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Trend analysis of streamflow with different time scales: a case study of the upper Senegal River

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ABSTARCT
This study investigates long-term trends of three different time scales including monthly, seasonally and annually at the upper Senegal River basin. Daily streamflows for the period 1961–2014 at Bafing Makana station were used and analyzed to conduct this research. The serial structural of the different time series (monthly, seasonal, and annual) were investigated in order to detect the presence of autocorrelation. Mann–Kendall test was applied to no autocorrelated series and the Modified Mann–Kendall test for the autocorrelated. Theil and Sen's slope estimator test was used for finding the magnitude of change and Pettitt test was applied for detecting the most probable change year. Results exhibited a decreasing trend of the annual stream flow yet at the 5% significance level, streamflow series did not have any statistically significant trend for the whole period; however, integrating the different change years, decreasing trend is significant before the first breaking point (1976) and increasing trend is significant from first breaking point to the second change point (1993). For the monthly series, all months exhibit a non-significant decreasing trend except for the month of June. The seasonal series show a decreasing trend which a significant at MAMJ season. Change years were varying accordantly to the scale.

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Streamflow characteristic; trend analysis; statistical test; upper Senegal River

1. Introduction

In any development and planning of flood control, mitigation, irrigation, hydro-power, and several other applications, the analysis of streamflow pattern is highly significant concern for hydrologist (Bodian et al. 2016; Fereydooni et al. 2012). In sub-Saharan Africa, the availability of freshwater is the fundamental to economic growth and social development (Kankam-Yeboah et al. 2013). Thus, studying the characteristics time series of any river discharges are considered one of the most importance objective in water resources engineering and especially in the field of planning and establishing the annual water balance in addition to management of dam's projects (Hyvärinen 2003).

In water resource management, historical data time series is a very vital component that can explain certain conditions. Salarijazi (2012) stated that hydrological time series are supposed to meet a set of ideal conditions, such as being trend-free and without change points. However, hydrology of river basins is impacted by several factors such as climate change, land use, hydraulic infrastructure managements (Raje 2014; Salarijazi 2012). As a result, a hydrologic series may exhibit a non-stationary pattern. Therefore, stationarity should no longer serve as a default assumption in water-resource management (Milly and Julio 2008). In another research, Xiong and Guo (2004) highlighted that in many published studies, the hydrological data series from many regions demonstrate significant non-consistency or non-stationarity. Due to this concern, trend analysis and change point detection in streamflow series and other related variables (rainfall, evapotranspiration, index of aridity) have been investigated by many researchers in different river basin and time scale throughout the world. Onyutha et al. (2016) investigated the annual rainfall trend in the Nile River basin by using 39 gage stations and concluded a decrease annual rainfall of 26 out of 39 stations. They found a decreasing trend in the mean annual rainfall for 26 stations. Diop and Bodian (2016) studied the long-term trend of annual rainfall over Senegal in West Africa. They used the Mann-kendell and sen's slope tests to investigate the direction and the magnitude of the trend. The authors found that there is a negative trend in the annual rainfall pattern for the period (1940–2013). Whereas, for the period (1984–2013), they stated that out of 22 stations only 7 exhibited a significant trend at 5% level. Wang et al. (2013) used the Mann-Kendall and the Mann-Kendall-Sneyers tests to investigate trend and change point in annual streamflow from 1960 to 2009 at the Kaidu River in the Northwestern Arid Region of China. They reported a significant annual streamflow increase and a change point at 1993. Bassiouni and Oki (2013) analyzed streamflow data from 1913 to 2008 by using Mann-Kendell test. They stated that high flow exhibited significant decreases trends in Hawai. Trend and change points analysis are two tests which have often used at the same time as mentioned by (Villarini et al. 2011), who claim that before evaluation of trend in hydrological time series, change point test must be applied on time series. Several methods are used to study the change points of a time series (Chen et al. 2011; Koutsoyiannis 2013; Lavielle

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and Teyssiere 2006; Minville et al. 2008; Picard 1985; Wong et al. 2006), among all these methods, the Pettit test is one the most efficient technique.

However, for the best knowledge of the authors, no study has investigated these issues in the upper Senegal River basin. Hence, this research investigates whether the discharge records of the upper Senegal river basin at the Bafing Makana station exhibit evidence of gradual change (trend) or abrupt change (jump) over the past five decades (1961–2014).

2. Material and method

2.1. Case study and data description

This study was conducted at the upper Senegal River basin (latitudes 10°30′ and 12°30′ N and longitudes 12°30′ and 9°30′ W). The study area covers a part of Guinea Conakry and Mali with a catchment area of 21,290 km^2 at the gaging station of Bafing Makana (Figure 1). Daily streamflow data monitored at Bafing Makana station from 1961 to 2014 by the Senegal River Basin Organization (OMVS) are used for this study. The station of Bafing Makana controls the Multi-functional Manantali Dam inflow which is vital hydraulic infrastructure for the Senegal river basin organization. The upper Senegal River basin has a dense hydrographic network (Bodian et al. 2016), but the natures of the soil, as well as the geological formations are not favorable to the existence of large aquifers. The elevation varies from 215 to 1389 m and the slope indices decreases from upstream to downstream, reflecting the importance of the mountainous region of Fouta Djalon and strong relief incision. The climate of the basin is Guinean-Sudanese with a majority of the rainfall falling from April to October. The average rainfall of the basin is 1490 mm/year. It is induced by the movement of the inter-tropical convergence zone from south northwards, allowing the penetration of the West-African monsoon which is driven by the thermal contrast between the sea and the continent.

2.2. Change point test

By reviewing the literature studies, several methods are used to evaluate and recognize the change points in hydrological time series (Abdul Aziz and Burn 2006; Bawden et al. 2014; Kundzewicz et al. 2005; Zarenistanak et al. 2014). In the current research, we used a nonparametric test called Pettitt test change point test proposed by (Pettitt 1979). The approach was used to detect the occurrence of the abrupt change. In the last decade, this approach has been proved its usefulness in evaluating and detecting hydrological time series (Hendrix and Salehyan 2012; Ho et al. 2003; Michaelides et al. 2009; Tarhule and Woo 1998). Pettitt is a rank-based and distribution-free test for detecting a significant change in the mean of a time series and no hypothesis is required about the location of the change point. Theoretically, the Pettitt test is applicable for testing the unknown change point by considering a sequence of random variables $X_1, X_2, \ldots, X_t$, which have a change point at t.

Assuming we consider T to be the length of the time series and t the year of the most likely change point; thus, the single time series becomes two samples represented by $X_1 \ldots, X_t$ and $X_{t+1} \ldots, X_T$.

