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Rainfall Variability and Trends over Central Ethiopia

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Abstract

The rainfall variability and trends over North Shewa investigated using gauge as well as gridded rainfall data from 1985 to 2018. The variability of rainfall in both annual and seasonal scales were evaluated using coefficient of variation (CV), standardized rainfall anomaly, precipitation concentration index (PCI), and standardized precipitation index. Mann-Kendall test and Sen's slope estimator were used to assess the rainfall trends. The rainfall in North Shewa was found to be highly variable both in space and time; i.e., irregular rainfall distribution was observed (PCI = 20%). The coefficient of variation showed moderate variation in both annual and Kiremt (June-September) rainfall as compared to the rainfall in Belg (February-May) and Bega (October-January) seasons. Mann-Kendall test resulted a decreasing trend in Belg and Bega seasons and an increasing trend for annual and Kiremt rainfall. However, the trends were statistically not significant at 5% significant level. The onset and cessation dates showed a non-significant decreasing and increasing trends, respectively. Whereas, the length of growing period showed a significant increasing trend. Overall, in North Shewa, the wet season (Kirmet) has been wetter while the dry and small rainy seasons (Bega and Belg) have been drier; North Shewa has been vulnerable to drought during Belg season (CV > 30%). Due to the high contribution of Kiremt season for annual rainfall amount of about 75%, the annual rainfall has also showed an increasing trend.

Keywords: Rainfall onset & ending; Anomaly; Dry spell; LGP; SPI; Gauge & gridded data; North Shewa

Abbreviations: CT: Contribution of Seasonal Rainfall to Annual Rainfall; PCI: Precipitation Concentration Index; SRA: Standardized Rainfall Anomaly; LGP: Length of Growing Period; SPI: Standardized Precipitation Index; Kiremt: 'Main' Rainy Season (June-September); Bega: 'Dry' Season (October-January); Belg: 'Small' Rainy Season (February-May)

Introduction

Rainfall is one of the most important climate elements for agricultural production throughout the world [1]. It is also the most important climate element for rainfed agriculture and the general socio-economic development of Ethiopia [2]. Rainfall variability affects water resources sustainability which includes the availability, management, and utilization of water resources. This, in turn, may affect ecosystems, land productivity, agriculture, food security, water quantity and human health [3]. When the uneven distribution of rainfall results in a mismatch between water availability and demand, irrigation structures are required to redistribute water concerning the requirements of a specific region [4]. Hence, for ecosystem resilience and sustainable agricultural activities, accurate estimation of the spatial and temporal distribution of rainfall is crucial, particularly for rain-fed agriculture [5,6].

Various trend analysis of rainfall at different spatial (e.g., regional and national) and temporal (e.g., annual, seasonal, and monthly) scales have been studied which indicated changes in the spatial and temporal variability and trends. For example, according to Gamachu [7] rainfall in Ethiopia has shown large variations across time and space, due to the complex topography and varying latitude of the country [7]. Spatially, the amount, seasonal cycle, onset and cessation times of rainfall as well as the length of growing period, have shown variability across the country [7,8]. Temporally, it varies from days to decades, with the magnitude and direction of historic rainfall trends varying from region to region and season to season [9-12]. This complex Spatio-temporal variability of rainfall over Ethiopia is attributed to the large variations in altitude, variations in sea surface temperatures (SSTs) over the Indian, Pacific and Atlantic Oceans and the interseasonal and interannual variation of the strength of the monsoon over the Arabian Peninsula [7,8,13-15].

Although various studies indicated changes in the variability and trends of rainfall over Ethiopia, they are not consistent and clear. Because the climate of Ethiopia is geographically quite diverse, due to its equatorial positioning and varied topography (Enyew & Steeneveld, 2014). Also, the national (even the regional) rainfall variability studies mask zonal scale variabilities as Ethiopia is a large country in size; more than three times bigger than Germany. Therefore, investigation of rainfall variability and trends at a local level (at a smaller area with higher resolution) has enormous advantage for a country like Ethiopia where the economy is mainly dependent on rain fed agriculture; it helps the decision-makers to take appropriate measures. In view of that, Fitsum et al. [16] are probably the first to analyze rainfall variability and trends at Bale zone (southeastern part of Ethiopia).

In contrast to the study by Fitsum et al. [16], in this study, the spatial variability and the temporal trend of rainfall using gauge as well as gridded rainfall data are investigated in a more detailed way for North Shewa (central part of Ethiopia). Consideration of the analysis of both the spatial variability and the temporal trend of the number of rainy days, onset, ending, and length of growing period (LGP) for the main rainy season (Kiremt) makes this study unique. On top of that, consideration of the precipitation concentration index as well as consideration of the analysis meteorological drought indices such as the probability of dry spell occurrence, standardized rainfall anomaly, and standardized precipitation index for Belg and Kiremt seasons makes this study unique. Note also that the study sites are located in different climate regions [17]. For example, North Shewa received the highest rainfall amount during Kiremt season (75% of the annual rainfall); whereas, Bale zone received it during Belg season (42.5% of the annual rainfall); Bale zone received only 33.3 % of the annual rainfall during Kiremt season [16,17].

As a final point, using gauge rainfall data is more reliable than satellite data because satellite rainfall values are just estimates which have various sources of uncertainty [18]. Also, the gauge-based data sets have generally provided long-term records of precipitation, which are suitable for climate studies whereas the satellite-related data sets have the limitations of their short length of record [19].

Data and Methodology

Description of the study area

The study was conducted in North Shewa which is one of the 11 administrative zones of Amhara National Regional State, Ethiopia (see Table 1 and Figure 1). It is located in between 9º - 11º N latitude, and 38º -40 º E longitudes with an area of about 15,936km^2. According to the Central Statistical Agency of Ethiopia (2007), North Shewa had a total population of 1,837,490; 928,694 men and 908,796 women.

Table 1: Location of the meteorological stations and length of rainfall series.

