

Research

Annual rainfall trends in the Burkina Faso Sahel: a comparative analysis between Mann–Kendall and innovative trend method (ITM)

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Abstract

The aim of this study is to analyse rainfall trends using the innovative trend method and the Mann–Kendall test. Rainfall data for the period 1981–2020 were obtained from the monthly CHIRPS (Climate Hazards Group Infrared Rainfall with Stations) database provided by the USGS (United States Geological Survey) to FEWSNET (Famine Early Warning Systems Network). The data were analysed using descriptive statistics and trend and Mann–Kendall tests. The study showed that rainfall data for the period 1981–2020 are subject to variability at all locations in the Sahel. In addition, annual rainfall is also subject to low, medium and high fluctuations depending on the location. The study shows an increasing trend in rainfall based on the Mann–Kendall test, while the innovative approach found high, medium and low trends. This means that the innovative method is more sensitive to local trends than the Mann–Kendall test, and it is therefore important for regional authorities to tailor their support to the reality of each Sahelian community in order to make rural populations more resilient.

Article highlights

- The study used the CHIRPS (Climate Hazards Group Infrared Rainfall with Stations) database because of the uneven and limited distribution of rain gauges in the Sahel region of Burkina Faso.
- The study uses the classic Mann–Kendall method as well as the innovative trend method for the analysis of trends in annual precipitation.
- The study informs on the general and local trend of annual precipitation in the Sahel region of Burkina Faso.
- The study provides important conclusions that could help decision-makers to put in place effective adaptation strategies for the benefit of the rural population.

Keywords Innovative trend method · Mann–Kendall test · Variability · Rainfall · Burkina Faso

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1 Introduction

Rainfall is of vital importance to the Sahelians of West Africa, as water resources are the driving force behind many human activities in the region. Agricultural and pastoral activities in the Sahel are also dependent on it. Indeed, the majority of the Sahelian population depends on rain-fed subsistence and/or export agriculture (particularly cotton and groundnuts [1]). Climate monitoring is therefore crucial to ensure food security for a population that is expected to grow from 330 million in 2050 to more than 650 million in 2100 [1]. Knowing when it will rain has therefore become important for decision-makers and international organisations working in the Sahel. This situation has led to the launch of several programmes, including the African Monsoon Multidisciplinary Analysis (AMMA), the associated Model Intercomparison Project (ALMIP), the AMMA Catch experiment, which extends AMMA southwards to Benin, and the JET2000 experiment, which focuses on the African easterly jet [2] as well as studies [3–7] aimed at understanding the character of rainfall in West Africa, including the Sahel.

As a result, an increasing number of studies have focused on the changes in rainfall trends following the drought decades of the 1970s and 1980s [8–13]. Today, most studies focus on the temporal evolution of rainfall in Sahelian countries such as Mali [14, 15], Senegal [16], Burkina Faso [17], Nigeria [18–20] and Mauritania [21, 22]. These studies show that methods to assess trends (Mann–Kendall (MK) test, Spearman rank correlation coefficient) and their amplitude (Sen slope estimator, Thiel–Sen (TS)) are commonly used. However, several studies have reported bias in non-parametric tests such as the Mann–Kendall test. In fact, Refs. [23, 24] note that the Mann–Kendall (MK) test show an overall upward or downward trend in the series, but the length of the data, the strength of the pre-established significance level and the strength of the trend can create biases that affect the results of the Mann–Kendall (MK) test. This fact has led to the proposal of new evaluation methods, in particular that of Şen [25, 26], designed as the method of innovative trends (ITM). This method is non-parametric and represents the weak, average and strong trends in a series [25, 27]. It has been used in several studies in Europe [28–30] and Asia [31–33]. However, very few studies have used this approach in Africa, with the exception of North Africa [34] and East Africa [35, 36]. Nevertheless, North Africa is dominated by Mediterranean, oceanic and desert climatic conditions, which means that rainfall characteristics are different from those in West Africa and the Sahel. The same applies to East Africa, where there are two types of rainy season, one long and one short. Sahelian West Africa, on the other hand, is dominated by a single rainy season triggered by warm winds (from the Sahara) and humid winds (from the oceans). Intertropical convergence, dominated by the moist wind known as the ‘monsoon wind’, brings rain to the whole of Sahelian West Africa. The differences between North and East Africa and West Africa mean that studies carried out in these two parts of the continent cannot be correlated with Sahelian West Africa, including the Sahel and Burkina Faso.

It is therefore important to study the evolution of temporal trends in annual rainfall in the Sahel, especially as the majority of the local population depends on this rainfall for agriculture. This study therefore focuses on the temporal analysis of annual rainfall in the Sahel of Burkina Faso in order to contribute to the development of effective adaptation strategies. To this end, unlike the majority of studies carried out in the region, this study uses two complementary methods: the Mann–Kendall test and the innovative trend method, in order to better understand the nuances of the trends over the period 1981–2020.

2 Data and methods

2.1 Geographical location of the study area

The study area is located in the extreme north of Burkina Faso (Fig. 1). It is part of the Sahel zone of West Africa. The area is in the Sahelian zone, with rainfall varying between 600 and 900 mm. The region has two seasons, the dry season and the rainy season. The vegetation is mainly shrubs and steppe.

2.2 Study data

The data are from the monthly Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), a near-global precipitation dataset spanning more than 35 years. Spanning 50°S to 50°N (and all longitudes) from 1981 to the

