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Indications of the changing nature of rainfall in Ethiopia: The example of the 1st decade of 21st century

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Climate change was defined as a statistically significant variation in the mean state of climate. Accordingly, with regards to rainfall, a working hypothesis that reads as: there is a statistically significant change (increase/decrease) in the mean annual and seasonal rainfall values at weather stations was forwarded for testing. Eight years (2001-2008) annual and seasonal rainfall data of 17 weather stations from most parts of Ethiopia were used for the purpose. Setting the significance level at 0.05, the simple correlation and regression techniques were used to reach results. Most stations from the western part of Ethiopia were seen to exhibit statistically significant increasing trend in annual rainfall receipt. Albeit not significantly, northward and eastward from here, the receipt was also seen tending first to increase then decrease. This tendency was observed to overlap with the traditional distribution of rainfall in the country. The alternating of dry and wet years and the more localizing of wet years than dry years were identified. The four seasons considered were observed to be statistically significant, but increasing and decreasing trends in seasonal rainfall receipt at the respective stations were not significant. Most conspicuously, 94% of the total number of stations considered in this study show increasing trend in autumn rainfall receipt. Based on the findings of the study, some conclusions policy makers may be taking into consideration were finally drawn.

Key words: Annual, Ethiopia, rainfall, seasonal, significant.

INTRODUCTION

The hypothesis

Climatologically speaking, Ethiopia is a world in miniature, in that, dictated by its high amplitude of relief (Mesfin, 1970), the largeness of its size, 1,127,127 Km^2 (US Library of Congress, 2005: 4) and its location in the heart of the Horn of Africa, it enjoys varieties of climate that are comparable to the effects of latitude, so much so that the high latitude equivalents can be found along the uplands and the low latitude equivalents along the lowlands (Daniel, 1977).

This fact lends the country to serve as a laboratory for examining change in climate. As per the series of the syntheses reports of the Intergovernmental Panel on Climate Change (IPCC) the working definition of climate change is put as a statistically significant change in the mean state of climate and/or its variability over prolonged period (WMO-IPCC, 2001, 2007, 2013).

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With respect to rainfall, its variability has been a topic of discussion by several research works both from outside Ethiopia (Otun and Adewumi, 2009; Hendrix and Salehyah, 2010; Wolff et al., 2011) and from within Ethiopia (Woldeamlak, 2009; Hongwei et al., 2011; Rientiger et al., 2013).

Otun and Adewumi (2009) looked at rainfall variability in the Sudano-Sahilian regions of Nigeria, and its connection with the sahelian drought. They used daily rainfall series from seven stations that spanned over 30 year climate interval (1940 – 1970 and 1970 – 2000). Their conclusion includes the fact that the drought condition of 1970's might be recurring in the future (Otuned and Adewuni, 2009). Hendrix and Salehyan (2010), established relationship between rainfall variability and socio political conflict in Africa. They particularly found out that dry and wet years are associated with all types of small scale and large scale instances of political conflict (Hendrix and Salehyan, 2010). Based on their evidence from laminated lake sediment record from Southern Kenya Wolff et al. (2011) reported of changes in El-Nino related Variability of East Africa's rainfall during the last three millennia (Wolff et al., 2011)

Studies on rainfall trends and variability made in Ethiopia include Weldeamlak (2009) and Hongwei et al. (2011). Using rainfall data spanning from 1975-2003 for 12 stations from the Amhara region, Woldeamlak (2009) reported, among other things, of lower variability of rainfall in the western part of the region than the eastern. From their trend analysis of 53 years' daily precipitation data at Debremarkos Hongwei et al. (2011) found no increasing trend in the extreme precipitation at Debre Markos. In their assessment of the diurnal cycle of rainfall across the Upper Blue Nile basin Rientjes et al. (2013) revealed the fact that over most parts of the basin rainfall is highest between mid-and-late afternoons. They used seven years (2002-2008) satellite derived precipitation data (Rientjes et al., 2013).