Stations	Latitude (North)	Longitude (East)	Altitude (in m)	Years of Observation
Alemketema	10.03°	39.71°	2204	1985-2018
Alyuamba	9.56°	39.78°	1813	1985-2018
Debrebirhan	9.7°	39.5°	3206	1985-2018
Effeson	10.34°	39.87°	1447	1985-2017
Enewari	9.8°	39.2°	2667	1985-2018
Ginager	9.34°	39.58°	3112	1985-2017
Gisherabel	10.54°	39.6°	3041	1985-2018
Gudoberet	9.8°	39.68°	3075	1985-2017
Gundomeskel	10.2°	38.9°	2504	1985-2018
Majete	10.5°	39.85°	1573	1985-2018
Mehalmeda	10.3°	39.7°	3084	1985-2018
Meragna	10.2°	39.09°	2572	1985-2017
Molale	10.12°	39.66°	3046	1985-2016
Rema	10.34°	39.58°	2054	1985-2017
Shewarobit	10°	39.9°	1277	1985-2017
Sholagebeya	9.2°	39.6°	2839	1985-2018
Yigem	10.23°	39.77°	3257	1985-2018
Zemero	10.23°	39.43°	2850	1985-2018

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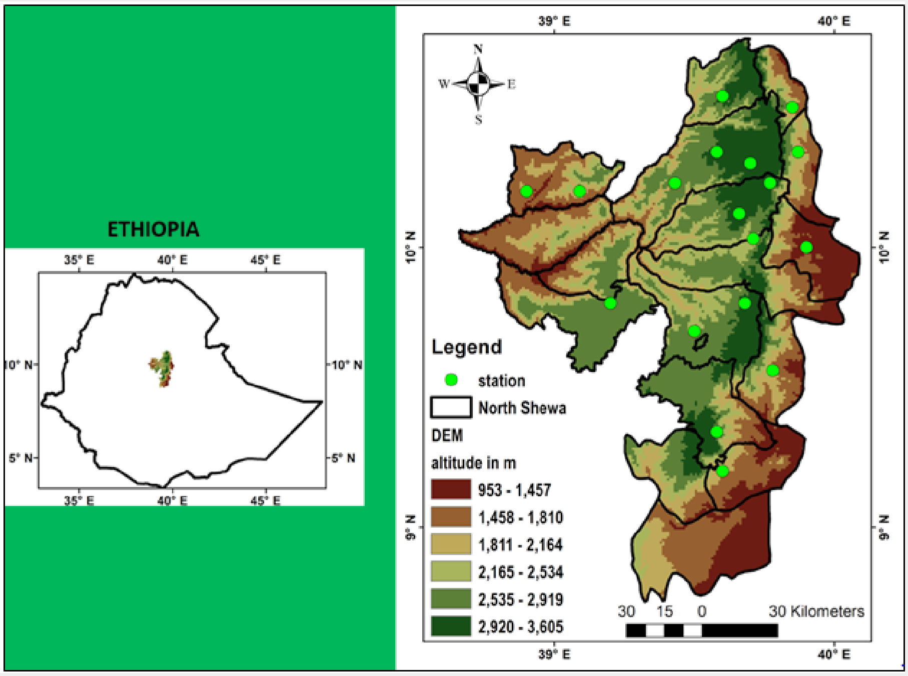

Figure 1: Map of North Shewa zone (study area).

The topography comprises uneven and rugged mountainous highlands in the northern and central parts of the zone, extensive plains and also deep gorges and cliffs in the periphery [20]. The topographic feature of the administration is lower in the south, west and east peripheries and higher in the central part of the zone [21]. The zone has four agro-ecological zones; namely, lowland: 500-1500m a.s.l, mid-latitude: 1500-2300m a.s.l, highland: 2300-3200m a.s.l, and 'Wurch': above 3200m a.s.l.

North Shewa is characterized by three distinct seasons with four months each, classified based on the climatology of rainfall and temperature. These seasons are locally known as 'Bega' (ONDJ), 'Belg' (FMAM), and 'Kiremt' (JJAS) (Mekonnen et al. 2018). Kiremt and Belg are the main and small rain seasons, respectively while Bega is the dry season of the zone. The rain seasons have been inconsistent with respect to the onset, ending, distribution, and amount of rainfall due to the seasonal movement of the ITCZ to north in July and south in January, the atmospheric circulation associated with ITCZ, and the complex topography with a marked contrast in elevation. As a result of climate change, currently, the rain seasons (Kiremt and Belg) are becoming more inconsistent [22].

According to current studies, on average North Shewa receives a mean annual rainfall ranging between 790.3-1765.1mm. At the seasonal scale, it receives 633.2-1071.2, 121.1-483.5, and 25.3-209.1 millimeters in Kiremt, Belg and Bega seasons, respectively.

Data sources and data quality control

Source of data

Very good quality of gauge or station as well as gridded daily rainfall data was obtained from the National Meteorological Agency of Ethiopia (NMA) from 1985 to 2018 for the selected 18 meteorological stations.

Data quality control assessment

Detected outliers were removed using the Turkey fence approach [23]. The data series was also examined for homogeneity and no heterogeneity was detected. Missing data in the time series was filled with data from neighboring stations using statistical regression techniques as described in [24] and applied in various studies [9,25]. Additionally, the missing data were filled with gridded data. The gridded data are constructed data series based on records of gauge stations and satellite observations. This data is very useful because weather stations are limited in number and unevenly distributed and have sometimes a short period of observations.

Methodology

In this study, we employed INSTAT, Genstat, XLSTAT, R (RStudio), and MS Excel spreadsheet tools to analyses our data set. Graphs were mapped using ArcGIS software; inverse distance weighting was used for spatial interpolation [26,27].

Analysis of rainfall variability

Variability of rainfall has been computed using coefficient of variation (CV) (see Hare 1983), standardized rainfall anomaly (SRA) (see Agnew & Chappel 1999), precipitation concentration index (PCI) [28], and standardized precipitation index (SPI) [29]. Contribution of seasonal rainfall to the total annual rainfall in percent (CT) for each station is also computed.

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For analysis, the monthly rainfall of all the stations was used to calculate an areal average rainfall for North Shewa using the equation of Nicholson [30], i.e., $R_j = \frac{\sum_{k=1}^{J} X_{ij}}{J}$ [30]; where R_j is a real integrated rainfall for year j; X_{ij} is rainfall at station i for year j and I_j is the number of stations available for year j.

