climate

MDPI

Article

Trend Analysis for Extreme Rainfall at Sub-Daily and Daily Timescales in Côte d'Ivoire

Gneneyougo Emile Soro [1,*], Dabissi Noufé [1], Tié Albert Goula Bi [1] and Bernard Shorohou [2]

[1] Unit Training and Research in Science and Environment Management, University Nangui Abrogoua, 02 BP 801 Abidjan 02, Côte d'Ivoire; goulaba2002@yahoo.fr (D.N.); dnoufe@hotmail.com (T.A.G.B.)
[2] Department of National Meteorology (SODEXAM), 15 BP 950 Abidjan 15, Côte d'Ivoire; srohoroub@yahoo.fr
* Correspondence: ge_soro@yahoo.fr; Tel.: +225-07371070

Academic Editor: Christina Anagnostopoulou
Received: 28 April 2016; Accepted: 26 July 2016; Published: 5 August 2016

Abstract: Extreme rainfall events are meteorological hazards that cause great damage and many casualties in the world. This paper examines the trends in extreme rainfall from 10 sub-daily time series and 44 daily time series in Côte d'Ivoire. Rainfall data were converted into indices. In total, six (6) indices were used for daily extreme rainfall and one (1) index for sub-daily extreme rainfall (15 to 240 min). Two statistical tests for trend detection were used to evaluate the possible trend in these precipitation data. The first is a Mann-Kendall non-parametric trend test, used to evaluate the existence of monotonic trends. The second is a linear regression method, based on a parametric approach to trend detection. Results show that very few statistically significant decreasing trends can be detected at the sub-daily and daily timescales. Some decreasing trends in extreme rainfall events were localized in the south and southeast. These results could enhance the implementation of adaptation systems to flood risk.

Keywords: climate change; Côte d'Ivoire; extreme rainfall; trend

1. Introduction

The changes in extreme events, such as heavy precipitation and associated floods, heat waves, and hurricanes (or typhoons), have attracted a lot of attention because of their devastating consequences on society and economics [1]. The extreme events are grouped into two broad categories [2]: (i) yearly extreme events based on simple statistics such as very low or very high daily temperature and heavy daily rainfall; and (ii) more complex event-driven extremes characterized by severe drought, flood, or hurricanes. Extreme rainfall is one of the most frequent weather hazards responsible for damage to buildings and infrastructures, serious social disruption, and loss of human life worldwide each year. Changes in extreme rainfall have attracted much attention in recent years. Indeed, the Intergovernmental Panel on Climate Change (IPCC) in its first Assessment Report of the century presented a global picture of trends in precipitation during different periods [3]. Since then, the research on climate extremes has considerably progressed over the last few decades across the globe. Significant increases in extreme precipitation have been observed in western China, in the mid-lower reaches of the Yangtze River, and in parts of the southwest and south China coastal area [4], in India [5], in United States except for more easterly locations, particularly in South Carolina [6], in Bulgaria [7], in Germany [8], in France [9], in Brazil [10], and in south-western Montenegro [11]. In contrast, some regions show decreasing trends in extreme rainfall events especially in Kerala in India [12], in Poland [13], in South Asia and parts of the Central Pacific [14], in the north and east New Zealand [15], and in an ecological reserve in Federal District of Brazil [16]. Other parts of the world show no significant trend in extreme rainfall events: Portugal [17], Netherlands [18], Brazil [19]. In Africa, a number of studies on extreme precipitation revealed some significant increases in high daily precipitation amounts and average rainfall intensity [20]. In sub-Saharan Africa, some studies indicate an increase in extreme rainfall events, particularly in Nigeria [21], in Western Niger [22] or a decrease in Nigeria [23], Guinea Conakry [24], or in Eastern Niger [25].

This was mainly due to international coordinated efforts to collect, control the quality, and analyze data and events that represent the more extreme aspects of the changing climate [26]. It should be noted that most scientists agree that climate and weather extremes are likely to increase vulnerability and cause catastrophic disruptions to both human society and natural system. Nevertheless, few works have been devoted to the detection of trends in extreme rainfall in Africa, particularly in sub-Saharan Africa. This is due to several reasons including the scarcity and poor quality of daily observational data in this region of the globe and also because several countries have restrictive policies on data sharing [26]. Despite these shortcomings in data availability and access, understanding the extreme rainfall pattern is crucial for water management in the warming climate. Indeed, trend analysis in rainfall time series are crucial for mobilizing and planning water resources.

This analysis can help resilience building and adaptation planning to floods. This study seeks to provide more insight on the evolution of extreme rainfall at sub-hourly, sub-daily, and daily timescales in Côte d'Ivoire.

2. Materials and Methods

2.1. Study Area

Côte d'Ivoire lies between latitudes 4°20′ N and 10°50′ N and longitudes 2°30′ W and 8°40′ W on the south central coast of West Africa. It is bordered to the south by the Atlantic Ocean. The land area is approximately 322.642 km^2. In this country, the mountainous areas lie west and northwest. Two main types of ecosystems share the territory: the forest to the south and west and savannah in the center and north. The average of annual temperatures range from 21 °C to 32 °C; with temperatures varying with distance from sea, elevation, and season. Côte d'Ivoire is characterized by humid equatorial climate and dry sub-tropical climate (Figure 1). Two rainy seasons are predominant to the South of latitude 8°45′, from April to July and September to October. In the north, there is one rainy season, from April to October. The amount of rainfall is higher in the south and the mountainous areas. The wettest area (Tabou in South-West) has an average annual rainfall amount of 2000 mm. In the north annual rainfall is less than 1000 mm.

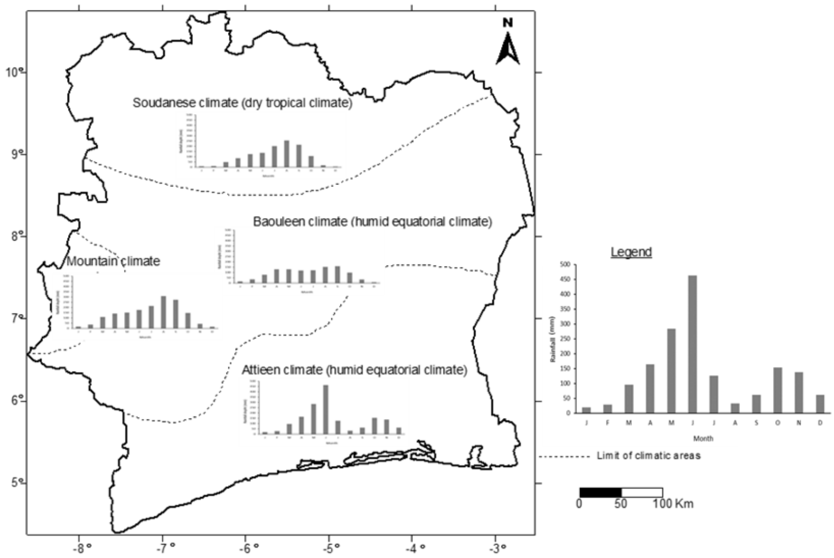

Figure 1. Principal climatic areas in Côte d'Ivoire with the monthly hyetograph observed in 2000.

2.2. Datasets

The locations of the rain gauge stations and the length of series used in trend analysis are given in Figure 2. The density of the network is particularly low in the eastern belt and north-western region of Côte d'Ivoire. The observation periods of rain gauge stations used in this study are presented in Figures 3 and 4. The observed sub-daily and daily precipitation data from 10 and 44 rain gauge stations of Côte d'Ivoire, respectively, with time series ranging from 1 January 1942 to 31 December 2002 were obtained from the National Meteorological Office of Côte d'Ivoire. To avoid biases in the trend analysis due to the missing data, we restricted our analysis to the period from 1942 to 2001.