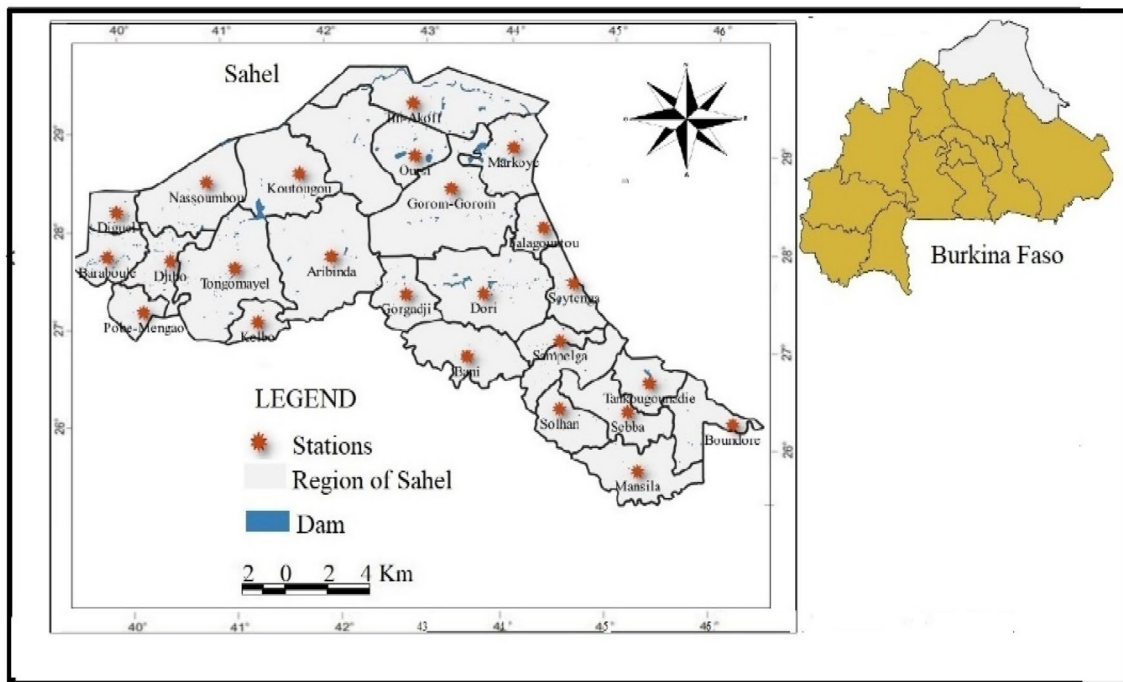


Fig. 1 Location of study sites

present, CHIRPS integrates our in-house climatology, CHPclim, 0.05° resolution satellite imagery and in situ station data to produce gridded precipitation time series for trend analysis and seasonal drought monitoring. CHIRPS data were chosen for several reasons:

Firstly, the limited number of stations in the region and the terrorist attacks since 2015 are obstacles to adequate coverage of stations in the region; Second, several studies show high performance for CHIRPS data in Africa [37–39]. In Burkina Faso, CHIRPS and TAMSAT data slightly underestimate rainfall in the Sahelian and Sudano-Sahelian zones by 2.1–8.3%, while the other datasets overestimate it by 3.7–13.2%, such as RMM-3B42v7, RFEv2, ARC2, PERSIANN-CDR and GPCPv3.1 [40]. Furthermore, the CHIRPS dataset showed the most accurate estimation of ground precipitation in all regions of the country, while TAMSAT showed unsatisfactory performance, hence the choice of CHIRPS. CHIRPS as a satellite precipitation product has its own limitations. These include sensor limitations such as spatial and temporal resolution, indirect estimation methods that mischaracterize the relationship between precipitation and cloud properties, topographic effects that make estimates difficult over complex terrain, and field validation difficulties caused by the scarcity of rain gauge networks [41]. The data can be downloaded from <http://http.chc.ucsb.edu/pub/org/chc/products/CHIRPS-2.0>. The study covered 25 stations in 25 communes in the Sahel region of Burkina Faso (Table 1).

2.3 Methodology

In order to guide the trend method in the study, the data from this study were subjected to normality tests. The following normality tests were used: Shapiro–Wilk (SW), Anderson–Darling (AD), Lilliefors, Jarque–Bera (JB). The normality test is a test of the data against the null hypothesis that the data are normally distributed. According to [42], if the significance level is $\alpha > 0.05$, the data are normal; if the significance level is $\alpha < 0.05$, the data are not normal. Table 2 below shows that the study data do not follow a normal distribution. This means that the use of non-parametric tests is recommended [43].

Table 2 shows that non-parametric trend tests should be used in this study. The Mann–Kendall test and trend innovation methods (TIM) are used in this study.

2.3.1 Innovative trend method (ITM)

The innovative trend method (ITM) is a new trend analysis that was first introduced by Şen [25, 44–46]. It is a simple and effective method for trend detection using a graphical distribution of historical data [30]. The method can be

Table 1 Characteristics of the stations selected in this study. Source: CHIRPS, 1981–2020

Location	Latitude	Longitude	Period of available data	Mean	SD
Gorom-Gorom	14.49699	− 0.23019	1981–2020	446	106
Markoye	14.69488	0.07164	1981–2020	404	99.1
Oursi	14.65567	− 0.40607	1981–2020	450	113
Tin-Akoff	14.90898	− 0.4158	1981–2020	438	114
Bani	13.691	− 0.15512	1981–2020	537	116
Dori	13.9937	− 0.07316	1981–2020	557	120
Falagountou	14.30917	0.21779	1981–2020	448	95
Gorgadji	13.99058	− 0.44962	1981–2020	522	109
Sampelga	13.76584	0.29621	1981–2020	525	109
Seytenga	14.04318	0.36487	1981–2020	468	92
Aribinda	14.17085	− 0.81208	1981–2020	507	121
Baraboule	14.16473	− 1.89885	1981–2020	474	105
Diguel	14.38017	− 1.85402	1981–2020	482	107
Djibo	14.14775	− 1.59376	1981–2020	469	104
Kelbo	13.85563	− 1.17028	1981–2020	544	104
Koutougou	14.57001	− 0.96876	1981–2020	452	110
Nassoumbou	14.52521	− 1.4191	1981–2020	457	105
Pobe-Mengao	13.90039	− 1.72197	1981–2020	500	106
Tongomayel	14.11336	− 1.27977	1981–2020	500	102
Boundore	13.3631	1.13433	1981–2020	572	99.1
Mansila	13.14094	0.67248	1981–2020	674	126
Sebba	13.42559	0.62436	1981–2020	589	118
Solhan	13.4407	0.29464	1981–2020	615	122
Tankougounadie	13.56313	0.73067	1981–2020	572	126

applied to different time scales such as year, month, week or day [26, 45]. The method consists of dividing the main hydrometeorological data into two class categories and then classifying the data points independently in ascending order [35]. Subsequently, the first series is plotted horizontally (X) and the second series is plotted vertically (Y), and finally the point cloud of the time series is placed on a Cartesian coordinate system (45°) [36]. Mathematically, the procedure of the method is translated as follows [35]:

$$X_i : i = 1, 2, 3, \dots, n/2 \quad (1)$$

With, $X_i = X$ -axis.

$$X_j : i = n/2 + 1, n/2 + 2, \dots, n \quad (2)$$

With, $X_j = Y$ -axis.