In order to detect the change point, the null hypothesis H0: no change (no change point) is tested against the alternative hypothesis H1: (there is a change point) by using the non-parametric statistic $K_T = \max|U_t, T| = \max(K_{T+}, K_{T-})$

where:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}\left(X_t - X_j\right) \tag{1}$$

$$\operatorname{sign}(\alpha) = \begin{cases} +1 & \text{if } \alpha < 0 \\ 0 & \text{if } \alpha = 0 \\ -1 & \text{if } \alpha < 0 \end{cases}$$

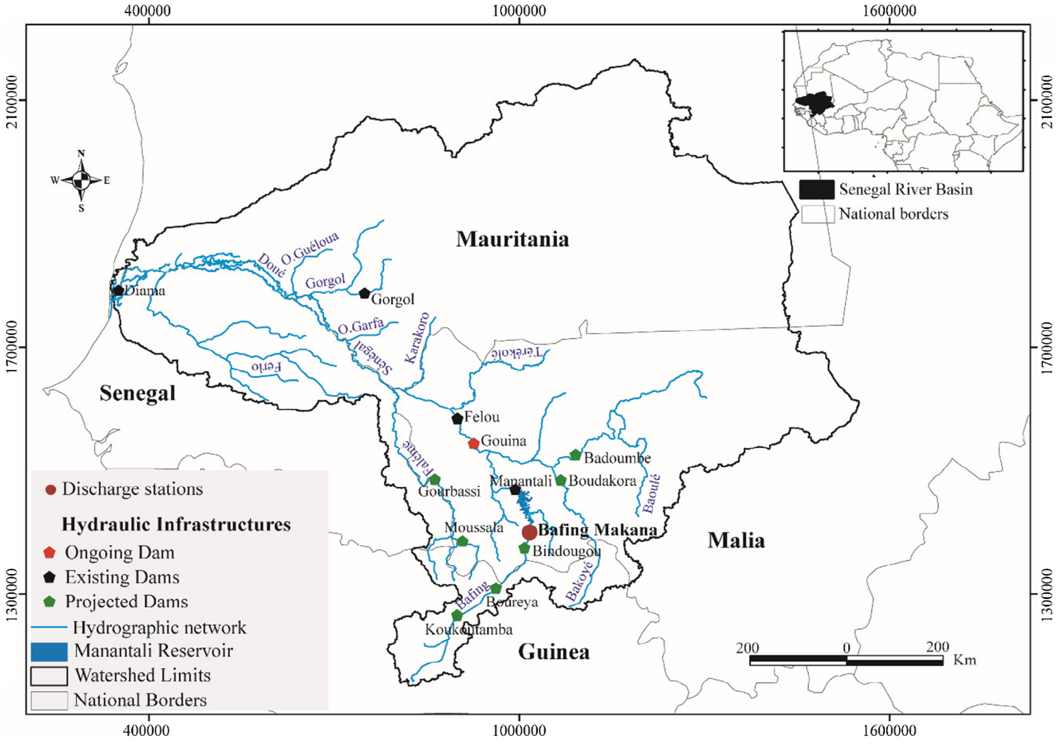

Figure 1. Map location of the Bafing Makana river basin. Source: The authors.

The most significant change point t can be identified as the point where the value of $|U_t, T|$ is maximum. The probability of a change point being at the year where $|U_t, T|$ is the maximum and approximated by:

$$p = 1 - \exp\left[\frac{-6K_T{}^2}{T^3 + T^2}\right] \tag{2}$$

2.3. Trend analysis

2.3.1. Trend

Annual streamflow trend detection was examined using non-parametric approaches namely Mann-Kendall and Sen's slope estimator (magnitude of trend). The main advantage of using these non-parametric trend test approaches is owing to the efficiency of handling any distribution of time series. These approaches need an independent data pattern.

2.3.2. Mann–Kendall test

Based on the latest research conducted in the field of hydro climatic time series, the Mann–Kendall (MK) test has shown a significant modeling among other statistical methods (Tabari et al. 2015). In addition, numerous researches have been undertaken in trend analysis for different hydrological applications and successfully implemented (Gocic and Trajkovic 2013; Hamed 2008; Karmeshu 2015; Mondal et al. 2012; Önöz and Bayazit 2012; Yue and Pilon 2004). The mathematical concept can best describe through calculating the Mann-Kendall Statistics S, Var (S), and standardized test statistics Z are as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}\left(x_j - x_k\right) \tag{3}$$

$$\operatorname{sign}\left(x_j - x_k\right) = \begin{cases} +1 & \text{if} \quad \left(x_j - x_k\right) < 0 \\ 0 & \text{if} \quad \left(x_j - x_k\right) = 0 \\ -1 & \text{if} \quad \left(x_j - x_k\right) < 0 \end{cases} \tag{4}$$

$$\operatorname{Var}(S) = \frac{\left[[n(n-1)(2n+5)] - \sum_{i=1}^{n} t_i\left(t_i - 1\right)\left(2t_i + 5\right)\right]}{18} \tag{5}$$

the n presents the number of the data points. t_i defines the number of ties for the i value. Here, the statistical Z usually follows the standard normal distribution for n value more than 10:

$$z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & if \quad S < 0 \\ 0 & if \quad S < 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & if \quad S < 0 \end{cases} \tag{6}$$

A positive value of Z indicates an increasing trend and a negative value indicate a decreasing trend. The null hypothesis H0: there is no significant trend of the annual rainfall is reject at 5% if $|Z| > 1.96$. If the series is auto correlated, the variance has to be modified by the Equation 7.

$$\operatorname{Var} \times (S) = \operatorname{Var}(S) \cdot \frac{n}{n^*} \tag{7}$$

where Var × (S) is the modified variance, Var (S) is the variance of Mann-Kendall before the modification, n is the actual sample size of the sample data and n^* is the effective sample size.

$$n^* = \frac{n}{1 + 2\sum_{k=1}^{n-1}(1 - \frac{k}{n}) \cdot r_k} \tag{8}$$

where r_k is the significant lag-k serial correlation coefficient given by the Equation (9).

$$r_k = \frac{\frac{1}{n-k}\sum_{t=1}^{n-k}\left[X_t - \left(\frac{1}{n}\sum_{t=1}^{n} X_t\right)\right]\left[X_{t+k} - \left(\frac{1}{n}\sum_{t=1}^{n} X_t\right)\right]}{\frac{1}{n}\sum_{t=1}^{n}\left[X_t - \left(\frac{1}{n}\sum_{t=1}^{n} X_t\right)\right]^2} \tag{9}$$

$$zc = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var} \times (S)}} & if \quad S < 0 \\ 0 & if \quad S < 0 \\ \frac{S+1}{\sqrt{\operatorname{Var} \times (S)}} & if \quad S < 0 \end{cases} \tag{10}$$

2.3.3. Theil-Sen's slope

The slope of n pairs of data points was estimated by using Theil–Sen's estimator. The slope calculated by Theil–Sen's estimator is a robust estimate of the magnitude of a trend (Onyutha et al. 2016). The trend magnitude is estimated as follows.

$$B = \operatorname{median}\frac{x_j - x_i}{t_j - t_i} \tag{11}$$

where x_j and x_i are values at times t_j and t_j respectively.