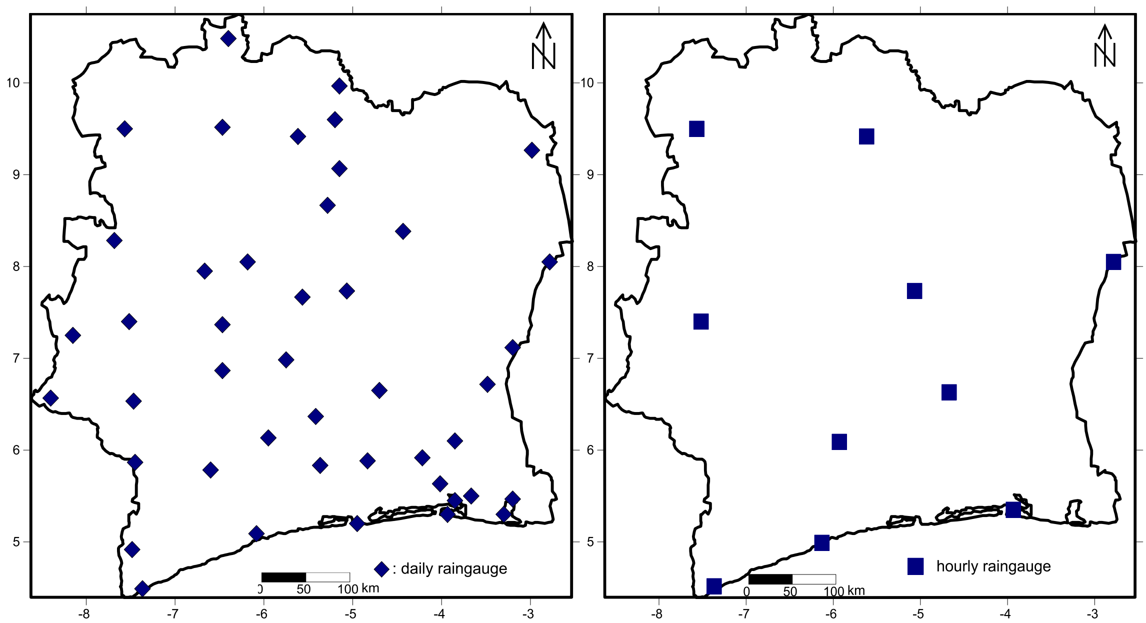

Figure 2. Network of rain gauge stations used in this study.

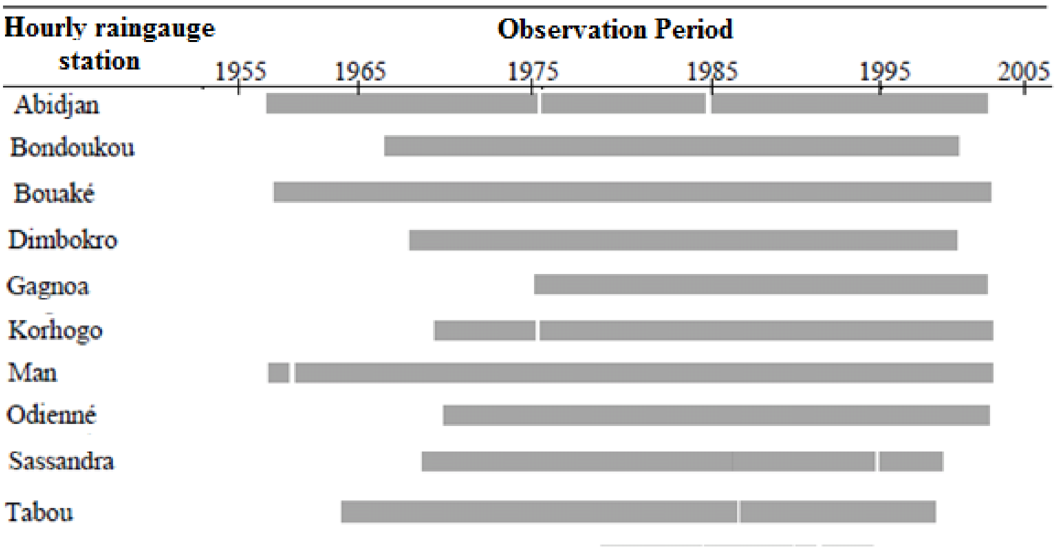

Figure 3. The observation periods of hourly rain gauge stations.

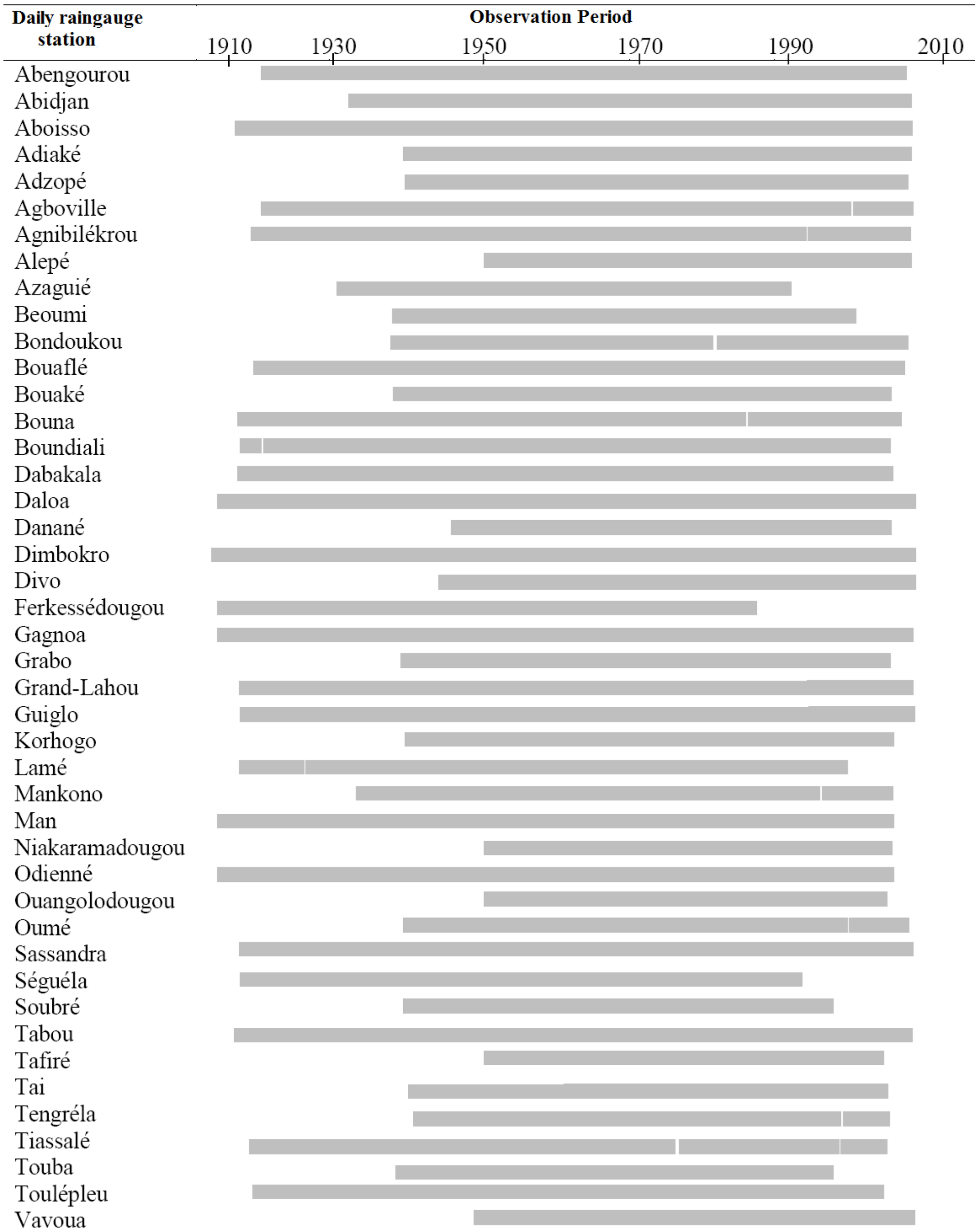

Figure 4. The observation periods of daily rain gauge stations.

2.3. *Indices of Climate Extremes*

The definition of what constitutes an extreme event has been widely discussed [27]. Fundamentally, an extreme event can be selected based on frequency, intensity, or a threshold of exceedance and physical expected impacts [28]. This choice depends on the intended use in term of design or future planning. Several indicators such as the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI) have been established and used in undertaking several regional analyses for understanding climate extremes and trends [29]. We explained which kind of index we adopted in this study. For the analysis of the annual cycle of precipitation, the CWD10, CWD20, R1 day (annual), R10 mm and R20 mm indices were calculated for each year. For the analysis of the monthly cycle of precipitation, the R1 day (monthly) index is calculated for each month. In addition to yearly and seasonal maxima, one index of extreme rainfall to the sub-daily scale was used. This index, the R1 day (hourly) is calculated for durations of three sub-hourly durations (15 min, 30 min, 45 min) and four sub-daily durations (1 h, 2 h, 3 h, and 4 h). Summary of selected indices with specific definitions are provided in Table 1.

