Variability and trend analysis of temperatures, rainfall, and characteristics of crop-growing season in the eastern zone of Tigray region, northern Ethiopia

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Abstract
In this study, auto-correlated Mann–Kendall (MK) and Sen’s slope estimator tests were utilized to determine trends of rainfall, temperatures, and characteristics of crop-growing season during 1980–2009. Moreover, the Van Belle and Hughes’ for homogeneity of general trend and Pettitt’s test for the occurrence of abrupt changes were applied. On monthly, Kiremt (June–September) and annual time scale, the MK-trend test for rainfall exhibited non-significant increasing trend, while in Belg (February–May) rainfall season exhibited non-significant decreasing trend at the most of the stations. On the contrary, temperatures showed significant increasing trends in annual and Belg at the 5% significant level. In Kiremt season, however, the maximum temperature showed non-significant increasing, while the minimum temperature showed non-significant decreasing trend. Results of homogeneity for general trend obtained by the Van Belle and Hughes’ test seem fairly consistent with those of the MK-trend test. Moreover, results of Pettitt’s test indicated a homogeneous trend in monthly, annual, and seasonal rainfall series and no break point was distinguished, except few stations. On the contrary, the abrupt changes were found to be quite variable in temperatures. The study also found that trends of growing season characteristics (June–September) have not changed significantly at the 5% significant level. Nevertheless, the high coefficient of variation in Kiremt rainfall (21–31%) as well as dry spell length (25–43%) in conjunction with the short nature of the length of growing period (68–90 days) had negative implications to crop production in the eastern zone of Tigray region.

1 Introduction
Impacts of climate change and variability are predominantly noticed through changes of two most important climate parameters which are temperature and precipitation. The trends of these parameters, which are crucial for crop production, have been changed in Ethiopia for the last several decades. Looking at the past four decades, Ethiopia’s annual average temperature has increased by 0.37 °C per decade since 1951 (NMA 2007; Aragie 2013). Moreover, the country has experienced a high degree of inter-annual rainfall variability (Cheung et al 2008; Gebremicael et al. 2017; Mekasha et al. 2014; Meze-Hausken 2004; Seleshi and Zanke 2004). The impacts of increased temperature and changes in rainfall patterns are expected to reduce crop production and water availability for irrigation and other water-consuming sectors. The impacts of the climate parameters are more pronounced in the north, northeastern, and eastern lowlands of the country (Aragie 2013). The changes in temperature and rainfall patterns as a result of climate change and variability are very critical to the majority of the populations of the country who are dependent on rain-fed agriculture for their livelihoods, such as the Tigray region.

Tigray is one of the drought- and famine-prone regions in Ethiopia (Weldearegay and Tedla 2018; Sara 2010). Most of the droughts caused by climate variability and change...
have occurred in the eastern and southern part of region (Gebrehiwot and van der Veen 2013). Similarly, eastern zone of the Tigray region, where the study area is located, is affected by frequent droughts. Consequently, crop yield has been severely affected during part of its growing period (Araya and Stroosnijder 2010). Indeed, moisture stress stands to be the major limiting factor for crop and animal production in the eastern zone of the Tigray region (Meles et al. 1997). Almost every year, localized drought associated with variable and erratic rainfall has been the main reasons for crop productivity failures; as a result, it jeopardized the livelihoods and development activities of the region (Awulachew et al. 2011; Gebrehiwot and Van der Veen 2013; Oxfam 2010).

Although rainfall variability and associated localized droughts have been the greatest concern in the study area, few attempts have made so far to quantify the variability and trend analysis of rainfall and temperatures. Yet, the emphasis by the most of the studies on trends analysis so far carried out in Tigray region has been limited to rainfall analysis (Abrah and Simhadri 2015; Cheung et al. 2008; Gebrehiwot et al. 2011; Gebrehiwot and van der Veen 2013; Gebremicael et al. 2017; Hayelom et al. 2017; Mekasha et al. 2014; Meze-Hausken 2004; Seleshi and Zanke 2004), whereas temperature analysis has been ignored in many of these studies, although it is also vital for crop production and water-related issues. Furthermore, the rainfall trend analyses made by many of the studies listed above are based on few station data and/or with few number of years especially regarding the study area (eastern zone of Tigray region) and many of the studies were restricted to even trends of annual or monthly or seasonal total values. Rainfall variability based on agricultural practices, such as onset and cessation at an interval of days, length of growing period (LGP), and dry spells were not included in those studies with the only exception of Araya et al. (2010) who determined LGP of two crops, Teff (Eragrostis tef) and barley (Hordeum vulgare) in Giba catchment of the Tigray region. Yet, the rainfall and rainy season characteristics are important to make proper crop-based decisions in seeding, fertilizing, selecting crop variety, selecting suitable cropping pattern, and selecting the best agro-techniques. Assessing long-term trends of rainfall and rainy season characteristics (including onset, cessation, and LGP) can help to formulate farming strategies to efficiently use the available water (Fiwa et al. 2014). In addition, rainfall statistics for dry spells are also very important for planning and management of water resources (Almazroui et al. 2017).

Therefore, the aim of this study is to assess long-term variability and trends of temperatures, rainfall, and crop growth season characteristics, which is essential to better understand the uncertainties associated with rainfall and temperature patterns and favor knowledge-based management of agriculture, irrigation, and other water-related sectors in the region.

2 Materials and methods

2.1 Description of the study area

This study was carried out in the eastern zone of Tigray region located in northern Ethiopia. Its geographical location lies between 13°33′ N to 14°40′ N latitude and 39°11′ E to 39°59′ E longitude (Fig. 1). The total area of the zone is 561,000 ha, which is divided in to seven districts: Erob, Hawzen, Wukro, Atshi-Womberta, Ganta-Afeshum, Gulo-Mekeda, and SaeSis-TsaedaEmba. The altitude ranges from 1500 to 3280 m above sea level and divided into three traditional agro-ecologies: (i) highland, with areas over 2300 m above sea level; (ii) midland, between 1500 and 2300 m above sea level; and (iii) lowland, with areas less than 1500 m above sea level (Meles et al. 1997). Eastern zone of Tigray is a semi-arid climate zone characterized by a heavy rainy season (June–September), locally known as “Kiremt” and a small rainy season (February–May), locally known as “Belg.” The rainfall is highly variable due to the complex influences of topography (Meles et al. 1997). The mean annual rainfall ranges from 520 to 680 mm, and the mean annual temperature varies between 16 and 20 °C (Kahsay et al. 2019).

