Spatio-Temporal variations of rainfall in eastern Burkina Faso from 1988 to 2021

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Abstract : **This paper has investigated the spatio-temporal changes in rainfall within eastern Burkina Faso using the recently developed trend analysis method known as Innovative Trend Analysis (ITA). For this purpose, the rainfall time series of 09 rain gauges stations lasted for 1988 to 2021 was collected and the innovative trend analyses (ITA) package was applied in R software. In parallel to this study, Man kendall statistical were performed to determine trend. The Innovative trend analysis displayed significant divergences among rain gauges. Indeed, a slight negative trend of the rainfall mainly in Fada N'Gourma (s = -0.113), Komin Yangha (s = -1.680), Mahadaga (s = -1.522), and Ouargaye (s = -2.945) is observed. However, the stations of Dialgaye (s = 5.050), Diapaga (s = 1.899), Namounou (s =0.089), Pama (s = 0.670), and Sangha (s =2.834) indicated a positive trend of the annual rainfall. In general, the result is in conformity with the Mann-Kendall trend analysis for all stations except for Dialgaye and Mahadaga which demonstrated respectively negative and positive trend. Overall, the findings of this study could provide comprehensive information to researchers and policy makers in water resources management and prediction under future climate change scenarios.**

Keywords : **climate change, innovative trend analysis, rainfall, variability.**

1. Introduction

Assessment of rainfall time series trends turns out to be a fundamental step in efficiente water resources management processes. Under global warming, hydro-meteorological parameters are proned to a great variability in some regions with a repercussion on water availability for ecosystems and socio-economic purpose. IPCC (2022) claimed that global surface temperature has increased by a rate of 1.09°C between 2011 and 2020. In addition, global warming will reach or exceed 1.5°C in the near-term, even under insignifiant greenhouse gas emissions. According to Xiao et al. (2021) regional and global-scale effects of climate change on temperature and precipitation may lead to high changes in river runoff and groundwater level, with repercussion in the evolution of water resources and social development at a regional level. A forecasting of hydroclimatic parameters time series by Bonsal (2017) indicated that the future will be quite severe. The impact is forecasted to be severe in Africa countries in which vulnerability to climate change is hyghly proven (Challinor et al ;2007, Schilling et al ; 2012, Hänsler et al ;2013, Welborn et al ;2018). In Burkina Faso, a wide range of scientific research on hydroclimatic trend can be found in the litterature. Stalled et al (2012) have reported an upward trend in temperature at the rate of 0.6 °C across most of Burkina Faso since 1975. Tazen et al (2019) have studied the flood trends in Ouagadougou and their relationship to extreme rainfall events and found few significant trend in rainfall indices over the period 1961–2015. Funk et al (2012) analysed recent trends in rainfall and air temperatures. They found that rainfall trend have remained steady over the past 20 years. Béwentaoré et al (2022) have studied the trend analysis of extreme precipitation event in Burkina Faso. They concluded that there is a significant increasing trend for the 50 and 100 year return levels over some parts of the country. The overall goal of this study is to analyze the spatio temporal trend in annual rainfall time series data using the ITA method. As stated by Hao et al ., 2014, effective monitoring, prediction, and early warning of drought are critical for decision making and mitigation measures to reduce negative effects. However, lack of accurate information related to the patiotemporal characteristics of droughts may lead to chaotiques decision-making that results in additional drought-related costs and damages (Saadat et al., 2013). Thus, the motivation for this paper stems from the increasing needs for drought related information to adress water managment issues in semi-arid countries. A wide range of indices is available for monitoring and characterizing droughts from different perspectives. The most commonly indices applied for meteorological drought analysis are the rainfall deciles (Gibbs et al ; 1967), the Palmer drought severity index (PDSI) developped by Palmer et al., (1965), the standardized precipitation index (SPI) setted by McKee et al., (1993) and the standardized precipitation-evapotranspiration index (SPEI) recently devepopped by Vicente et al ; 2018. In this study, the Innovative Trend Analysis (ITA) is applied to analyse the geospatial signature of drought over eastern Burkina Faso.