Data above the 1:1 line indicate an upward trend in the data, while data below the 1:1 line indicate a downward trend in the data [27, 34]. However, if the data is 1:1. This is shown graphically in Fig. 2 below.

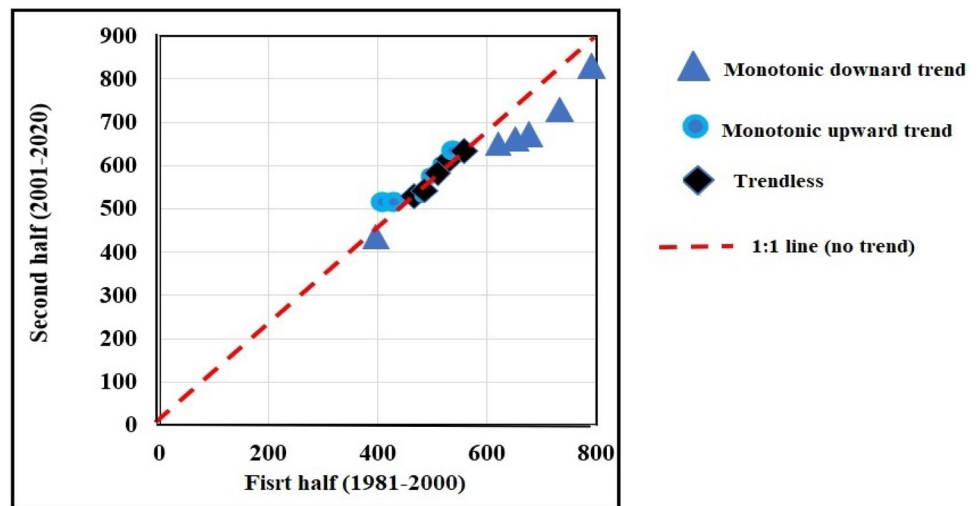
2.3.2 The innovative approach classifies trends

If all the points of dispersion are not completely above, below or parallel to the 1:1 line, the trend is non-monotonic and the horizontal axis of the graph is divided into ranges such as low, medium, low, medium, high [47, 48]. The identification of the ranges: low, medium and high, is done by considering the first time series X, the mean \bar{X} and the standard deviation σ , which allows us to determine intervals of low, medium and high values [49]:

Table 2 Normality test for study data

Localities	Test			
	Shapiro–Wilk test	Anderson–Darling test	Lilliefors test	Jarque–Bera test
Gorom-Gorom	0.824	0.916	0.772	0.703
Markoye	0.427	0.629	0.657	0.529
Oursi	0.509	0.528	0.609	0.622
Tin-Akoff	0.514	0.663	0.755	0.525
Bani	0.259	0.422	0.416	0.200
Dori	0.498	0.326	0.403	0.648
Falagountou	0.443	0.203	0.282	0.943
Gorgadji	0.810	0.729	0.928	0.931
Sampelga	0.222	0.383	0.578	0.316
Seytenga	0.532	0.577	0.774	0.674
Aribinda	0.461	0.509	0.524	0.513
Baraboule	0.822	0.900	0.963	0.762
Diguel	0.939	0.963	0.946	0.841
Djibo	0.872	0.918	0.923	0.744
Kelbo	0.338	0.193	0.164	0.468
Koutougou	0.132	0.112	0.290	0.651
Nassoumbou	0.532	0.567	0.757	0.713
Pobe-Mengao	0.565	0.759	0.581	0.568
Tongomayel	0.483	0.479	0.181	0.686
Boundore	0.411	0.463	0.496	0.374
Mansila	0.617	0.495	0.504	0.711
Sebba	0.502	0.552	0.536	0.652
Solhan	0.412	0.514	0.746	0.328
Tankougounadie	0.372	0.436	0.475	0.602

Fig. 2 Interpretation of results of innovative trend method (ITM)



$$\left\{ \begin{array}{l} \text{Trend Low} \rightarrow X < \bar{X} - \mu_X \\ \text{Medium Trend} \rightarrow \bar{X} - \mu_X < X < \bar{X} + \mu_X \\ \text{Trend High} \rightarrow X > \bar{X} + \mu_X \end{array} \right\} \tag{3}$$

where \bar{X}_1 and \bar{X}_2 are the arithmetic means of the first and second halves of the dependent variable, and n is the amount of data. Figure 3 shows the low, medium and high graphical trend. The data was calculated using the Excel 2021 spreadsheet.

2.3.3 The Mann–Kendall trend test

The Mann–Kendall test is a non-parametric test used to detect a trend in the data based on relative rankings over a period of time [50, 51]. It can be operated using the following formulae [52, 53]:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(X_j - X_i), \text{sign}(x_j - x_i) = \begin{cases} +1 (x_j - x_i) > 0 \\ 0 (x_j - x_i) = 0 \\ -1 (x_j - x_i) < 0 \end{cases} \tag{4}$$

A positive S value indicates an upward trend, while a negative value indicates a downward trend. The variance of the precipitation is calculated to obtain the Z value. The variance (S) is calculated as follows:

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{l=1}^M t_l(t_l-1)(2t_l+5)}{18} \tag{5}$$

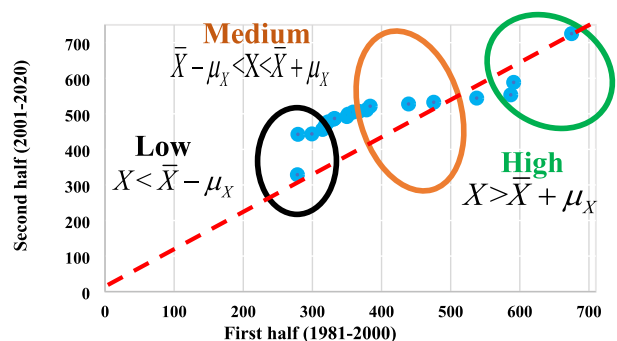
According to [52], an equal group (m) is a set of rainfall data having the same value when the sample size is $n > 10$.