Analysis of rainfall trend

To estimate the sign and slope of long-term rainfall trends for the selected study sites, Mann-Kendall's trend test [31,32] and Sen's slope estimation method [33] were used.

The presence of a statistically significant trend is evaluated using the ZMK value [31,32]. In a two-sided trend test, the null hypothesis H_o should be accepted if $|Z_{MK}| < Z1-\alpha/2$ at a given level of significance. Z1-α/2 is the critical value of ZMK from the standard normal table. E.g. for 5% significant level, the value of Z1-α/2 is 1.96. In this study, a 5% significant level is used. Note also that the modified Mann-Kendall test [34] was not applied as the data has no serial dependence.

Results and Discussion

Temporal and spatial rainfall distribution

Annual and seasonal rainfall variability

Table 2: Mean annual and seasonal rainfall (mm), coefficient of variation (CV %), the contribution of seasonal rainfall to the annual rainfall (CT %) and precipitation concentration index (PCI %) for 18 meteorological stations.

Stations	Kiremt Rainfall			Belg Rainfall			Bega Rainfall			Annual Rainfall		
	Mean	CV	CT	Mean	CV	CT	Mean	CV	CT	Mean	CV	PCI
Alemketema	834	23	80	164	65	16	43	103	4	1040	20	21
Alyuamba	714	29	54	397	69	31	177	97	15	1362	30	13
Debrebirhan	721	18	79	156	37	17	39	84	4	908	13	23
Effeson	702	36	66	265	53	24	112	81	11	1060	22	17
Enewari	748	31	83	154	64	16	31	143	2	878	29	22
Genager	1071	20	61	484	56	27	209	72	12	1765	19	14
Gisherabe	673	27	81	135	46	15	37	76	3	812	21	25
Gudoberet	950	39	81	175	54	14	84	91	6	1150	40	21
Gundomeskel	776	24	80	166	45	16	43	71	3	952	20	20
Majete	739	23	63	301	39	26	136	80	12	1174	16	16
Mehalmeda	633	42	76	166	47	19	40	84	5	824	36	21
Meragna	742	24	82	150	55	16	32	82	3	900	21	22
Molale	693	25	75	161	50	17	70	104	8	925	20	21
Rema	747	19	83	121	67	13	31	102	3	904	17	24
Shewarobit	687	30	64	239	52	23	132	90	13	1083	26	16
Sholagebeya	762	31	77	178	54	18	45	101	5	996	29	20
Yigem	790	39	76	223	50	20	65	82	4	1005	32	20
Zemero	654	23	82	135	50	16	25	98	2	790	18	24
Areal mean	**757**	**28**	**75**	**209**	**53**	**19**	**75**	**91**	**6**	**1029**	**24**	**20**

Table 2 shows that the study area received annual rainfall ranging from 790mm to 1765mm with a mean of 1029mm and CV of 24%; CV varied from 13-40%. At the seasonal level, Kiremt rainfall varied from 633-1071mm with mean of 757mm. For Kiremt, the mean CV was 28%; CV revealed high (CV=42%) and less (CV = 18%) variability. The mean total rainfall amount for Belg and Bega were 209 and 75 millimeters; they varied from 121-484mm and 25-209mm, respectively. Bega rainfall was extremely variable (CV > 70%) for all stations. As compared to Kiremt season, the Belg rainfall was more variable. For example, CV for Belg was 53%; it ranged from 37-69%. This agrees with the study by Woldeamlak & Conway (2007) [35]. Based on Hare (1983) classification, North Shewa has been vulnerable to drought during Belg season (CV > 30%). Generally, the seasonal variability was higher than the annual variability. This agrees with the findings of previous studies conducted in Ethiopia [36].

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CT for Kiremt was very high (CT = 75%); it ranged from 54-83 %. This is supported by Bewket & Conway [35] and Ayalew et al. [5]. Belg rainfall also contributed a considerable amount for the annual total rainfall (CT = 19%); it ranged from 13-31 %. For Bega rainfall the mean areal CT was 6%; it ranged from 2-15 %. The analysis of PCI showed that in all stations the rainfall pattern was not uniformly distributed. Generally low or no rainfall was received from October to February while intensive rainfall was received between July and September. The maximum and minimum Kiremt rainfall amount was 942.9mm (occurred in 2007) and 361mm (occurred in 1987). Refer Figure 2 for the corresponding values for Belg and Bega seasons.

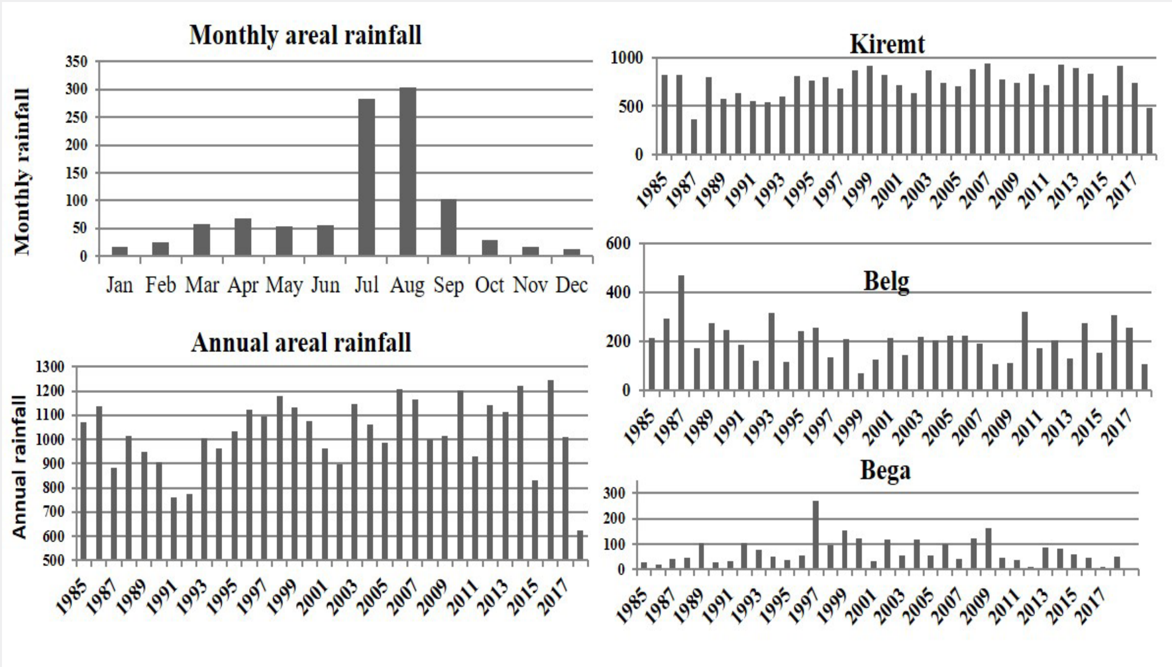

Figure 2: Monthly, Annual, and Seasonal rainfall climatology (in mm).

