to detect trend over the period 1985-2014. The Mann-Kendall trend test is an effective method of evaluating time series whether it is statistically significant or not.

The non-parametric Mann–Kendall trend test (Mann, 1945; Mitchell *et al*., 1966; Kendall, 1970; Sneyers, 1999 in Łupikasza et al. 2010) is one of the most frequently applied methods to assess trend directions (Heino *et al*., 1999; Zhai *et al*., 1999; Su *et al*., 2006; Garcia *et al*., 2007 in Łupikasza et al. 2010), besides linear regression fitted with the least squares method. The test may also be used to detect the statistical significance of trends (Heino *et al*., 1999; Zhai *et al*., 1999; Ramos and Martinez-Casanovas, 2006 in Łupikasza et al. 2010). The significance information from the Mann–Kendall test can be used interchangeably with the *t* -test in practical applications, as both methods largely deliver almost identical results (O¨ no¨z and Bayazit, 2003 in Łupikasza et al. 2010). The test is widely used for analysing environmental data, including precipitation data (Partal and Kahya, 2006 in Jung et al., 2011).

This test does not require that data be normally distributed and simply evaluates whether the variable of interest is increasing or decreasing with time (Collins 2009). This trend detection method is also preferred for its advantages that it allows missing data and can tolerate outliers. Currently, the Mann–

Kendall trend test is widely applied to identify trends in hydro-climatological variables with respect to climate change (Kundzewicz *et al*. 2005; Svensson *et al*. 2005; Petrow and Merz 2009; Burn *et al*. 2010 in Degefu & Bewket, 2015). Moreover, the application of the test can be found in Mitosek in Hisdal et al. (2001), who compared different trend tests to detect signals of climate variability and changes in monthly and annual discharges of 176 series from all over the world. Degefu & Bewket (2015) employed the Mann–Kendall non-parametric test for their hydro-meteorological drought analysis. Deshpande et al (2011) also used the Mann–Kendall test to examine the significance of long term trends in the time series of number of rain hours. The non-parametric Mann–Kendall trend test is one of the most frequently applied methods to assess trend directions (Garcia *et al*.; Heino *et al*.; Su *et al*.; Zhai *et al*., in Łupikasza et al., 2010) and it is recommended by the World Meteorological Organization (WMO).

Result and discussion

The mean annual rainfall in the catchment varies from 652 mm in Dire Dawa to 928mm in *Kulubi*. All the stations in the catchment experiences mean annual rainfall less than 1000mm and *kiremt* is the season when much of the annual rainfall concentrated. The coefficients of variation in table 2 shows that relative inter annual rainfall variability among stations is highest in Kombolcha with coefficient of variation >30% and Dire Dawa, Kulubi & Kersa >20%. Similarly, Cheung et al (2008), have stated that relative rainfall variability proved to be high (CV > 0.20) throughout Ethiopia. In general, the catchment experiences moderate inter-annual variability. The *belg* rainfall shows high variability than *kiremt* rainfall. Highest *belg* & *kiremt* rainfall variability is observed in Dire Dawa located in semi-arid environment, with coefficient of variation of 46% & 40% respectively. Sileshi & Zanke (2004) noted that year to year *belg* rainfall variability in Jijiga and Dire Dawa is extremely high (CV=0.50). Similar result has also been found by Bewket & Conway (2007), that the *belg* rainfall is much more variable than the *kiremt* rainfall in their study area of Amhara National Regional State, northern highlands of Ethiopia. Moreover, Mersha (1999, 2003) in Bewket & Conway (2007) concluded that rainfall variability is higher in areas of low annual rainfall where arid & semi-arid condition is persistent. The contribution of kiremt rainfall to total rainfall is highest as compared to belg season.

Similarly, the voice of pastoralists & agro-pastoral community in the study area revealed that in the recent years the rain is falling irregularly and the numbers of rainy months are considerably decreased. According to them, the *Belg* rain which used to fall from March to May is now appears only for one or two weeks in April and the main rainy season which used to appear from July to September is now occurs during July or the month of August for not more than two weeks. This variability in rainfall has produced considerable negative implications on agricultural outputs and livestock productivity; due to shortage of fodder for livestock feed.