If the sample contains ten or more data, the distribution of the test statistic Z below will be approximated by accentred Gaussian:

$$Z = \begin{cases} \frac{s-1}{\sqrt{\text{Var}(s)}}, & \text{if } s > 0 \\ 0 & \text{if } s = 0 \\ \frac{s-1}{\sqrt{\text{Var}(s)}}, & \text{if } s < 0 \end{cases} \tag{6}$$

The null hypothesis H_0 (no trend) is rejected when the significance level or the eigenvalue (p-value) is greater than 5% [49]. the calculation of trends using MK was carried out in PAST, a paleontological statistical software package (<https://past.en.lo4d.com/windows>).

Fig. 3 Low, medium and high graphical trends



2.3.4 Statistical analysis of data

Statistical analysis of meteorological data to describe data status in terms of rainfall data centrality and variability rainfall [54]. According to [55], it allows to capture the statistical behavior of the hydrological series according to a certain number of parameters as follows: mean, median, standard variance, variance and skewness. However, mean, standard deviation, coefficient of variation and coefficient of skewness describe the variability of rainfall [56, 57]. Descriptive statistics were calculated using the Hyfran-Plus software.

3 Results and analysis

3.1 Rainfall variability over the period 1981–2020

Moving averages are an effective way of smoothing out fluctuations in a time series. This technique consists of calculating the average of a fixed number of consecutive observations. In the study, a four-year interval was used. Figure 4 below shows the variability of annual rainfall in the Sahel region of Burkina Faso over the period 1981 and 2020. Moving averages show little variation in Ouarkoye, Gorom-Gorom, Markoye, Oursi, Oury and Tin-Akoff. Bani, Dori, Falagountou, Gorgadji, Sampelga and Seytenga show average fluctuations. On the other hand, Arbinda, Baraboule, Diguel, Djibo, Kelbo, Koutougou, Nassoumbou, Pobe-Mengao, Tongomayel, Boundore, Mansila, Sebba, Solhan and Tankougounadie show average variations. The variation in the Sahel region could be explained by the influence of climatic zones. Locations with low variations are close to the Sudano-Sahelian zone, with annual rainfall of between 600 and 900 mm. On the other hand, strong fluctuations are observed in localities close to the Sahelian climatic zone, with annual rainfall of 600 mm of water.

In addition, the analysis of the annual precipitation data on a year-by-year basis also shows a considerable variability over the period 1981–2020 (Table 3).

This table shows that the degree of variability varies from decade to decade. In the decade 1981–1990, the variability is moderate (mean CV = 20.5%). In the decade 1991–2001, the mean CV = 15.31%, in the decade 2002–2011, the mean CV = 14.97% and in the period 2012–2020, the mean CV = 15.3%, showing that the variability is low. The table also shows that average annual rainfall was low during the period 1981–2001. It varied between 311 and 621 mm. However, the trend changes after 2001, when rainfall is higher. In fact, in the period 2002–2020, the average rainfall varied between 478 and 725 mm. This indicates that the area is in a wet phase.

3.2 Analysis of the annual trends in precipitation in the Sahel region of Burkina Faso

The MK and ITM methods are used to analysed annual rainfall trends, and the comparison of the two methods will allow us to understand the contribution of the ITM approach.

3.2.1 Trend in precipitation according to innovative trend method (ITM)

Figure 5 below shows the general rainfall trend between 1981 and 2020 in the 25 communes of the Sahel region.

According to the ITM, several trends have been observed in the Sahel. Increasing trends were observed in Gorom-Gorom, Markoye, Tin-Akoff, Dori, Seytenga, Arbinda, Baraboule and Mansila. This situation could be explained by the fact that the severe droughts that hit the region in the 1980s did not have a significant impact on these communes, which showed an upward trend. The 1990s, marked by a wet period, undoubtedly contributed to the continuation of this upward trend. Conversely, downward trends were observed in Sampelga and Solhan. The other zones (Tankougounadie, Oursi, Bani, Gorgadji, Diguel, Djibo, Koutougou, Kelbo, Nassoumbou, Pobe-Mengao, Tongomayel, Boundore and Sebba) showed downward, intermediate and upward trends. This could be explained by the fact that these localities were severely affected by the droughts of the 1980s and the periods of low rainfall until the 1990s. This could explain the random distribution of the points, which can help us to understand the downward, average and upward trends.

3.2.2 Trend in precipitation according Mann–Kendall test

Table 4 below shows an upward trend at all stations. Gorom-Gorom, Markoye, Oursi, Tin-Akoff, Bani, Dori, Gorgadji, Diguel, Djibo, Koutougou, Kelbo, Pobe-Mengao, Boundore, Sebba, Sampelga, Arbinda and Solhan have high levels of importance. Falagountou, Seytenga, Nassoumbou and Mansila are very important.

