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Historical Trends in Extreme Precipitation Events, Their Relationship and Potential Implication on the Environment in Sub-Saharan Africa

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Abstract

Understanding trends in extreme rainfall events is important in mitigating their impacts on socioeconomic sectors such as health, agriculture, water resources and the environment. In this study, historical trends in total annual precipitation and number of days with heavy precipitation events, their relationships and potential implications on the environment in Sub Sahara Africa were investigated. Gridded daily precipitation data from National Oceanic Atmosphere Administration (NOAA) with the spatial coverage of 0.50 - degree latitude x 0.50 - degree longitude grid (720x360) and temporal coverage from 1979 to 2018 were used. Mannkendall test was used to generate trends in days with heavy precipitation events (d95P) and total annual precipitation (prcptot) at 5% significance level. Trends in d95P and prcptot were then assessed and correlated to determine their relationships and potential impact on the environment. Results of the study indicate statistically significant decreasing trends in prcptot over Central Africa, the southern part of West Africa and in some parts of Southern Africa. Some pockets of significant increasing trends in prcptot were observed around Southern Africa, some parts of East Africa and the northern parts of West Africa. The largest portion of sub-Sahara Africa shows non significant trends in prcptot. Variable trends observed in prcptot could be attributed to regional differences in climate. In terms of d95P, significant decreasing trends are observed in Central Africa, South Central Africa and the southern parts of West Africa. Significant increasing trends in d95P events were observed in some parts of East Africa and some northern parts of West Africa. However, the magnitudes of these trends in terms of the Sen's slope are minimal. Like prcptot, the largest parts of sub-Saharan Africa shows non significant trend in d95P. Trends in d95P and prcptot show a positive correlation. This indicates that the increase in d95P contributes greatly to the increase in prcptot over the base period. Regions which showed positive correlation between significant increasing trends in prcptot and d95P may be prone to flooding, landslides and related disasters. It should however be noted that most parts of sub-Saharan Africa indicate non significant trends in both prcptot and d95P at 5% significant level.

Keywords

Precipitation, Extreme Events, Africa

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1. Introduction

It is reported that changes in climate in various parts of the world will likely cause high variability in water resources including higher frequencies or intensities of floods and droughts [2]. Therefore, understanding the variability of precipitation trends is important in various socioeconomic sectors such as health, agriculture, environment and natural resources management. Extreme climatic events such as floods and droughts threaten sustainable development in terms of agricultural productivity and other sectors, and also the security and stability of many countries. Developing

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countries with low adaptive capacity coupled with other social stresses are expected to suffer the worst effects of climate change [3]. It is imperative to note that the vulnerability of people and the environment to catastrophic effects of extreme climatic events can be influenced by several factors such as landscape usage and societal infrastructure. A distinct link between extreme precipitation events and human-induced warming was observed through satellite observations and climate model simulations, with heavy precipitation events increasing during warm periods and decreasing during cold periods [4].

Trends in extreme precipitation events have been variable across the globe in recent decades [1, 5]. Studies have shown that some parts of the globe have shown an increase in extreme rainfall events while some appear to show a decline. However, there has been limited information on trends in extreme rainfall events in some parts of Africa [7]. According to [6], the biggest obstacle to quantifying the changes in extreme events in Africa over the past decades is due to lack of long-term climate data. Based on available limited data in Africa, some studies have however shown some variability in precipitation patterns across the continent. From 1950 to 2000, it is reported that the West African region experienced a decrease in annual total rainfall [9]. In terms of extreme daily rainfall, [10] noticed an increase over the central Sahelian region of West Africa over the past decades. Furthermore, some studies show that some West African countries are prone to increases in extreme rainfall (in Nigeria) while others (in Guinea Conakry and in Niger) show a clear reduction in annual total precipitation amounts [11].

In Southern African region, an increase in inter-annual rainfall variability such as higher rainfall anomalies and more intense widespread droughts have been observed since 1970 [12]. A recent study done in South Africa revealed an apparent increase in daily rainfall extremes in the southern to western interior of that country although not statistically significant [13]. Many authors reported longer dry periods interspersed with more intense rainfall events associated with droughts, floods and decreased river flows were also postulated in South Africa. According to [23, 15], an assessment of historical climate data in Zambia revealed a decline in total annual rainfall patterns across the country from 1980 to 2017. Global circulation models of climate change predict that Zambia will experience increasing temperatures with longer dry periods, more intense rainfall and increased storm events over the next 20 to 30 years [16]. The southern part of Zambia has been consistently experiencing climatic shocks in terms of floods and droughts, and water scarcity [17]. Frequent long dry spells in this region have led to critical water shortages due to the reduction in groundwater recharge, reduced agricultural productivity and lowering of surface water bodies such as the Lake Kariba. For instance, during 1982/83 rainy season, water scarcity caused by frequent dry spells in Southern Province of Zambia which led to poor performance in the agricultural sector and consequently increased the poverty levels among the local communities [18]. Generally, rainfall trends have been difficult to determine in Southern African as whole due to significant regional (from country to country) differences [5].