Three watersheds, namely, Agulae, Suluh, and Genfel were selected from the eastern zone of Tigray region for this study based on high population growth, expansion of urbanization, and availability of small-scale irrigation schemes in each watershed (Fig. 1). The livelihood of the farming communities in the eastern zone of Tigray region is mainly dependent on rain-fed agriculture. Common rain-fed crops in the watersheds include teff, wheat, barley, maize, sorghum, and pulses. However, irrigated agriculture has been increased significantly at household level in the recent years (Nyssen et al. 2010). According to Gebreyohannes et al. (2013), the dominant soil texture classes in the area is clay loam (40%) followed by sandy clay loam (30%), clay (19%), loam (10%), and sandy loam (1%).

2.2 Data used

Thirty years (1980–2009) of climate data (rainfall and temperatures) from the currently existing seven meteorological stations within and nearby the eastern zone of Tigray region were collected from Enhancing National Climate Services Initiative (ENACTS), which is recently implemented at Ethiopian National Meteorological Agency (Table 1). The climate data provided by ENACTS is available with high spatial resolution and the quality of the data is improved by
combining careful quality control of data from the weather stations with that of satellite estimates. This is the best available dataset for the country which is homogeneous and recommended for climate analysis (Dinku et al. 2014). The detailed information about ENACTS is elucidated in Dinku et al. (2014) and Dinku et al. (2018).

2.3 Data analysis

Long-term variability and trends of rainfall and temperatures data series were analyzed using the non-parametric methods: Mann–Kendall and Sen’s estimator of slope. Linear regression was utilized to visualize the trend directions. Moreover, the Van Belle and Hughes’ homogeneity for general trend test and Pettitt’s test for the occurrence of abrupt changes were utilized. More specifically:

2.3.1 Linear regression

A straight line was fitted to the data series to determine whether the slope was different from zero or not. A simple linear regression method was utilized to determine the tendency.

2.3.2 Mann–Kendall and Theil-Sen’s slope estimator

The presence of non-linear trends was assessed using the Mann–Kendall (MK)-trend test (Kendall 1975) and Sen’s slope estimator (Sen 1968). The MK and Sen’s estimator of slope tests are two non-parametric tests and widely applied in various trend detection studies (Asfaw et al. 2017; Chattopadhyay and Edwards 2016; Hamza et al. 2017; Palaniswami and Muthiah 2018; Samo et al. 2017).

2.3.3 Influence of serial correlation

Prior to applying the MK and Theil-Sen’s slope estimator tests, it is essential that the time series data sets require consideration of auto-correlation or serial correlation. Specifically, if positive serial correlation is contained in the data, it can complicate the results of the trend detection on the MK-trend test since the positive auto-correlation can increase the expected number of false positive outcomes (Kulkarni and Von Storch 1995; Von Storch and Navarra 1999; Yue et al. 2002; Yue and Wang 2004). Therefore, in view of the above fact, it is imperative to pre-whiten the time series data before applying the MK-trend test.

Table 1 Geographical location of the meteorological stations

| Station  | Latitude (N) | Longitude (E) | Elevation (meter) |
|----------|--------------|---------------|------------------|
| Illala   | 13°31'12"    | 39°30'0"     | 2012             |
| Adigrat  | 14°16'48"    | 39°27'0"     | 2470             |
| Edagahamus | 14°7'12"   | 39°19'48"    | 2700             |
| Atsbi    | 13°52'48"    | 39°44'24"    | 2600             |
| Sinkata  | 14°4'12"     | 39°34'12"    | 2480             |
| Wukro    | 13°49'48"    | 39°36'0"     | 1995             |
| Hawzen   | 13°58'12"    | 39°25'48"    | 2255             |

Fig. 1 Location of the study area and selected watersheds
and Theil-Sen’s slope estimator (Von Storch and Navarra 1999). Yue et al. (2002) suggested that removal of serial correlations by pre-whitening can effectively eliminate the influence of serial correlation on the MK test. Thus, this study incorporates pre-whitening approach modified by Yue and Wang (2004) for the variables having significant serial correlation in the time series data. The presence of auto-correlation in each of the time series was tested at the 5% significant level using lag-1 auto-correlation function. Pre-whitening method has been applied in many of the previous studies in precipitation and temperature trend analysis (Milan and Slavisa 2013; Oguntunde et al. 2011; Yue and Hashino 2003; Zhang et al. 2000).

### 2.3.4 Van Belle and Hughes’ homogeneity of trend tests

To make catchment wise statement about all possible trend features using a single method, application of a homogeneity test (Van Belle and Hughes 1984) is useful to combine data from several stations to obtain a single global trend test. This test provides a single statistic value to indicate whether the months/seasons/annual are behaving in similar (homogeneous) or different (heterogeneous) fashion from each other. This test uses Z-values (standardized test statistics) from MK-test statistics for each station. To get the trend homogeneity of temperatures and rainfall at multiple stations, Van Belle and Hughes proposed a procedure based on the partitioning of the sum of squares. The analysis procedure uses chi-square ($\chi^2$) test statistics of various chi-squares. A similar approach was applied as in Jhajharia et al. (2014), Kahya and Kalayc (2004), and Panda et al. (2007).

### 2.3.5 Change point detection analysis

The recognition of change points is a statistical technique that plays a vital role in spotting climate jumps in the long-term climate data series. Pettitt’s test is commonly applied non-parametric approach to detect a single change-point in climate and hydrological time series with continuous data sets (Pettitt 1979). This test method detects a significant change in the average of a time series when the exact time of the change is unknown (Gao et al. 2011). To carry out change point detection analysis, mean monthly rainfall, seasonal rainfall, and seasonal maximum and minimum temperatures were analyzed with the help of Pettitt’s test at the 5% significant level. This approach has been applied in different studies to detected abrupt changes in climate and hydrological time series (Chakraborty et al. 2017; Gao et al. 2011; Gebremicael et al. 2017; Gulakhmadov et al. 2020; Salarijazi et al. 2012).

### 2.4 Crop risk assessments

Crop risks associated with extreme events including dry spells and other growing season characteristics were assessed using R-Instat (V.0.6.2) software developed under the African Math’s Initiative (https://africandata.org/) (AMI 2018). Growing season characteristics, such as onset and cessation date, LGP, and dry spell length, were determined using 30 years of rainfall data.