Fig. 4 Temporal variability of annual rainfall over the period 1981–2020

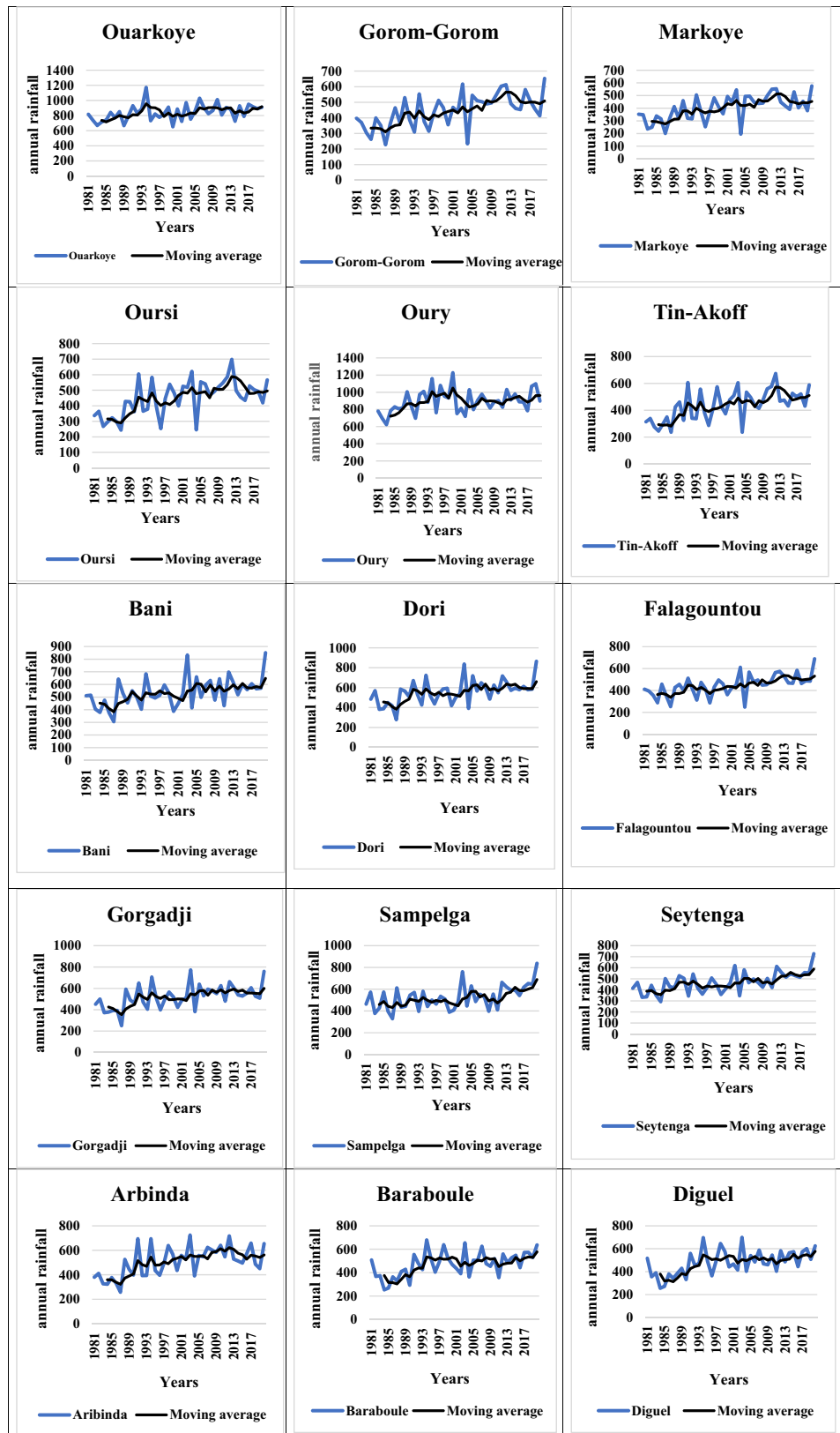
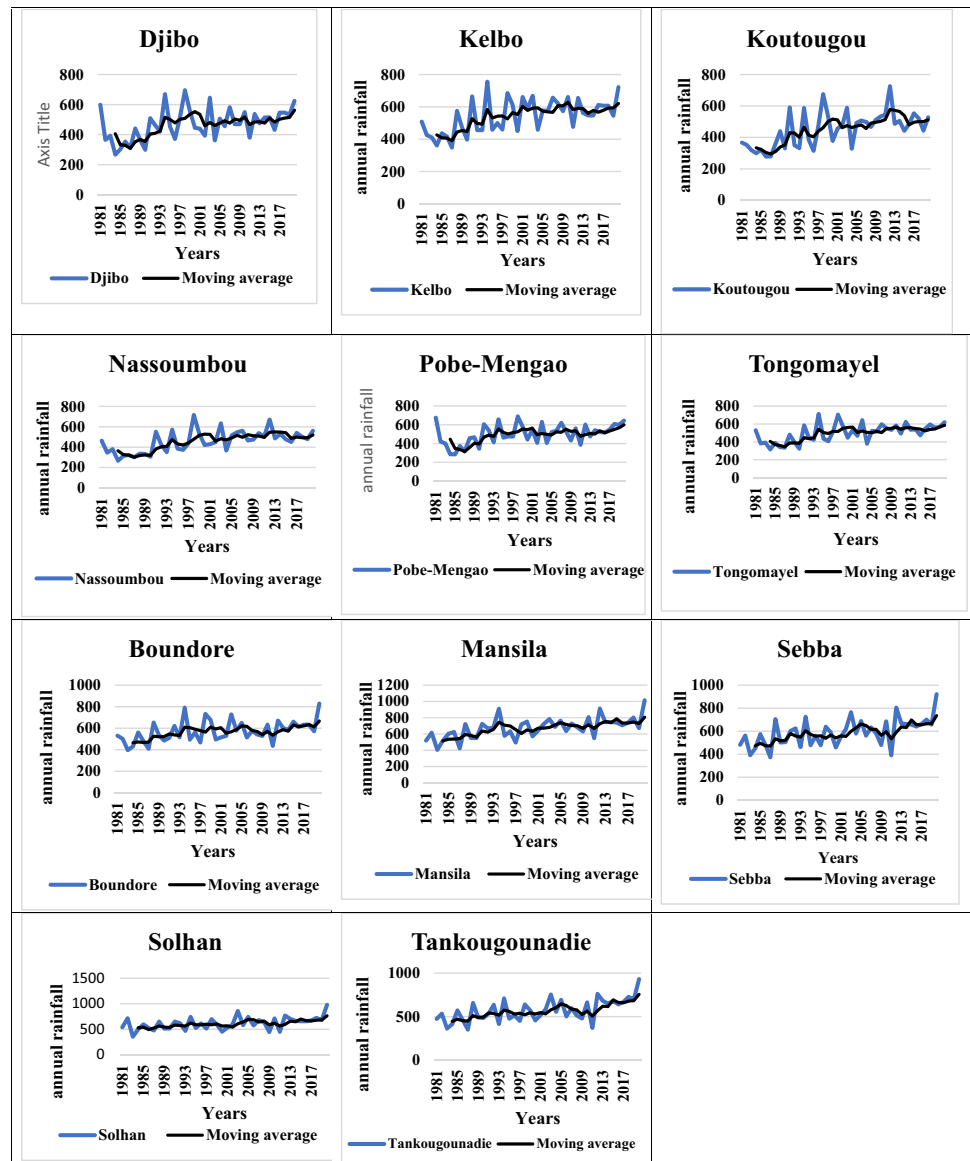


Fig. 4 (continued)



The observed trends in precipitation are strongly upward, with a p -value of less than 5%. This means that the observed trends in annual precipitation are clearly revealed.