Table 1. List of the extreme precipitation indices used in this study.

Indicator	Indicator Name	Indicator Definitions	Units	Number of Stations	Scale
CWD10	Consecutive wet days	Maximum number of consecutive days when precipitation ⩾ 10 mm	days	44	annual
CWD20	Consecutive wet days	Maximum number of consecutive days when precipitation ⩾ 10 mm	days	44	
R1 day max (annual)	Maximum one-day precipitation	Highest precipitation amount in one-day period	mm	44	
R10 mm	Number of heavy precipitation days	Annual count when precipitation ⩾ 10 mm	days	44	
R20 mm	Number of very heavy precipitation days	Annual count when precipitation ⩾ 20 mm	days	44	
R1 day max (monthly)	Max 1 day precipitation amount	Monthly maximum 1 day precipitation	mm	44	monthly
R1 max (hourly)	Max 1 day precipitation amount	Hourly maximum 1 day precipitation	mm	10	sub-hourly and sub-daily

2.4. Mann-Kendall Test and Linear Regression Method

The data analysis was done using two statistical tests: (1) The Mann-Kendall (MK) test is a non-parametric approach originally used by [30]. Subsequently the test statistic distribution was implemented by [31]. Mann-Kendall test is a statistical test widely used for the analysis of climatological trends [32]. There are two advantages of using this test. First, it is distribution-free and does not assume any special form for the distribution function of the data, including censored and missing data [33]. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series [34]. According to this test, the null hypothesis H_0 assumes that there is no trend (the data are independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend [35]; (2) Linear Regression (RL) method is a parametric approach used to test for linear temporal trends [36]. This test verified the hypothesis of stationarity against a linear trend. The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship [37]. A linear trend is reported when the slope of the regression line is demonstrated to be statistically different from zero (using a *t*-test); a positive slope indicates an increasing trend and a negative slope a decreasing trend [38].

3. Results

3.1. Trends in Daily Extremes Rainfalls

3.1.1. Consecutive Wet Days (Annual Scale)

Figures 5 and 6 provides the spatial distribution of the trends highlighted for CWD10 and CWD20 indices, respectively. Overall, a small number of trends were detected for these indices. For CWD10 index, the Mann-Kendall test showed 47% decreasing trends against 27% for the Linear Regression method. For CWD20 index, both methods detected 27% of gradual changes in extreme rainfall events. There are no increasing trends for the extreme rainfalls. The southwest region of high rainfall area shows no significant trends. The rain gauge stations in the southeast region exhibit some decreasing trends in consecutive wet days. If the significance level is 99%, 95%, or 90% (tantamount to 1%, 5%, or 10% in another convention), there is a high chance that a change exists (decrease or increase) in the rainfall time series subject to analysis. This explanation is valid for all the graphs (5 to 13).

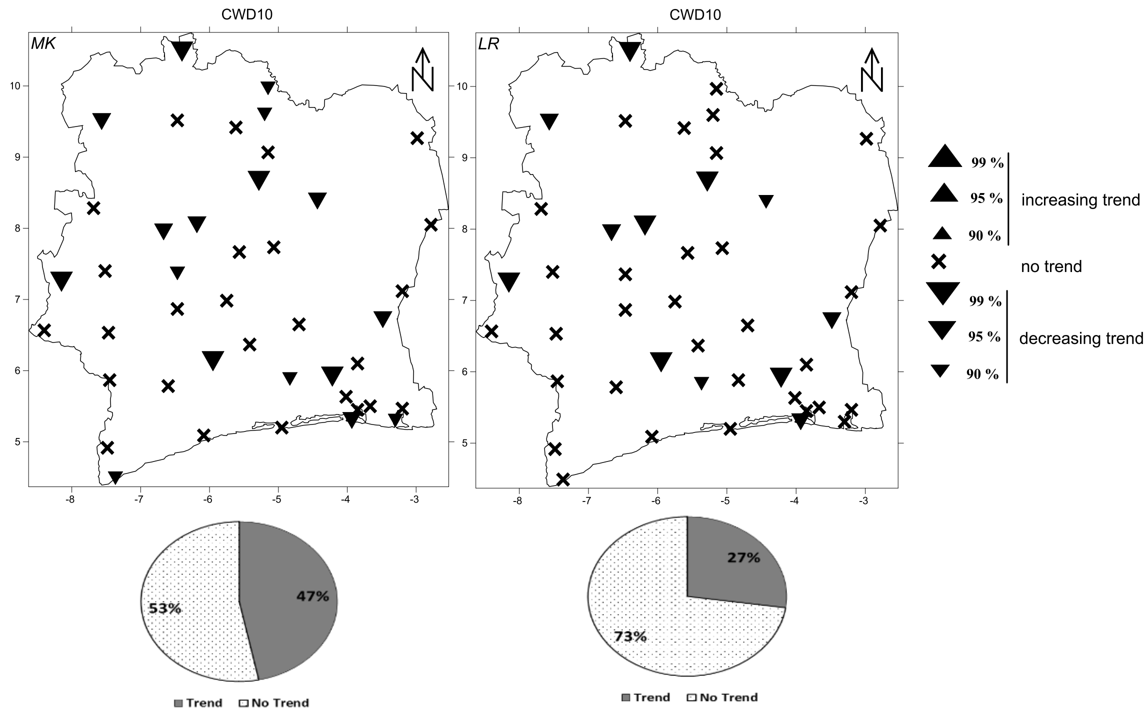

Figure 5. Spatial distribution of trends from CWD10 indices.

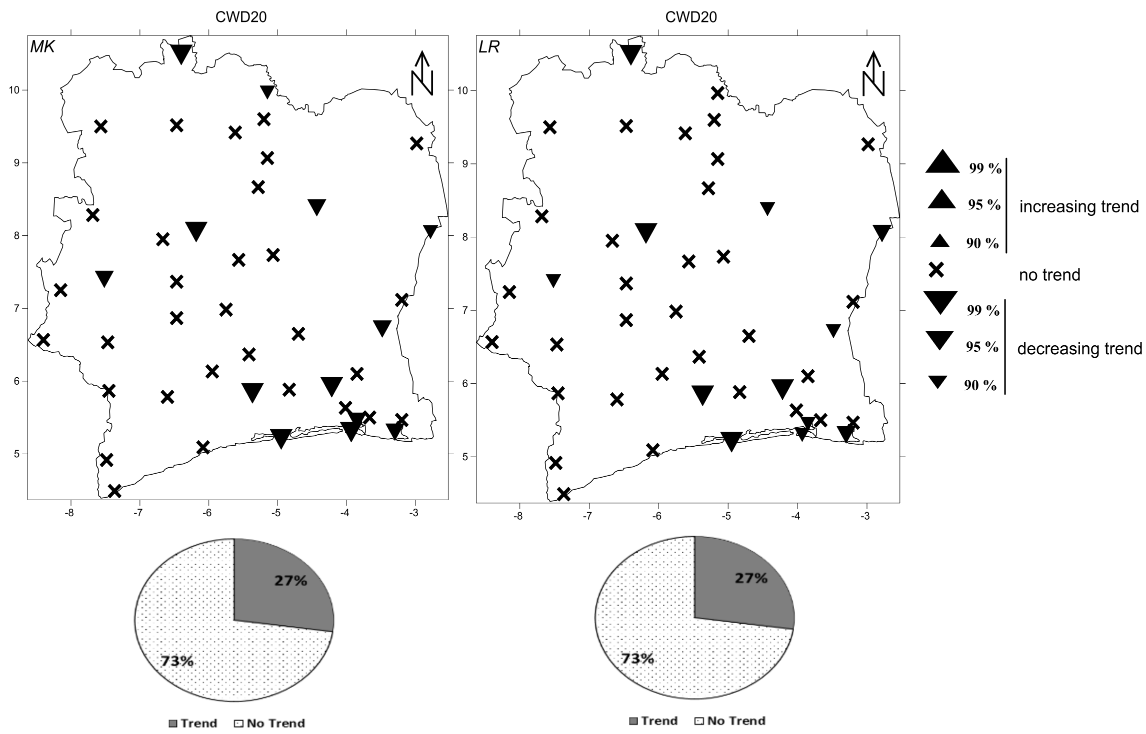

Figure 6. Spatial distribution of trends from CWD20 indices.