With regards to rainfall again, research works done in Ethiopia in the style amenable to the definition of climate change given above includes Yilma and Zanke (2004), as quoted by Cheung et al. (2008), and Cheung et al. (2008). Using decadal rainfall records of 134 gauging stations with differing study period (ranging between 35 and 43 years) and employing the regression and correlation techniques, Cheung et al. (2008) analyzed trends in seasonal and annual rainfall at national, watershed, and gauging station levels. In their seasonal analysis, they considered two seasons – *kiremt* (July to September) and *belg* (March to May) (Cheung et al., 2008). At the seasonal level, their findings brought in a significant decline in *kiremt* rainfall for some watersheds eg. the southern Blue Nile watershed (Cheung et al., 2008), and at gauging station level – their finding include a significant increase at Hirna and a significant decrease at Robe from the eastern region of the country (Cheung et al., 2008). Yilma and Zanke (2004), as quoted by Cheung et al. (2008) reported of the decline in annual rainfall in southwestern and eastern Ethiopia (Cheung et al., 2008). Much earlier, Conway and Hulmes (1993), as quoted by Yilma (1996), reported of decrease in annual rainfall in north central highlands, later on confirmed by Yilma (1996).

Unlike such a previous work like Cheung et al. (2008) which based its analyses on two seasons, *kiremt* and *belg*, and non-uniform, but large number of years (35 to 43 years), this research work is based on mean annual and four seasons' mean rainfall of 17 weather stations[1] drawn from most parts of Ethiopia (Figure 1), and spread over eight uniform years (2001-2008) almost the first decade of the twenty first century, would endeavor to test one central hypothesis: that there is statistically significant change (increase/decrease) in mean annual and seasonal rainfall values at the stations.

Although this paper has several shortcomings including the briefness of the study period and the unevenness in the distribution of the stations considered, it is my conviction that the paper may serve two purposes, (a) that it may be indicative of the general direction on the changing nature of rainfall in Ethiopia and (b) it may be a modest addition to the related works in Ethiopia and serve as a reference material for future researches.

METHODOLOGY

Data source

All the eight years mean annual and seasonal values of the 17 stations used in this study were based on the monthly rainfall records collected from the National Methodological Agency[2] (NMA). The years and seasons considered in this study were meteorological years and meteorological seasons. A meteorological year comprises four seasons each composed of three months (Ahrens, 1988). In the northern hemisphere the meteorological definition of winter would be December, January and February; spring would be March, April, and May; summer would be June, July, August; and autumn, September, October, and November (Ahrens, 1988). In order to fit to the meteorological definition, the first month of winter, December, considered here, in each case, was the previous year's December. This procedure was strictly observed throughout. Setting up the mean annual and seasonal

1 Originally the writer intended to consider more than seventeen stations distributed over the northern, southern, eastern, western and central parts of Ethiopia, and a minimum study period of 10 years, complete with twelve calendar months of rainfall data. After excluding station with incomplete data and taking cognizance of their distribution over most parts of the country, the author, finally, concentrated on the seventeen stations with comparable data from 2001 to 2008, nearly the first decade of the twenty first century. Monthly rainfall data in two cases, however, i) Dessie for November and December (2006); and ii) Goba, for January and February (2005), and May (2006) were missing. In all these cases, nevertheless, the missing data were filled with the respective arithmetic average of the immediate proceeding and succeeding months with data.)

2 It would be appropriate to mention here the fact that most of the data on the monthly rainfall of the seventeen stations were secured from the National Meteorological Agency (NMA) by my students for a course work on GeEs 1012 (Applied climatology). The author also obtained a good stock of data straight from the same agency for cash.

