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Verification of Climate Change Using Rainfall and Temperature Data as Indicators in the Arid Zone of the Sudan 1981 to 2010

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ABSTRACT

Climate change is one of the most serious environmental and socio-economic problems of our time especially in arid areas. Sudan with the new boarders, most of its land classified as arid and semiarid regions, therefore it is very important to investigate the climate change in these areas. This research aimed to investigate the climate change reality in the arid zone in Sudan using rainfall and temperature data only. Five focal points (Kassala, Wadmedni, Eldouim, Elobied, Elfasher) were selected to represent the whole zone. The climate data of monthly and annual rainfall, minimum and maximum air temperature were obtained from Sudan Meteorological Authority (SMA) during the period from 1980 to 2010. Other climatic factors were calculated and estimated from temperature and rainfall data, such as: Potential Evapotranspiration, Cumulative Rainfall Departure, Effective Rainfall, rainfall coefficient of variance, Aridity Index and Standardized Precipitation Index. The relationship between rainfall and temperature were obtained. The period of this study (1981 – 2010), was divided into three decades and analyzed the different between each sub-period on rainfall and temperature using Duncan Multiple Range (DMR) at $P \geq 0.05$. The trend of annual mean air temperature had been increased with statistically significant evidences in Kassala, Wadmedni, Eldouim and Elfasher stations; where annual rainfall trend had been increased with statistically significant evidences in Elobied station. Regarding other climatic factors: Potential Evapotranspiration trend showed significant increase in Kassala, Wadmedni and Elfasher stations; Cumulative Rainfall Departure trend showed significant increase in Wadmedni, Elobied and Elfasher stations; where Effective Rainfall, rainfall coefficient of variance, Aridity Index and Standardized Precipitation Index trends showed significant increase in Elobied station only. There were negative significant correlation between rainfall and temperature in Kassala and Elobied stations.

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There were no significant different between the three sub-period in annual rainfall in all stations except in Elobied station, where in mean air temperature showed significant different between the three sub-period in Kassala, Eldouim and Elfasher.

Keyword: Climate Change, Rainfall, Temperature and Arid Zone

1. INTRODUCTION

Sudan the one of the largest countries in Africa, with an area of about 1 860 000 km². The country lies on the geographical coordinates of latitude from 8.45 to 23.8° N and longitude from 21.49° to 38.24° E. Mean annual temperatures vary between 26 °C and 32 °C across the country, except for the elevated points of Jebel Marra in the West (22.6 °C), and the Red Sea mountains (22.8 °C). The hottest areas, based on mean annual temperatures of 32 °C, lie within the northern parts of central Sudan, within the geographic triangle of Atbara, Kassala and Khartoum. In all areas outside of this triangle, the air temperature decrease particularly towards the northwest [1]. Annual rainfall in Sudan varies from close to zero near the border with Egypt, to about 200 mm around the capital Khartoum and reach to 700 mm at Eldamazin. Where it rains, the rainy season is limited to two or three months with the rest of the year remaining virtually dry. Moreover, the rain usually comes in isolated showers, which are highly variable in time and location. Average of rainfall also declined over the same period [2]. Declining and uncertain rainfall makes life very difficult for traditional farmers and herders and severely affects their Livelihoods.

Sudan is one of the most vulnerable countries to climate change and climate variability. Drought is one of the most important natural phenomena that Sudan faces. There are two types of droughts: the first is widespread drought, which is caused by below normal rainfall across the country; the second is localized drought that affects only some parts of the country [2]. Recurring series of dry years has become a normal phenomenon in the Sudan Sahel region. Between 1961 and 1998, episodes of drought have inflicted Sudan with varying severity.

In arid and semi-arid regions of Sudan, water is a limiting factor for economical yields and the main source of water for crops, in areas not equipped with irrigation network, and pastures is the annual rainfall. The yield under these conditions is highly dependent on the amount of rainfall and its distribution, the physical properties of the soil and the weather during the different stages of growth of plants. Water and soil vegetation are the main requirements for human life in rural areas in Sudan, because of their essential contribution for both crop and animal production, which are considered [3]. The two zones are hot and dry during the long summer months, interrupted only by short rainy periods, mainly during July to September. The average annual rainfall varies in total amount from year to year and also with remarkable variations in shower intensity and shower interval. These areas are most vulnerable to climate change, which affects the agriculture productivity, flora and fauna. Sudanese economy depends largely on agriculture (70 % of the population of the country work in agriculture, 90 % of them lives in rural areas) [4]. Most of the national Sudanese agriculture projects are sited in these two zones. Therefore it is very important to study the effect of climate change on these areas. Rainfall and temperature seem as most important microclimate factors in the climate change process. These two factors have a direct effect on human activities and people live hood. Hence, there urgent need to investigate the climate change in arid zone in Sudan.

Therefore the objective of this study was to calculate rainfall and temperature data and estimate other climatic factors such as Potential Evapotranspiration (ETp), Cumulative Rainfall Departure (CRD), Effective Rainfall (RF_{effect}), Aridity Index (AI) and Standardized Precipitation Index (SPI) for the period (1981 – 2010); as a parameters to identify its impacts on Sorghum yield the climate variability and climate change in five selected stations (Kassala, Wadmedani, Eldouim, Elobied and Elfasher) represent the whole region.

2. MATERIAL AND METHODS

2. 1. Study areas

The climatic zones of the Sudan have been identified according to the classification reported by [1] using Sylianinov parameter as follows: desert, semi-desert, arid, semi-arid, semi-humid, humid and very humid. On the other hand, the UNSO classification in 1997 the aridity zones of the Sudan are as follows :hyper-arid, arid, semi-arid dry, sub-humid and moist humid. Beside that there are other classifications of climatic zones in Sudan. However, in this study we used the classification of [1], as it provides more divisions for the climatic zones which were based on long-term average rainfall issued by the recognized authority of the Sudan. Five meteorological stations were used as focal points, to represent the whole arid zone in Sudan. Kassala, Wad Medani, El douim, El obied and Elfasher meteorological stations were selected according to their suitable geographical location.