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted in the eastern Burkina Faso located betweem 12°15′ Nord and 1°00′ (figure 1). The study encompasses a geographical area of about 46 256 km^2 representing 17% of the national territory. The relief is mainly characterized by the predominance of Precambrian basement of metamorphic construction. However, sparse sandstone and sandstone-schistose occured in the south-eastern border constituting the massif of Gobnangou. The altitudes vary from 160 m to 330 m and the highest altitude (408m) is located in Dymaci at the nordern part of Gayéri. The dominant soil types include sandy (on the surface), sandy-clayey (in depth), gravelly on compact substrate, armourstone and outcropping rock. The climate of the region is Sudanian, characterized by a dry season lasting from October to April. The study area receives an average yearly rainfall ranging from 200 to 1000 mm while the mean temperature is around 26˚C. Hydrologicaly the region extends from the Niger to the Oti basin and is watered by the Faga, the Sirba, the Goroubi, the Dyamougou, the Tapoa, (Niger basin tributaries) and the rivers Kourtiagou, Arly, Doubodo, Singou, Koulpelogo (Pendjari tributaries).

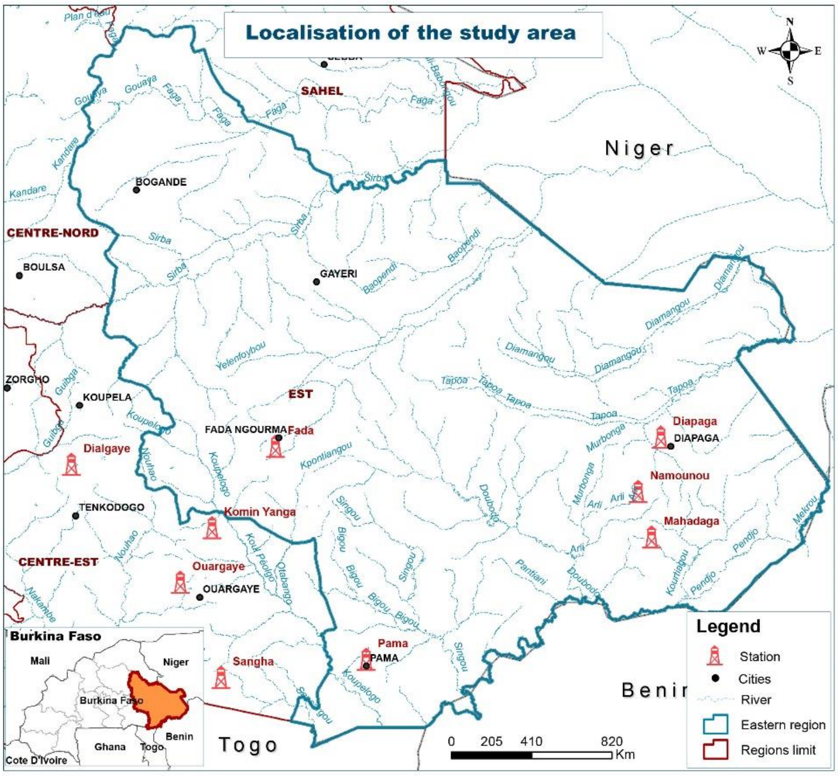

Figure1 : Localisation of the study area

2.2 Dataset

Monthly rainfall data records from 9 synoptic stations over the period 1988–2021 were collected from the National Meteorological Agency (NMA) of Burkina Faso. Table 2 shows the details and the basic statistics of the rain gauges time series for the selected stations. Previous studies have demonstrated the quality and representiveness of the selected records. Nonetheless, the data was subjected to quality control and missing data were filled on the basis of linear regression methods.

Table 2: Statistical and geographic characteristics of the rainfall observation stations in the study

Station name	**Coordinates**		**Annual Rainfall (mm)**					
	Longitude	Latitude	Min	**1st Qu**	**Median**	**Mean**	**3rd Qu**	**Max.**
DIALGAYE	-0.3833	11.9667	221.0	590.1	723.2	921.8	903.2	1295.0
DIAPAGA	1.7833	12.0667	279.0	700.2	814.5	848.9	988.2	1262.0
FADA	0.3667	12.0333	575.0	771.2	821.1	849.4	921.4	1084.0
KOMIN YANGHA	0.1333	11.7333	71.43	733.25	864.50	864.50	988.00	1222.00
MAHADAGA	1.75	11.7	610.1	833.0	922.0	921.8	1007.7	1279.0
NAMOUNOU	1.7	11.8667	481.2	481.2	839.6	848.9	941.0	1313.0
OUARGAYE	0.0167	11.5333	543.0	543.0	855.5	849.4	971.0	1165.0
PAMA	0.7	11.25	625.0	625.0	931.0	927.9	1041.5	1287.0
SANGHA	0.1667	11.1833	394.9	869.6	919.5	933.3	1066.2	1361.5