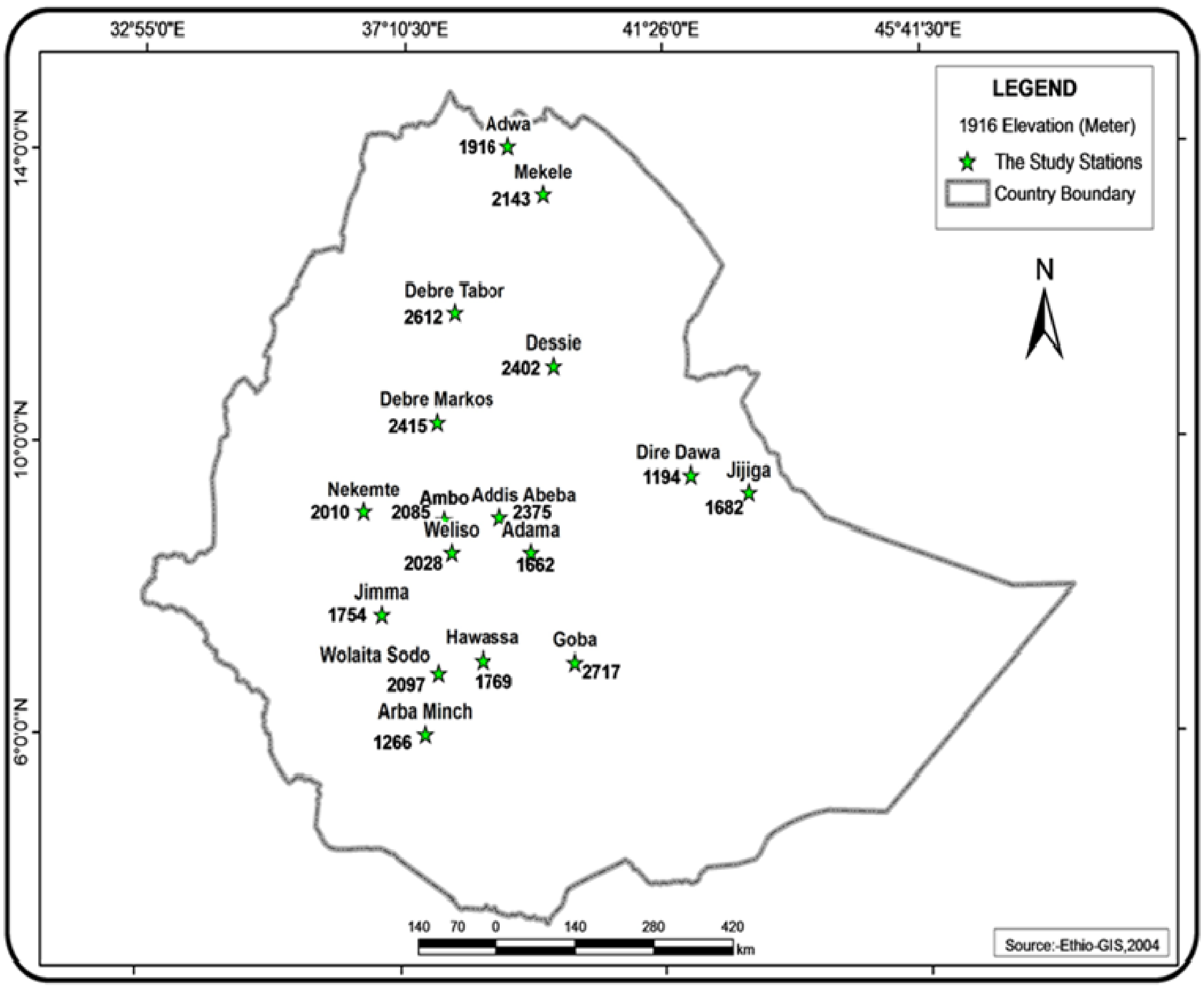

Figure 1. The study stations.

rainfall values as dependent variables: the years and the seasons there in as independent variables; and putting the significance level at 0.05, the regression and correlation techniques (Berenson and Levine, 1983) were used to arrive at the results.