**Onset and cessation date** The onset of rainfall can be described as the start of the growing season during which sufficient rain is received for the seedling (Ati et al. 2002), while the cessation is a period that is characterized by the end of rainfall of the growing season; this also means the scanty few days of rainfall which may occasionally occur (Ojo and Ilunga 2018). Similar to previous studies (Sivakumar 1988; Tesfaye and Walker 2004), the onset of the main rainy season (June–September) in the study area was assumed to start as of June 19 after the wet spells occurred for at least three consecutive days and when the total rainfall is 20 mm or more if there was no dry spell longer than 7 or more days within 30 days. Moreover, cessation date was assumed as the date when the stored soil moisture reaches 100 mm that is after the rainfall falls below half of the reference evapotranspiration (ETo) values (Stern et al. 1982). The choice of 100 mm is based on the evidence that annual crops utilize 75–100 mm sored soil moisture during their harvest time (Higgins and Kassam 1981).

**Length of growing period** It was computed using the difference between the onset and cessation of total seasonal rainfall (cessation date minus onset date).

**Dry spell length** It was computed considering a time period with no rain or less than 1-mm rain for more than 7 days within 30 days. The average value of the dry spells was computed at a seasonal time scale during the main rainy season (Sivakumar 1992).

### 3 Results and discussion

#### 3.1 Annual and seasonal rainfall variability

The mean annual rainfall amount throughout the study area was found to be 572 mm (Fig. 2). A minimum and a maximum total rainfall amount of 554 mm and 617 mm were observed in Edagahamus and Hawzen stations, respectively. The contribution of the Kiremt season to that of the annual total rainfall amount was very large at all stations which varied between 54 and 84%. In addition, the contribution of the Belg season was not to be underestimated. At the most of
the stations, it contributed from 15 to 35% of the total annual rainfall. In the study area, the Belg season is very useful for long maturing crop varieties. These crop varieties are planted in this season before the main rainy season, Kiremt. Moreover, farmers are utilizing this season for land management practices, such as repeated ploughing and in situ soil moisture conservation activities.

The coefficient of variation (CV) in Fig. 2 (blue line) indicated that the rainfall had high inter-annual variability at the most of the stations. Likewise, the variability was much higher for Belg season that ranged from 37 to 45% than Kiremt season rainfall (21–31%), indicating a very high temporal variability of the seasons. Several studies also showed that the CV of Belg season is higher than Kiremt season in the northern Ethiopia (Hadgu et al. 2013; Kiros et al. 2017; Weldesenbet 2019). Of all stations, Hawzen station showed the highest both Kiremt and Belg inter-annual variability with 31% and 45%, respectively. Overall, the variability of the seasonal total rainfall in the study area can be categorized from moderate to high variability (25–41%). Our finding is in agreement with the previous studies that have reported the annual and seasonal rainfall variability showed moderate and high inter-annual variability (Ademe et al. 2020; Ayalew et al. 2012; Bewket and Conway 2007; Hadgu et al. 2013).

3.2 Trend analysis of rainfall and temperatures

3.2.1 Monthly, seasonal, and annual rainfall trend

Results of statistical tests for monthly, seasonal, and annual rainfall are presented in Table 2. As shown, the two-tailed MK-trend statistical test for monthly rainfall showed an increasing trend at the most of the stations and in all months. The magnitude of change is indicated by Sen’s slope estimator that ranges from 0.29 to 0.99 mm/month for June, 0.27 to 2.51 mm/month for July, 0.82 to 2.96 mm/month for August, and 0.22 to 0.55 mm/month for September. The fitted linear regression in Fig. 3 also revealed the presence of positive linear trend at all stations as well as in all of the months. Nevertheless, only significant trends were observed at few stations. For example, June and July months exhibited statistically significant increasing trend at only Hawzen station. And, September
month exhibited statistically significant increasing trend at Sinkata and Wukro stations. August month, however, showed statistically non-significant increasing trends at all of the stations. All at the 5% significant level.

Likewise, annual rainfall showed an increasing trend at the most of the stations and varied from 0.8 to 5.51 mm/year (maximum at Hawzen station). In addition, Kiremt season rainfall values also showed an increasing trend varied from 2.34 to 6.78 mm/season (maximum at Hawzen station), while Belg rainfall season showed a decreasing trend varied from 0.74 to 2.29 mm/season (maximum at Edaghamus station). Trend analysis using the fitted linear regression is also presented in Fig. 4 from which it is clear that the results are inconsistent with the Sen’s test results found in Table 2. Although there were increasing and decreasing trends in annual and seasonal rainfall values, the trends are found to be non-significant at the 5% significant level. Our results corroborate with the findings of previous studies that indicated non-significant rainfall trend, neither annually nor in any of the seasons in northern Ethiopia at the 5% significant level (Cheung et al. 2008; Gebremicael et al. 2017; Seleshi and Camberlin 2006; Seleshi and Zanke 2004; Viste et al. 2012).

In general, the findings of the auto-correlated MK-trend test revealed that there was non-significant trend in the annual and seasonal rainfall series at all stations. Moreover, most of stations showed non-significant trends in monthly rainfall series: June at 6 out of 7 stations, July at 6 out of 7 stations, August at 7 out of 7 stations and September at 5 out of 7 stations. Contrary to this, monthly rainfall of June and July at only 1 of 7 stations and September at 2 of 7 stations showed statistically significant increasing trend over the study area. All at the 5% significant level.