3.1.2. Number of Heavy Precipitation Days (Annual Scale)

Figures 7 and 8 displays the spatial distribution of trends for R10 mm and R20 mm indices, respectively. It is noteworthy that several stations across Côte d'Ivoire show a decreasing trend in number of heavy precipitation days. For the R10mm, the results from linear regression method indicate that 61% stations shows significant negative trend against 27 % for the Mann-Kendall test. For this index, the number of heavy precipitation days is decreasing significantly in south and south-east areas. The central region was also affected. The decrease in the number of heavy precipitation days is even more noticeable for R20 mm. The south and south-west areas are most affected by decreasing trend.

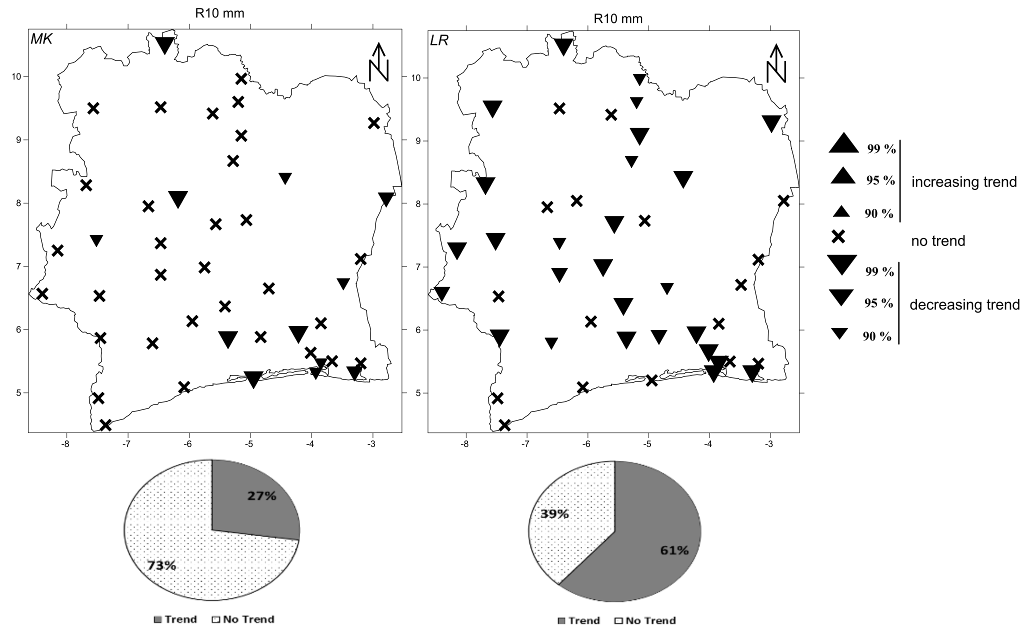

Figure 7. Spatial distribution of trends from R10 mm indices.

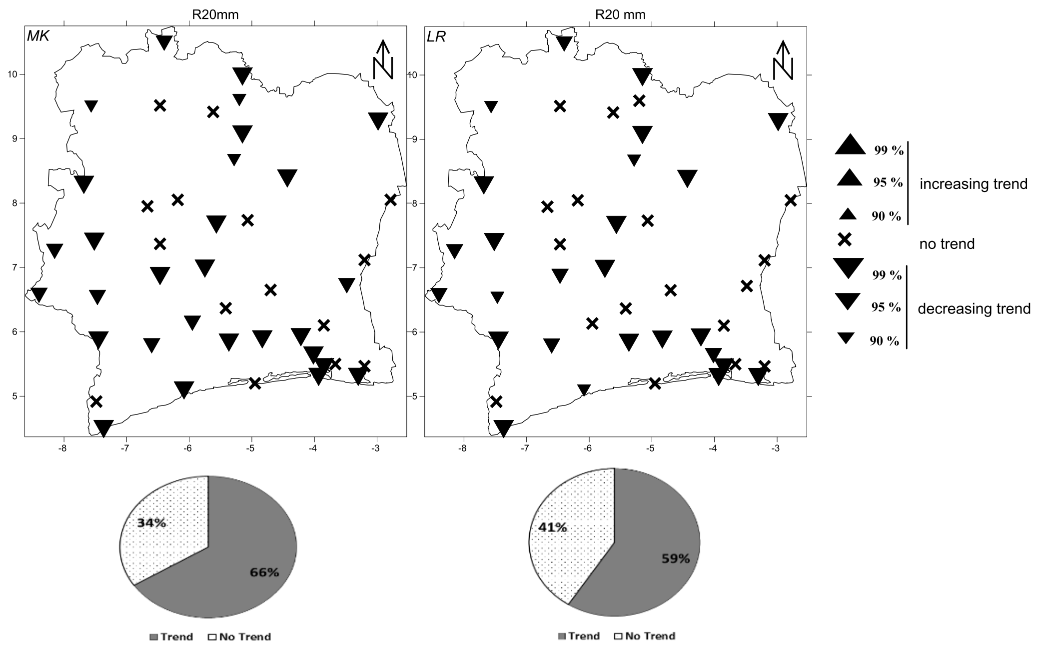

Figure 8. Spatial distribution of trends from R20 mm indices.

3.1.3. Maximum One-Day Precipitation (Annual Scale)

For R1 day max, few stations experienced decreasing trend (Figure 9). The Mann-Kendall test has detected 25% of decreasing trends against 27% for linear regression method in the maximum one-day precipitation. There is no increasing trend. Moreover, a concentration of trends is observed in the southeast coastal area.

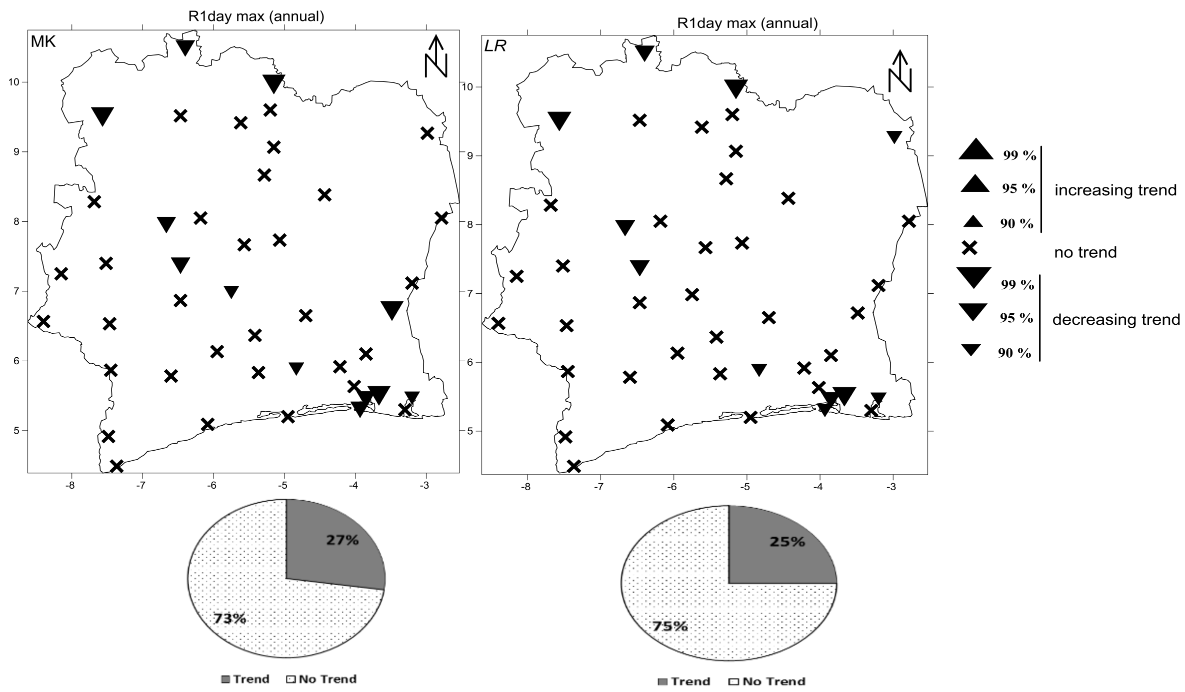

Figure 9. Spatial distribution of trends at annual scale from R1 day max indices.