3.2.3 Precipitation trends: comparison between the Mann–Kendall test and the innovative trend method

The results of the two methods are very different. This is shown in Table 5 below.

This table shows that the MK trend is generally upwards, whereas the ITM shows different trends depending on the station. In fact, 33.33% of the stations show an upward trend, 54.16% show a non-monotonic upward trend and 4.16% show a downward trend. This difference between the MK and ITM tests could be explained by the fact that the MK test shows the overall trends of the series. In fact, all the stations studied show an upward trend, which is supported by the characteristics of the time series. The period 1981–2000 is generally bearish, dominated by the dry phase. The period 2001–2020 is characterised by a wet phase. The MK test takes into account the overall trend for the period 1981–2020, which eliminates the nuances and retains only the overall trend for the period in question.

For its part, ITM highlights local trends. Stations such as Ouesi, Bani, Falagountou, Gorgadji, Djibo, Koutougou, Kelbo, Nassoumbou, Kelbo, Nassoumbou, Pobe-Mengao, Tongomayel, Boundore, Sebba and Tankougounadie, which

Table 3 Study area rainfall descriptive statistics. *Source:* CHIRPS, 1981–2020

Years	Average (mm)	Minimum (mm)	Maximum (mm)	Median (mm)	SD	Coefficient variation (%)	Skewness coefficient	Kurtosis coefficient
1981	544	348	756	554	104	19	0.000479	1.95
1982	450	339	717	416	104	23	0.914	2.63
1983	359	236	411	376	47.8	13.3	- 1.21	3.04
1984	341	245	520	319	82.2	24.1	0.694	2.14
1985	417	269	604	396	113	27.1	0.370	1.63
1986	389	278	625	369	78.9	20.3	1.39	4.22
1987	311	201	477	309	66	21.2	0.654	2.86
1988	511	322	721	490	124	24.3	0.152	1.56
1989	460	333	566	459	56.8	12.4	- 0.0949	2.55
1990	401	293	549	398	79.4	19.8	0.303	1.60
1991	583	459	725	571	66.7	11.4	0.398	2.22
1992	482	320	669	468	102	21.1	0.270	1.86
1993	411	309	675	409	78.8	19.2	1.55	5.82
1994	658	474	910	681	101	15.3	0.240	2.73
1995	455	376	578	456	57	12.5	0.217	1.94
1996	420	254	633	402	110	26.3	0.302	1.97
1997	471	371	535	475	471	8.47	- 0.598	2.60
1998	621	481	733	638	79	12.7	- 0.349	1.64
1999	546	410	752	548	77.2	14.1	0.544	3.37
2000	425	356	572	429	51.2	12	0.802	3.65
2001	497	408	661	493	65.8	13.2	0.904	3.15
2002	502	392	723	496	79.9	15.9	0.898	3.33
2003	691	544	858	661	87.4	12.6	0.400	1.85
2004	399	196	688	387	126	31.6	0.491	2.48
2005	592	492	763	562	83.6	14.1	0.676	1.94
2006	522	457	637	513	41.4	7.93	0.834	3.29
2007	575	437	728	590	74.9	13	- 0.174	2.20
2008	529	414	681	521	73.8	13.9	0.427	1.86
2009	491	398	631	479	55.1	11.2	0.808	2.96
2010	592	481	807	561	77.9	13.2	0.941	3.19
2011	478	358	603	479	77.8	16.3	0.0262	1.46
2012	669	537	913	666	88	13.2	0.826	3.38
2013	559	448	746	533	85.9	15.4	0.659	2.01
2014	546	419	748	534	76	13.9	0.906	3.28
2015	543	391	739	538	90.9	16.7	0.381	2.09
2016	553	432	708	551	71.6	12.9	0.102	2.34
2017	579	404	738	584	76	13.1	- 0.185	2.65
2018	578	454	801	562	90.6	15.7	0.826	2.69
2019	539	380	698	540	91	16.9	0.118	1.90
2020	725	528	1010	672	144	19.9	0.584	1.88

received little rainfall during the period 1981–2000, show decreasing, intermediate and increasing trends. On the other hand, stations such as Gorom-Gorom, Markoye, Tin-Akoff, Dori, Seytenga, Arbinda, Baraboule and Mansila show an upward trend because the decades 1981–2000 were relatively wet. The ITM, which subdivides the time series, influences the temporal trends over the period 1981–2020. This makes it easier to identify trends in low, medium and high values in the time series. Its ability to detect low, medium and high trends in series sets it apart from MK.