In this regard Dire Dawa Administration (2015), in the region's meher seasonal assessment report noted that the *belg* rain was late by 4 weeks; the amount was poor and uneven in its distribution and this negatively impacted land preparation and planting of long cycle crops. There was no rain during July to Mid of August which make a dry spell of 5 weeks. The rain has ceased earlier than the normal time in early September. Because of the poor performance of both the *belg* & *kiremt* rains, planting was delayed by 1-2 months; failure of germination, drying and wilting of *kiremt* crops after germination and at vegetative stage.

The rainfall pattern in the study catchment is bimodal type with two rainfall peaks: one occurring in the period from March to May and the other from July to September. The first peak occurs in the last week of March while the second peak occurs in the beginning of August (Tilahune, 2006). The first peak is the short rainy season (*Belg*) and the second peak is the main rainy season (*Kiremt*). June is therefore, the dry spell that separate the two rainy seasons. The northern and eastern part of the country have longer dry spell especially at the beginning of the main rainy season. This is partly because in these areas, i.e. along the eastern escarpment and in the rift valley region, the *kiremt* rainy season starts late, June being a relatively dry month (Sileshi & Camberline, 2006).

Table 2; mean and coefficient of variation at annual and seasonal rainfall basis, 1985-2014

	Annual		*Kiremt*		*Belg*	
Stations	Mean	CV	Mean	CV	Mean	CV
Dengego	848	0.20	414	0.30	286	0.42
Dire Dawa	652	0.24	283	0.40	242	0.46
Haramaya	816	0.19	399	0.20	275	0.38
Kombolcha	744	0.31	373	0.36	252	0.38
Kulubi	928	0.26	482	0.37	280	0.38

Precipitation concentration Index (PCI)

As presented in table 3; the results of the annual PCI for the catchment in all the stations under investigation during the record periods showed that 100% of the years for which the annual PCI was estimated fell within the irregular precipitation distribution range or high precipitation concentration. The distribution of rainfall in the main rainy season (*kiremt* rainfall) showed that high precipitation concentration or irregular rainfall distribution in the two stations (Dengego & Dire Dawa) and there is low precipitation concentration in the remaining three stations (Haramaya, Kulubi, &Combolcha) while the distribution during short rainy season (*Belg* rainfall) has fallen within high precipitation concentration or irregular rainfall distribution in all the stations in the catchment. During the dry season (October to February including June), PCI indicates a strong irregularity of precipitation distribution or very high precipitation concentration. As indicated in table 3; the trend detection shows that only in Combolcha that PCI has exhibit significant decreases (at $p< 0.1$ level of significance).

Table 3; the Precipitation Concentration Index (PCI), 1985–2014.

Station	Annual PCI	Main rainy season	short rainy season	Dry season PCI	Trend of PCI
Dengego	17	11	11	21	-0.04
Dire Dawa	18	11	12	24	-1.14
Haramaya	16	9	11	21	1.5
Combolcha	17	10	11	24	-1.78+
Kulubi	18	9	12	22	-0.89

+signify significant at 0.1 level of significance

Annual and seasonal rainfall trends (1985-2014)

Table 4 shows trends of rainfall in the study catchment for the annual time step, the *Kiremt* or main rainy season (July-September) and *Belg* or short rainy season (March-May), over the entire period of the study. Accordingly, the annual rainfall has showed a negative trend in most of the stations for the period 1985-2014 (table 4). However, only in Combolcha that the trend showed positive with statistically significant at $p<0.05$ level of significance. The result is in agreement with the findings of Verdin et al (2005) in Cheung et al (2008) that annual rainfall decline in south western & eastern Ethiopia but has no trend. The Mann–Kendall trend test during *kiremt* season shows a positive trend in Dengego, Dire Dawa, Combolcha and Haramaya and the increasing tendency is significant at $p<0.1$ in Degego, $p<0.05$ in Dire Dawa, $p<0.05$ in Combolcha and $p<0.01$ in Haramaya. Similarly, Kulubi has showed an increasing tendency of *Kiremt* rainfall but this is statistically not significant. On the contrary to *Kiremt* rainfall, *Belg* rainfall has showed a negative trend in all the stations except Combolcha. The decreasing tendency of *Belg* rainfall is significant at $p<0.1$ in Dengego. The negative trend in the other stations is statistically not significant.