2.3.4. Relative change

The relative change (RC) can be calculated using the following formula:

$$R_c = \frac{n \times \beta}{|x|} \tag{12}$$

where n is the length of trend period, β is the magnitude of the trend slope of the time series (Sen's slope), and $|x|$ is the absolute average value of the time series.

Daily time series hydrological data-sets at different time horizons 'i.e. monthly and annually' were investigated. In addition, each year was divided into three grand seasons, each season represents four months. In particular, November to February (NDJF season), March to June (MAMJ season) and July to October (JASO season). The trend analysis was performed at each time step.

3. Results and discussion

3.1. Statistical characteristics of streamflow

3.1.1. Monthly streamflow

In this section, the analysis of monthly time scale streamflow at Bafing Makana is discussed. Figure 2(a) results showed that monthly streamflow varies from 0 m^3/s (May) to 1902 m^3/s (September). The mean streamflows of the months from January to May presented lowest values with means situated between 6.6 m^3/s and 52.5 m^3/s. The months of July, August, and September and October presented the highest monthly streamflow with the highest value in September.

The months of high streamflow coincide with the wet season which clearly point out that streamflow in this area is largely dependent on rainfall.

The Figure 2(b) exhibited the variation of monthly streamflow from 1961 to 2014, it can be seen that monthly streamflow between 1964 and 1976 presented the highest values for all the months. These periods of high streamflows were followed by

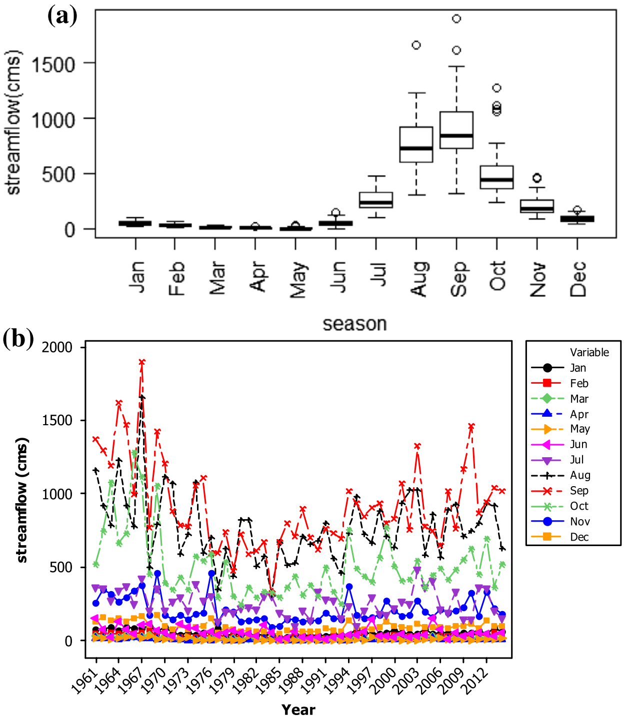

Figure 2. (a) Boxplot of Monthly streamflow. (b) Time series of monthly streamflow.

a decrease of the mean monthly streamflow and in the recent year, we noticed a trend of increase. But, overall, it can be easily noticed a trend of decreasing.

In order to evaluate the difference between August and September months (the months with the highest streamflow), the paired *t* test was applied to inspect if the difference is significant or not. Results show a significant difference at 5% (p-value < 0.001) with 95% confidence interval for mean difference situated between 205.4 and −85.7 m^3/s. These results confirm that the month of September is the month of the peak streamflow which is significant different in comparison with the other months.

3.1.2. Seasonal streamflow

The seasonal streamflows analysis was displayed in Figure 3(a) which shows clearly that streamflows are concentrated in the JASO season with an average streamflow value of 608 m^3/s while the MAMJ exhibited the lowest streamflow value (20.8 m^3/s). These results confirm again the correlation between streamflow and rainfall, in this region most of the rain falls between June and October with a peak event in September.

On the other hand, Figure 3(b) presented the variation of the seasonal streamflow across the years (1961–2014). For all years, the JASO season gave the highest streamflow with a peak value (1277 m^3/s) in 1967 and mean value of 584.6 m^3/s. The MAMJ season showed the lowest streamflow with a streamflow value of 18.1 m3/s and the NDJF season exhibited a mean streamflow value of 98 m^3/s

The ratio between JASO and NDJF, MAMJ streamflows were varied from 3 at (1966) to 10 at (1974 and 1985) and from 10 (1968) to 177 (1991), respectively. Whereas, the ratio between NDJF and MAMJ was varied from 2 at (1968, 1973) to 24 at (1991). These results showed that 1968 exhibits the highest difference between seasonal streamflows.

3.1.3. Annual streamflow

Figure 4 explained the variation of annual streamflow. The analysis of the annual streamflow time series indicated that

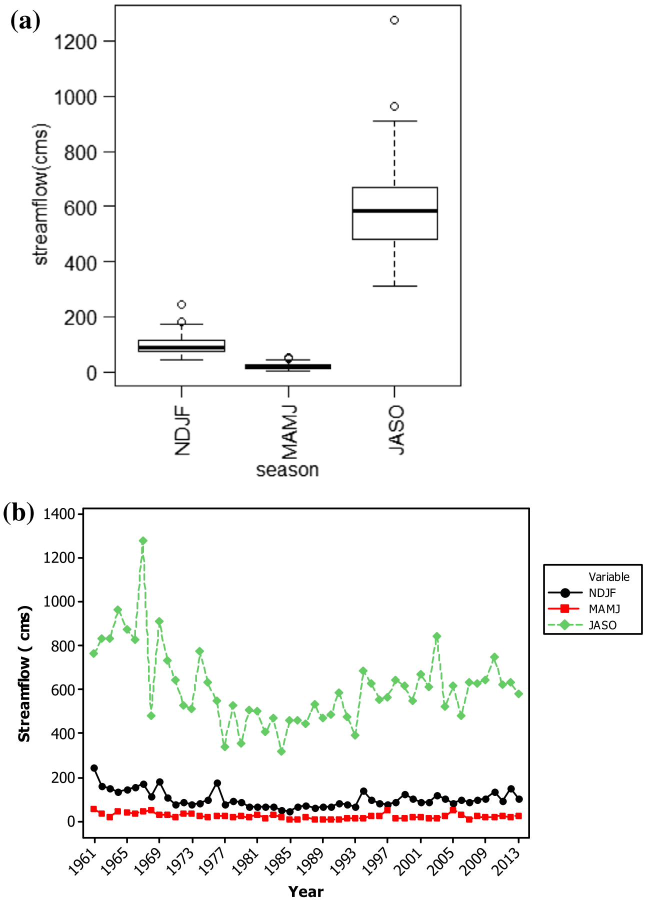

Figure 3. (a) Seasonal streamflow at Bafing Makana. (b) The variation of the seasonal streamflow over (1961–2014) time period.