In East Africa, particularly in Kenya, Ethiopia and Somali, climate related extreme events have been the dominant trigger of natural disasters in recent years [20]. It is further reported that the East African region has in the recent times experienced frequent episodes of both excessive [21, 22] and deficient rainfall [21, 24]. Furthermore, it is reported that some parts of East Africa are perennially prone to floods and droughts. Just like other parts of Africa, the East African region has poor long terms daily climatic records for improved analysis of climate extremes. Against this background, this study intends to investigate and understand historical trends in total annual precipitation and extreme precipitation events (d95P) and their relation in sub-Saharan Africa using global gridded data.

The specific objectives of this study include the following;

i. To determine the trends in number of days with rainfall exceeding the 95th percentile
ii. To determine the trend in total annual rainfall
iii. To determine the relationship between total annual precipitation and number of days with rainfall exceeding 95th percentile

Site Location and Description

Sub-Saharan Africa is the region south of the Sahara desert in Africa. It is a fast developing region of great ecological, climatic and cultural diversity [25]. It is estimated that the population of the region will approach 9.8 billion people by the year 2050, a figure which could rise to about 11 billion by 2100 [26]. The Gross Domestic Product growth rate increased from 3.7% in 2012 to 4.7%. In terms of the national poverty rates, there has been a decline in most Sub-Saharan African countries. However, the Sub-Saharan still has the largest proportion of people living below the poverty line of all world regions [27]. The agricultural sector is the major employer in sub-Saharan Africa and accounts for approximately 65% of Africa's total labor force [28]. Despite the expansion of the agricultural sector, some parts of sub-Saharan face challenges with water resources and agricultural inputs such as fertilizers. Furthermore, the agricultural sector is mainly rain-fed (about 96% of overall crop production) which makes vulnerable it vulnerable to climatic shocks [29].

Figure 1. Map of Africa showing Sub-Sahara Africa represented by the green portion ([19] (Source: https://francistapon.com/Travels/Africa/Defining-Sub-Saharan-Africa-And-The-Countries-In-It).

2. Methodology

Data Collection and Analysis

In this study, gridded daily precipitation data from National Oceanic Atmosphere Administration (NOAA) Climate Prediction Center (CPC) was employed. CPC data has the spatial coverage of 0.50 - degree latitude x 0.50 - degree longitude grid (720x360) and temporal coverage from 1979 to date. In this study, the temporal coverage of the data is from 1979/01/01 to 2018/12/31.

After extraction of the data, trend analysis was performed using Mann-Kendall test (a non parametric test) recommended by the World Meteorological Organization (WMO) to explore trends hydroclimatological time series [8]. Trend in total annual precipitation and trend in number of precipitation days exceeding the 95th percentile for each grid cell were determined.

Since the Mann-Kendall test is non-dimensional and does not quantify the scale or the magnitude of trend, the Sen.'s non-parametric method was used to estimate the slope of the trend. With Mann-Kendall, the Z statistic and p-value were used to test the null hypothesis, H_o, which states that the data come from a population with independent realizations and are identically distributed against the alternative hypothesis, H_1, that there is an increasing or decreasing monotonic trend.

Table 1. List of Indices used in this study.

Index	Description	Unit
Prcptot	Annual total precipitation in wet days,	mm
d95p	Number of days with precipitation >95th percentile	Days