3.1.4. Maximum One-Day Precipitation (Monthly Scale)

The spatial distributions of trends in different seasons across of Côte d'Ivoire are shown in Figures 10 and 11. For seasonal precipitation extremes, few stations showed a trend, especially during the monsoon season (May to July). For this period, the percentage of change observed lies between 7% and 20%. Trends detected by the Mann-Kendall test and Linear Regression method are substantially the similar. In addition, the spatial distributions of changes observed were not a homogeneous.

3.2. Trends in Sub-Hourly and Sub-Daily Extreme Rainfall

Maximum One-Day Precipitation (Sub-Hourly and Sub-Daily Scale)

The spatial trends in short-duration (15 to 240 min) extreme rainfall over the entire country are shown in Figures 12 and 13. The significance levels as explained by legends in Figures 10 and 11 still apply in Figures 12 and 13. The results show a significant decreasing in short-duration extreme rainfall. It appears that the trends are much more significant as the duration of sub-daily rainfall increases. For the shortest durations of 15–120 min, few decreasing trends have been observed by the tests applied. The percentages of change observed is between 20% and 50%. The spatial distributions of observed trends were not homogeneous. For the durations of 150–240 min, the decrease is strongly perceptible in sub-daily extreme rainfall.

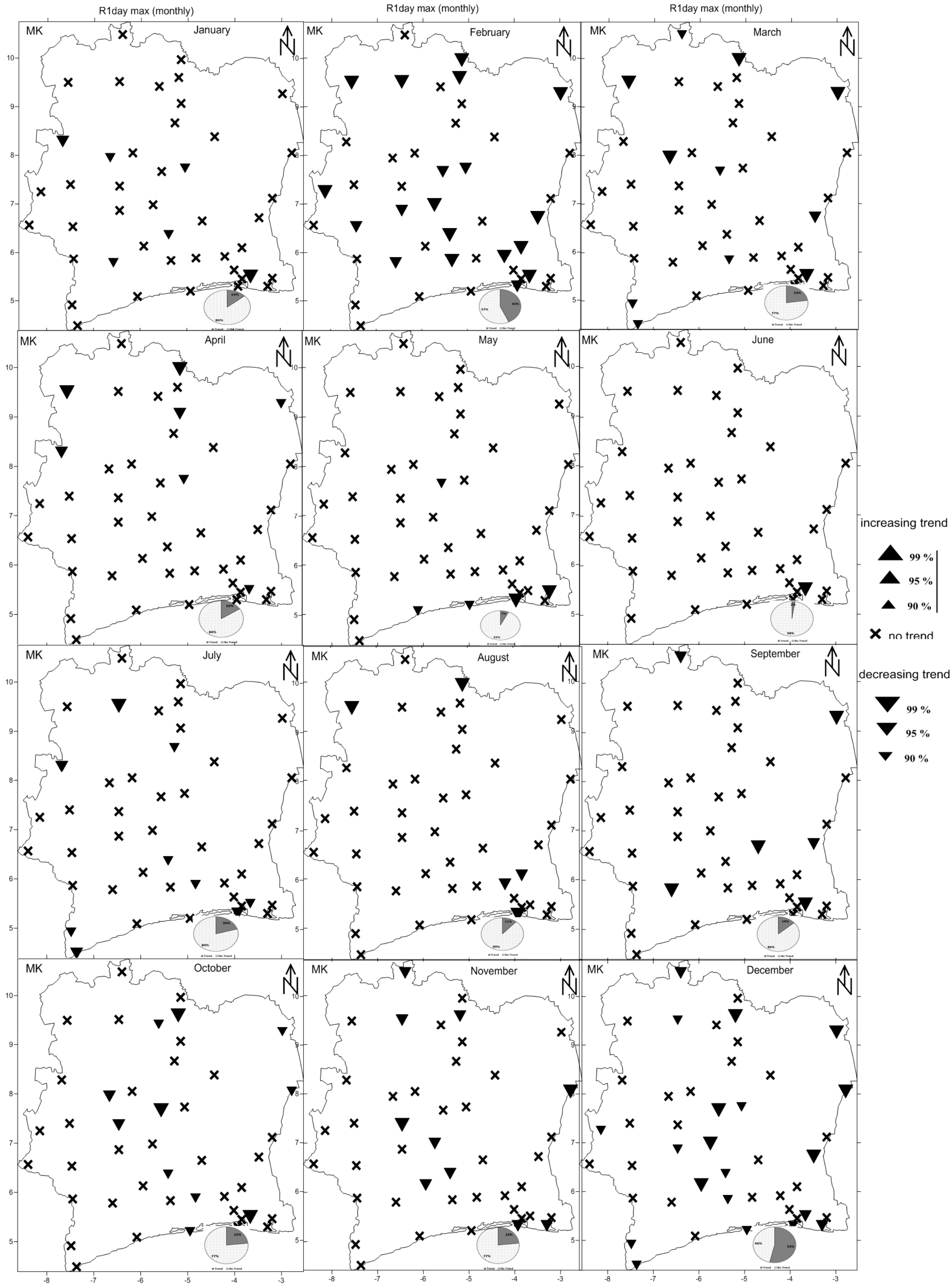

Figure 10. Spatial distribution of trends detected by Mann-Kendall test at monthly scale from R1 day max indices.

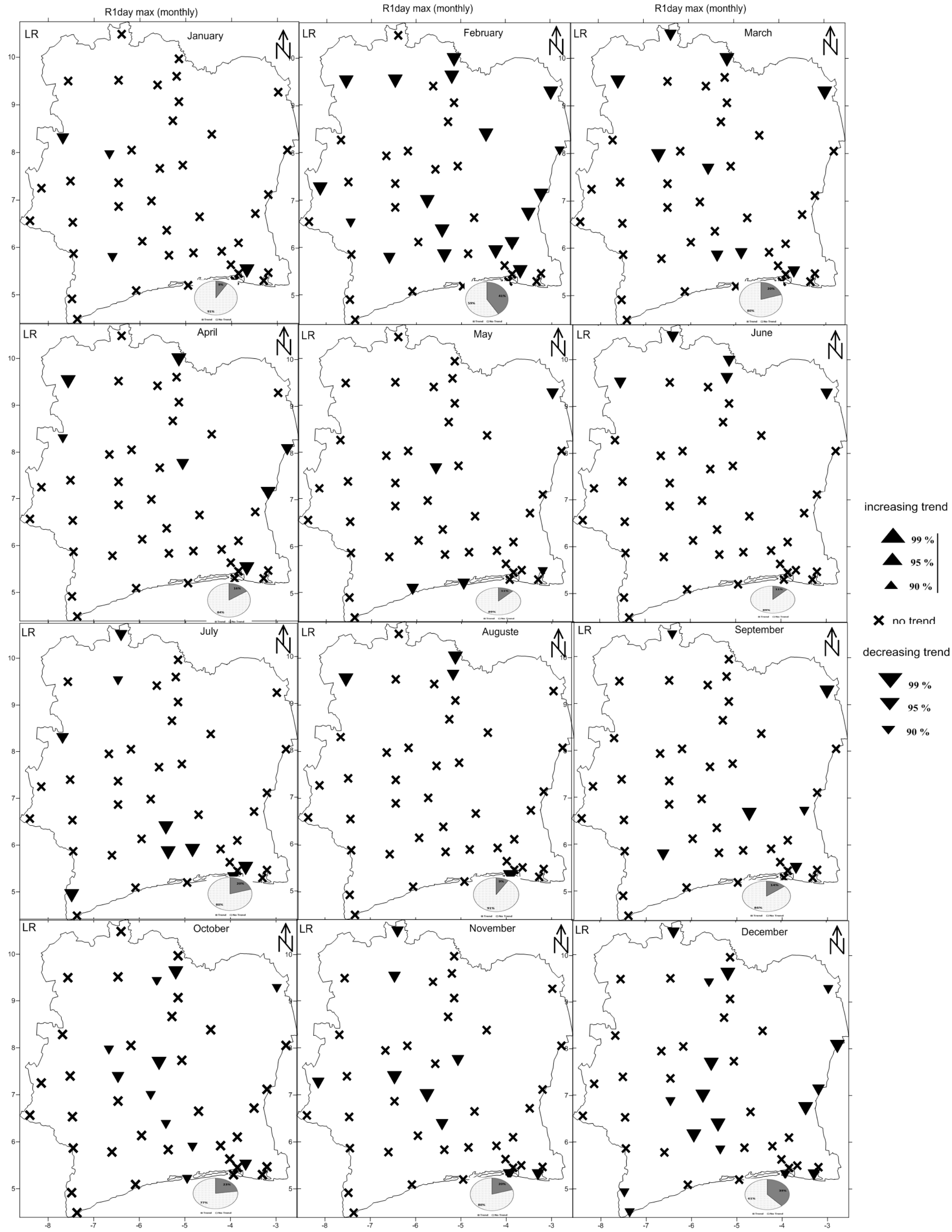

Figure 11. Spatial distribution of trends detected by linear regression method from R1 day max indices at monthly scale.