### 3.2.2 Seasonal maximum and minimum temperature trends

Results of MK and Sen’s slope estimator statistical tests for maximum and minimum temperatures are presented in Table 3. In addition, Figs. 5 and 6 also showed the fitted linear regression for the mentioned parameters. On the annual and Belg time scale, statistically significant increasing trend was detected at the 5% significant level for both maximum and minimum temperatures, with a magnitude of (0.04–0.07 °C/year, 0.024–0.06 °C/year) and

| Stations | Rainfall Statistics | MK (z-test) | θ | (95% CI) | θ | (95% CI) | θ | (95% CI) | θ | (95% CI) | θ | (95% CI) |
|----------|---------------------|-------------|---|----------|---|----------|---|----------|---|----------|---|----------|
| June     | MK (z-test)         | 1.75        | 0.52 | 0.4–0.7  | 1.16 | 1.0–1.6  | 0.54 | 0.5–1.3  | 0.89 | 0.2–2.0  | 0.90 | 0.1–0.3  |
| July     | MK (z-test)         | 1.82        | 0.27 | 0.1–0.6  | 1.03 | 0.8–1.7  | 1.07 | 0.8–1.7  | 1.14 | 0.8–1.7  |
| August   | MK (z-test)         | 0.54        | 1.17 | 2.04     | 1.36 | 1.4–2.5  | 0.89 | 1.82     | 1.53 | 0.2–2.0  |
| September| MK (z-test)         | 0.89        | 0.22 | 0.2–0.3  | 1.89 | 1.2–1.5  | 1.90 | 1.7–2.8  | 1.61 | 1.6–2.7  |
| Belg     | MK (z-test)         | −1.07       | −1.27 | −1.7–(−1) | −1.89 | −1.9–(−1.5) | −1.32 | −1.0–1.7 | −1.03 | −0.8–1.6  |
| Kiremt   | MK (z-test)         | 1.14        | 2.34 | 1.6–2.9  | 1.61 | 1.5–1.8  | 1.78 | 1.6–2.8  | 1.64 | 1.5–1.8  |
| Annual   | MK (z-test)         | 0.32        | 0.8  | −0.82    | 0.86 | 2.12     | 0.6–1.8 | 2.2–3.9  | 1.43 | 1.5–1.8  |

*Statistically significant at the 5% significance level

θ Sen’s slope
Fig. 3  Monthly rainfall trends of a Illala, b Edagahamus, c Adigrat, d Sinkata, e Wukro, f Atsbi, g Hawzen
Fig. 4 Annual, Kiremt, and Belg total rainfall of a Illala, b Edagahamus, c Adigrat, d Sinkata, e Wukro, f Atsbi, g Hawzen
Unlike the annual and Belg season, the maximum and minimum temperature for Kiremt season showed an increasing and decreasing trend patterns, respectively. Increasing trends were detected at 71.43% of the stations for maximum temperature, while a decreasing trends were detected at 85.7% of the stations for minimum temperature. Yet, the Kiremt season maximum and minimum temperatures trends were not statistically significant at the most of the stations. Few stations, however, such as Edagahamus showed a significant increasing trend for maximum temperature with a magnitude of 0.08 °C/season. Moreover, Adigrat and Hawzen station showed a significant decreasing trend in minimum temperature by 0.04 °C/season and 0.03 °C/season, respectively. Figures 5 and 6 also revealed consistent linear trend direction as of the Sen’s slope magnitude. It is generally expected that an increase in maximum temperature increases the rate of evapotranspiration and increase the rate of water consumption by the crops and causing more water stress. In addition, temperature increment beyond the threshold level can affect the growth and reproduction which reduces crop yield and the risk of crop failure.

### 3.3 Van Belle and Hughes’ trend test for the general case

To obtain a single global trend for the entire basin, van Belle and Hughes’ homogeneity trend test was applied to the rainfall and temperatures series. Accordingly, in the monthly rainfall series (June–September), all of the months showed an evidence of trend since $X^2$ trend of each month is greater than the $X^2$ critical values (with d.f. = 1, i.e., 3.84) at the 5% significant level (Table 4). Table 4 also indicated that trends in all months were in the same direction. However, trends of June, July, and September months were stronger than August month as indicated by larger magnitude of the $X^2$ trend.

In the annual and seasonal rainfall series, $X^2$ for annual and seasons exhibited trend heterogeneity since $X^2$ for annual and seasons is greater than $X^2$ critical values, while the stations were found to have homogeneous trends (Table 5). Hence, trend direction analysis for annual and each season was conducted. Annual and each season was tested using the average MK-trend test statistics ($Z_k$). Here, the $M \overline{Z_k}$ was obtained to test the overall trend homogeneity and referred to the value of $X^2$ critical (with d.f. = 1, i.e.,

### Table 3 Seasonal maximum and minimum temperature statistical trend values

| Stations          | $T_{\text{max}}$ (°C) | Statistics | Illala | Edagahamus | Adigrat | Sinkata | Wukro | Atsbi | Hawzen |
|-------------------|------------------------|------------|--------|------------|---------|---------|-------|-------|--------|
| **Annual** MK (z-test) | 4.85*                  | 2.53*      | 3.23*  | 4.57*      | 3.42*   | 4.04*   | 4.59* | 4.14* | 5.07*  |
| $\theta$          | 0.05                   | 0.07       | 0.05   | 0.05       | 0.06    | 0.06    | 0.07   | 0.08   | 0.09   |
| $\theta$ (95% CI) | 0.05–0.06              | 0.07–0.08  | 0.047–0.05 | 0.051–0.06 | 0.04–0.05 | 0.046–0.05 | 0.05–0.06 | 0.05–0.06 | 0.05–0.06 |
| **Kiremt** MK (z-test) | 1.25                   | 3.32*      | 0.43   | 1.25       | 0.00    | 0.32    | 1.86   | 1.86   | 1.86   |
| $\theta$          | 0.02                   | 0.08       | 0.004  | 0.015      | −0.0007 | −0.002  | 0.022  | 0.022  | 0.022  |
| $\theta$ (95% CI) | 0.01–0.02              | 0.07–0.09  | 0.0–0.012 | 0.01–0.02 | −0.01–0.01 | −0.01–0.00 | 0.02–0.03 | 0.02–0.03 | 0.02–0.03 |
| **Belg** MK (z-test) | 4.42*                  | 2.89*      | 3.57*  | 4.42*      | 3.60*   | 4.39*   | 3.55*  | 3.55*  | 3.55*  |
| $\theta$          | 0.09                   | 0.08       | 0.07   | 0.09       | 0.083   | 0.108   | 0.068  | 0.068  | 0.068  |
| $\theta$ (95% CI) | 0.09–0.1               | 0.07–0.09  | 0.07–0.08 | 0.09–0.10 | 0.08–0.09 | 0.01–0.11 | 0.06–0.08 | 0.06–0.08 | 0.06–0.08 |
| **Annual** MK (z-test) | 4.75*                  | 2.82*      | 1.89   | 5.35*      | 4.60*   | 4.10*   | 3.93*  | 3.93*  | 3.93*  |
| $\theta$          | 0.063                  | 0.05       | 0.024  | 0.053      | 0.055   | 0.046   | 0.047  | 0.047  | 0.047  |
| $\theta$ (95% CI) | 0.06–0.07              | 0.06–0.06  | 0.02–0.03 | 0.05–0.06 | 0.05–0.06 | 0.042–0.05 | 0.04–0.05 | 0.04–0.05 | 0.04–0.05 |
| **Kiremt** MK (z-test) | 0.00                   | 0.79       | −2.89* | −0.46      | −1.39   | −1.18   | −1.93* | −1.93* | −1.93* |
| $\theta$          | −0.0005                | 0.01       | −0.04  | −0.01      | −0.02   | −0.02   | −0.033 | −0.033 | −0.033 |
| $\theta$ (95% CI) | −0.004–0.01            | 0.01–0.02  | −0.05–(−0.04) | −0.01–(−0.001) | −0.03–(−0.02) | −0.03–(−0.013) | −0.04–(−0.03) | −0.04–(−0.03) | −0.04–(−0.03) |
| **Belg** MK (z-test) | 5.00*                  | 1.93*      | 4.42*  | 5.67*      | 6.17*   | 5.17*   | 5.14*  | 5.14*  | 5.14*  |
| $\theta$          | 0.1                    | 0.057      | 0.088  | 0.1        | 0.117   | 0.089   | 0.098  | 0.098  | 0.098  |
| $\theta$ (95% CI) | 0.09–0.11              | 0.05–0.07  | 0.08–0.09 | 0.098–0.1 | 0.1–0.12 | 0.084–0.09 | 0.09–0.1 | 0.09–0.1 | 0.09–0.1 |