3. Results and Discussion

3.1. Trends in Heavy Precipitation Events Exceeding 95th Percentile (R95P)

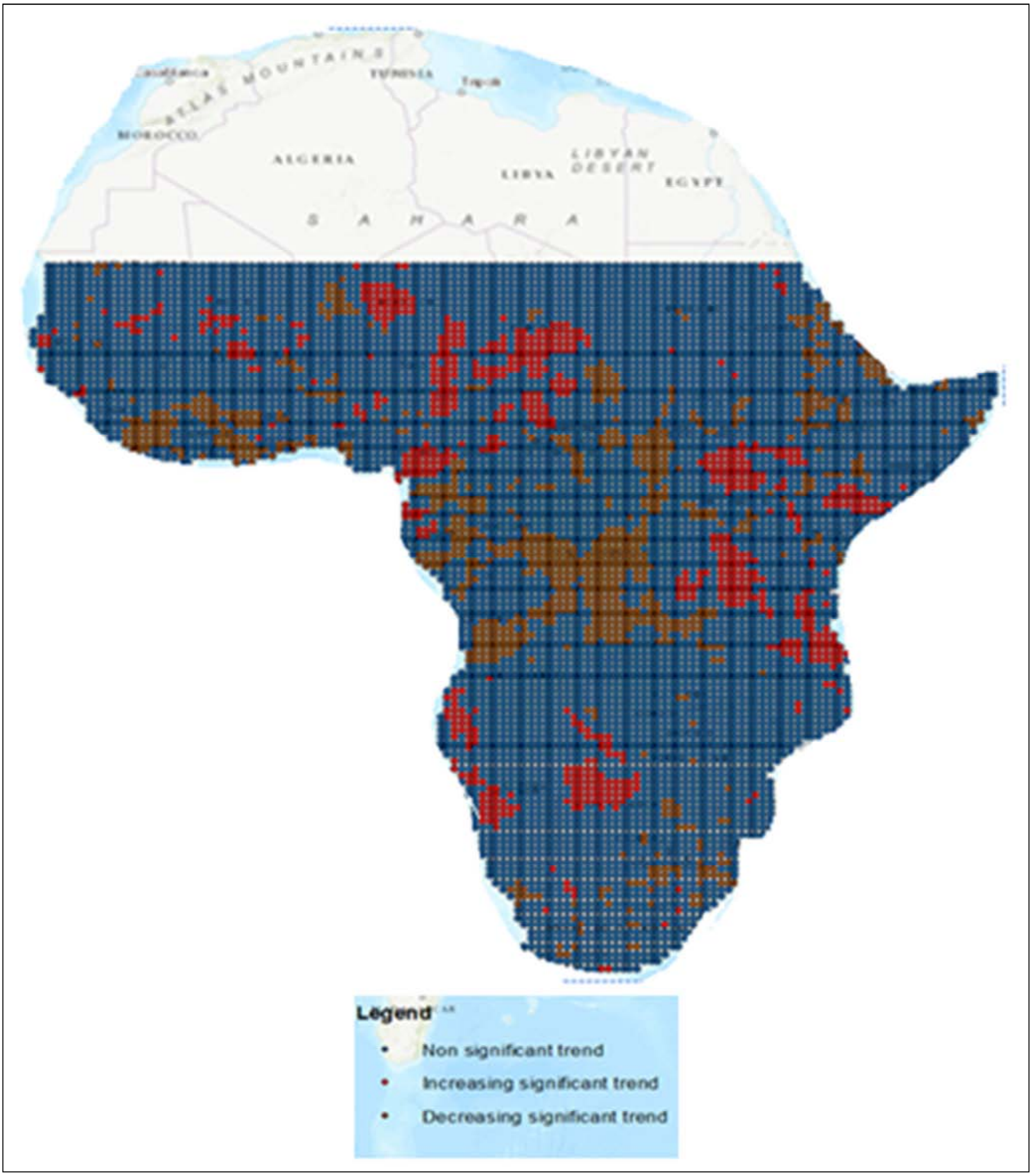

Figure 2. Trends in the number of days with precipitation greater than 95th percentile.

Note: Blue regions represent areas with non significant trend in d95P, red represents areas with increasing significant trend and brown represent areas with decreasing trends in d95P.

The d95P index measures the days with heavy precipitation events exceeding 95th percentile of the base period of each grid cell. In other words, this index measures the number of days per year with total daily rainfall that exceeds 95th percentile. The increase in number of days with heavy precipitation events is likely to increase the chances of occurrence of floods, landslides and related disasters. Based on the Mann-Kendall results of this study, some spatially variable patterns with significant decreasing and increasing trends in d95P at 5% significant level are observed across in some parts of Southern, East and West Africa. However, the largest portion of the study area shows no significant trends in d95P. The observed significant trends in d95P may be attributed to a lot of factors. According to [31], the rise in air temperatures can lead to more intense precipitation events as warmer air can hold more water vapor. For each degree of warming, the air's capacity for water vapor goes up by about 7 percent. As it can be observed from figure 2 above, relatively hotter regions around the Kalahari Desert in Southern Africa, some part of East Africa (Tanzania, Kenya and Uganda) and the northern parts of West Africa shows patterns with significant increasing trends in d95P. Also, land use practices such as deforestation or reduction in vegetation cover may contribute to the observed decreasing significant trends as the levels of deforestation in most parts of Africa are on the rise. Trees help to absorb carbon dioxide and other heat trapping green house gases that causes global warming which subsequently leads to more intense rainfall.