Figure 3 shows the spatial distribution of rainfall for the annual and seasonal time scales. Generally, the rainfall distribution showed a general decrease in annual mean rainfall from south to north. See Figure 3 for the corresponding seasonal rainfall distribution.

Annual and seasonal rainfall anomalies

Figure 4 shows the annual and seasonal rainfall anomalies. The result of SRA showed a 50% dry tendency and 50% wet tendency over the study area on annual basis. For Kiremt season 47% showed weak to strong negative departure from the long term mean rainfall and 53% recorded above the long-term average rainfall. Likewise, SRA during Belg and Bega season showed 50% and 59% dry tendency dominancy, respectively. According to the drought assessment method by Agnew and Chappel (1999), seven dry years: two extremes (1987 and 2018), two severe (1991 and 1992), and three moderate (1989, 1993 and 2015) dry years were identified. In contrast, 2007 and 2012 had experienced severe wet years; while that of 1998, 2003 and 2013 showed moderate wet years during Kiremt season.

Figure 5 shows the average of 3-month SPI for a period of three years (2016-2018) and ten years (2009-2018) for Belg season. According to the 3-month SPI analysis, in both periods North Shewa had experienced from extremely dry (SPI ≤ -2) to extremely wet (SPI ≥ 2) conditions. Comparatively, the three years (2016-2018) were a bit drier than the ten years (2009-2018). The areal average 3-month SPI for 1985-2018, 2009-2018, and 2016-2018 was 0.14, 0.13, and 0.09, respectively which is in agreement with the trend of SRA for Belg season (see Figure 4).

The Onset, Cessation, and Length of Growing Period of Kiremt season

The lowest, highest, and mean LGP was 55, 138, and 78 days, respectively (see Table 3). In a similar study conducted in Tigray region (northern Ethiopia) for the period 1980-2009, Hadgu et al. [37] found the average LGP to vary from 66 to 85 days. The coefficient of variation (CV) of LGP ranged from 14-87%. Higher CV (> 13%) of LGP gives less confidence in crop selection based on the maturity period.

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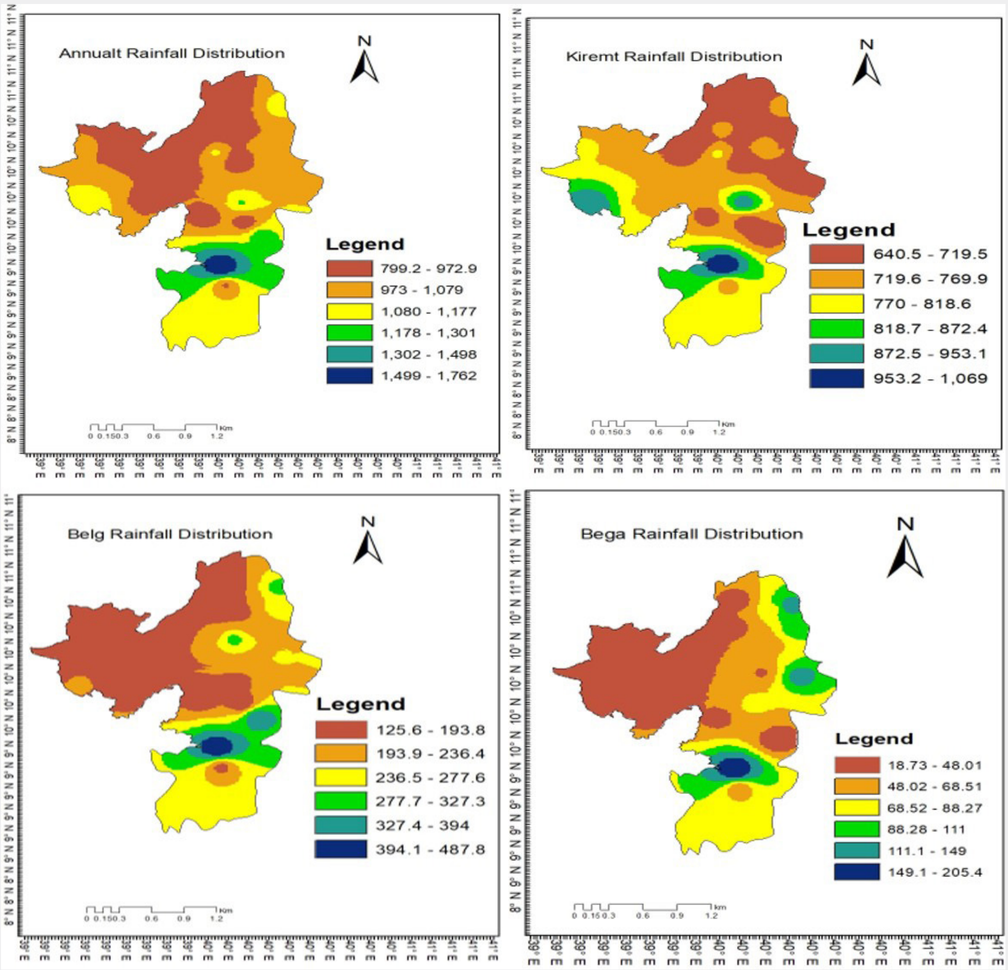

Figure 3: Spatial distribution of annual and seasonal rainfall climatology (in mm).