*Statistically significant at the 5% significance level  
\(\theta\) Sen’s slope

(0.07–0.1 °C/season, 0.06–0.12 °C/season), respectively, at all of the stations (Table 3).

Unlike the annual and Belg season, the maximum and minimum temperature for Kiremt season showed an increasing and decreasing trend patterns, respectively. Increasing trends were detected at 71.43% of the stations for maximum temperature, while a decreasing trends were detected at 85.7% of the stations for minimum temperature. Yet, the Kiremt season maximum and minimum temperatures trends were not statistically significant at the most of the stations. Few stations, however, such as Edagahamus showed a significant increasing trend for maximum temperature with a magnitude of 0.08 °C/season. Moreover, Adigrat and Hawzen station showed a significant decreasing trend in minimum temperature by 0.04 °C/season and 0.03 °C/season, respectively. Figures 5 and 6 also revealed consistent linear trend direction as of the Sen’s slope magnitude. It is generally expected that an increase in maximum temperature increases the rate of evapotranspiration and increase the rate of water consumption by the crops and causing more water stress. In addition, temperature increment beyond the threshold level can affect the growth and reproduction which reduces crop yield and the risk of crop failure.
Fig. 5  Annual, Kiremt and Belg Maximum Temperature of a Illala, b Edagahamus, c Adigrat, d Sinkata, e Wukro, f Atsbi, g Hawzen
Fig. 6 Annual, Kiremt and Belg Minimum Temperature of a Illala, b Edagahamus, c Adigrat, d Sinkata, e Wukro, f Atsbi, g Hawzen
3.84) at the 5% significant level. Accordingly, the annual and seasonal statistics of $M \bar{Z}_k$ for Kiremt and Belg seasons (Table 6) showed that annual and Kiremt rainfall indicated significant upward trend, while Belg season indicated significant downward trend. Although the individual MK-trend test for rainfall were not significant at the most of the stations in Table 2, Kiremt and Belg seasons have $M \bar{Z}_k$ values that are much larger than the annual rainfall. This means Kiremt and Belg rainfall seasons have trends that are stronger than that of the annual rainfall. The visible weaker trend in the annual rainfall series could be due to the results of the net cancelations of the trend effects from the seasonal series.

Results of trend homogeneity for maximum and minimum temperatures are also presented in Table 7. Table 7 reveals that the value of $X^2$ for annual and seasons for both maximum and minimum temperature was significant which suggests trend heterogeneity since $X^2$ for annual and seasons is greater than $X^2$ critical at the 5% (5.99). In other words,
we cannot assume a monotonic trend between annual and seasons, or trends of annual are different from those of Belg or Kiremt seasons, etc. In contrast, the value of \( X^2 \) station for maximum temperature was non-significant indicating trend homogeneity in the time series data; i.e., \( X^2 \) station is less than the \( X^2 \) critical at the 5% (12.59), but heterogeneous for minimum temperature. This means that maximum temperature across stations are consistent.

Since maximum temperature trends across stations are homogeneous, we can further test the significance of the overall maximum temperature trend of the annual and each season (Table 8). Accordingly, Table 8 indicates that the computed \( M \bar{Z}_k \) values for annual and each season were found to be greater than the \( X^2 \) critical (equal to 3.84) with d.f. = 1 at the 5% significance level. Table 8 collectively shows that annual and seasons for maximum temperature indicated a significant warming trends. From the values of \( M \bar{Z}_k \), it is clear that annual and Belg season have \( M \bar{Z}_k \) values that are much larger than Kiremt season. This means annual and Belg have trends that are stronger than that of the Kiremt season.

### 3.4 Change point detection analysis using Pettitt’s test

Pettitt’s test was used in a two-tailed test at which a change point can be detected and the mean of the dataset shifts at this break point. Accordingly, the homogeneity analysis for rainfall showed that only one station in annual rainfall series and two stations in monthly rainfall series (August month) indicated a significant change point, while other rainfall series at the rest of the stations can be considered homogeneous in nature. In the annual rainfall series, a significant upward shift can be statistically demonstrated at only Atsbi station, and the average amount of precipitation was 496.7 mm in the period before the date of the break point (the red line in Fig. 7), while it was 602.2 mm in the period after (the blue line in Fig. 7). The break point occurs in 1997. Likewise, a significant upward shift can be detected in August month at Atsbi and Wukro stations. The mean monthly amount of precipitation was 127.1 mm and 137.2 mm in the period before the date of the break point (the red line in Fig. 7) and 196.7 mm and 205.7 mm, in the period following the shift (the blue line in Fig. 7), respectively. The break point occurs in 1991 at the two stations. After extensive research in the archive information about historical registered values of concern, no physical reason which would explain for these change points could be found.