2.3 Methodology

The Innovative Trend Analysis (ITA) method is applied in this study to investigate historical rainfall variability. This recently method developed by Sen (2012) has been widely used in many watershed to analyse hydrometeorological trends. This trend analysis technics has several advantages. For instance, serial correlation and non-normality are not required (Caloiero et al. 2018 ; Wu and Qian 2017). In addition, short time series can be applied conversely to classical approches requiring at least 30 years of data Almazroui1 et al (2020). The methodology is fundamentally based on designing a scatter plot of a set of subseries derived from a given time series on a Cartesian coordinate system Şen (2012, 2014, 2017). Firsthly, the time series is divided into two equal parts and separately sorted in ascending order. Then a scatter diagram graph is drawn with the first half values plotted on the X-axis against the second half values on the Y-axis. Consequently, any data located on the 1 :1 line (45° line) shows no trend in the time series while data are located on the upper and lower triangular area of the 1 :1 line is indicating an increasing and decreasing trend in the time series respectively.

The basic equation for a trend in quantity related to the ITA method is given in the following expression as:

$$S = \frac{2(\bar{y} - \bar{x})}{n}$$

Here, s, $\bar{y}$, $\bar{x}$ and n stand for trend slope, arithmetic averages of the second and first sub-series and number of data, respectively. Positive slope values indicate increasing trends, while negative slope values stand for dereasing trends , when the slope value is zero, there is no trend. The trend indicator is calculated based on the following equation :

$$\boldsymbol{D} = \left(\frac{\overline{\boldsymbol{y} - \boldsymbol{x}} * \mathbf{10}}{\bar{\boldsymbol{x}}}\right)$$

The ssd is obtained through the following equation :

$$\boldsymbol{ssd} = \frac{(2\sqrt{2}) * sd(x) * \sqrt{(1 - cor(y - x))}}{\frac{n}{\sqrt{n}}}$$

The confidence limits (CL) of the trend slope at 90 percent is :

$$\boldsymbol{CLlower90 = 0 \; - \; 1.645 * ssd} \; ; \; \boldsymbol{CLupper90 = 0 + 1.645 * ssd}$$

The Confidence limits (CL) of the trend slope at 95 percent is :

$$\boldsymbol{CLlower95 < -0 \; - \; 1.96 * ssd; CLupper95 > -0 + 1.96 * ssd}$$

Mann-Kendall Test

Chandler et Scott (2011) claimed that trend analysis is an empirical approach for quantifing and explaining changes in a system over a period of time. The well-known Mann Kendall test is a non-parametric test widely applied to detect trends in climatic variables (McLeod, 2005 ; Hussain, 2019 ; Mondal, 2012). The MK test has low sensitivity to abrupt breaks due to in homogeneous time series and does not require the data to be normally distributed.

S statistic in the MK test (Mann 1945; Kendall 1975) is provided as :

$$\boldsymbol{S} = \sum_{a=1}^{n-1} \sum_{j=a+1}^{n} \boldsymbol{Sgn(xb - xa)}$$

where n is the number of observations and xb is the bth observation and Sgn stands for the sign function, defined as

$$\boldsymbol{Sgn(xb - xa)} = \begin{cases} \boldsymbol{+1;\; xb > xa} \\ \boldsymbol{0;\; xb = xa} \\ \boldsymbol{-1;\; xb < xa} \end{cases}$$

The Mann Kendall z value (Zs) which measures the trend significance is obtained through the following equation :

$$\mathbf{Zs} = \begin{cases} \dfrac{\boldsymbol{S - 1}}{\sqrt{\boldsymbol{Var(S)}}}, & \boldsymbol{S} > 0 \\ \mathbf{0}, & \boldsymbol{S = 0} \\ \dfrac{\boldsymbol{S + 1}}{\sqrt{\boldsymbol{Var(S)}}}, & \boldsymbol{S} < 0 \end{cases}$$

Var is the variance of S. A positive (negative) value of Zs indicates an upward (downward) trend.

3. Result and discussion

Figure 2 displays the annual variation trend of total precipitation obtained by applying the ITA method. The results indicate that there are slight spatial differences in the variation in annual precipitation among stations. Indeed, the result indicated significant divergences among rain gauges. A slight negative trend of the rainfall mainly in Fada N'Gourma (s = -0.113), Komin Yangha (s = -1.680), Mahadaga (s = -1.522), and Ouargaye (s = -2.945) is observed. However, the stations of Dialgaye (s = 5.050), Diapaga (s = 1.899), Namounou (s =0.089), Pama (s = 0.670), and Sangha (s =2.834) indicated a positive trend of the annual rainfall.