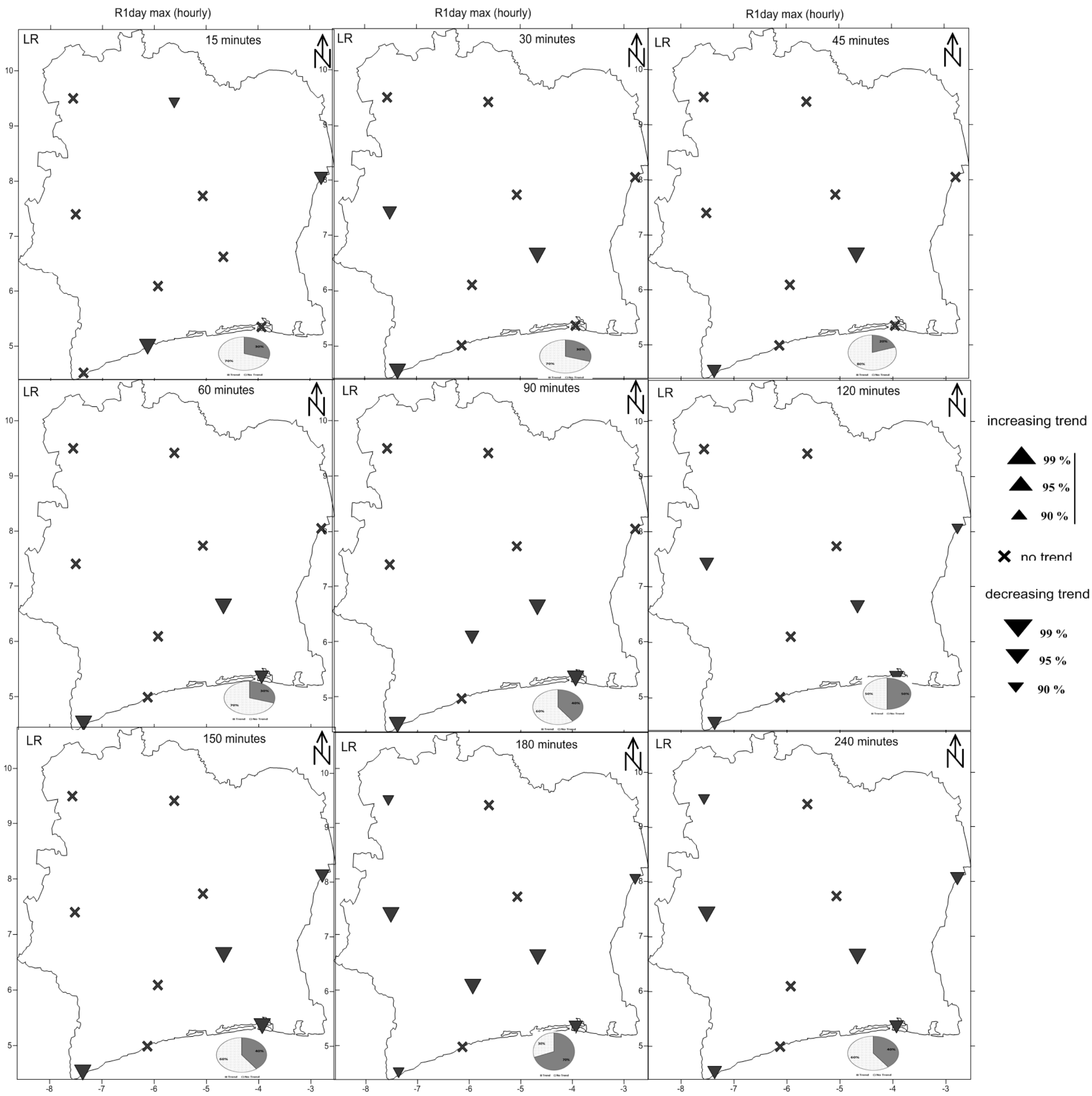

Figure 12. Spatial distribution of trends detected by linear regression method from R1 day max (sub-hourly and sub-daily) indices.

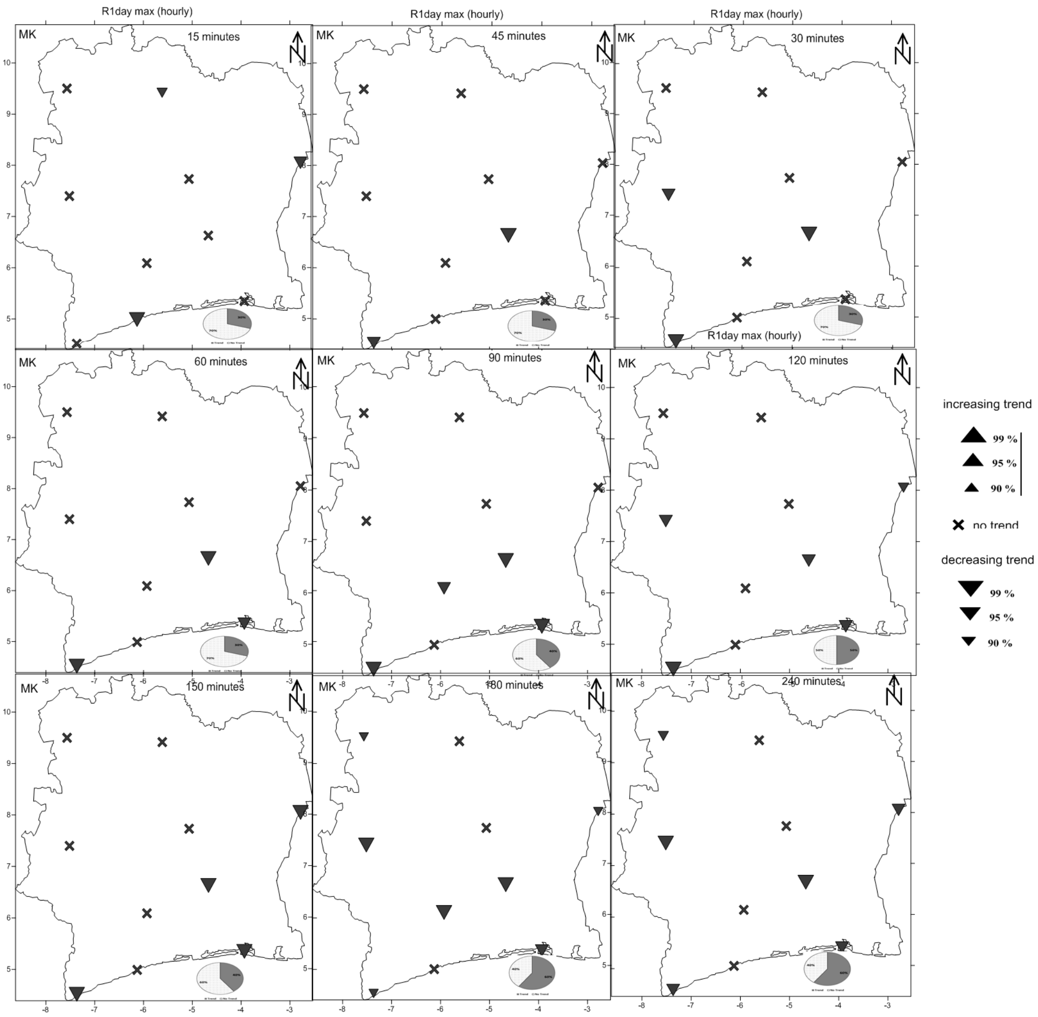

Figure 13. Spatial distribution of trends detected by Mann-Kendall test from R1 day max (sub-hourly and sub-daily) indices.