Separating the time series at the significant change point, no significant trend could be recognized in the annual and in the August month rainfall series. This implies that the shift in the mean in the annual and August rainfall amounts at few of the stations might be due to abrupt and drastic shifts not as a result of slow and gradual changes. In contrary, although significant increasing trend tendencies were observed in Table 2 using the auto-correlated MK-trend test at few of the stations, i.e., at Hawzen station in June and July months, and at Sinkata and Wukro stations in September month, no break points could be detected. The significant increasing tendency should be accepted as fact. Hence, the result of the significant trends was not as a consequence of the shift of the mean, but as a result of long-term changes of the rainfall.

However, the change points were found to be quite variable in temperatures as compared to rainfall series (Table 9). The change point analysis for maximum temperature in annual Kiremt and Belg season indicated different change points. Annual rainfall series in year 1994 to 1999, and Belg in years 1989, 1993, and 1997 indicated a significant upward change at all stations, while Kiremt season indicated a significant change only in 2 out of 7 stations: Edagahamus in a year 1996 (upward shift) and Wukro in a year 1984 (downward shift). Likewise, minimum temperature analysis also indicated a significant upward change point in the series of annual at all stations in years 1990 and 1991, Belg season indicated a significant upward change in 5 out of 7 stations in year 1991 and 1994. Kiremt season, however, indicated a downward change in 3 out of 7 stations in year 2000.

Overall, the change point analysis results of the temperature variables indicated different change points from year 1984 to 2000, with maximum change points in year 1997 for maximum temperature and in year 1991 for minimum temperature. Moreover, most of the stations showed upward shift, while few stations, such as Wukro, Adigrat, Atsbi, and Hawzen, indicated a downward shift in Kiremt season (Table 9). The significant upward change points in these series observed during 1984 to 2000 might be due to the influence of high population growth and expansion of urbanization in the region. Besides these factors, the probable cause of the abrupt change in the temperatures might have also associations with frequent drought occurrence in the region. The study is known by one of the drought-prone areas in the Tigray region. And the region has suffered frequent meteorological droughts (e.g., in 1982, 1983, 1984, 1985, 1987, 1991, 1999, 2000, 2002, 2004, and 2009) (Gebrehiwot et al. 2011). However, after extensive research

| Table 8 | Annual and seasonal maximum temperature trend homogeneity test statistics |
|---------|-----------------------------|
|          | \( T_{max} \) | \( \bar{Z}_k \) | \( \bar{Z}_k^2 \) | \( M \bar{Z}_k^2 \) | Sign |
| Annual   | 4.64           | 21.56          | 150.95          | S               |
| Kiremt   | 1.11           | 1.23           | 8.64            | S               |
| Belg     | 3.81           | 14.50          | 101.49          | S               |
in the archive information about historical registered values of concern, the physical reasons for the downward trend for minimum temperature in Kiremt season could not be found.

### 3.5 Trend characteristics of crop-growing season

The determination of the trend characteristics of crop-growing season is very useful information for planning land preparation and planting activities. In this study, the trends of crop-growing season characteristics was analyzed using 30 years of data in Kiremt season and computed at the 5% significant level (Table 10). As shown, the 30-year median early-onset date of the Kiremt season was found to be within the range of 30-June/182.5 DOY (Day of Year) at Hawzen to 8-July/190 DOY at Wukro stations. Likewise, the onset dates of Ilalla, Adigrat, Edagahamus, Wukro, and Atsbi stations were found to be very close to the Hawzen station. The median cessation date, however, indicated a wide range of dates among the stations. The earliest cessation was on 11-Sep./255 DOY at Edagahamus and late cessation was on 25-Sep/269 DOY at Hawzen. Onset and cessation variability were found to be very low (CV < 10%) at all of the stations, indicating a relatively stable onset and cessation dates. Stable onset and cessation dates are an advantageous for the farmers in searching of the off-farm activities once they have stabilized these dates.

There was a general increasing trend of LGP which could be attributed to the observed early in onset and delay in the cessation date, although not significant at the 5% significant level. Mean LGP values in the study area varied from 68 days at Edagahamus to 85 days at Hawzen. Previous studies using different criterions for the onset and the cessation
analysis reported that the LGP in the North Eastern stations found to be in a range of 60–100 days (Berhe 2011; Gebre et al. 2013). The CV of the LGP was low (<20%) at all of the stations, which is very helpful to plant crops based on their maturity period, and providing such kind of information is essential for deciding on crop types and cultivars and dates for land preparation. But the short nature of LGP in the study area is very challenging to produce long maturing crop varieties that need greater than 90 days. Hence, farmers in the study need to adopt husbandry practices which can fit to the shortened growing period.

Similarly, the mean seasonal dry spell length was analyzed and found to be in a range of 23 days at Wukro to 30 days at Edagahamus. The dry spell length was highly variable with CV from 25 to 43%. These findings agree with those of Gebreselassie and Moges (2016) who reported larger than 30% of variability in the dry spell length of daily rainfall in Northern Ethiopia. High CV of dry spells indicate the possibility of soil water deficit during the peak rain fall period in the study area. Hence, water conservation activity becomes very important to supplement with irrigation during the season as well as after cessation of the rain to cover the crop water requirement. In addition, the use of early maturing and drought tolerant cultivars can be highly beneficial.

### 4 Conclusions

Variability and trends of rainfall, temperatures, and characteristics of crop-growing seasons were analyzed using MK-trend test in the eastern zone of Tigray region over the period of 1980–2009. In addition, the study analyzed the homogeneity test for general trend analysis using the Van Belle and Hughes method as well as for change point detection using Pettitt’s test. According to the results, the individual MK-trend analysis for monthly, annual, and Kiremt rainfall showed an increasing trend, while Belg rainfall season showed a decreasing trend at almost all of the stations. Nevertheless, only statistically significant trends were observed at few of the stations in monthly time series. Annual, Kiremt and Belg rainfall series were found to be statistically non-significant. On the contrary, temperatures (\(T_{\text{max}}\) and \(T_{\text{min}}\)) showed statistically significant increasing trends in annual and Belg at all of the stations. However, Kiremt season temperatures showed non-significant trend at the most of the stations, all at the 5% significant level.