Much of Central Africa experiences normal to abnormal temperatures throughout the year [30]. Moreover, anomaly of about +0.6 °C above the 1961 to 1990 reference period in Cameroon and an annual mean temperature of 25.9°C, which is about 0.9°C above the 1961–1990 average for Brazzaville, Congo were recorded. Despite relatively high temperatures and low pressures experienced around the Equatorial region, trends in d95P significantly decrease. This could be attributed to the rampant deforestation in the region.

Despite some observed patterns of significantly decreasing and increasing trends in Sub-Sahara Africa, the magnitudes of the trends (Sen's slope) are minimal. The Sen's slope or rate of change of significant decreasing trends in d95P varies from 0.0days per year to 0.25day/year, with an average of 0.1days per year. The rate of change for the significant increasing trend in d95P varies from 0days per year to 0.48day per year, with an average of 0.08days per year.

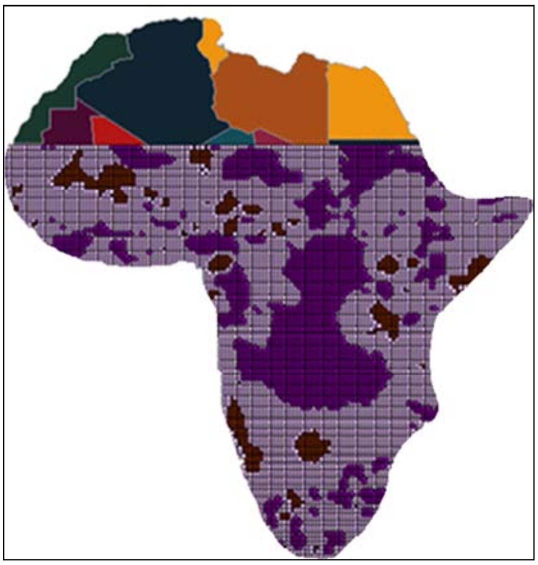

Figure 3. Trends in total annual precipitation events in Sub-Saharan Africa.

3.2. Trends in Total Annual Precipitation (Prcptot)

Trends in total annual precipitation (PRCPTOT) are probably the most important climatic index reflecting rainfall variations over the entire year. From the Mannkendall trend analysis results (figure 3 above), it can be observed that trends in total annual precipitation were variable across the Sub Sahara Africa. Some significant decreasing (purple regions) and increasing trends (brown regions) in total annual precipitation at 5% significance level were observed in some regions of the study area while other regions showed non significant trends (grey regions), which dominate much of the area. The variations in total rainfall trends across the Sub-Saharan Africa could be attributed to the regional differences in climate.

The Equatorial Africa which includes the southern coast of West Africa and the rainforests of Central Africa show significant decreasing trends (purple regions) in total annual precipitation. This is in conformity with the study done by the World Meteorological Department which states that southern parts of West Africa and a large portion of central Africa and parts of Southern Africa are affected by significant total annual rainfall deficits [30].

Significant increasing trends (brown regions) in total annual precipitation are also recorded in some parts of East Africa (around Kenya, Tanzania and Uganda) and some northern parts of West Africa. Portions of significant decreasing trends in the aforementioned areas were also recorded. It should however be noted that some parts of East Africa and northern parts of West Africa showed non significant trends (grey regions) in total annual precipitation at 5% significant level.

Significant increasing trends in total annual precipitation vary across the study area from 0mm/year to 31.1mm/year with an average of 5.2mm/day. On the hand, significant decreasing trends in total annual precipitation ranges from 0mm/year to 30.3mm/year with an average of 8.9mm/year. With the high magnitudes of the decreasing trends observed in some regions, water resources and rain fed agriculture which is largely practiced in Africa will likely be impacted.

Figure 4. Overlay of significant increasing trends in d95P and increasing trends in total annual precipitation.

Figure 5. Overlay of significant decreasing trends in d95P and significant decreasing trends in total annual precipitation.