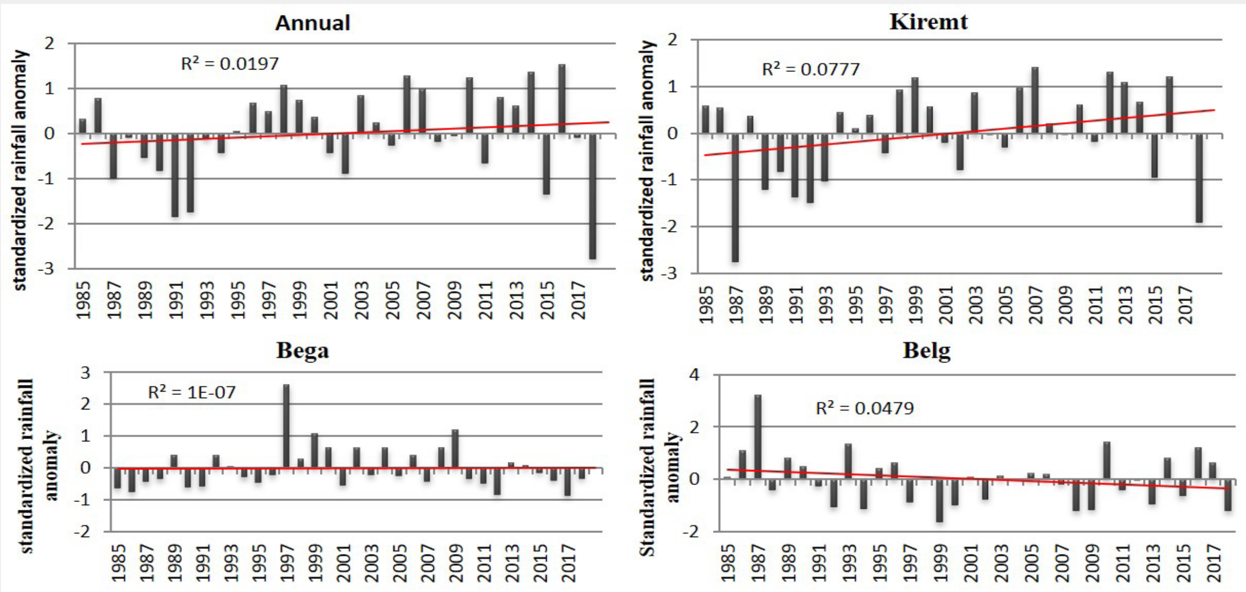

Figure 4: Annual and seasonal areal rainfall anomaly (in mm) in North Shewa.

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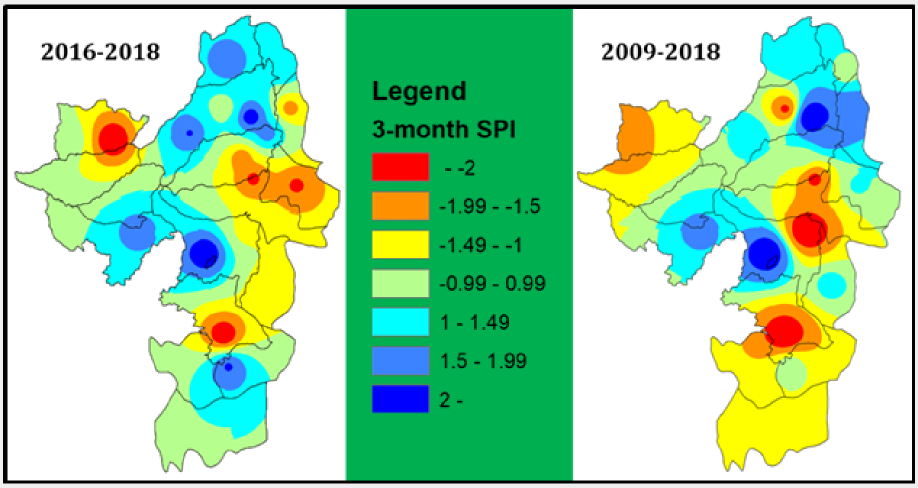

Figure 5: Areal average 3-month SPI for 2016-2018 and 2009-2018 over North Shewa.

Table 3: The mean and coefficient of variance of onset, cessation, length of the growing period and number of rainy days of Kiremt season (1985-2018).

Stations	Onset		Cessation		Length of Growing Period		Number of Rainy Days	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Alemketema	175	6.3	277	3.3	65	78.6	67	12.9
Alyuamba	182	7.4	282	4.1	82	51.6	40	24.5
Debrebirhan	182	15.3	277	5.2	80	60.9	63	22.6
Effeson	189	10.3	278	5.3	57	87.4	52	17.3
Enewari	169	18.5	276	2.8	70	80.1	68	21.9
Ginager	171	7	295	5.7	79	78.8	62	17.4
Gisherabel	186	6.1	271	3	56	76.5	61	15.8
Gudoberet	173	19.1	283	6.8	70	86.3	66	27.5
Gundomeskel	171	6.4	283	5.1	87	58.9	59	27.3
Majete	184	9.1	286	3.8	102	19.6	58	12.7
Mehalmeda	159	23.4	297	9.7	138	29.7	57	31.3
Meragna	179	6.1	278	3.5	63	78.8	68	16.1
Molale	185	6.7	274	4.4	55	82.9	61	18.7
Rema	173	7.3	290	7.1	74	82.1	66	17.9
Shewarobit	178	9	287	6.9	111	44.8	57	18.2
Sholagebeya	177	7.4	280	3	104	14	65	15.5
Yigem	183	8.7	278	5.3	62	81	64	21.5
Zemero	184	6.6	272	2.7	57	76	64	15
Areal mean	**178**	**10**	**281**	**4.9**	**78**	**64.9**	**61**	**19.7**

In a study conducted in northern Ethiopia, Hadigu et al. [37] found the start (onset) date of Kiremt growing areas to be between the 1st and 3rd week of July. In contrast, in this study, the mean onset date was varied from 159 DOY (June -6) to 189 DOY (July-6). The areal mean onset date was 178 DOY (June -25) in the study area. The observed variability of Kiremt onset was varied from 6-19 %. The onset date of Kiremt growing areas had experienced dependable patterns across Gisherabel; while at Gudoberet the patterns were not easily understood and consequently decisions of crop plantation and related activities should be taken with great care. Similarly, the mean cessation date ranged from 271 DOY (Sep-26) to 297 DOY (Oct-23) areas; the areal mean cessation date was 281 DOY (Oct-7). At all the probability levels considered, the end of Kiremt season was more extended at Mehalmeda compared to other areas.