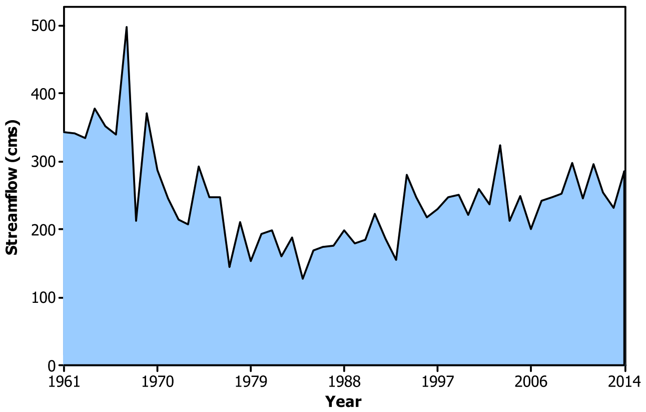

Figure 4. The annual streamflow analysis over (1961 and 2014).

streamflow varies from 126.9 m^3/s (1984) to 498 m^3/s (1967) with a mean annual value of 244 m^3/s, standard deviation value 69.7 m^3/s and the coefficient of variation of 28.5%. Preliminary analysis showed that the highest value of streamflow was concentrated around the period before 1972, followed by relative low values of streamflows until 1995 and after that period a relative increase in streamflows have been noted.

3.2. Trend analysis

Before proceeding with analyzing the data time series, an investigation for the serial structural of the different time series (monthly, seasonally, and annually) was conducted. The results of the auto correlation analysis for the period 1961–2014 are

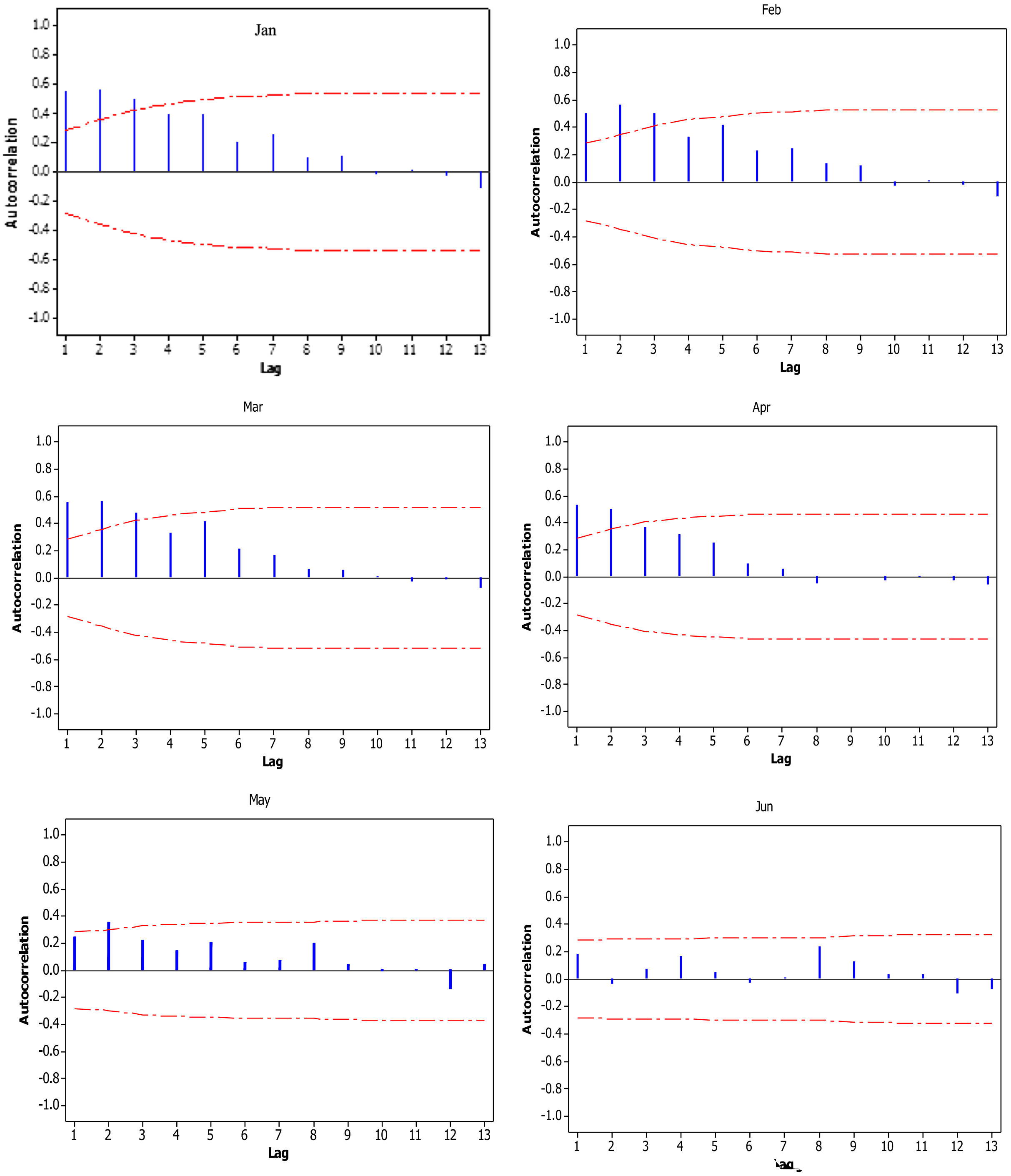

Figure 5. Serial correlation function of the monthly time scale streamflow series at Bafing Makana January to December (The 95% confidence intervals are marked with dotted lines).

presented in Figures 5, 6, and 7 for monthly, seasonally and annually, respectively. From these figures, we can conclude that statistically, some series were auto-correlated at 5% with significance level at certain lags. For example for the seasonal streamflow, the autocorrelation is significant at 5% at lag 1, 2 and 3 levels for JASO and NDJF seasons, and at lag 1 for MAMJ season (Figure 6); while the monthly streamflow exhibited significant autocorrelation at 5% at lag1, 2, and 3 for December, January, and February (Figure 5), whereas other months do not present any streamflow autocorrelation (June, July, August, and November), the remain months present either a significant autocorrelation at lag 1 or 2. When we are considering the annual streamflow series, the autocorrelation is significant at 5% at lag 1, 2 and 3 (Figure 7). The existence of significant serial correlations in the streamflow time series necessitates the removal of the effect of the serial correlations in the trend tests. Thus, only the value of Z statistics values after the removal of serial correlation are presented in Figure 8(a), (b) and (c).