2. 2. Data collection

The climate data of the mentioned stations was obtained from the Sudan Meteorological Authority (SMA). Meteorological observations of monthly temperature (maximum, minimum air temperature) and rainfall, for a period from 1981 to 2010 were used to obtain the objectives of this study.

2. 3. Analysis of climate data

To achieve the objective of this study the following analyze were be conducted: time series, correlation, regression and multi-regression model equation. The statistical formula and equations were done using computer programs Statistical Package for Social Science (SPSS) version 16.0 and Microsoft Excel 2007.

Time series analysis

A time series analysis provides the basis for planning for future changes. The review of historical data over time provides the decision maker with a better understanding of what has happened in the past, and how estimates of the future values may be obtained. The time series model generally used is a multiplicative model [5], which shows the relationship between each component and the original data (*Y*) of a time series as follows:

$$Y = Ty * S * C * I \quad \text{(1)}$$

Trend is the long-term growth movement of a time series. The linear trend method simplyinvolves the application of a simple, two-variable, regression technique:

$$Ty = a + bx \qquad (2)$$

where:

Ty = trend values of the variable Y
x = point in time
a = intercept or estimated value when x equal to zero
b = slope of line or average change in Y per unit of time

Effective rainfall

The definition of effective rainfall is the fraction of rainfall, that is effectively intercepted by the vegetation or stored in the root zone and used by the plant soil system for evaporation [6]. FAO/ AGLM was determined the coefficient of the linear empirical formula for different arid and sub humid climates as following equations:

$$R_{eff} = 0.6\ P_{tot} - 10 \quad \text{For: } (P_{tot} \text{ less than 70 mm}) \qquad (3)$$

$$R_{eff} = 0.8\ P_{tot} - 24 \quad \text{For: } (P_{tot} \text{ more than 70 mm}) \qquad (4)$$

where:

R_{eff} : Effective rainfall
P_{tot} : Total rainfall

Cumulative Rainfall Departure (CRD)

Rainfall is the driving element of the water budget; therefore, characterization of trends in rainfall time-series is of great importance in any study of long-term hydrologic relationships. The cumulative rainfall departure (CRD) from normal rainfall is a concept used by hydrologists to characterize rainfall trends. There are a number of empirical formula to estimated cumulative rainfall departure, in this study [7] formula had been used as follows:

$$CRD = CRD_{i-1} + RF_i - C \qquad (5)$$

where:

CRD = cumulative rainfall departure
I = ith month
RF = amount of rainfall (mm)
C = long-term average rainfall (mm)

Rainfall probability and return period

Rainfall probability and return period are very important, to describe climate characterization of any climate zone. There are several methods to estimate rainfall probability and return period. In this study Hazen plotting position method, have been used as follow:

$$\text{probability (Fa)} = \frac{100(2n-1)}{2y} \quad \ldots \text{(6)}$$

where:

Fa = Probability of occurrence (%)
n = Rank of each event
y = Total number of events
Period of return = 100/Fa

Aridity Index (AI)

Aridity is the continuous occurrence of rainfall below an arbitrary but very low threshold. It should be noted that aridity can be considered on seasonal or monthly basis [8]. To achieve the main objective of this study, aridity index based on rainfall and temperature data has been used in order to classify the aridity situation in the selected points. The De Martonne formula (1926) aridity index is used to evaluate the monthly aridity index as follow:

$$\text{AI} = \left[\frac{P}{T+10} + \frac{12\,p}{(t+10)}\right] /2 \quad \ldots \text{(7)}$$

where:

P : is the mean annual precipitation in mm
T : is mean annual temperature in ºC
p : the precipitation of the direst month in mm
t : the mean temperature of the direst month in ºC

De Martonne 1926 defined the bioclimatic zones based on the climate aridity index as given in Table (1).

Table 1. Aridity index values and classification according to De Martonne (1926)

Aridity Index Value	Climate Class
5	Arid
5-12	Semi-arid
12-20	Dry Sub-humid
20-30	Moist sub – humid
30-60	Humid
>= 60	Wet

Standardized Precipitation Index to identify drought (SPI)

The Standardized Precipitation Index (SPI) is a tool which was developed primarily for defining and monitoring drought [9]. In this study the following formula was obtained to identify SPI values:

$$SPI = \frac{M_m - M_a}{SD \pm_a} \qquad (8)$$

where:

M_m = Monthly mean of rainfall
M_a = Annual mean of rainfall
$SD \pm_a$ = Standard deviation of annual rainfall

Positive SPI values indicate greater than median precipitation (wet condition), while negative values indicate less than median precipitation. This indicates that SPI is helpful in monitoring the development and relief of a drought. [10] suggested the SPI classification scale given in Table (2).

Table 2. Classification scale for SPI values [10]

SPI	Category
More than 2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to + 0.99	Near normal
-1.00 to – 1.49	Moderately dry
-1.50 to -1.99	Severely dry
-2.00 and less than that	Extremely dry

3. RESULTS AND DISCUSSION

3. 1. Annual rainfall trend

There are noticed variations in annual rainfall between the five stations as shown in Figures (1, 2, 3, 4 and 5) and there are logical findings, because the stations located in different geographical zone. The remarkable different between the five stations in the graph was confirmed by compared using multiple range tests (Duncan Test).The results showed that there are highly significant differences between stations (Table 3). Where the highest value in Kassala (348.2 mm) and the lowest value in Elfasher (192 mm).