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Figure 6 presents the spatial distributions of onset, cessation, LGP, and number of rainy days. The first two graphs show the mean spatial onset (the start) and the cessation (the end) of Kiremt season where the numbers in the legend are the DOYs. For example, DOY of 159.1 (~159) means the 6th of June and DOY of 188.8 (~189) means the 7th of July, and so forth. Accordingly, the western part and some pocket areas in the northern, central and southern parts of the study area had early onset of Kiremt rainfall while late onset was observed in the northern and at some pocket areas in the central parts of the study area. Similarly, the cessation date of Kiremt season was early (27th of September) in a few northern and western pocket areas; it was late (23rd of October) in a few southern, northern and eastern pocket areas.

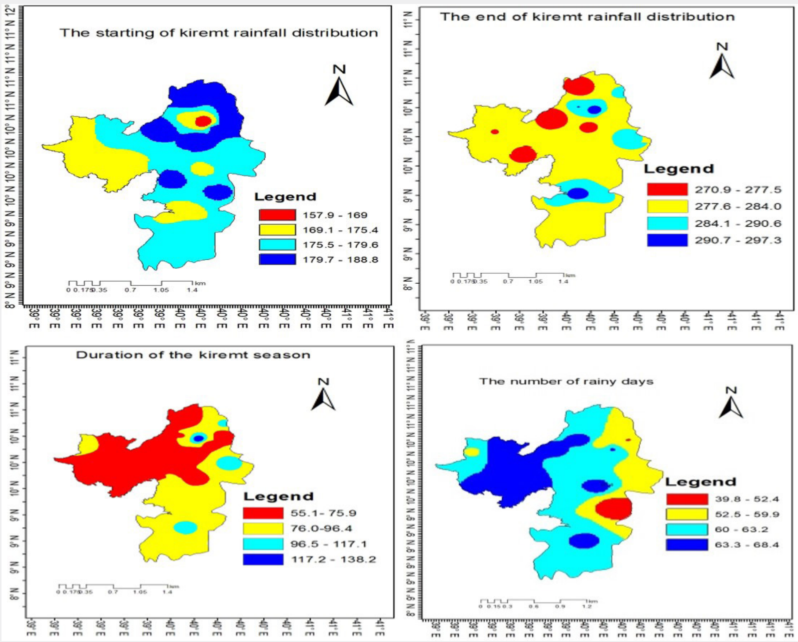

Figure 6: Onset, cessation, duration, and number of rainy days distribution of Kiremt.

Number of rainy days and probability of dry spell length

For Kiremt season, the number of rainy days varied from 40-68 days with an areal mean of 61 days (see Table 3). The inter-annual variability of the number of rainy days ranged from 13-31% with an areal mean of 19.7 days.

The probability of dry spell occurrence for Belg (DOY = 32-152) and Kiremt (DOY = 153-274) seasons for ten selected stations is shown in Figure 7; dry spell lengths of 5,7,10, and 15 days were considered. Observations of the rainfall data illustrated that the probability of dry spells occurring within the growing seasons varied from month to month. During Belg season, the probability of the occurrence of dry spells for 5, 7, 10, and 15 dry spell days was above 40% in all stations. In the main rainy season (Kiremt), the probability of 7, 10, and 15 days dry spell occurrence in July and August was zero; whereas for 5 days dry spell it was more than 30% at all stations.

Generally, the shorter dry spell events have a higher probability of occurrence, compared to the longer ones. Also, Belg season had a higher probability of dry spells than Kiremt season and is liable to meteorological drought.

The challenges of the risk of the dry spell were more at Molale, Gundomeskel and Enewari areas. This implies that, in these areas, the risk of planting long cycle crops before June is above 65%.

Annual and seasonal rainfall trends

The Mann–Kendall trend test showed a decreasing trend of annual rainfall at Alemketema, Alyuamba, Rema and Shewarobit areas (see Table 4). Only at Alyuamba station, the detected trends were significant at 5% significant level. This agrees with the results of Seleshi [9]; Cheung & McSweeney C [10]; Viste et al. [12]; NMA [38]; they reported statistically non-significant declining tendency in annual rainfall across Ethiopia between 1960 and 2006. On the contrary, the annual and Kiremt rainfall in North Shewa showed a statistically non-significant increasing trend (increased by a factor of 37 and 39mm per decade, respectively). This agrees with the result of the study by Bewket & Conway [35]; they showed that the annual and Kiremt rainfall at Dessie and Lalibela for the period 1975-2003 had a significant increasing trend. Belg and Bega rainfall had shown a non-significant decreasing trend.