3.3. *Change points*

Table 1 tabulated the results of the changing point probability in monthly, seasonal, and annual streamflow. The change points were computed using Pettitt test. The table gave the most probable date of change point for each time series.

The results showed, for the annually streamflow, that 1976 is found to be the most probable change year using Pettitt test with a p-value = 0.0047. For the monthly series, results exhibited different change points. Some are significant at a level of 5% others not. The months of September, October, December,

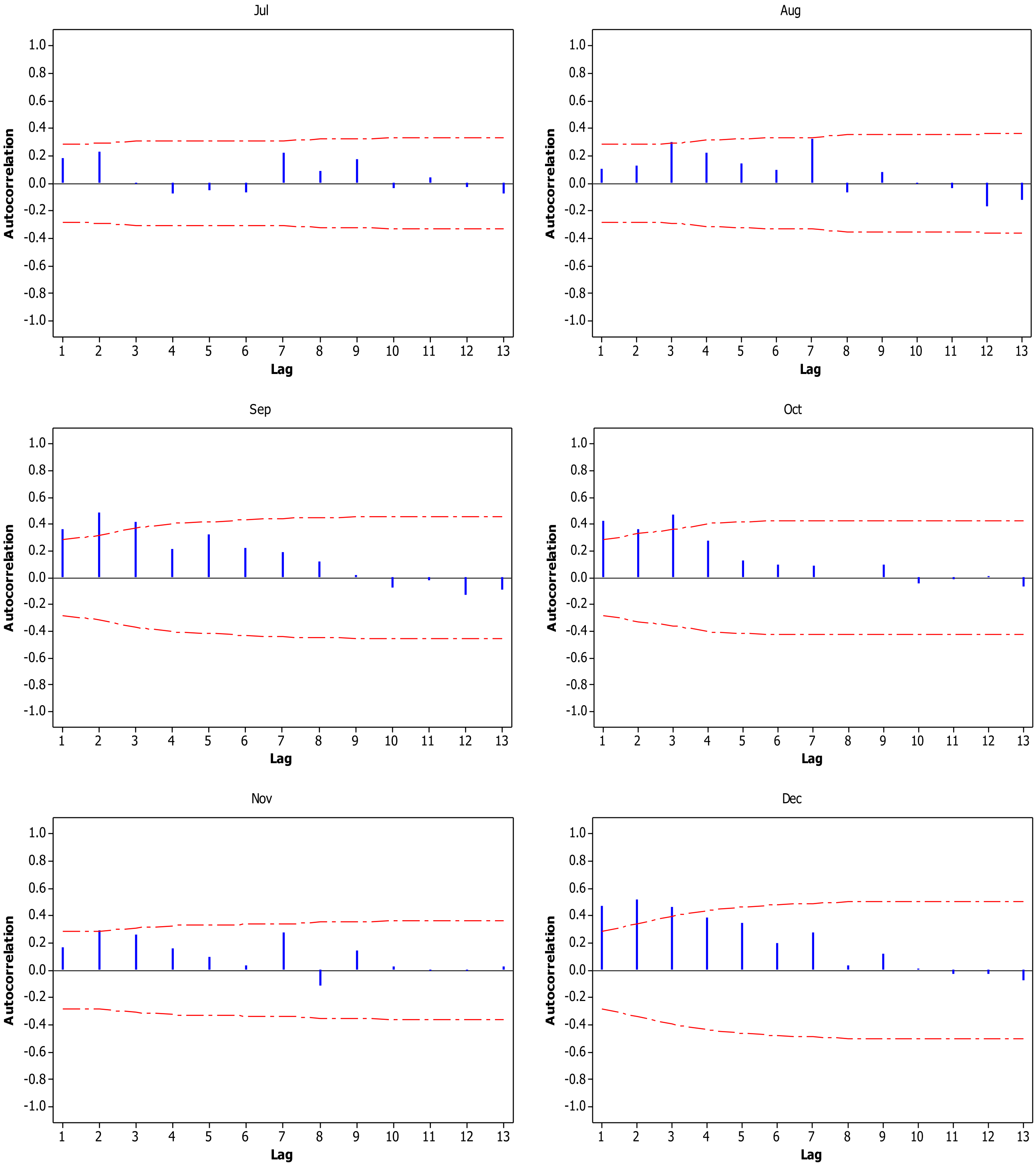

Figure 5. (*Continued*).

April, May, and June presented significant change points which coincide with 1976, 1970, 1976, 1972, 1974, and 1989, respectively. For the seasonal time series, all change points are significant (p-value < 0.05). These years are 1983, 1976, and 1972 for MAMJ, JASO, and NDJF seasons.

For Monthly scale, July, September, and December show the same change point (1976) than the yearly scale as well as the JASO season. All these points are significant at a level of 5%. These results point out that the change point may depend on the scale chosen, however, the annual and the seasonal peak flow show the same year. As extreme values influence the calculation of mean, therefore the JASO which exhibit the essential of the annual streamflow may conduct to have same change in both series (annual and JASO season).

After determining the change points, the trend analysis was performed both at the entire time series and the series after breaking points for the different scales (monthly, seasonal, and annual).

3.4. *Result of Mann-Kendall test*

The Figure 8(a) shows the result of trend test of the monthly streamflow. The trend analysis of the time series after taking into account all significant serial correlations indicates decreasing trends of all months. These decreasing trends are not statistically significant except for the month of June (Z less than −2).

Over all, considering the 1961–2014 period, the monthly streamflow exhibited a decreasing trend. This result is