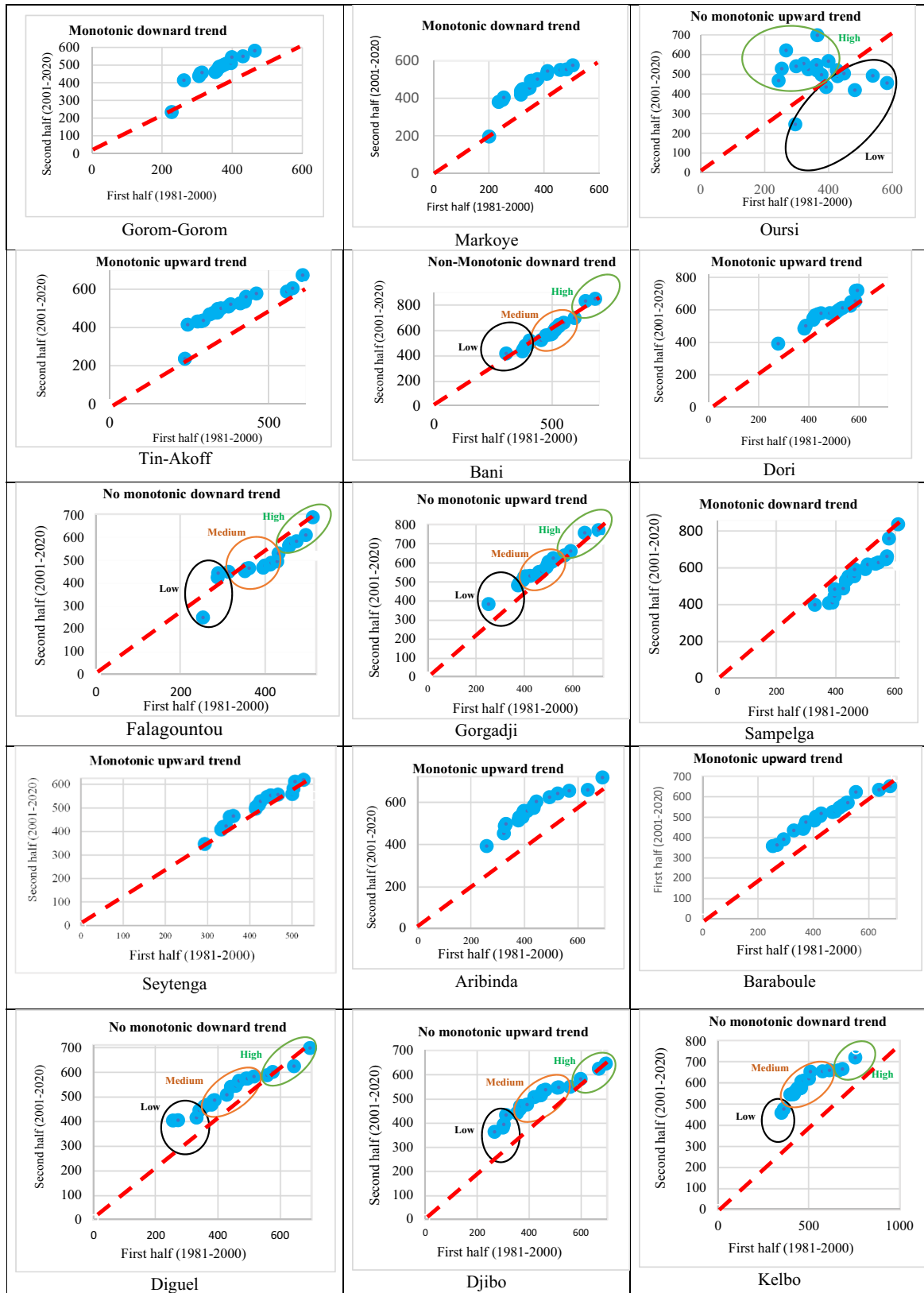


Fig. 5 ITM results for annual precipitation over the period 1981–2020

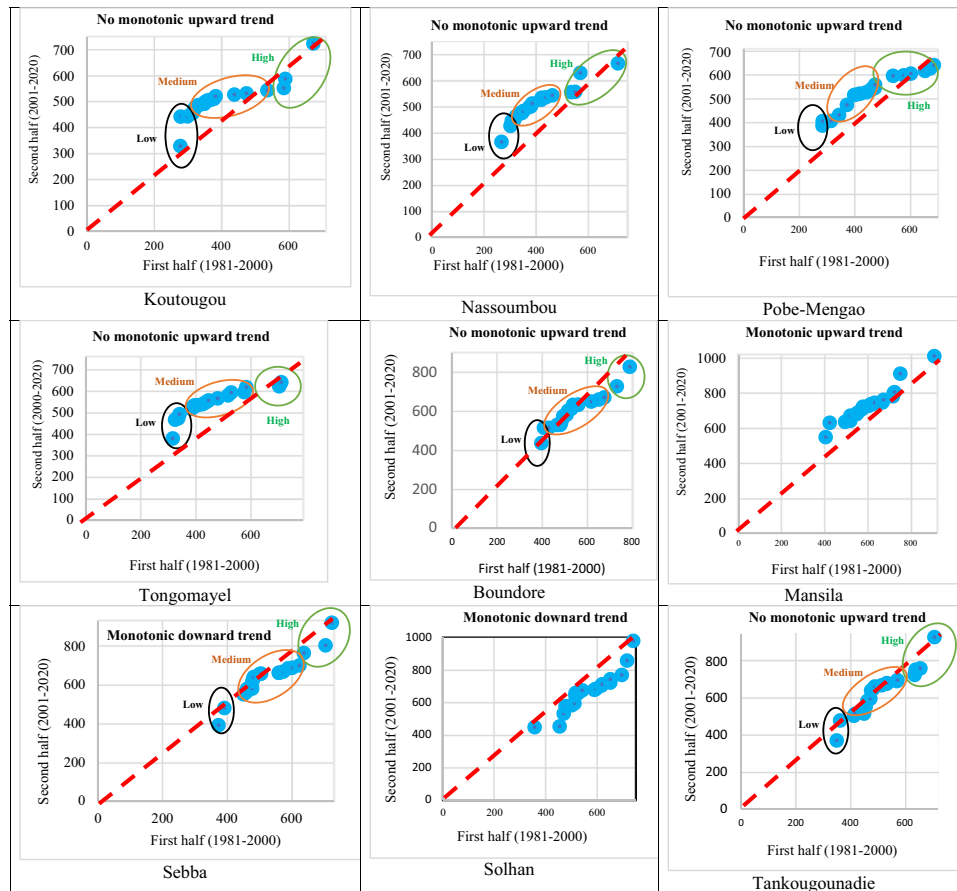


Fig. 5 (continued)

4 Discussion

4.1 Rainfall variability in the Sahel in West Africa

The study notes that the precipitation data between 1981 and 2020 will only vary to a small or even moderate extent, with a CV of between 13 and 20. The mean values of the precipitation time series fluctuate between 1981 and 2020. The application of Innovative Trend Method reveals both an upward and a downward trend over the Sahel region as a whole. This means that there is local variability between the communes that make up the Sahel region of Burkina Faso. Several other studies carried out in Burkina Faso reflect this situation. A national study showed that rainfall was highly variable between 1941 and 2000 [58]. In the Centre-North region, high rainfall variability was also observed between 1991 and 2015 [58]. The work of [59–62] and shows that the North and Southwest regions of Burkina Faso also experience rainfall variability over the period 1991–2020. In the savannah zone of Ghana, [63] has observed similar results. In southern Mali, the same observations were made between 1989 and 2019 [64]. Rainfall variability is also high in the Sudano-Sahelian region of Nigeria [65]. These results confirm a trend observed over a 1000-year period (850–1850) over the West African region [66]. Indeed, over the period 850–1850, the region experienced decadal, multi-decadal and centennial variability in precipitation. The work of [67] also shows that this variability continued between 1801 and 1900, although it was characterized by interannual precipitation variability. It then continued between 1901 and 2015 [68]. According to projections for the Sahel region of West Africa for the period 2030–2070, rainfall trends will continue to be highly variable whatever the scenario (RCP2.6 or RCP6.0) [69]. The significant upward trend in rainfall in the Sahel region over the last 30 years is mainly due to the convergence of climate moisture flows [70], the Tropical North-East Atlantic (TNEA) [71] and Atlantic multidecadal variability (AMV) [72].