The time series analysis conducted using long-term annual rainfall for the four stations bordering the study area, showed that there was gradual increase in the annual rainfall during the period of 1980 to 2010 for all stations, as showed in Figures (1), (2), (3), (4) and (5) represent Kassala, Wadmedni, Eldouim, Elobied and Elfasher station, respectively. These results are agree with [11], who cited that the time series analysis conducted using monthly and long-term annual rainfall (1970-2005) for Shambat and Wad Medani from 1970 to 2004, showed that there has been a gradual increase in the monthly and annual rainfall during this period. In the other hand [12] reported that since 1980, increasing rainfall has been accompanied by rapid increases in air temperature on the order of more than 1 °C. This warming, which is two and a half times greater than global warming, is increasing evapotranspiration and making normal years effectively drier, especially in the extended Darfur and southern Sudan regions. Other findings was reported by [13] who cited that" analyzed the rainfall records from twelve meteorological stations in the Sudan located between latitudes 11 °C and 20 °C. Results showed that there has been a clear decrease in the annual rainfall over the last 30 to 40 years". These results were not in agree with the mentioned research findings.

Regarding (R^2) values find that noticed variations between the stations, where highest value recorded in Elobied R^2 = 0.17 followed by Elfasher R^2 = 0.08, Wadmedni R^2 = 0.07, Eldouim R^2 = 0.03 and Kassala R^2 = 0.001. In general the higher the R-squared is better for model fits data, so value of 0.17 obtained in Elobied is dependable to predict the change in annual rainfall.

Table 3. Compression between different means of annual rainfall using multiple range tests (Duncan Test) during the period from 1981 to 2010

Station	Kassala	Wadmedni	Eldouim	Elobied	Elfasher
Mean annual rainfall (mm)	234.7^{c}	286.2^{b}	244.6^{bc}	348.2^{a}	192^{c}