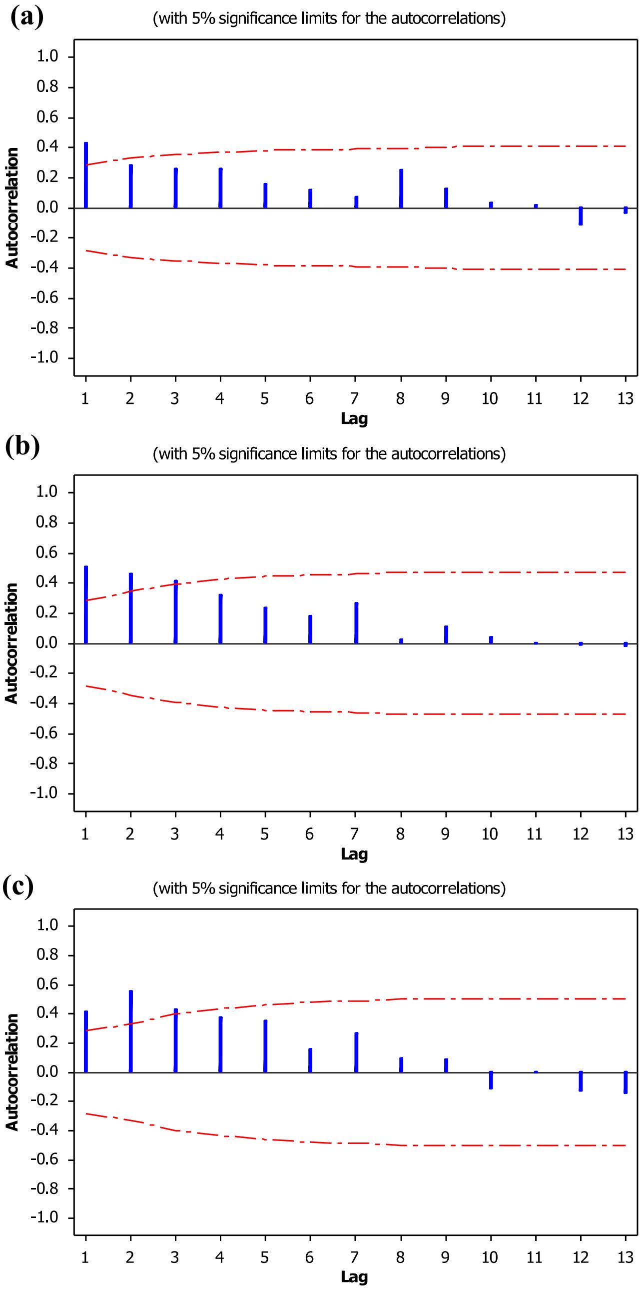

Figure 6. Serial correlation function of the seasonal streamflow series at Bafing Makana (The 95% confidence intervals are marked with dotted lines). (a) NDJF season, (b) MAMJ season, (c) JASO season.

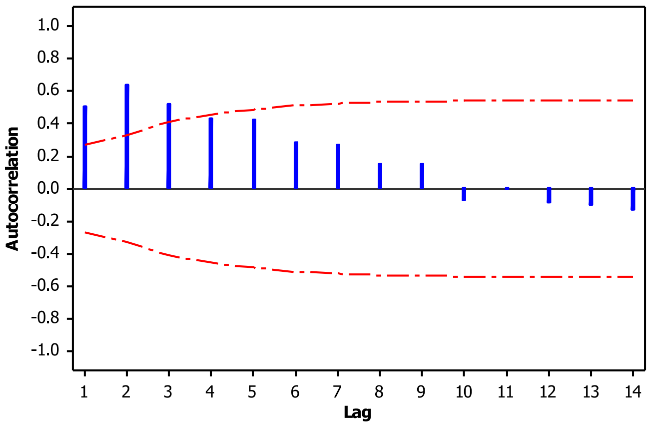

Figure 7. Serial correlation function of the annual streamflow series at Bafing Makana (The 95% confidence intervals are marked with dotted lines).

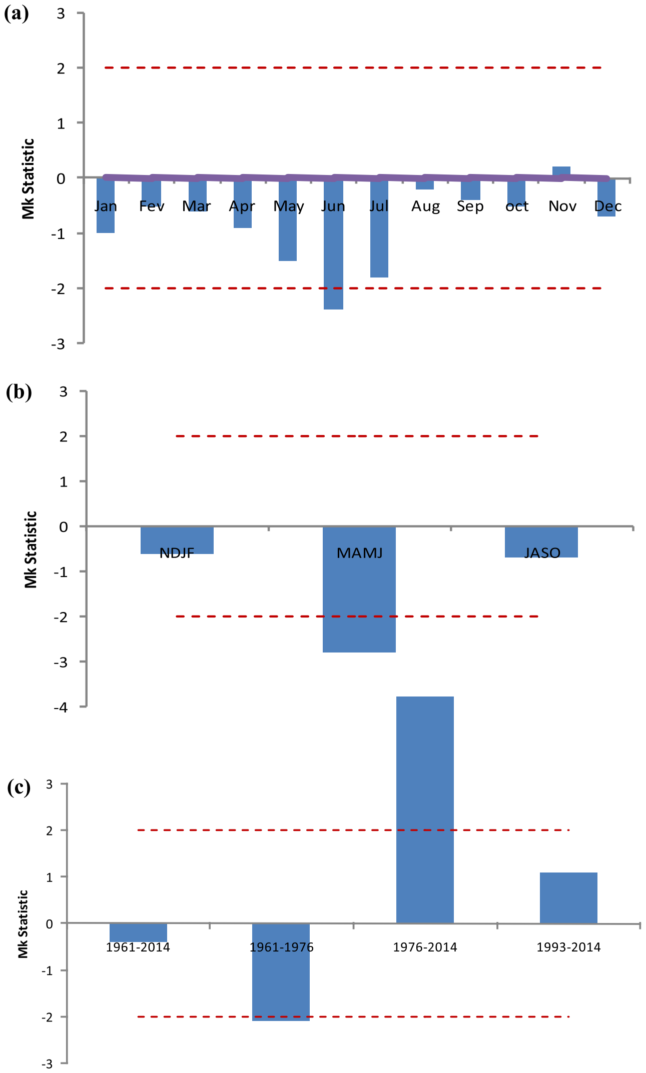

Figure 8. (a) Trend tests for the monthly streamflow time series with the 95% confidence intervals in red dotted lines. (b) Trend tests for the seasonal streamflow time series with the 95% confidence intervals in red dotted lines. (c) Trend tests for the annual streamflow time series with the 95% confidence intervals in red dotted lines.

Table 1. Change point date accordantly to time series scale.

Time scale	Date	*P* value
Monthly		
January	1977*	0.001431
February	1977*	0.002181
March	1972*	0.002181
April	1972*	0.002556
May	1974*	0.0024
June	1989*	0.004458
July	1976	0.051
August	1975	0.08983
September	1976*	0.00488
October	1970*	0.03158
November	1970	0.05365
December	1976*	0.002325
Seasonal		
JASO	1976*	0.005187
NDJF	1972*	0.00586
MAMJ	1983*	0.001475
Annual		
	1976*	0.004736