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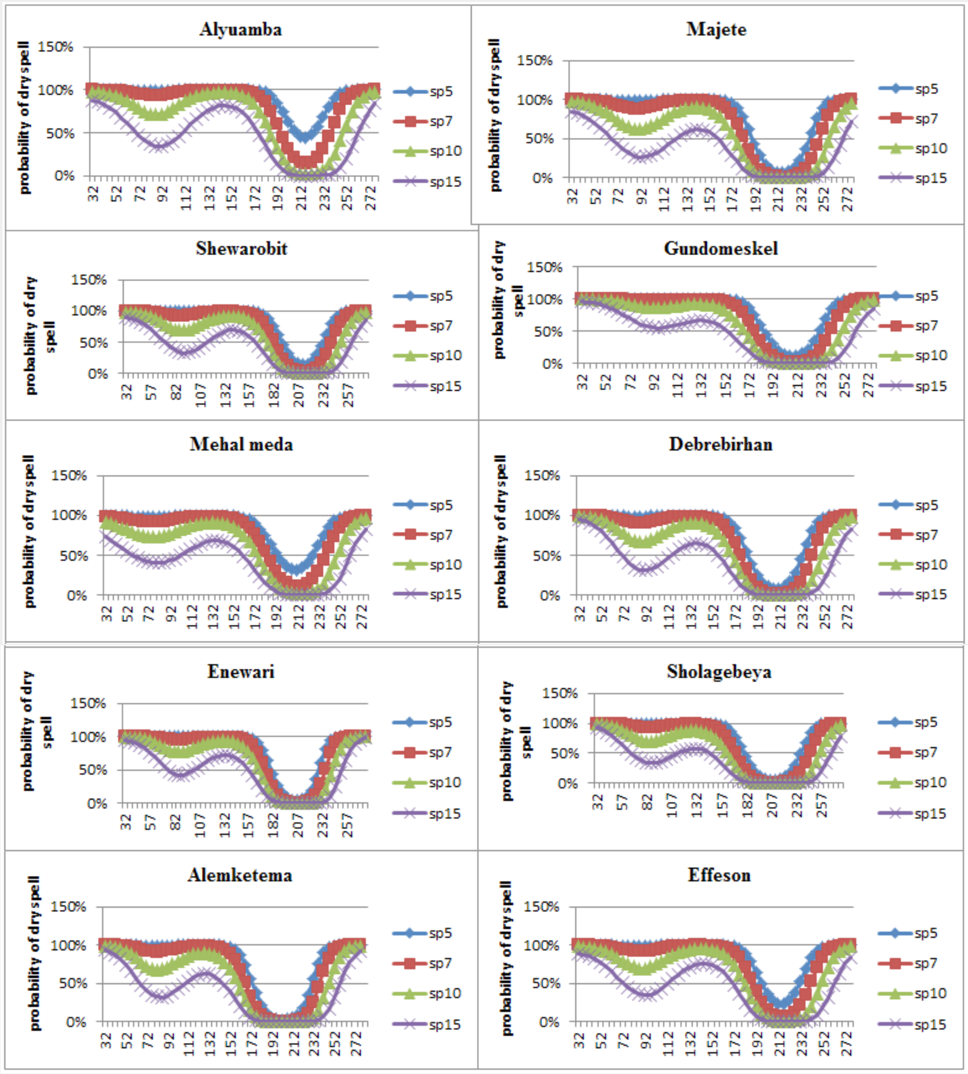

Figure 7: The probability of dry spell occurrence for 5, 7, 10, 15 days in Belg and Kiremt seasons.

Table 4: Trends of annual and seasonal rainfall in North Shewa (1985-2018).

Stations	Annual Rainfall			Kiremt Rainfall			Belg Rainfall			Bega Rainfall		
	ZMK	Q	P	ZMK	Q	p	ZMK	Q	P	ZMK	Q	p
Alemketema	-0.12	-3.9	0.33	-0.04	-0.93	0.75	-0.15	-1.5	0.22	-0.08	0.28	0.49
Alyuamba	-0.45	-25.4	0	-0.29	-9.5	0.01	-0.36	-12.8	0	-0.01	-1.44	0.43
Debrebirhan	0.21	3.9	0.08	0.18	3.2	0.14	-0.02	-0.13	0.86	0	-0.02	1
Effeson	0.12	5.3	0.33	0.37	9.9	0	-0.25	-5.9	0.39	-0.09	-1.33	0.43
Enewari	0.37	12.7	0	0.31	9.3	0.01	0.22	2.85	0.07	0.28	0.8	0.02
Ginager	0.01	0.42	0.94	0.15	5.6	0.21	0	-0.38	0.99	-0.06	-1.1	0.61
Gisherabel	0.45	11.9	0	0.44	12.1	0	-0.14	-1.4	0.23	0.19	0.68	0.12
Gundoberet	0.39	21.6	0	0.43	18	0	0.23	3.7	0.06	0.14	1.28	0.25
Gundomeskel	0.32	10.2	0.01	0.31	9.2	0.01	-0.06	-0.55	0.64	0.08	0.34	0.53

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Majete	0.09	2.9	0.44	0.23	6.1	0.07	-0.14	-2.5	0.26	0.07	1.04	0.59
Mehalmeda	0.31	6.8	0.01	0.31	7.3	0.01	-0.05	-0.53	0.7	0.23	0.82	0.06
Meragna	0.29	9.9	0.02	0.23	6.3	0.07	0.19	2.6	0.13	0.31	0.92	0.01
Molale	0.14	4.5	0.27	0.23	6	0.06	-0.22	-2.1	0.08	0.19	1.01	0.11
Rema	-0.08	-2.2	0.53	-0.08	-1.7	0.51	-0.11	-0.89	0.38	0.05	0.13	0.67
Shewarobit	-0.06	-3.1	0.66	-0.12	-3.8	0.32	-0.03	-0.37	0.84	0.04	0.59	0.73
Sholagebeya	0.01	0.3	0.93	0.11	2.8	0.36	-0.21	-2.45	0.08	0	0	1
Yigem	0.47	23.1	0	0.44	21	0	0.21	3.8	0.08	0.14	1.14	0.25
Zemero	0.33	9	0.01	0.37	7.7	0	0.11	1.3	0.38	0.18	0.4	0.14
Areal mean	**0.17**	**3.7**	**0.16**	**0.21**	**3.9**	**0.08**	**-0.12**	**-1.6**	**0.34**	**-0.01**	**-0.04**	**0.95**

Trends of onset and cessation days of rainfall for Kiremt season

The Mann-Kendall trend test on onset of Kiremt rainfall showed a decreasing trend in all stations except Alyuamba and Meragna stations (see Table 5). The observed trends were statistically significant only at Gisherabel, Yigem and Gundomeskel stations while in the remaining stations the trends were not significant. The cessation date of Kiremt rainfall showed an increasing trend in fourteen stations; in the four stations (Gudoberet, Mehalmeda, Rema and Zemero), the trend was statistically significant.

Table 5: Trends of onset and cessation days, length of growing period and number of rainy days during Kiremt season at eighteen stations for the period 1985-2018.