RESULTS AND DISCUSSION

Annual increases and decreases

Table 1 provides a summary of the correlation and regression analyses done on the mean annual rainfall of the fourteen stations. Three distinct groups can be identified. The first group comprises Ambo, Debre Tabor, Nekemte, and Woliso, all but Debre Tabore, from the western part of the Ethiopia, where mean annual rainfall exhibited statistically significant increase over the study period. The second group has Adama, Addis Ababa, Arba Minch, Debre Markos, Goba, Hawassa, Jijiga, Jimma, and Wolaita Sodo – most of which are from the central and southern Ethiopia – which observed increased annual rainfall, albeit not significantly. The third group composed of Dessie, from north east Ethiopia that showed a statistically significant decrease in the mean annual rainfall, plus Adwa and Mekele from northern and Dire Dawa for eastern Ethiopia, which showed decreased rainfall, though not statistically significant again.

It appears, then when, in general annual rainfall receipt in the western part of the country is tending to experience statistically significant increase-northward and eastward from here the tendency is first to continue to increase (in almost all cases not significantly) then decrease (in almost all cases not significantly again). There is the established fact that amount of rainfall in the country is decreasing as one goes northward and eastward from the western part of Ethiopia to modestly increase over the northern and eastern highlands, and decrease thereafter (Kebede, 1964; Mesfin, 1972; Daniel, 1977; Nigtu, 2011), a fact which can also be read from the data on the mean annual rainfall of the 17 stations given in Table 2 and illustrated in Figure 2. Adwa and Mekele (northern most

Table 1. Correlation co-efficient, slope (b_1) decreases/increases and t-test statistics for seventeen stations in Ethiopia (2001 – 2008).

Station	r	Slope (b_1)	I=increased D=decreased	t_{cal}	t_{tab}	R=Reject H_0 A=Accept H_0
Adama	0.500	+3.412	I	1.410	1.9432	A
Addis Ababa	0.261	+1.375	I	0.657	1.9432	A
Adwa	-0.204	-0.979	D	-0.208	1.9432	A
Ambo	0.690	+3.451	I	2.350	1.9432	R
Arba Minch	0.272	+1.645	I	0.689	1.9432	A
Debre Marcos	0.349	+1.040	I	1.196	1.9432	A
Debre Tabor	0.660	+4.400	I	2.200	1.9432	R
Dessie	-0.346	-6.930	D	-2.327	1.9432	R
Dire Dawa	-0.011	-0.043	D	-0.028	1.9432	A
Goba	0.083	+0.587	I	0.206	1.9432	A
Hawassa	0.385	+1.801	I	1.007	1.9432	A
Jijiga	0.176	+0.712	I	0.434	1.9432	A
Jimma	0.106	+0.657	I	0.259	1.9432	A
Mekele	-0.161	-0.820	D	-0.403	1.9432	A
Nekemte	0.835	+7.332	I	3.752	1.9432	R
Wolaita Sodo	0.461	+3.747	I	1.274	1.9432	A
Woliso	0.674	+2.910	I	2.243	1.9432	R

H_1 = There is significant increase/decrease in the mean annual rainfall; $H_0 = H_1$ is not true. Significance level =0.05. Source: Original data from NMA, compiled by the writer, r = regression.

Table 2. The annual mean, the wettest and driest years for seventeen weather stations is Ethiopia (2001 – 2008).

Station	Annual mean (mm)	Wettest year (W)	Driest year (D)	Difference in N^0 years between W and D
Adama	898.2	2007	2002	5
Addis Ababa	1277.2	2001	2002	1
Adwa	778.4	2001	2002	1
Ambo	990.2	2007	2002	5
Arba Minch	738.5	2007	2002	5
Debre Marcos	1336.9	2006	2002	4
Debre Tabor	1411.1	2006	2002	4
Dessie	1390.0	2003	2008	5
Dire Dawa	602.1	2007	2005	2
Goba	1031.1	2006	2002	4
Hawassa	989.3	2007	2003	4
Jijiga	591.9	2006	2008	2
Jimma	1415.2	2001	2002	1
Mekele	476.7	2006	2004	2
Nekemte	2036.3	2008	2002	6
Wolaita Sodo	1385.0	2007	2002	5
Woliso	1196.6	2006	2001	5

Source: Original data from NMA, compiled by the writer.