Results of tests of trend homogeneity by the Van Belle and Hughes method for general trend showed that the trends for monthly, annual, and Kiremt rainfall showed upward trend direction, while Belg rainfall showed downward trend direction. Likewise, on the annual and Belg time scale,

| Station | Period | K-value | Shift | Year of shift | K-value | Shift | Year of shift |
|---------|--------|---------|-------|---------------|---------|-------|---------------|
| Illala  | Annual | 213     | Yes ▲ | 1996          | 212     | Yes   | 1991 ▲        |
|         | Kiremt | 96      | No    | —             | 108     | No    | —             |
|         | Belg   | 200     | Yes ▲ | 1997          | 214     | Yes   | 1991 ▲        |
| Edagahamus | Annual | 194     | Yes ▲ | 1999          | 134     | Yes   | 1991 ▲        |
|         | Kiremt | 195     | Yes ▲ | 1996          | 68      | No    | —             |
|         | Belg   | 142     | Yes ▲ | 1989          | 116     | No    | —             |
| Adigrat | Annual | 195     | Yes ▲ | 1994          | 136     | Yes   | 1991 ▲        |
|         | Kiremt | 89      | No    | —             | 167     | Yes   | 2000 ▼        |
|         | Belg   | 178     | Yes ▲ | 1997          | 188     | Yes   | 1991 ▲        |
| Sinkata | Annual | 213     | Yes ▲ | 1996          | 214     | Yes   | 1991 ▲        |
|         | Kiremt | 96      | No    | —             | 94      | No    | —             |
|         | Belg   | 200     | Yes ▲ | 1997          | 212     | Yes   | 1991 ▲        |
| Wukro   | Annual | 197     | Yes ▲ | 1994          | 188     | Yes   | 1991 ▲        |
|         | Kiremt | 35      | Yes ▼ | 1984          | 127     | No    | —             |
|         | Belg   | 170     | Yes ▲ | 1993          | 217     | Yes   | 1994 ▲        |
| Atsbi   | Annual | 205     | Yes ▲ | 1996          | 199     | Yes   | 1990 ▲        |
|         | Kiremt | 63      | No    | —             | 151     | Yes   | 2000 ▼        |
|         | Belg   | 188     | Yes ▲ | 1993          | 214     | Yes   | 1991 ▲        |
| Hawzen  | Annual | 214     | Yes ▲ | 1997          | 201     | Yes   | 1990 ▲        |
|         | Kiremt | 97      | No    | —             | 155     | Yes   | 2000 ▼        |
|         | Belg   | 158     | Yes ▲ | 1997          | 208     | Yes   | 1991 ▲        |

▲ symbolized an upward trend change; ▼ symbolized a downward trend change; K-value is Pettitt’s test statistics; \(T_{\text{max}}\) is maximum temperature (°C); \(T_{\text{min}}\) is minimum temperature (°C).
temperatures ($T_{\text{max}}$ and $T_{\text{min}}$) showed upward trend direction. \textit{Kiremt} season, however, showed upward trend direction for $T_{\text{max}}$ and downward trend directions for $T_{\text{min}}$. The results obtained from Van Belle and Hughes test seem fairly consistent with those of the individual MK-trend tests. Moreover, the results of the Pettitt test showed that most of the stations indicated a homogeneous trend in the annual and seasonal rainfall series and no break point was distinguished except few stations. However, the change points were found to be quite variable in temperatures as compared to rainfall series. The change point analysis results of the temperature variables indicated different change points from year 1984 to 2000. The significant upward change points in these series might be due to the influence of high population growth and expansion of urbanization in the region. Besides these factors, the probable cause of the abrupt change in the temperatures might have also associations with frequent drought occurrence in the region. Nevertheless, after extensive research in the archive information about historical registered values of concern, the physical reasons for the upward trend changes in rainfall as well as a downward trend changes for minimum temperature could not be found. Thus, further research study may be conducted to find out the possible causes of these changes over the study area.

Moreover, the results of the Pettitt test showed that most of the stations indicated a homogeneous trend in the annual and seasonal rainfall series and no break point was distinguished except few stations. However, the change points were found to be quite variable in temperatures as compared to rainfall series. The change point analysis results of the temperature variables indicated different change points from year 1984 to 2000. The significant upward change points in these series might be due to the influence of high population growth and expansion of urbanization in the region. Besides these factors, the probable cause of the abrupt change in the temperatures might have also associations with frequent drought occurrence in the region. Nevertheless, after extensive research in the archive information about historical registered values of concern, the physical reasons for the upward trend changes in rainfall as well as a downward trend changes for minimum temperature could not be found. Thus, further research study may be conducted to find out the possible causes of these changes over the study area.

It is important to note that in line with the non-significant trends of rainfall and temperatures in \textit{Kiremt} season, the trends of growing season characteristics have not changed significantly at all of the stations over the study period. In addition, the coefficient of variation of the onset (CV, <10%) and the cessation (CV, <5%) was found to be very small, indicating relatively stable onset and cessation. Furthermore, the CV of LGP was less than 20%, which is vital to plant crops based on their maturity period. Contrary to this, the CV of the dry spell length was larger than 25% at all of the stations. This showed the high possibility of soil water deficit during the peak rain fall period in the study area. Moreover, despite non-significant trends of rainfall and temperatures in \textit{Kiremt} season at the most of the stations, there was highly significant increasing of temperatures and significant decreasing of rainfall trends in \textit{Belg} season. Although future research is needed on the influence of the short rainy season (\textit{Belg}) to that of the long rain season (\textit{Kiremt}), it is certain that it will cause more complications to land preparation and cropping long maturing