Table 4 Precipitation trends according to the Mann–Kendall test between 1981 and 2020. Source: CHIRPS, 1981–2020

Stations	S	Z	p-value	Trend
Gorom-Gorom	312	3.6235	0.0002	Increase
Markoye	322	3.74	0.0001	Increase
Oursi	308	3.57	0.0003	Increase
Tin-Akoff	334	3.88	0.0001	Increase
Bani	264	3.06	0.0022	Increase
Dori	292	3.39	0.0007	Increase
Falagountou	356	4.13	3.53E–05	Increase
Gorgadji	298	3.46	0.0005	Increase
Sampelga	290	3.37	0.0007	Increase
Seytenga	340	3.95	7.82E–05	Increase
Arbinda	304	3.53	0.0004	Increase
Baraboule	292	3.39	0.0007	Increase
Diguel	312	3.62	0.0003	Increase
Djibo	276	3.20	0.0013	Increase
Koutougou	324	3.76	0.0001	Increase
Kelbo	272	3.16	0.0016	Increase
Nassoumbou	344	3.99	6.43E–05	Increase
Pobe-Mengao	242	2.81	0.0050	Increase
Tongomayel	342	3.97	7.09E–05	Increase
Boundore	272	3.16	0.0016	Increase
Mansila	340	3.95	7.82E–05	Increase
Sebba	308	3.57	0.0003	Increase
Solhan	252	2.92	0.0034	Increase
Tankougounadie	336	3.90	9.5E–05	Increase

4.2 Analysis of rainfall trends: comparison between the Mann–Kendall test and the innovative trend method

The difference between the Mann–Kendall test results and the innovative trend method has been noted by several authors around the world. For example, in Croatia, Ref. [4] found that the August rainfall trends tended to be positive, while the trend for the ITM results was less clear. In Turkey, [70] came to the same conclusion regarding the difference between MK and ITM results, noting that an overall positive trend was observed, in contrast to ITM where both increasing and decreasing trends were observed. For [73], the difference in results between MK and ITM is inevitable because ITM is able to detect secondary trends, whereas MK only shows the monotonic trend. Reference [74] agree with the previous authors but add that ITM is better than MK because ITM allows to understand the trends for low, medium and high values. Therefore, according to [46], ITM is effective for trend analysis of water parameters, especially in assessing low, medium and high data values. Furthermore, Ref. [75] state that the results of ITM can be used to assess both global and partial trends. Reference [76] state that ITM can also be used to identify trends in the maximum and minimum values of total annual precipitation time series.

5 Limitations and suggested future research

The aim of this study was to analyse annual rainfall trends in the Sahel region of Burkina Faso. Two non-parametric methods were used: the Mann–Kendall test and the innovative trends method. These two methods are complementary, as the Mann–Kendall test was used to identify general trends in annual rainfall over the period 1981–2020, while the innovative trends method was used to identify local trends in annual rainfall. The weakness of these two non-parametric methods is that they do not take into account the seasonal trend in precipitation time series. Future

Table 5 Comparison between the Mann–Kendall test and the innovative

Stations	Trend Mann-Kendall (MK)	Trend Innovative Trend Method (ITM)
Gorom-Gorom	Increase	Increase
Markoye	Increase	Increase
Oursi	Increase	No monotonic upward trend
Tin-Akoff	Increase	Increase
Bani	Increase	No monotonic upward trend
Dori	Increase	Increase
Falagountou	Increase	No monotonic upward trend
Gorgadji	Increase	No monotonic upward trend
Sampelga	Increase	Decrease
Seytenga	Increase	Increase
Arbinda	Increase	Increase
Baraboule	Increase	Increase
Diguel	Increase	No monotonic upward trend
Djibo	Increase	No monotonic upward trend
Koutougou	Increase	No monotonic upward trend
Kelbo	Increase	No monotonic upward trend
Nassoumbou	Increase	No monotonic upward trend
Pobe-Mengao	Increase	No monotonic upward trend
Tongomayel	Increase	No monotonic upward trend
Boundore	Increase	No monotonic upward trend
Mansila	Increase	Increase
Sebba	Increase	No monotonic upward trend
Solhan	Increase	Decrease
Tankougounadie	Increase	No monotonic upward trend

Increase
 No monotonic upward trend
 Decrease

research should therefore use advanced statistical methods, such as ARIMA, to analyse predictive rainfall trends in the Sahel region of West Africa.

6 Conclusion

Rainfall trends are essential for understanding rainfall trends in the country. The study shows that rainfall data for the Sahel region show slight variations. However, rainfall trends are increasing for the MK test and both increasing and decreasing for the ITM. This indicates a difference between the trend results of the two tests. The MK test shows general trends while the ITM shows trends for low, medium and high values. This situation should lead central and regional authorities to modify their interventions in the Sahel. Public policies orient agropastoral policies to the overall rainfall trends in the zone. This study shows that there is no single overall trend in the Sahel, with some communities experiencing increases in rainfall, others decrease, and still others both increases and decreases. It is therefore important that regional policies take these specificities into account by promoting agriculture in communities with upward trends, and promoting livestock in communities with downward, intermediate and upward trends. These measures should strengthen the resilience of the population in the face of climate change.

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Author contributions YJ processed and then analysed the cumulative annual rainfall data and wrote this study.



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Data availability The data supporting the conclusions of this study were extracted from the CHIRPS database and are available at the following address: <https://data.chc.ucsb.edu/products/CHIRPS-2.0/>.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Sole authorship of the manuscript Annual rainfall trends in the Burkina Faso Sahel: a comparative analysis between Mann–Kendall and Innovative Trend Method (ITM). I declare that I am the sole author of the study described in this document. This means that I am solely responsible for the design of the study, the presentation of the results, and the preparation of the manuscript. The manuscript is therefore our property, and we are the author.

Competing interests The authors declare no competing interests.

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