stations) reported mean annual rainfall of 778.4 and 476.7 mm, respectively; and Dire Dawa and Jijiga (eastern most stations) revealed mean annual rainfall of 602.1 and 591.9 mm, in that order Nekemte and Jimma (western most stations) presented 2036.3 and 1415.22 mm of annual rainfall, the highest and the second highest, respectively, among the stations considered in this study. The other stations, in general, took the

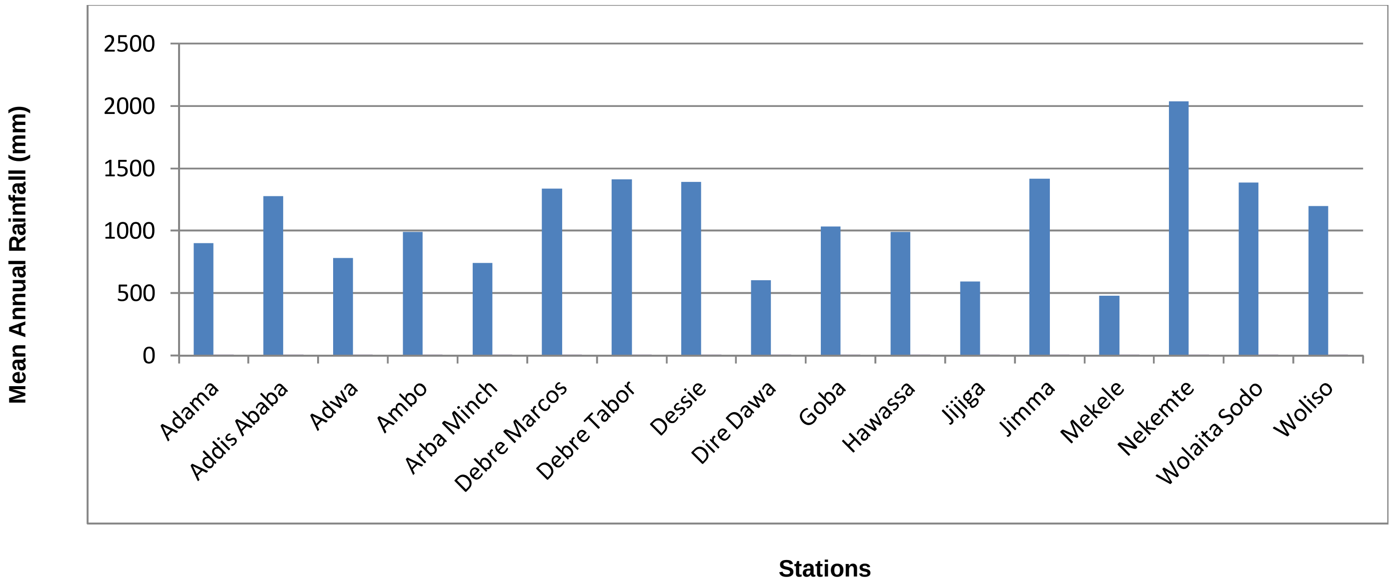

Figure 2. Graphic rrepresentation of the mean annual rainfall of the 17 Stations (2001-2008).

intermediate position between these two extremes. It can be said then that the behaviour of the 17 stations' increases and decreases in the mean annual rainfall amounts observed over the study period, somehow, tends to overlap with the traditional distribution of rainfall in Ethiopia.

Exceptions to this general trend were, however, presented by some stations. For instance, when Jimma from mid-west Ethiopia experienced an increase in the annual rainfall receipt which was not statistically significant; most of the neighbouring stations revealed a statistically significant increase. Likewise, Debre Tabor and Dessie both from northern highlands and at about the same distance from mid-west Ethiopia produced contrasting annual results-statistically significant increase for Debre Tabor and statistically significant decrease for Dessie. Difference in annual values was also observed between the eastern most stations – Dire Dawa, decreasing (not significantly), and Jijiga, increasing (not significantly). These differences may be decidedly explained by local circumstances including elevation factor.