*The mean difference is significant at the 0.05 level = 0.001**

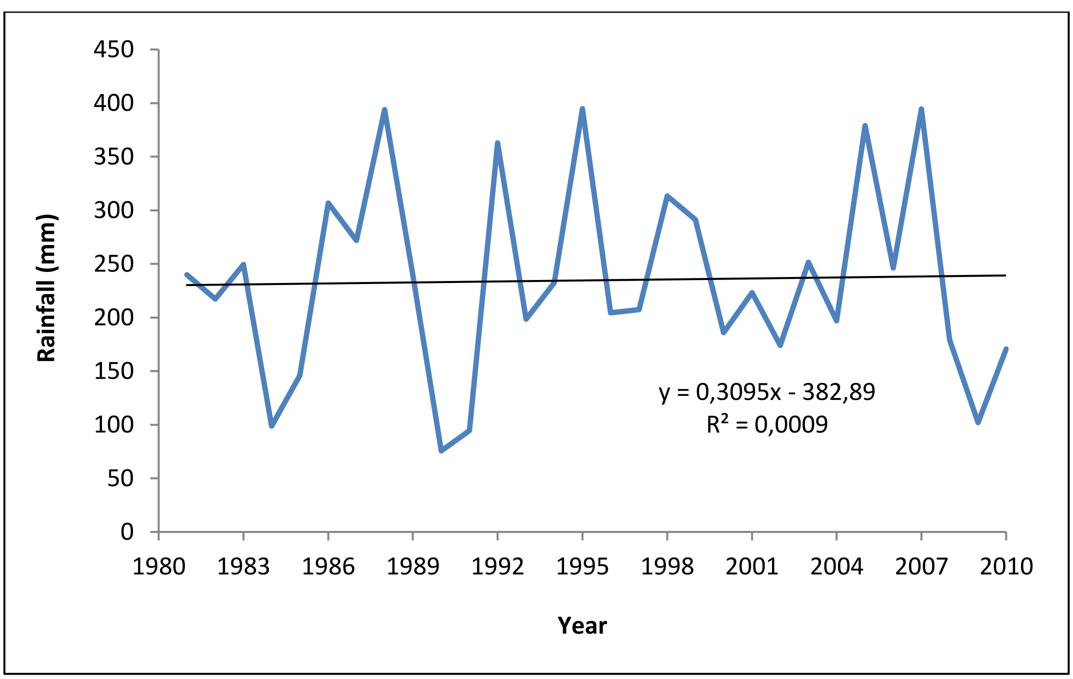

Figure 1. The trend of the annual rainfall for Kassala period 1981-2010

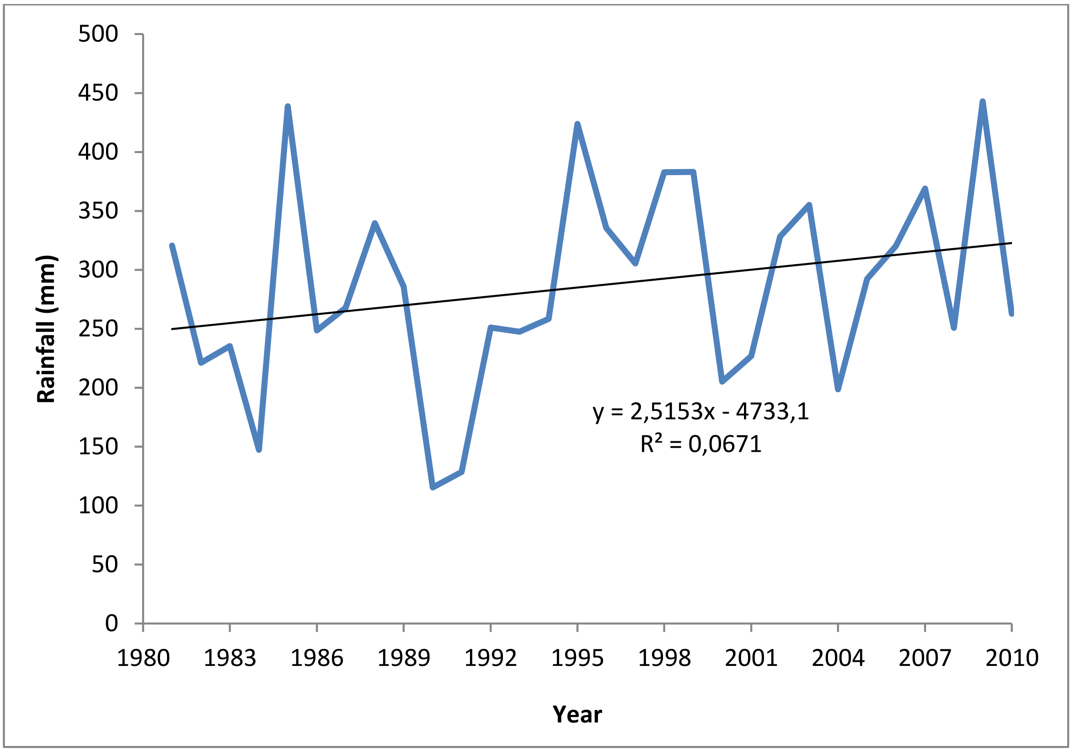

Figure 2. The trend of the annual rainfall for Wadmedni in period 1981-2010

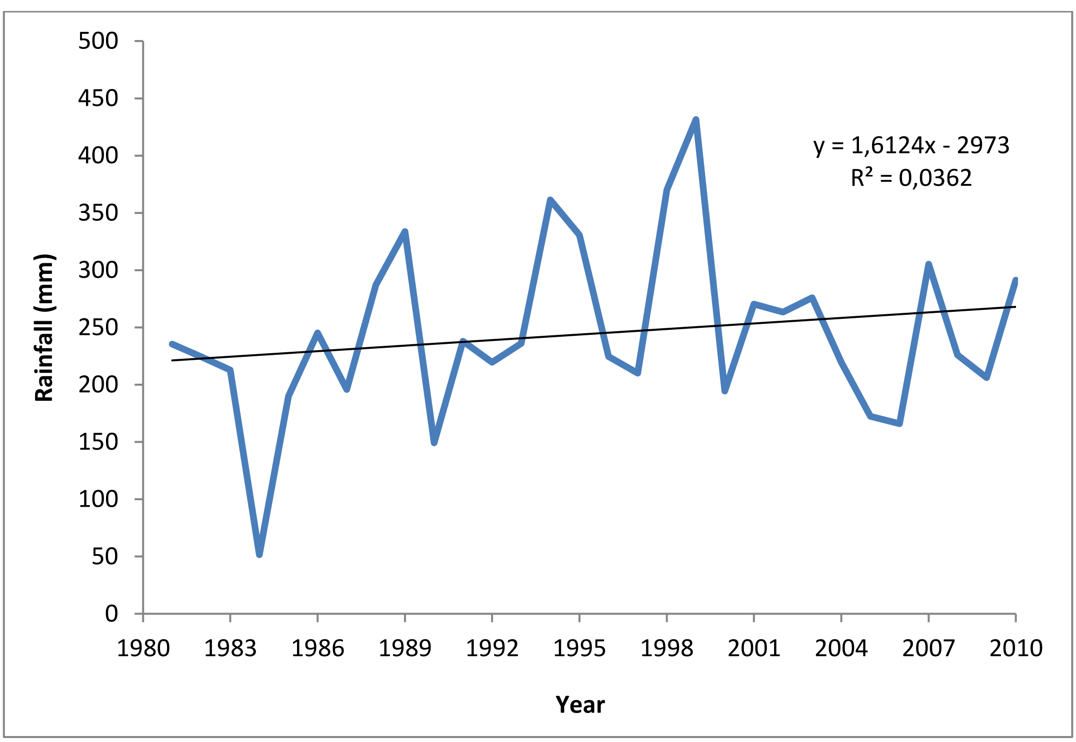

Figure 3. The trend of the annual rainfall for Eldouim period 1981-2010

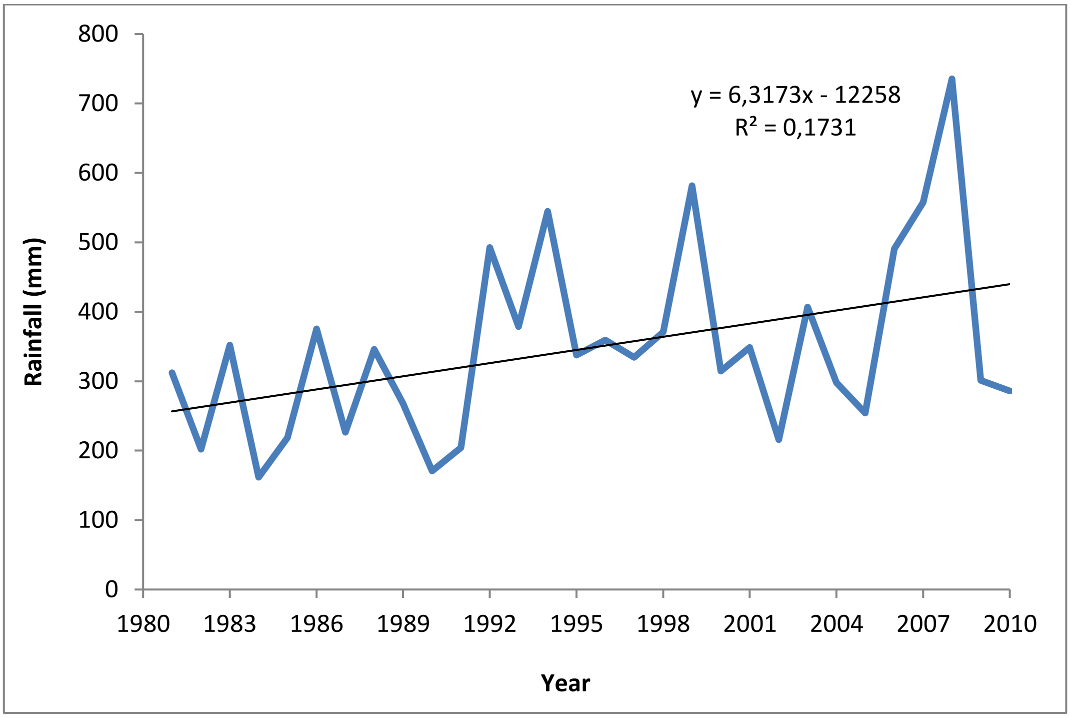

Figure 4. The trend of the annual rainfall for Elobied in period 1981-2010

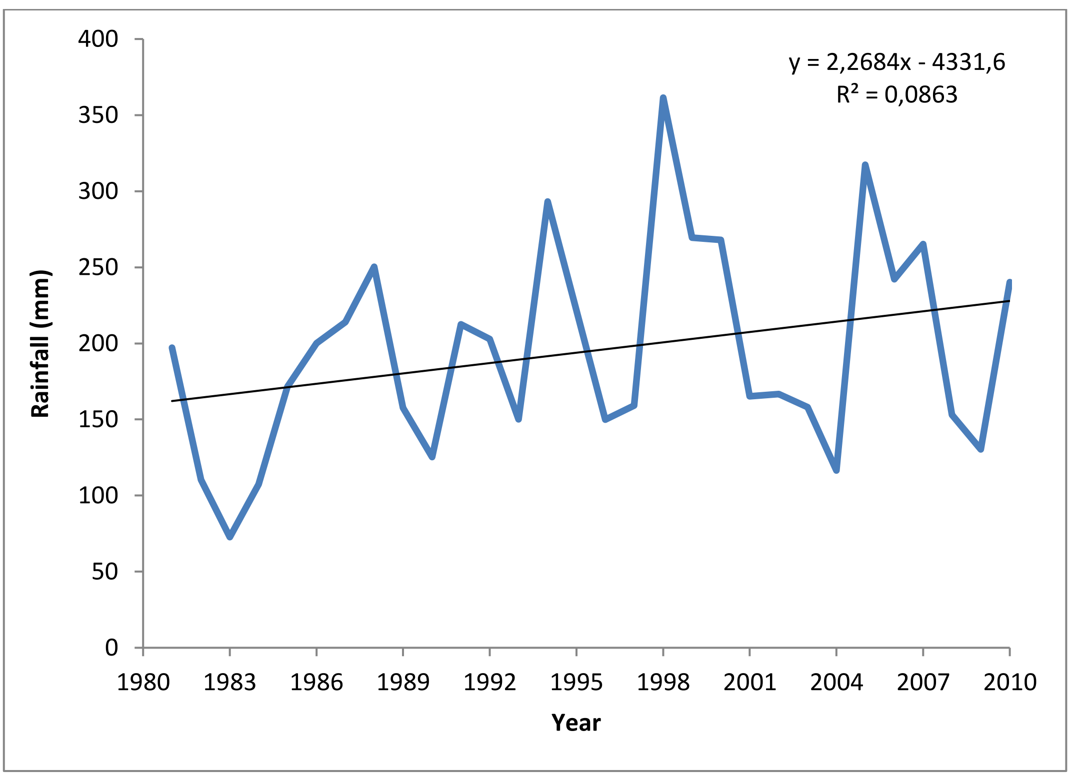

Figure 5. The trend of the annual rainfall for Elfasher in period 1981-2010

3. 2. Annual effective rainfall

The most important characteristic of rainfall vary from place to place day to day, month to month and also year to year is “effective rainfall". In its simplest sense, effective rainfall means useful or utilizable rainfall [14]. The variability of the annual effective rainfall in the five stations showed that the highest edge was very clear in Elobied which reached maximum value 564.4 mm in other hand the lowest edge was in Elfasher with value only 34.2 mm and Kassala 36.4 mm, this results explain the high variation between different stations (Figure 6). Regarding the mean effective rainfall range there were relatively different between station, where Elobied station recorded the highest value by range equal 452 mm and there relative rapprochement in Wadmedni and Kassala values, where Eldouim and Elfasher recorded lowest value by 17.2, 34.2 mm in 1983, 1984 respectively. The percentages between effective rainfall to annual rainfall (RF_{effe}/RF) were rapprochement in the five stations, where it recorded 67.7%, 70.6%, 68.6%, 72.2%, 66.1% in Kassala, Wadmedni, Eldouim, Elobied and Elfasher respectively. This finding agrees with [15] who cited that The percentages of (RF_{effe}/RF) rarely can exceed 70% in arid and semi-arid zone, where it may reach 85% in humid and sub-humid zone.