4. Discussion

The lack of long-term climate data suitable for analysis of extremes is the biggest obstacle to quantifying whether extreme events have changed over the last decades in Africa [39]. Côte d'Ivoire, like many other West African countries, is facing the same difficulty. However, we tried to present an analysis of extreme precipitation in Côte d'Ivoire. Overall, our analyses at various timescales showed that extreme rainfall is declining. This same observation was highlighted in West African Sahel region by [40]. Their study also showed that observed trends in rainfalls are not homogeneous. The difficulty in detecting changes in extreme rainfall appears to be related to high inter-annual natural variability. This has been highlighted by [24] in Guinea Conakry. The absence of significant trends in extreme rainfall could be linked to the fact that statistical identification of the effects of anthropogenic global warming are not yet well explored [41]. These few trends detected in sub-daily and daily extreme rainfall events are consistent with the regional trend in annual rainfall in West Africa since 1970 up to the beginning of the century. The findings are also in accordance with the work carried out in Nigeria by [42], which indicates that the decrease in heavy rainfall events is coincident with a decrease in annual totals. In addition, a recent special IPCC report states that West Africa will likely experience longer and more intense droughts in the near future [43].

The analysis also shows that there is no significant positive trend on any station presented despite an intensification of global water circulation due to global warming. The increase in the atmospheric moisture content would be expected to lead to an increase in extreme precipitation when other factors do not change [43]. The changes in precipitation extremes with temperature also depend on changes in the moist-adiabatic temperature lapse rate, in the upward velocity, and in the temperature when precipitation extremes occur [44]. This may explain why there have not been increases in precipitation extremes everywhere in world, although a low signal-to-noise ratio may also play a role. Several factors such as the complexity of the West African climate system are at the origins of this detected decrease in rainfall extremes. Thus, three intertwined factors have been pointed out as responsible for this decrease in rainfall: the changes in the monsoon, warm anomalies in sea surface temperature (SST) in the tropical Atlantic Ocean, and deforestation in West Africa. Indeed, there is a relationship between warm SST anomalies and negative precipitation anomalies in West Africa [45]. These authors observed that the monsoon reduction causes a decrease in rainfall. Moreover, surface processes certainly have an important role. In addition, the West African region is one of the areas where the coupling between the surface and the atmosphere is strongest [46]. Deforestation could decrease the rainfall in relation to the easterly waves [47]. According to [48], past modeling studies have collectively documented that the climate system in West Africa is highly sensitive to both anthropogenic land cover changes and natural vegetation dynamics, in the past, present, and future. In Côte d'Ivoire, the co-evolution of rainfall and forest area was demonstrated by [49]. These factors appeared to contribute to the rainfall decrease in the 1970s. Moreover, in this study, the Mann-Kendall test and linear regression have different results. The Mann-Kendall test detected more significant trends than the linear regression. The difference may be related to several factors such as skewness of extreme rainfall series. In general, parametric tests are more powerful when the variable is normally distributed, but much less powerful when it is not, compared with the non-parametric tests [50]. The strengths of the Mann-Kendall are usually associated with its simple concept and with the fact that as a nonparametric procedure that does not assume a specific joint distribution of the data, it is minimally affected by departures from normality [51].

5. Conclusions

This paper examined the trends of sub-daily and daily extreme rainfall events across in Côte d'Ivoire. Two tests (Mann-Kendall and Linear Regression) were applied to detect trends at 99%, 95%, and 90% significance levels. It was found that the sub-hourly (15 min to 240 min), sub-daily time series (60 min to 240 min), and total daily rainfall showed few statistically significant negative trends (decrease). No significant positive trend was observed in Côte d'Ivoire. Overall, the climate change signal is currently difficult to detect in sub-daily and daily extreme rainfall events in Côte d'Ivoire. Several reasons may explain this situation, among which the difficulty to access accurate data is likely the most important factor. The absence of significant changes in extreme rainfall events seems to confirm the hypothesis that the worsening impact of floods over the past decade in Côte d'Ivoire would be related to the construction of habitats in floodplains and illegal occupation of the river beds.

Acknowledgments: The authors thank the National Meteorology (SODEXAM) for rainfall data acquisition.

Author Contributions: Gneneyougo Emile Soro and Tié Albert Goula Bi developed the ideas; Dabissi Noufé contributed to the realization the map. Bernard Shorohou has realized the data pre-processing (extraction of indices extremes). Gneneyougo Emile Soro analyzed data and wrote the paper with inputs from Dabissi Noufé, Bernard Shorohou, and Tié Albert Goula Bi.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chu, P.-S.; Chen, D.-J.; Lin, P.-L. Trends in precipitation extremes during the typhoon season in Taiwan over the last 60 years. *Atmos. Sci. Lett.* **2013**, *15*. [CrossRef]
2. Easterling, D.R.; Meehl, G.A.; Parmesan, C.; Changnon, S.A.; Karl, T.R.; Mearns, L.O. Climate extremes: Observations, modeling and impacts. *Science* **2000**, *289*, 2068–2074. [CrossRef] [PubMed]