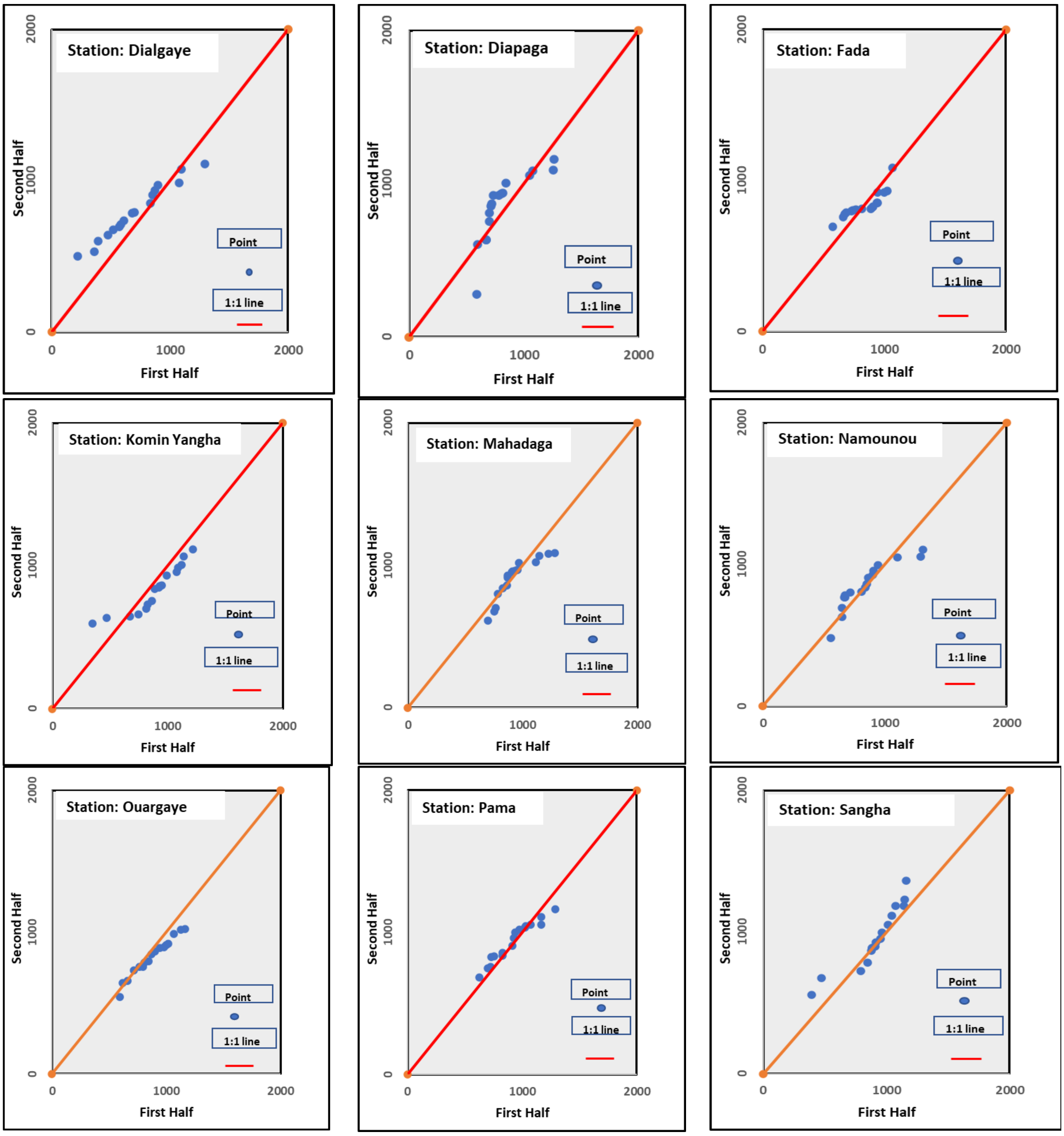

Figure 3. ITA graphics for the annual rainfall records in eastern Burkina Faso.

Table 3 reports the Innovative trend information for the stations. The first column represents the slope s, the second column represents the Trend indicator D , the third column represents the standard deviation ssd. The column 4 ,5 ,6 and 7 represents lower and upper confidence limits of the trend slope at 90 and 95 percent. Positive value of s displays an increasing trend while a negative value shows decreasing trend. Globally, at yearly scale, the results of the ITA slope evidenced that a negative trend of the rainfall anomalies has been detected mainly in Fada N'Gourma, Komin Yangha, Mahadaga and Ouargaye. However, significant upwarding trends were observed in 05 stations namely Dialgaye, Diapaga, Namounou, Pama and Sangha. According to Caloiero et al,2018 the inovative trend indicator (D) is used to detect wheter the precipitation trends are statistically significant. Positive value of D indicated an increasing trend of precipitation. Conversely, negative value depicts a decreasing trend. This result is in concordance with the above standing on the trend of rainfall over the eastern region of Burkina Faso.