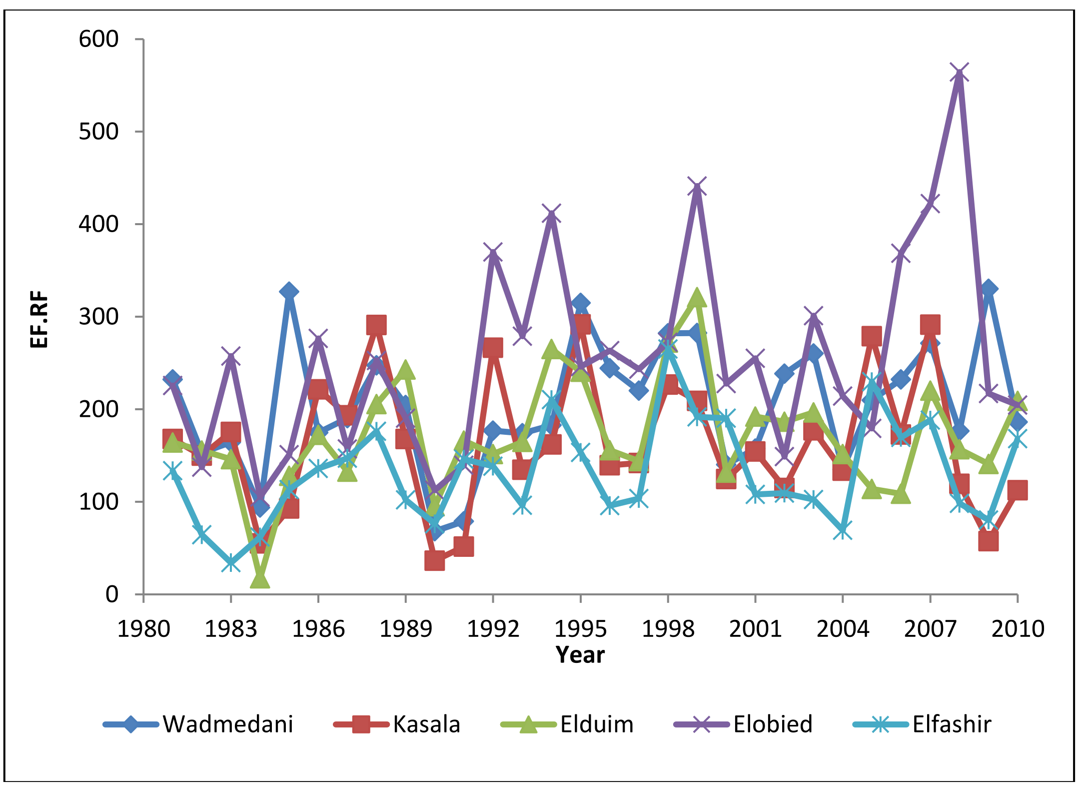

Figure 6. Annual effective rainfall for the five stations

3. 3. Cumulative Rainfall Departure (CRD)

The Cumulative Rainfall Departure (CRD) was increased during the certain period in this study for all five stations, where the highest edge was very clear in Elobied which reach maximum value 945 mm in 2008, while the lowest edge was clear in year 1991 in Kassala and Wadmedni which recorded - 45.2 - 42.4 mm, respectively (Figure 7). The time series analysis conducted using long-term annual cumulative rainfall departure for the five stations bordering the study area, showed that there was a gradual increase in the annual cumulative rainfall departure especially in Elobied station during the period of 1980 to 2010 for all stations, as showed in Figure (7).

These results agree with [11], who cited that the time series analysis conducted using monthly and long-term annual rainfall (1970-2005) for Shambat and Wad Medani from 1970 to 2004, showed that there has been a gradual increase in the monthly and annual rainfall during this period.

Regarding (R^2) values find that a noticed variation between station, where highest value in Elobied $R^2 = 0.32$ followed by Elfasher $R^2 = 0.13$, Wadmedni $R^2 = 0.14$, Eldouim $R^2 = 0.04$ and Kassala $R^2 = 0.006$.

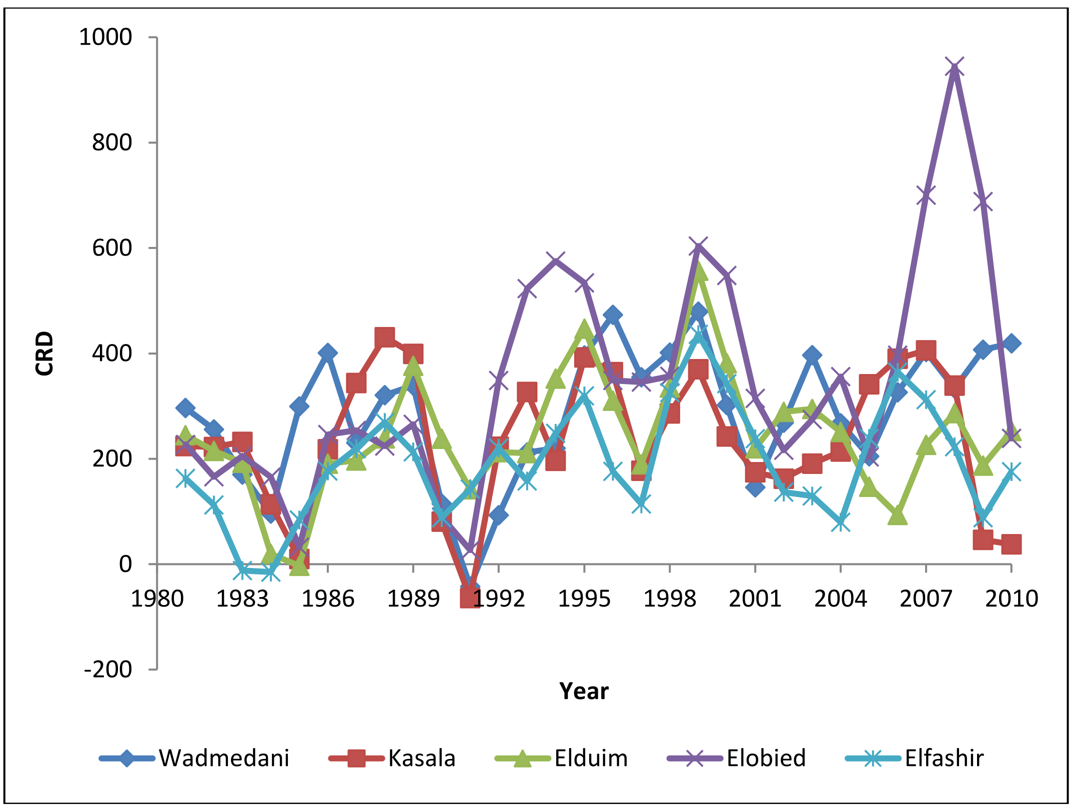

Figure 7. Cumulative Rainfall Departure (CRD) for the five stations

3. 4. Rainfall probability and return period

Recent attention has been focused toward determination of threshold rainfall levels in the estimation and prediction, one of important method to predict rainfall is rainfall return period. Additional attention should be paid toward use of rainfall return periods (RPs) for the estimation of mass wasting event occurrences, leveraging advances in computing and rainfall data collection.

The probability of the total annual rainfall not-exceeding 300 mm is 0.22, 0.41, 0.18, 0.61 and 0.08 for Kassala, Wadmedni, Eldouim, Elobied and Elfasher, respectively (Figure 8).