Table 4; Annual and seasonal rainfall trends (1985-2014)

Station	Annual rainfall trend	Kiremt rainy season trend	Belg rainy season trend
Dengego	-0.14	1.68+	-1.71+
Dire Dawa	-0.25	2.50*	-1.61
Combolcha	2.23*	2.21*	0.89
Haramaya	-0.11	3.10**	-1.18
Kulubi	0.29	1.63	-1.13

**,*, + signifies levels of significance at $p< 0.01$, 0.05 and 0.1 respectively

Trends in extreme rainfall events

As presented in table 5; the 5th and 10th percentiles and also the 90th & 95th values show higher in Kulbi and Haramaya stations, implying that the frequency of extreme rainfall events highest in these stations than the remaining three stations. The heavy rainfall events, the 90th & 95th percentiles, to all the stations showed an increasing pattern but except in Combolcha the trends have not statistically significant to other stations. In Combolcha an increasing pattern of the heavy rainfall events is statistically significant at $p<0.05$ level of significance. The low extremes (5th & 10th percentiles) exhibit a decreasing trend in Dengego, and this decrease is statistically significant at $p<0.1$ for both 5th & 10th percentiles in Dengego. Other stations (Dire Dawa, Haramaya, Kulubi for both 5th & 10th percentiles and Combolcha for 10th percentile) show an increasing trend but this is not statistically significant.

Table 5; Extreme frequency and trends, (1985-2014)

Extreme events	Dengego	Dire Dawa	Combolcha	Haramaya	Kulubi
5 percentile	2.29(-1.94+)	1.72(0.21)	1.77(-0.13)	3.0 (0.23)	5.54(1.01)
10 percentile	3.90(-1.71+)	2.82(0.00)	3.15(0.66)	4.90(0.39)	8.33(1.12)
90 percentile	52.42(1.03)	45.58(0.24)	49.3(1.98*)	54.24(1.09)	60.37(0.15)
95 percentile	64.36(0.86)	57.51(0.92)	57.35(2.54*)	63.86(1.29)	71.94(1.01)

*, + signifies levels of significance at $p< 0.05$ and 0.1 respectively

Conclusion

This paper presents the analysis of Rainfall variability and trends of extreme rainfall events in the Oda Gunufeta - Cherecha -Dechatu watershed, Awash Drainage Basin, Eastern Ethiopia. To calculate the rainfall variability that causes extreme meteorological events, the study employed the coefficient of variation and the Precipitation Concentration Index (PCI) as statistical descriptors of rainfall variability. The indices at the five stations were subjected to non-parametric Mann-Kendall test to detect trend over the period 1985-2014. The Mann-Kendall trend test is an effective method of evaluating time series whether it is statistically significant or not.

Accordingly, the catchment experiences moderate inter-annual variability. The *belg* rainfall shows high variability than *kiremt* rainfall. Highest *Belg* rainfall variability is observed in Dire Dawa with coefficient of variation of 46%. High *kiremt* rainfall variability is observed in Dire Dawa located in semi-arid environment, with coefficient of variation 40%.

The results of the annual PCI for the catchment in all the stations under investigation during the record periods showed that 100% of the years for which the annual PCI was estimated fell within the irregular precipitation distribution range or high precipitation concentration. The irregular precipitation distribution also extended to all the stations in short rainy season (*Belg* rainfall) and in two stations in the main rainy season (*Kiremt* season) which has fallen within high precipitation concentration in the catchment.

With regard to rainfall trend, the annual rainfall has showed a negative trend in three stations and positive trend in the remaining two stations for the period 1985-2014. The Mann–Kendall trend test during *kiremt* season shows a positive trend in Dengego, Dire Dawa, Combolcha and Haramaya and the increasing tendency is significant at p<0.1 in Degego, p<0.05 in Dire Dawa, p <0.05 in Combolcha and p <0.01 in Haramaya. Contrary to *Kiremt, Belg* rainfall has showed negative trend in all the stations but this has significant only in Dengego at p<0.1 level of significant.

The heavy rainfall events, the 90th & 95th percentiles showed an increasing pattern in all the five stations but except in Combolcha the trends have not statistically significant. In Combolcha an increasing pattern of the heavy rainfall events is statistically significant at p<0.05 level of significance.

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