*Significant change point at alpha = 5%

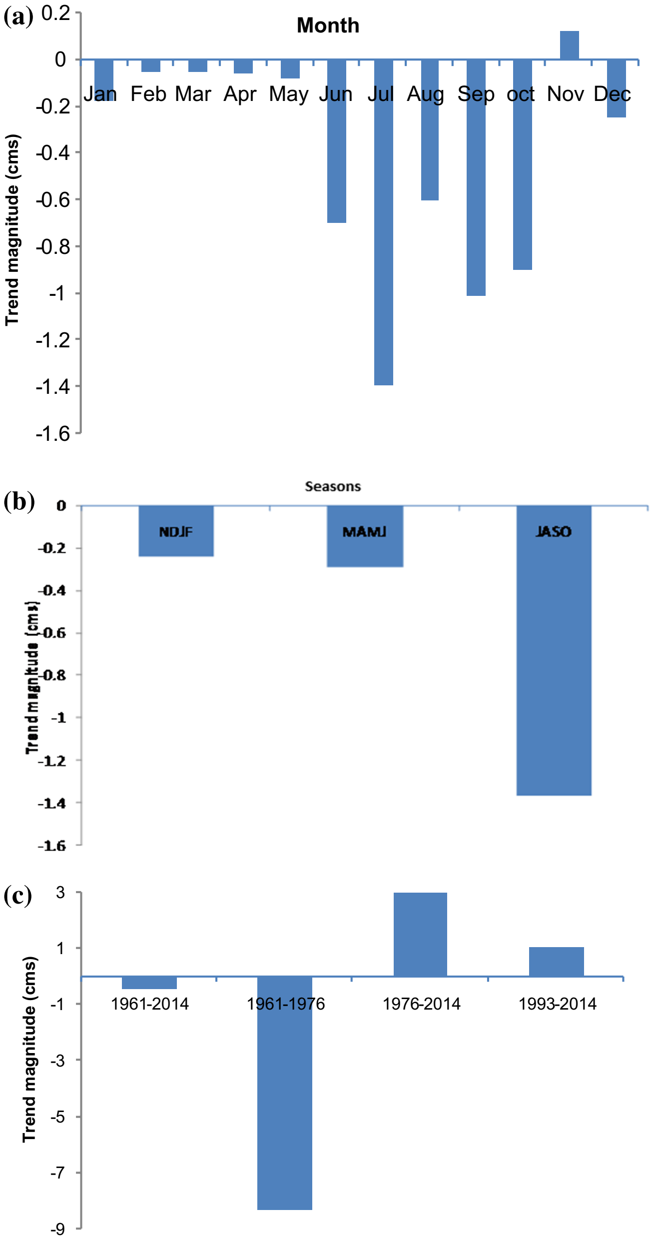

Figure 9. (a) Trend magnitude for monthly streamflow time series. (b) Trend magnitude for Seasonal streamflow time series. (c) Trend magnitude for the annual streamflow time series.

confirmed by several studies in West Africa. In most recently, a research accomplished and pointed out that most of the rivers in West Africa show a decreasing trend of streamflow since 1970 (Roudier et al. 2014). Like the annual monthly scale, the seasonal series show decreasing trend. Taking individually the season, the seasonal series indicated a significant decreasing trend in the MAMJ season while the two other seasons (NDJF and JASO) presented a non-significant decreasing trend (Figure 8(b)).

The trend analysis of the annual streamflow indicates decreasing trends (Figure 9(c)). These decreasing trends are found to be not statistically significant. Further analysis after breaking points show different patterns. Before the first breaking point (1961–1976), the decreasing trend is statistically significant ($Z = -2.1$). After the first breaking point, it can be seen a significant increasing trend ($Z = 3.1$). Further analysis showed another change point at 1993. However, the period after this year shows a non-significant increasing trend.

3.5. Estimation of magnitude of trend slope

The Sen's slopes for monthly, seasonally, and annually streamflows are shown in Figure 9. At the monthly scales, all months exhibited a decreasing trend except for the month of November which demonstrated a trend magnitude of 0.12 m^3/s. Monthly trend magnitudes vary from -1.4 m^3/s to 0.12 m^3/s. The month of July expressed the highest decreasing trend (-1.4 m^3/s) while the months of February, March, and May exhibited the lowest decreasing with values of -0.05; -0.05, and -0.06 m^3/s, respectively.

For the seasonal scale, it can be shown clearly that the JASO season presents the highest decreasing trend (-1.37 m^3/s) while the NDJF shows the lowest decreasing trend. This result confirms those of monthly scale with the highest decreasing trend observed from July to October.

Figure 9(c) showed the trend magnitude for different annual series (before and after breaking points). In general, the magnitude trend revealed values of -0.43, -8.32, 2.99, and 1.03 m^3/s for 1961–2014; 1961–1976, 1976–2014, and 1993–2014, respectively. This result points out that the trend is more pronounced during the period before the first change point (1961–1976).

3.6. Relative change analysis

Figure 10 displayed the relative change (RC) of streamflow at monthly scale. RC is varying from −67% (June) to 4% (November). The highest negative relative changes have been notice for the months of April, May, and June. These months present the lowest average streamflow, particularly for April and May with a value of 6.8 and 6.9 m^3/s, respectively. The months presenting the highest average streamflow exhibit the lowest relative change, August (−4%) and September (−6%). Only the month of November presents a positive relative change but very small (3%). In addition, results showed that lower streamflow tend to present extreme high negative relative change. Therefore, it is expected in the future that low streamflow will experience more decreasing trend if the decreasing persists.

Another angle to look the results is that any small increase or decrease of low values can lead to high value of relative change which could explain the high negative relative change noticed for the month of low streamflow. The seasonal time series (Figure 10(b)) present the same trend. In this case, relative changes are −12, −13, and −76% for JASO, NDJF, and MAMJ seasons showing clearly the higher negative relative change for the months just before wetting periods.

The relative change for the annual streamflow showed for the entire series (1961–2014) a value of (−9%) compared to the value just before the first change point which exhibits a high negative relative change (−43%). For the period 1976–2014, result shows high positive relative change (52%) compared to the period 1993–2014 (8%).

3.7. Extreme high and low streamflow analysis

Daily average streamflow data were ranked and divided into 10 equal series (S1, S2…,S10). In other word, we have defined 9 thresholds (Q0.1, Q0.2…, Q0.9), In this study, we have chosen an exceedance of probability of 10% and 90% as the threshold of the extreme low and high flow, respectively. Thus, the extreme low flow is defined as flow lesser than Q0.1 (S1) and the extreme higher flow as flow greater than Q0.9 (S10). In