\begin{table}
\centering
\caption{Statistical values and trends of onset, cessation, LGP, and dry spell length at 7 stations over the period of 1980–2009}
\begin{tabular}{|l|l|l|l|l|l|l|l|l|}
\hline
\textbf{Characteristics} & \textbf{Statistics} & \textbf{Stations} & \textbf{Illala} & \textbf{Adigrat} & \textbf{Edagahamus} & \textbf{Wukro} & \textbf{Hawzen} & \textbf{Sinkata} & \textbf{Atsbi} \\
\hline
\textbf{Onset} & Median & 7-Jul & 7-Jul & 6-Jul & 8-Jul & 30-Jun & 4-Jul & 7-Jul \\
Kendall’s tau & $-0.07$ & $-0.10$ & $-0.16$ & $-0.06$ & $-0.01$ & $-0.18$ & $0.07$ \\
Slope & $-0.10$ & $-0.13$ & $-0.29$ & $-0.07$ & $-0.05$ & $-0.27$ & $0.06$ \\
$P_{\text{Value}}$ & $0.60$ & $0.45$ & $0.23$ & $0.68$ & $0.94$ & $0.17$ & $0.60$ \\
SD (days) & 9 & 9 & 11 & 8 & 13 & 12 & 7 \\
CV\% & 5 & 5 & 6 & 4 & 7 & 6 & 4 \\
\hline
\textbf{Cessation} & Median & 22-Sep & 20-Sep & 11-Sep & 21-Sep & 25-Sep & 20-Sep & 23-Sep \\
Kendall’s tau & $0.16$ & $0.24$ & $0.03$ & $0.18$ & $0.15$ & $0.19$ & $0.20$ \\
Slope & $0.14$ & $0.13$ & $0.00$ & $0.20$ & $0.15$ & $0.13$ & $0.30$ \\
$P_{\text{Value}}$ & $0.23$ & $0.09$ & $0.85$ & $0.17$ & $0.25$ & $0.15$ & $0.13$ \\
SD (days) & 6 & 7 & 3 & 7 & 7 & 6 & 9 \\
CV\% & 2 & 3 & 1 & 3 & 3 & 2 & 3 \\
\hline
\textbf{LGP} & Mean & 74 & 72 & 68 & 74 & 85 & 77 & 78 \\
Kendall’s tau & $0.10$ & $0.16$ & $0.14$ & $0.16$ & $0.06$ & $0.19$ & $0.11$ \\
Slope & $0.25$ & $0.35$ & $0.29$ & $0.33$ & $0.20$ & $0.50$ & $0.25$ \\
$P_{\text{Value}}$ & $0.44$ & $0.24$ & $0.30$ & $0.22$ & $0.68$ & $0.15$ & $0.40$ \\
SD (days) & 11 & 11 & 12 & 11 & 14 & 13 & 11 \\
CV\% & 15 & 16 & 17 & 15 & 16 & 17 & 15 \\
\hline
\textbf{Dry spell} & Mean & 26 & 24 & 30 & 23 & 26 & 27 & 29 \\
Kendall’s tau & $-0.10$ & $-0.12$ & $-0.25$ & $-0.12$ & $-0.06$ & $-0.07$ & $0.06$ \\
Slope & $-0.18$ & $-0.11$ & $-0.23$ & $-0.16$ & $-0.10$ & $-0.08$ & $0.08$ \\
$P_{\text{Value}}$ & $0.47$ & $0.35$ & $0.06$ & $0.38$ & $0.65$ & $0.59$ & $0.67$ \\
SD (days) & 11 & 8 & 7 & 9 & 10 & 10 & 10 \\
CV\% & 43 & 34 & 25 & 39 & 37 & 36 & 34 \\
\hline
\end{tabular}
\end{table}

Kendall’s tau is MK-trend test, slope (Sen’s slope) is the change (days)/annual, $P_{\text{Value}}$ is significant level at $\alpha=0.05$, SD standard deviation, CV coefficient of variation

\begin{itemize}
\item Temperatures ($T_{\text{max}}$ and $T_{\text{min}}$) showed upward trend direction.
\item \textit{Kiremt} season, however, showed upward trend direction for $T_{\text{max}}$ and downward trend directions for $T_{\text{min}}$.
\item The results obtained from Van Belle and Hughes test seem fairly consistent with those of the individual MK-trend tests.
\item Moreover, the results of the Pettitt test showed that most of the stations indicated a homogeneous trend in the annual and seasonal rainfall series and no break point was distinguished except few stations. However, the change points were found to be quite variable in temperatures as compared to rainfall series. The change point analysis results of the temperature variables indicated different change points from year 1984 to 2000.
\item The significant upward change points in these series might be due to the influence of high population growth and expansion of urbanization in the region.
\item Besides these factors, the probable cause of the abrupt change in the temperatures might have also associations with frequent drought occurrence in the region.
\item Nevertheless, after extensive research in the archive information about historical registered values of concern, the physical reasons for the upward trend changes in rainfall as well as a downward trend changes for minimum temperature could not be found. Thus, further research study may be conducted to find out the possible causes of these changes over the study area.
\item It is important to note that in line with the non-significant trends of rainfall and temperatures in \textit{Kiremt} season, the trends of growing season characteristics have not changed significantly at the 5\% significant level at all of the stations over the study period.
\item In addition, the coefficient of variation of the onset (CV, <10\%) and the cessation (CV, <5\%) was found to be very small, indicating relatively stable onset and cessation.
\item Furthermore, the CV of LGP was less than 20\%, which is vital to plant crops based on their maturity period. Contrary to this, the CV of the dry spell length was larger than 25\% at all of the stations.
\item This showed the high possibility of soil water deficit during the peak rain fall period in the study area.
\item Moreover, despite non-significant trends of rainfall and temperatures in \textit{Kiremt} season at the most of the stations, there was highly significant increasing of temperatures and significant decreasing of rainfall trends in \textit{Belg} season.
\item Although future research is needed on the influence of the short rainy season (\textit{Belg}) to that of the long rain season (\textit{Kiremt}), it is certain that it will cause more complications to land preparation and cropping long maturing
\end{itemize}
variety. Because local farmers utilize this season for planting long maturing crop varieties as well as for land management practices, such as repeated ploughing and in-situ soil moisture conservation activities, hence, crop production in the study area demands adaptation strategies that considers the erratic nature of the rainfall associated with long dry spell length in Kiremt season as well as the high temperatures and declining rainfall trends during the Belg season. It is worthwhile to note that the results may be of practical implications for formulating long-term adaptation strategies for sustainable crop production as well as sustainable management of water resources in the region.

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Author contribution All the authors made a valuable contribution to this study. AGB has designed the study, collected and analyzed data, interpreted the results, and wrote the draft manuscript. SHM, GGA and AZA have participated in designing the study, analysis and interpretation, structuring the manuscript; and provided critical comments and suggestions on the draft manuscript. All authors read and approved the final manuscript.

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Data availability The weather data used in the study were obtained from Ethiopian National Meteorological Agency (NMA). Access to the data can be obtained from NMA based on justifiable request.

Code availability Not applicable.

Declarations

Ethics approval All the authors confirm that this article is an original research and has not been published or presented previously in any journal or conference in any language.

Consent to participate Not applicable.

Consent for publication All the authors consented to publish the paper.

Conflict of interests The authors declare no competing interests.

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