3.3. Correlation Between Total Precipitation and d95P

Although increases in heavy precipitation may not always lead to increases in total precipitation over a season or over a year, figure 4 above show some discrete regions in Southern, East and Northern parts of West Africa with positive correlation between the significant increasing trends in d95P and total annual precipitation. Figure 5 shows some regions with positive correlation between the significant decreasing trends in d95P and significant decreasing trends in total annual precipitation around South Africa, Central Africa and Ethiopia and the southern parts of West Africa. Regions with the above observed correlations could indicate that significant increase number of heavy precipitation events greatly contributes to the increase in total precipitation and vice-versa. Regions which showed positive correlations between significant increasing trends in prcptot and increasing significant trend in d95P may be prone to flooding, landslides, degradation of water quality, and may also harm the ecosystem and human health.

Figure 6. Overlay of significant increasing trend in d95P and significant decreasing trend in total annual precipitation.

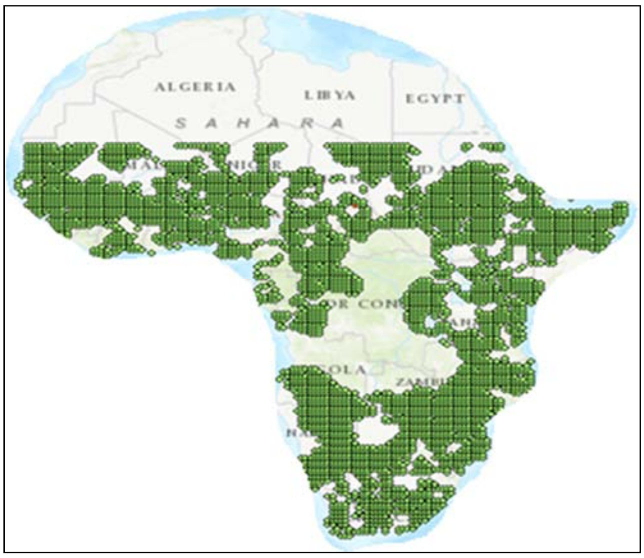

Figure 7. An overlay between non significant trends in prcptot and d95P.

As can be observed from the figures 6, there is generally no correlation between the significant decreasing trend in total precipitation and d95P and vice versa. This indicates that areas where significant decreasing trends in heavy precipitation events are recorded do not receive significant total annual precipitation. The same applies with total annual rainfall. Areas receiving significant total annual precipitation do not exhibit decreasing trends in heavy precipitation events. These areas are likely not vulnerable to landslides and flooding.

Based on figure 7 above, there is a strong positive correlation between non significant trend in total annual precipitation and non significant trend in d95P at 5% significant level. The positive correlation between non significant trends in prcptot and d95 cover the largest part of Sub-Saharan Africa. This indicates that most parts of the sub-Saharan Africa may not be negatively impacted by extreme precipitation in terms of heavy precipitation events.

4. Conclusion

Trend analysis of extreme rainfall events over the period 1979 to 2018 in sub-Saharan Africa using Mannkendall test revealed variable patterns. Statistically significant decreasing trends in annual total precipitation at 5% significance level have been recorded in Central Africa, the southern part of West Africa and in Southern Africa (around South Africa, Lesotho and Swaziland). Some significant increasing trends are observed around the Kalahari Desert, some parts of East Africa (Uganda, Tanzania and Kenya) and the northern parts of West Africa. The largest portion of sub-Sahara Africa showed non significant trends in total annual precipitation. Observed variable trends in annual total precipitation could be attributed to regional differences in climate. In terms of heavy precipitation events, significant decreasing trends are observed in Central Africa, some southern parts of West Africa and around the Kalahari area in Southern Africa. Significant increasing trends in heavy precipitation events are observed in some parts of East Africa (Uganda, Kenya and Tanzania) and some northern parts of West Africa. However, the magnitude of these trends in terms of the Sen's slope is minimal. Just like prcptot, the largest parts of sub-Saharan Africa shows non significant trend in d95P. Trends in d95P and prcptot reveal a positive correlation. This implies that significant increasing trend in prcptot contributes greatly to the increase in heavy precipitation events. Areas showing positive correlation between significant increasing trends in prcptot and d95P may be prone to flooding, landslides, degradation of water quality, and may also harm the ecosystem and human health. It should however be noted the largest parts of sub-Saharan Africa shows positive correlation between non significant trends in prcptot and d95P.

Future Work

Future work will involve the use of climate projection models to analyze future trends in d95P and prcptot in the study area and their implications on water resources and environment.

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