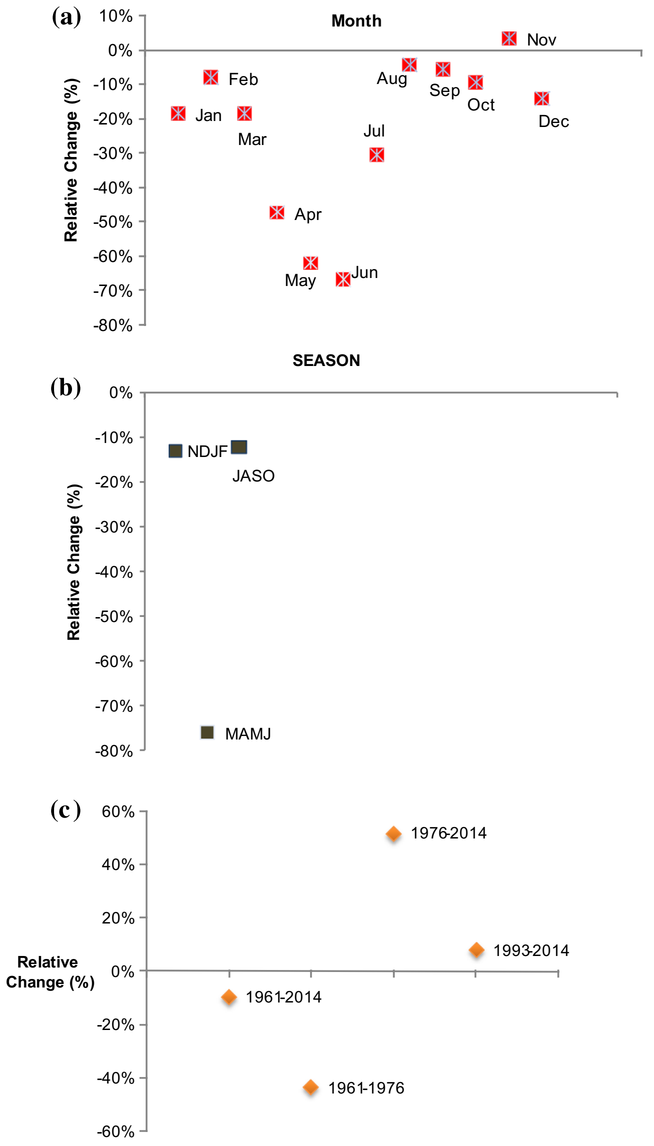

Figure 10. Results for relative changes obtained using (a) monthly, (b) seasonally and (c) annually mean streamflows.

Table 2. Results of the trend tests for extreme high and low streamflow time series.

	Extreme low flow	Extreme high flow
Mean	1.78 m^3/s	1100 m^3/s
MK	13.5	−11
Relative change	1%	−18%

these two series, we have applied the Man Kendall test to investigate the trend of those series. Results show that extreme low flows exhibit a statistically significant increase trend with a relative change of 1% and extreme high flow a statically decreasing trend with a relative change of −18% (Table 2). Extreme high and low flow change points occurring in 1971 and 1996, respectively (Figure 11).

This result points out that extreme high flows have experienced a substantially decreasing trend compared to the extreme low flow which shows a little increase trend. The change point for the high flow occurred just before the change point for the mean annual streamflow and the main monthly mean streamflow while the change point for extreme low flow intervenes just after the second change point of the annual streamflow.

The results of this study indicated that streamflows at different scale (monthly, seasonal, annually) tend to decrease if we take the long terms time series (1961–2014). The decreasing trend is not statistically significant for most of the series except for the MAMJ seasons and the month of June. Considering the annually season, the period before the first change point indicated a highly statistically decrease trend. The change point depends on the scale using when studying trend; therefore, one has to be careful when analyzing times series. In the upper Senegal River basin, JASO is the most important season, because it provides most of the rainfall which coincide also with the highest streamflow. The decreasing of the streamflow during this period will inevitably impact the Manantali Dam energy production which is mainly feed by water coming from the upper Senegal river basin. The decreased streamflow will enhance future risk and vulnerability especially during the MAMJ season which is characterized by low flow; the production of hydropower is directly affected by the availability of streamflow. The variability of seasonal streamflow and decreasing trend observed may indicate that alternative strategies management may be enhanced mainly during the low flow seasons which is the most critical period for water management. The growth of population coupled to the new strategies to developed irrigated agriculture in the Senegal river basin will exacerbate the difficulties to manage water. Thus, supplementary effort is essential to be made in order to better manage the available water. One of the solutions could be the Integrated Water Resource Management (IWRM) at the appropriate level (from sub basin level to basin level). Even though, framework and legal texts do exist, the management of water resource has to be more comprehensive and effective.

Another important point is the design of hydraulic infrastructures. Most of the time, engineers do not integrate possible

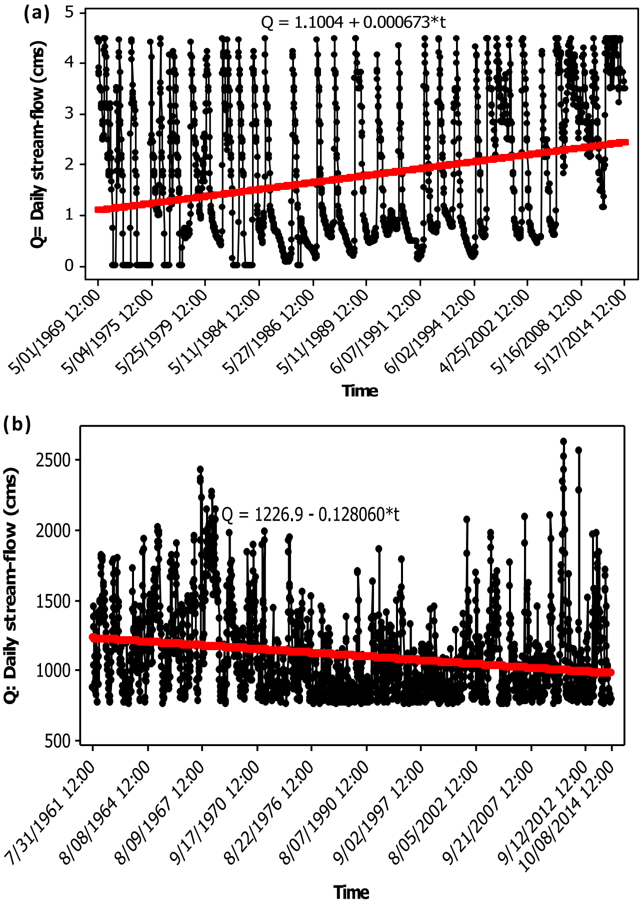

Figure 11. Time series daily streamflow and trend (red line): (a) extreme low flow and (b) extreme high flow.

trends and randomness of data in their studies . However, 'stationary is dead' as stated by (Milly and Julio 2008). Therefore, in the context of climate and anthropogenic change, we need to incorporate the non-stationary in hydrological analysis (Condon et al. 2014).

4. Conclusion

In this research, the trend analysis of different scales of streamflow namely monthly, seasonally and annually were identified. Daily streamflows for the upper Senegal River at Bafing Makana station over 54 years' time period (1961–2014) were used for this analysis. The main motivation of detecting the streamflow time series characteristics is owing to its significant for several objectives in term of hydrology and hydraulic engineering. At first, an auto correlation detection was inspected over all the time scales. On the other hand, the modeling was conducted using Mann-Kendall test for the non-correlated structural time series. Theil and Sen's slope estimator test was applied to find the magnitude of changing point and Pettitt test was applied for detecting the most probable change year. Based on the obtained results, the peak event of streamflow mainly occurred in September. The Mann-Kendall trend test showed a noticeable decrease in the annual streamflow trend. However, by integrating the different change years, there was a remarkable decrease trend between the first breaking point at 1976 and the second change point at 1993. The seasonal pattern of streamflow exhibited a significant decreasing trend and particularly in MAMJ season.

Disclosure statement

The authors of the current research declare that there is no conflict of interest in publishing this research.

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