Table 2 : ITA information

Station	s	D	ssd	CLlower90	CL upper90	CLlower95	CLupper95
Dialgaye	5.050	1.211	0.407	-0.669	0.669	-0.797	0.797
Diapaga	1.899	0.392	1.338	-2.202	2.202	-2.623	2.623
Fada N'Gourma	-0.113	-0.0229	0.606	-0.997	0.997	-1.188	1.188
Komin Yangha	-1.680	-0.331	1.193	-1.96	1.96	-2.339	2.339
Mahadaga	-1.522	-0.2769	0.721	-1.186	1.186	-1.414	1.414
Namounou	0.089	0.0179	0.809	-1.331	1.331	-0.586	0.586
Ouagaye	-2.945	-0.572	0.265	-0.436	0.436	-0.519	0.519
Pama	0.670	0.124	0.387	-0.637	0.637	-0.759	0.759
Sangha	2.834	0.5299	0.810	-1.332	1.332	-1.587	1.587

The Mann-Kendall test on rainfall data shows the following results in Table 4. The result shows a negative trend of the rainfall mainly in Dialgaye, Fada N'Gourma, Komin Yangha and Ouargaye while positive trend of rainfall is detected within Diapaga, Mahadaga , Namounou, Pama and Sangha.

Table 3: Results of the Mann-Kendall test for Annual rainfall for eastern Burkina Faso**.**

Stations	z	p-value	S	tau
DIALGAYE	-0.1186	0.9056	-9.00000000	-0.01604278
DIAPAGA	2.0754	0.03795	141.0000000	0.2513369
FADA	-0.50403	0.6142	-35.00000000	-0.06238859
KOMINYANGHA	-1.7789	0.07525	-121.0000000	-0.2156863
MAHADAGA	0.32614	0.7443	2.300000e+01	4.099822e-02
NAMOUNOU	0.088947	0.9291	7.000000e+00	1.247772e-02
OUARGAYE	-1.097	0.2726	-75.0000000	-0.1336898
PAMA	-1.097	0.2726	-75.0000000	-0.1336898
SANGHA	0.26684	0.7896	1.900000e+01	3.386809e-02

The nexus between climate change and water resources is well documented and this phenomeon sound to have a hugue impact on water ressources availability (Bharati, 2014 ; Koutroulis 2013 ; Charlton, 2006). In 2020 the national rate of access to water was estimated at 47% which can be probably attributed to rainfall variations. Therefore, assessing rainfall trend is for a paramount importance in water ressources management. This study has been conducted to investigate the ability of the ITA method to detect rainfall trend in the eastern part of Burkina Faso. The results indicated that under ITA, a slightly increasing trend of rainfall is observed at Dialgaye, Diapaga, Namounou, Pama and Sangha while a decreasing trend is observed in Fada, Komin Yangha and Ouargaye stations. The Man Kendall results indicated simular trend for all stations except for the stations of Dialgaye and Mahadaga. The innovative trend indicator (D) was then used to detect whether the precipitation trends were statistically significant. A positive value of D indicates an upward trend in rainfall time series. In contrast, a negative value of D indicates a downward trend. The results in table 2 shows that significant increasing trends were observed in 05 stations (table 2). The ITA (D) and the Mann-Kendall test shows some different results. This finding is congruent with Alifujiang et al (2021) who stated that ITA method has some advantages over the Mann-Kendall test. X et al emphasiezd by saying that the ITA technique detect trend better than the MK tests. Such trends are affecting the hydrological cycle at the region scale. Consequently, the Eastern Region of Burkina Faso is highly susceptible to climate variability. Drought is a recurrent phenomenon in the region and affect the main substantial activities.

4 Conclusion

The present study analyzed the rainfall data variability for the Eastern part of Burkina Faso. For this purpose, Innovative Trend analysis technics was applied to rainfall records from nine meteorological station. Globally, the results of the ITA slope evidenced that a negative trend of the rainfall anomalies has been detected mainly in Fada N'Gourma, Komin Yangha, Mahadaga and Ouargaye. The remainning localities especially Dialgaye, Diapaga, Namounou, Pama and Sangha, showed a positive trend. Such trends show that the eastern part of Burkina Faso is highly susceptible to climate variability. This will affecte the hydrological cycle and the main substantial activities at the region scale. The results of this study provide a more comprehensive understanding of precipitation changes in eastern Burkina Faso, which is beneficial for policymakers and managers to manage resources changing climatic conditions.

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