This means that the return period to receive annual rainfall of less than 300 mm is once every 4.61 year in Kassala and once every 2.4 years in Wadmedni and in Eldouim once every 5.4 years and every 2.61 in Elobied while in Elfasher it is once every 12.1 years. Regarding the probability of the total annual rainfall not-exceeding 350 mm 0.15, 0.21, 0.11, 0.38 and 0.1 for Kassala, Wadmedni, Eldouim, Elobied and Elfasher, respectively; with return period to receive annual rainfall of less than 350 mm is once every 6.6, 4.6, 8.6, 2.6 and 60 years for Kassala, Wadmedni, Eldouim, Elobied and Elfasher, respectively.

Figure (8) also demonstrates that 75% of the time the annual rainfall do not exceeded 240, 275, 278, 335, and 375 mm at Elfasher, Kassala, Eldouim, Medani and Elobied respectively. Similar results were found by [11] who cited that the probability of the total annual rainfall not-exceeding 350 mm is 0.98, 0.87, 0.7, and 0.05 for Shambat, Halfa, Wad Medani and El Gadaref respectively. Also demonstrates that 75% of the time the annual rainfall do not exceeded 170, 325, 382, and 656 mm at Shambat, Halfa, Wad Medani, and El Gadaref, respectively.

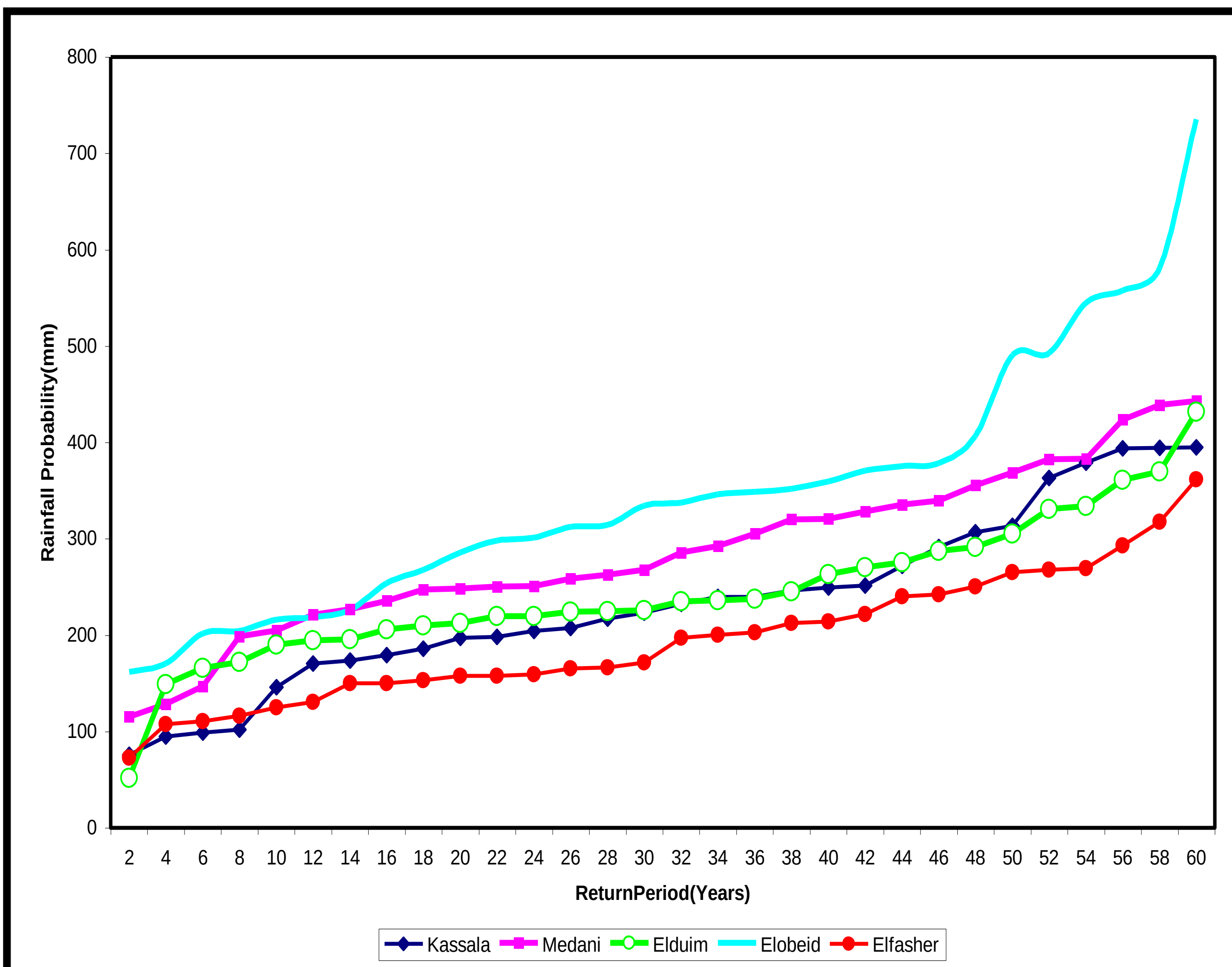

Figure 8. Rainfall probability and return period

3. 5. Temperature data analysis

The importance of temperature comes from its great effect on evapotranspiration. [16] analyzed the meteorological data of 63 stations in Sudan and concluded that the ratio between evapotranspiration (mm) and temperature (°C) is (ET_o/ T = 77.1) with standard error (SE = 2.1). In this study the mean annual temperature showed small variations between the five stations ranged in only 3.6 °C, however the maximum value was recorded in Kassala (30.1 °C) and the minimum was recorded in Elfasher (26.5 °C) as shown in Figure (9), where Wadmedni, Eldouim and Kassala record 29 °C, 29.7 °C, 27.8 °C respectively. Regarding temperature range the highest value recorded in Elobied (4.8 °C) followed by Elfasher (4.2 °C) while Kassala, Eldouim and Wadmedni recorded 2 °C, 2.3 °C, 2.8 °C, respectively. Also it is clear that the 0highest value of long-term mean air temperature was 31.1 °C which was recorded three times during period 1981-2010 in Eldouim 1997 and in Kassala 2008, 2009. The monthly long-term air temperature showed a notice rapprochement between Kassala, Wadmedni and Eldouim stations. The maximum value of monthly air temperature occurrence in May in Kassala, Wadmedni, Eldouim and Elobied while it was in June in Elfasher station; where lowest value occurrence in January for the all five stations with recorded 25.7 °C, 24.6 °C, 24 °C, 21.9 °C, 19.8 °C in Kassala, Wadmedni, Eldouim and Elobied, respectively (Figure 9).