Stations	Onset			Cessation			Length of Growing Period			Number of Rainy Days		
	ZMK	Q	p	ZMK	Q	P	ZMK	Q	P	ZMK	Q	p
Alemketema	-0.13	-0.22	0.28	-0.01	0	1	0.13	0.28	0.28	0.17	0.2	0.17
Alyuamba	0.08	0.11	0.43	-0.14	-0.22	0.25	-0.12	-0.33	0.32	0.19	0.25	0.12
Debrebirhan	-0.03	-0.02	0.83	0.01	0	0.95	-0.01	-0.1	0.95	0.29	0.33	0.01
Effeson	-0.08	-0.17	0.51	-0.04	-0.1	0.75	0.01	0	0.96	0.02	0	0.87
Enewari	-0.09	-0.17	0.41	0.04	0.04	0.77	0.06	0.21	0.6	0.01	0	0.96
Ginager	-0.08	-0.12	0.53	-0.21	-0.5	0.08	-0.13	-0.23	0.29	-0.14	-0.23	0.25
Gisherabel	-0.3	-0.33	0.01	0.23	0.22	0.06	0.29	0.56	0	0.42	0.46	0
Gundoberet	-0.19	-0.4	0.12	0.26	0.61	0.03	0.29	1.18	0.01	0.29	0.73	0.02
Gundomeskel	-0.29	-0.48	0.02	0.22	0.29	0.08	0.29	0.73	0.01	0.39	1.04	0
Majete	-0.1	-0.2	0.41	-0.08	-0.12	0.53	0.03	0.06	0.83	0.17	0.14	0.17
Mehalmeda	-0.18	-0.25	0.09	0.38	1.58	0	0.43	2.3	0	0.42	0.83	0
Meragna	0	1	0	0.13	0.2	0.29	0.06	0.1	0.63	0.19	0.23	0.12
Molale	-0.05	-0.1	0.71	0.05	0.1	0.67	0.07	0.2	0.56	0.19	0.33	0.11
Rema	-0.23	-0.44	0.06	0.24	0.71	0.04	0.28	1.4	0.02	-0.18	-0.38	0.14
Shewarobit	-0.06	-0.15	0.64	0.16	0.48	0.21	0.1	0.45	0.41	-0.15	-0.25	0.24
Sholagebeya	-0.04	-0.04	0.7	0.06	0.1	0.63	-0.04	-0.1	0.73	0.22	0.27	0.08
Yigem	-0.28	-0.67	0.02	0.01	0	0.93	0.39	1.5	0	0.42	0.73	0
Zemero	-0.19	-0.33	0.11	0.27	0.18	0.03	0.25	0.4	0.04	0.25	0.28	0.04
Areal mean	**-0.71**	**-3.6**	**0**	**0.22**	**0.2**	**0.07**	**0.34**	**0.5**	**0.01**	**0.32**	**0.31**	**0.01**

Generally, the Mann-Kendal trend test showed that the onset date had been decreasing non-significantly by 36 days per decade while that of cessation date had been increasing non–significantly by 2 days per decade in the study area.

The length of the growing period (LGP) showed an increasing trend in fourteen stations; in seven stations the trend was statistically significant. In line with this Kelemu S [39] reported decreasing trends of the length of the growing period at Debretabor and Wereta stations in South Gonder zone for the period 1985-2014. Generally, in North Shewa the test showed statistically significant increasing trends of rainfall by 5 days per decade over the last 34 years.

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On the other hand, the number of rainy days had shown increasing trends in all areas except at Ginager, Rema, and Shewarobit areas. Generally, the number of rainy days had shown statistically significant increasing trends in the study area; it had increased by 3.1 days per decade [40].

Conclusion

In this study, detailed analysis of the temporal and spatial characteristics of rainfall using rainfall data obtained from the National Meteorological Agency of Ethiopia for 34 years (1985-2018) is presented. The data used is a combination of gauge and gridded rainfall data which is believed to be more reliable than using lonely satellite rainfall data. Rainfall is the major climatic parameter that needs to be analyzed for its statistical characteristics in order to conduct successful rain-fed agriculture over central Ethiopia. Variation of rainfall in both time and space has a significant effect in the performance of agricultural productivity, particularly over central Ethiopia where agriculture heavily relies on seasonal rainfall.

North Shewa is characterized by bimodal rainfall pattern where much of the rainfall concentrated in the main rainy season called Kiremt (June-September) and a small amount of rainfall received in the second rainy season called Belg (February-May). Bega (October-January) is a relatively dry season. The mean annual rainfall amount was 1029mm while Kiremt, Belg, and Bega received 757, 209, and 75 millimeters respectively. The mean onset and cessation dates were June 25th and October 7th, respectively while the mean duration of the Kiremt season was 78 days.

The result showed that there was considerable temporal and spatial variation of rainfall over North Shewa. The coefficient of variation of the annual and Kiremt rainfall revealed moderate inter-annual and seasonal variability. However, much larger variation was observed during Belg and Bega season. On the other hand, the result of coefficient of variation showed low variability in the onset and cessation dates; whereas, the length of growing period was highly variable. Spatially, a general decrease of mean annual rainfall from south to north was observed. Moreover, the rainfall was characterized by a sporadic fluctuation of wet and dry years in a periodic pattern.

Trends of rainfall at annual and seasonal time scales for the study period were analyzed using the Mann-Kendall test and Sen's slope estimator. The tests for annual and Kiremt rainfall resulted in non-significant increasing trends; increased by 37 and 39mm per decade, respectively. The result of the test showed non-significant decreasing trends by 16 and 0.4mm per decade, during Belg and Bega seasons, respectively. Also, the onset dates decreased non-significantly by 36 days per decade; whereas, cessation dates showed a non–significant increasing trend of 2 days per decade. Likewise, the length of growing period also showed a statistically significant increasing trend of 5 days per decade. On the other hand, the number of rainy days increased significantly by 3.1 days per decade.

During Belg season, the probability of the occurrence of dry spells for 5, 7, 10, and 15 dry spell days was above 40% in all stations. The information on the length of dry spells can be used as input in decision making concerning crop selection, supplementary irrigation water demand scheduling, and in other agricultural activities.

This study has offered useful information for a better understanding of the temporal trends and spatial distribution of rainfall in the study area, which is of great importance for water and forest resources management particularly in securing sustainable agricultural production. Moreover, this study can be used as an input for a more comprehensive study that may include the impact of the temporal rainfall trends and the spatial rainfall variabilities on water, agriculture, and forests as well as on the driving forces that caused the variabilities and trends.

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Data Availability Statement

All data used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated in the Acknowledgements. All code used during the study are available from the authors by request.

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