Table 2 also provides a list of the wettest and driest years each station experienced during the study period together with the interval in years between these extreme events. The first feature that may be deciphered from the table would be the fact that wetness tends to be more localized than dryness. This may be learned from the fact that, when in six cases-at Adama, Ambo, Arba Minch, Hawassa, Dire Dawa and Wolaita Sodo or about 35% of the total number of stations, 2007 was the wettest year; and in another six cases-at Debre Marcos; Debre Tabor, Goba, Jijiga, Mekele and Woliso or about 35% of the total again, 2006 was the wettest year; in 11 cases-at Adama, Addis Ababa, Adwa, Ambo, Arba Minch, Debre Marcos, Debre Tabor, Goba, Jimma, Nekemte, and Wolaita Sodo or about 65% of the total number of stations, 2002 was the driest year. The other feature worth mentioning would be the difference in years between the wettest and driest years. The average gap for the 17 stations was put at three and – half years. At some stations, however, that is Addis Ababa, Adwa and Jimma the driest and the wettest years occurred consecutively, while at Nekemte a gap of six years was required.

Seasonal increases and decreases

Table 3 shows the chief points of the statistical analyses done on the seasonal data. Two outstanding features can be learned from the table. First, the compatibility in the pattern of mean annual rainfall increases and decreases with the traditional spatial distribution of rainfall in the country mentioned above, in some way, seems to be repeated here. This is so, for again, mostly the same group of stations with statistically significant annual rainfall increase records, Ambo, Debre Tabor, Nekemte and Woliso emerged with the largest number of seasons with increased rainfall; Three seasons had increase in the case of Ambo, Nekemte and Woliso; and all the four seasons had increase in the case of Debre Tabor. Ambo observed increases in spring (significant), summer (significant) and autumn (significant at 0.10 level); Nekemte in spring (significant), in autumn (significant), and summer (not significant); Woliso in autumn (signify cant at 0.10 level), spring (not significant), and summer

Table 3. Increases and decreases in seasonal rainfall receipt and t-test statistics for seventeen stations in Ethiopia (2001-2008).

Station	Season			
	Winter	Spring	Summer	Autumn
Adama	I(A)	D(A)	I(A)	I(R)
Addis Ababa	I(A)	D(A)	D(A)	I(R)
Adwa	I(A)	I(A)	D(A)	I(R)
Ambo	D(A)	I(A)	I(R)	I(R)*
Arba Minch	D(A)	D(A)	I(A)	I(R)
Debre Marcos	D(A)	I(A)	I(A)	I(R)
Debre Tabor	I(R)	I(R)	I(A)	I(A)
Dessie	I(A)	D(A)	D(A)	I(A)
Dire Dawa	D(A)	I(A)	D(A)	I(A)
Goba	D(A)	I(A)	I(A)	I(A)
Hawassa	D(A)	D(A)	I(A)	I(R)
Jijiga	D(A)	I(A)	D(A)	I(A)
Jimma	I(A)	I(A)	D(A)	I(A)
Mekele	D(A)	I(A)	D(A)	D(A)
Nekemte	D(A)	I(R)	I(A)	I(R)
Wolaita Sodo	D(A)	I(A)	I(A)	I(R)
Woliso	D(A)	I(A)	I(A)	I(R)*

H_1=There is significant increase/decrease in the mean seasonal rainfall; H_2=H_1 is not true. Significance level= 0.05. Source: Original Data from NMA, Compiled by the writer. I = Increased; D = Decreased; A = Accept H_0; R = Reject H_0; * = Reject H_0 at 0.10 significance level.

(not significant). Debre Tabor which can be regarded as a 'moisture island' of the northern highlands witnessed increase in winter (significant), spring (significant), summer (not significant), and autumn (not significant). Other stations distributed over most parts of the country also joined the ranks of stations with three seasons of increased rainfall, which includes Adama, Adwa, Debre Markos, Goba, Jimma, and Wolaita Sodo. In contrast to all these Mekele, from Northern Ethiopia, experienced three seasons of decreased rainfall-in summer, autumn and winter (in all cases not statistically significant). The other stations, including Adama and Addis Ababa, from central Ethiopia, Dire Dawa and Jigjiga from Eastern Ethiopia, and Hawassa from south central part of the country, observed two seasons of decreased rainfall.