3. Houghton, J.; Ding, T.Y.; Griggs, D.J.; Noguer, M.; Van der Linden, P.J.; Dai, X.; Maskell, K.; Johnson, C.A. *Observed Climate Variability and Change. Climate Change 2001: The Science of Climate Change*; Cambridge University Press: Cambridge, UK, 2001.
4. Zhai, P.M.; Zhang, X.B.; Wang, H.; Pan, X.H. Trends in total precipitation and frequency of daily precipitation extremes over China. *J. Clim.* **2005**, *18*, 1096–1108. [CrossRef]
5. Rajeevan, M.; Bhate, J.; Jaswal, A.K. Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophys. Res. Lett.* **2008**, *35*. [CrossRef]
6. Powell, E.J.; Keim, B.D. Trends in daily temperature and precipitation extremes for the Southeastern United States: 1948–2012. *J. Clim.* **2015**, *28*, 1592–1612. [CrossRef]
7. Boers, N.; Donner, R.V.; Bookhagen, B.; Kurths, J. Complex network analysis helps to identify impacts of the El Niño Southern Oscillation on moisture divergence in South America. *Clim. Dyn.* **2014**. [CrossRef]
8. Tomassini, L.; Jacob, D. Spatial analysis of trends in extreme precipitation events in high-resolution climate model results and observations for Germany. *J. Geophys. Res.* **2009**, *114*. [CrossRef]
9. Cantet, P. Impacts du Changement Climatique sur les Pluies Extrêmes par l'utilisation d'un Générateur Stochastique de Pluies. Ph.D. Thesis, Université Montpellier II, Montpellier, France, 2009.
10. Sugahara, S.; Porfírio da Rocha, R.; Silveira, R. Non-stationary frequency analysis of extreme daily rainfall in Sao Paulo, Brazil. *Int. J. Climatol.* **2008**, *29*, 1339–1349. [CrossRef]
11. Burić, D.; Luković, J.; Bajat, B.; Kilibarda, M.; Živković, N. Recent trends in daily rainfall extremes over Montenegro (1951–2010). *Nat. Hazards Earth Syst. Sci.* **2015**, *15*, 2069–2077. [CrossRef]
12. Pal, I.; Al-Tabbaa, A. Trends in seasonal precipitation extremes—An indicator of "climate change" in Kerala, India. *J. Hydrol.* **2009**, *367*, 62–69. [CrossRef]
13. Bielec, Z. Long terme variability of thunderstorms and thunderstorms precipitation occurrence in Cracow, Poland, in the period 1896–1995. *Atmos. Res.* **2001**, *56*, 161–170. [CrossRef]
14. Griffiths, G.M.; Salinger, M.J.; Leleu, I. Trends in extreme daily rainfall across the South Pacific and relationship to the South Pacific convergence zone. *Int. J. Climatol.* **2003**, *23*, 847–869. [CrossRef]
15. Salinger, M.J.; Griffiths, G.M. Trends in New Zealand daily temperature and rainfall extremes. *Int. J. Climatol.* **2001**, *21*, 1437–1452. [CrossRef]
16. dos Santos, C.A.C. Recent changes in temperature and precipitation extremes in an ecological reserve in Federal District, Brazil. *Rev. Bras. Meteorol.* **2014**, *29*, 13–20. [CrossRef]
17. de Lima, M.I.P.; Santo, F.E.; Ramos, M.A.; Trigo, R.T. Trends and correlations in annual extreme precipitation indices for mainland Portugal, 1941–2007. *Theor. Appl. Climatol.* **2015**, *119*, 55–75.
18. Koning, A.; Franses, P.H. Are precipitation levels getting higher? Statistical evidence for the Netherlands. *J. Clim.* **2005**, *18*, 4701–7414.
19. Re, M.; Barros, V.R. Extremes rainfalls in SE South America. *Clim. Chang.* **2009**, *96*, 119–136. [CrossRef]
20. Collins, J.M. Temperature variability over Africa. *J. Clim.* **2011**, *24*, 3649–3666. [CrossRef]
21. New, M.; Hewitson, B.; Stephenson, D.B.; Tsiga, A.; Kruger, A.; Manhique, A.; Gomez, B.; Coelho, C.A.S.; Masisi, D.N.; Kululanga, E.; et al. Evidence of trends in daily climate extremes over southern and west Africa. *J. Geophys. Res.* **2006**, *111*, D14102. [CrossRef]
22. Ozer, A.; Ozer, P. Désertification au Sahel: Crise climatique ou anthropique? *Bull. Séances l'Acad. R. Sci. d'Outre-Mer* **2005**, *51*, 395–423.
23. Easterling, D.R.; Evans, J.L.; Groisman, P.Ya.; Karl, T.R.; Kunkel, K.E.; Ambenye, P. Observed variability and trends in extreme climate events: A brief review. *Bull. Am. Meteorol. Soc.* **2000**, *81*, 417–425. [CrossRef]
24. Aguilar, E.; Aziz Barry, A.; Brunet, M.; Ekang, L.; Fernandes, A.; Massoukina, M.; Mbah, J.; Mhanda, A.; do Nascimento, D.J.; Peterson, T.C. Changes in temperature and precipitation extremes in western central Africa, Guinea Conakry, and Zimbabwe, 1955–2006. *J. Geophys. Res.* **2009**, *114*, D02115. [CrossRef]
25. Ozer, P.; Hountondji, Y.C.; Laminou Manzo, O. Evolution des caractéristiques pluviométriques dans l'est du Niger de 1940 à 2007. *GEO-ECO-Trop* **2009**, *33*, 11–30.
26. Donat, M.G.; Peterson, T.C.; Brunet, M.; King, A.D.; Almazroui, M.; Koli, R.K.; Al-Mulla, Y.A.; Youssouf, N.A.; Aly, A.A.; Nada, T.A.A.; et al. Changes in extreme temperature and precipitation in the Arab region: Long-term trends and variability related to ENSO and NAO. *Int. J. Climatol.* **2013**, *34*, 581–592. [CrossRef]
27. Saidi, H.; Ciampittiello, M.; Dresti, C.; Ghiglieri, G. Observed variability and trends in extreme rainfall indices and Peaks-Over-Threshold series. *Hydrol. Earth Syst. Sci. Discuss.* **2013**, *10*, 6049–6079. [CrossRef]

28. Ntegeka, V.; Willems, P. *Climate Change Impact on Hydrological Extremes along Rivers and Urban Drainage Systems. III. Statistical Analysis of Historical Rainfall, ETo and River Flow Series Trends and Cycle*; K.U. Leuven—Ydraulics Section & Royal Meteorological Institute of Belgium: Leuven, Belgium, 2008.
29. Easterling, D.R.; Alexander, L.V.; Mokssit, A.; Detemmerman, V. CCI/CLIVAR Work shop to develop priority climate indices. *Bull. Am. Meteorol. Soc.* **2003**, *8*, 1403–1407. [CrossRef]
30. Mann, H.B. Non parametric tests against trend. *Econometrica* **1945**, *13*, 245–259. [CrossRef]
31. Kendall, M.G. *Rank Correlation Methods*, 4th ed.; Charles Griffin: London, UK, 1975.
32. Mavromatis, T.; Stathis, D. Response of the water balance in Greece to temperature and precipitation trends. *Theor. Appl. Climatol.* **2011**, *104*, 13–24. [CrossRef]
33. Yue, S.; Pilon, P.; Phinney, B.; Cavadias, G. The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrol. Process.* **2002**, *16*, 1807–1829. [CrossRef]
34. Tabari, H.; Somee, B.S.; Zadeh, M.R. Testing for long-term trends in climatic variables in Iran. *Atmos. Res.* **2011**, *100*, 132–140. [CrossRef]
35. Önöz, B.; Bayazit, M. Block bootstrap for Mann–Kendall trend test of serially dependent data. *Hydrol. Process.* **2012**, *26*, 3552–3560. [CrossRef]
36. Wang, Y.Q.; Zhou, L. Observed trends in extreme precipitation events in China during 1961–2001 and the associated changes in large-scale circulation. *Geophys. Res. Lett.* **2005**, *32*, L09707. [CrossRef]
37. Helsel, D.R.; Hirsch, R.M. Statistical Methods in Water Resources. In *Studies in Environmental Science 49*; Elsevier: New York, NY, USA, 1992.
38. Interstate Technology & Regulatory Council. *Groundwater Statistics and Monitoring Compliance, Statistical Tools for the Project Life Cycle. GSMC-1*; Interstate Technology & Regulatory Council, Groundwater Statistics and Monitoring Compliance Team: Washington, DC, USA.
39. Ozer, P.; Mahamoud, A. Recent extreme precipitation and temperature changes in Djibouti City (1966–2011). *J. Climatol.* **2013**, *2013*. [CrossRef]
40. Ly, M.; Traore, S.B.; Agali, A.; Sarr, B. Evolution of some observed climate extremes in the West African Sahel. *Weather Clim. Extrem.* **2013**, *1*, 19–25.
41. Mazvimavi, D. Investigating possible changes of extreme annual rainfall in Zimbabwe. *Hydrol. Earth Syst. Sci.* **2008**, *5*, 1765–1785. [CrossRef]
42. Tarhule, A.; Woo, M. Changes in rainfall characteristics in northern Nigeria. *Int. J. Climatol.* **1998**, *18*, 1261–1271. [CrossRef]
43. *IPCC Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Field, C.B., Barros, V., Stocker, T.F., Dahe, Q., Eds.; Cambridge University Press: Cambridge, UK, 2012.
44. Sugiyama, M.; Shiogama, H.; Emori, S. Precipitation extreme changes exceeding moisture content increases in MIROC and IPCC climate models. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 571–575. [CrossRef] [PubMed]
45. Folland, C.K.; Palmer, T.N.; Parker, D.E. Sahel rainfall and worldwide sea temperature 1901–1985. *Nature* **1986**, *320*, 602–607. [CrossRef]
46. Koster, R.D.; Dirmeyer, P.A.; Guo, Z.; Bonan, G.; Chan, E.; Cox, P.; Gordon, C.T.; Kanae, S.; Kowalczyk, E.; Lawrence, D.; et al. Regions of strong coupling between soil moisture and precipitation. *Science* **2004**, *305*, 1138–1140. [CrossRef] [PubMed]
47. Xue, Y.; Shukla, J. The influence of land-surface properties on Sahel climate. Part I: Desertification. *J. Clim.* **1993**, *6*, 2232–2245. [CrossRef]
48. Wang, G.; Alo, C.A. Changes in Precipitation Seasonality in West Africa Predicted by RegCM3 and the impact of dynamic vegetation feedback. *Int. J. Geophys.* **2012**, *2012*. [CrossRef]
49. Brou, T.Y.; Servat, E.; Paturel, J.E. Contribution à l'analyse des interrelations entre activités humaines et variabilité climatique : Cas du sud forestier ivoirien. *Acad. Sci.* **1998**, *327*, 833–838.
50. Hirsch, R.M.; Alexander, M.B.; Smith, R.A. Selection of methods for the detection and estimation of trends in water quality. *Water Resour. Res.* **1991**, *27*, 803–813. [CrossRef]
51. Yue, S.; Pilon, P. A comparison of the power of the *t*-test, Mann-Kendall and bootstrap tests for trend-detection. *Hydrol. Sci. J.* **2004**, *49*, 21–37. [CrossRef]