Indeed, here too, exceptions to the general trend mentioned earlier were observed, locally produced. The comparison of Adwa's and Mekele's four seasons increasing and decreasing trends present good example. Adwa, about 100 kilometers north west of Mekele, is at a lower elevation (1916 meters above sea level) than Mekele (2143 meters above sea level), (vide the map attached here with) and still Adwa experienced three seasons of increased rainfall (though not significant in all cases), while Mekele observed three seasons of decreased rainfall (in all the cases not significant again). Besides, Mekele reported of an eight year mean annual rainfall of 476.7 mm, when Adwa reported 778.4 mm (vide Table 2). Facts that exclude elevation factor like geographical position may explain this.

The second feature would be the season to season differences - six stations – Debre Tabor (significant), Adama, Addis Ababa, Adwa, Dessie and Jimma (not significant in the last five), or about 35 percent of the total, witnessed increasing trend in winter rainfall. Seven stations or about 41 percent of the total exhibited decreasing tread in summer. This includes – Addis Ababa, Adwa, Dessie, Jimma and Mekele. (in all cases not significant). Twelve stations or about 71 percent of the total number of stations which includes Deble Tabor (significant), Jijiga (not significant), Dire Dawa (not significant) saw increasing trend in spring rainfall. Lastly and probably most strikingly sixteen stations or about 94 percent of the total showed increasing trend in autumn rainfall. Nine stations, or about 51 percent of these comprising Adama, Addis Ababa, Arba Minch, Hawassa, Debre Markos, Plus Ambo and Woliso (both significant at 0.10 level), exhibited statistically significant increase in autumn.

Conclusion

The eight – year period mean annual and seasonal data of the 17 stations considered in this study supported the rejection and acceptance of the null hypotheses of no significant increase/decrease in the annual and seasonal rainfall. On the annual scale, most stations from western part of Ethiopia show statistically significant increasing trend in annual rainfall. In almost all directions from here the tendency, though inconsistently, was first to increase then to decrease albeit not significantly. This appeared to be in close parallelism with the normal distribution of rainfall in Ethiopia. The alternating recurrence of dry and wet years and the more localizing of wet years than dry years were recognized. At the seasonal level, every station witnessed either statistically significant or not significant increasing and/or decreasing trend in the respective seasonal rainfall amount, the pattern of which, taken as a unit, coincided with the traditional distribution of rainfall in the country. Moreover, more than half of the weather stations considered in this study, observed a statistically significant increase in autumn rainfall receipt.

The following conclusions, which policy makers may take into consideration, are drawn from the findings of the study mentioned above:

a) The establishment of the close parallelism in the behaviour of the increases/decreases in the mean annual and seasonal rainfall values with the traditional distribution of the rainfall in Ethiopian as a fact may persuade one to say that rainfall distribution in the country would continue to be as it was and as it is now with the wet and dry areas growing wetter and drier, respectively.
b) The alternating recurrence of dry and wet years and the localizing of wet years than dry years would mean that the resultants, positive or negative, would be local in scale when it comes to wetness and regional or beyond when it comes to dryness.
c) Autumn comes after summer-the observation of statistically significant increase in autumn rainfall at more than 50% of the total weather stations considered in this study could, therefore, mean (i) the continuation of summer rainfall into autumn when it comes to parts of central, northern and western Ethiopia; and (ii) the further augmentation of autumn rainfall when it comes to the eastern and southern Ethiopia.
d) Finally, it can be said that, climate change as associated with rainfall in Ethiopia would confront decision makers with decrease or increase in annual and seasonal amounts. What needs to be done is not hard to forward – all the possible means should be designed to combat all the possible consequences of the events.

Conflict of interests

The author did not declare any conflict of interest.

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