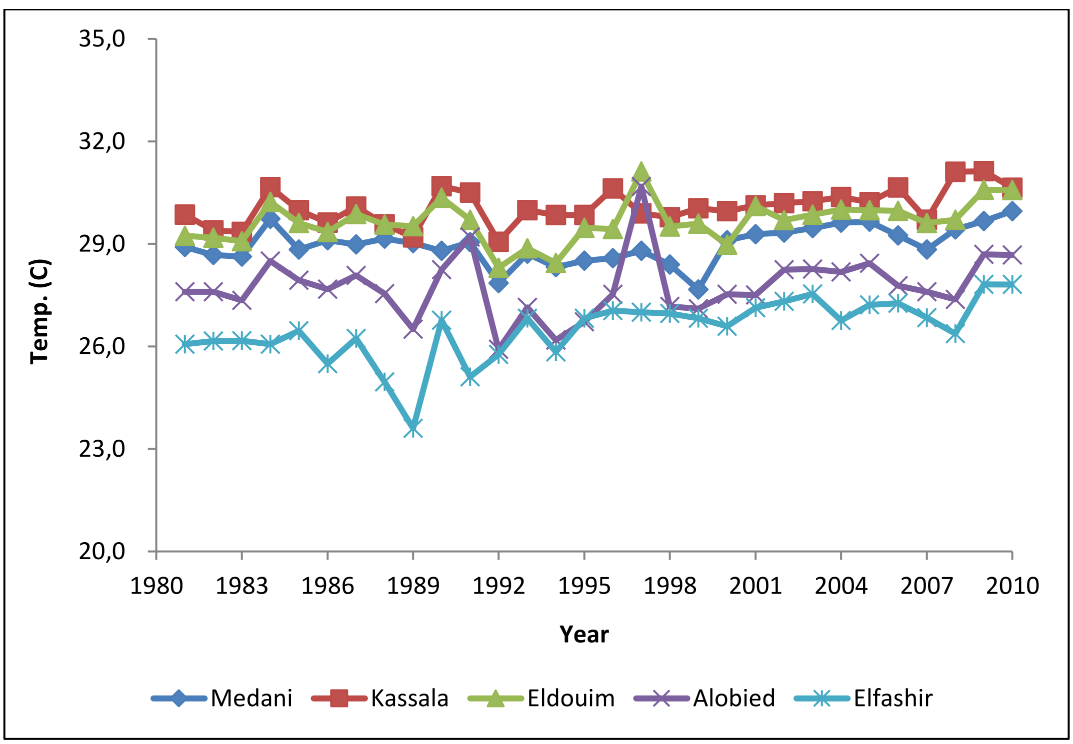

Figure 9. Annual mean air temperature of the stations (Kassala-Wadmedni- Eldouim-Elobied-Elfasher in period 1981-2010

The time series analysis for the maximum and minimum air temperature shows that there is an increasing trend for both maximum and minimum temperature in the five stations as illustrated in Figure (9) that represented Kassala, Wadmedni, Eldouim, Elobied and Elfasher stations respectively. This finding agree with [17] who cited that during the previous decades temperature is increasing in several places from decade to decade. In the extreme northern parts, the highest temperatures vary between 46 – 49 °C during May - June and the lowest minimum temperatures in winter vary between 2 – 10 °C during December – January. Also [2] reported that "Climate scenario analyses conducted as part of the preparation of Sudan's First National Communications indicated that average temperatures are expected to rise significantly relative to baseline expectations. By the end of 2060, it is expected that the warming ranges will increase from 1.5 °C to 3.1 °C during August to between 1.1 °C to 2.1 °C during the month of January".

Table (4) gives the result of the best-fit linear trend on the maximum and minimum air temperature of the five stations providing evidence of significant increasing variability for Kassala and Elfasher in the maximum air temperature with (p) values 0.021 and 0.009 respectively. On the other hand the minimum air temperature showed significant increasing variability for Kassala, Eldouim and Elfasher with (p) values 0.018, 0.002, 0.015, respectively. According to the [18], the global surface air temperature rose by 0.76 °C from 1850 to 2005. The IPCC observed that the rise in air temperature followed a linear trend over the previous 50 years. Similar finding were cited by [11] " Analysis of maximum and minimum air temperature long-term (1941-2004) data from Shambat, New Halfa, Elgadarief and Wadmedni stations, which located in arid and semi-arid zone, showed that there is an increasing trend for both maximum and minimum temperature, but it is not statistically significant for Shambat and Halfa. Also the maximum temperature of Wad Medani is not significant, although this station had a significant increase in the minimum temperature. El Gadaref station showed significant increase in both maximum and minimum temperature.

Table 4. Trends in inter–maximum and minimum air temperature their Significance levels ($p = 0.05$)

Station	Trend (Max)	Sig.	Trend (Min)	Sig.
Kassala	+ 0.039	0.021^{*}	+ 0.066	0.018^{*}
Wadmedni	+ 0.031	0.074^{ns}	+ 0.023	0.595^{ns}
Eldouim	+0.033	0.185^{ns}	+0.101	0.002^{*}
Elobied	+ 0.022	0.274^{ns}	+ 0.072	0.068^{ns}
Elfasher	+ 0.077	0.009^{*}	+ 0.078	0.015^{*}

ns = not significant; * = significant

3. 6. Rainfall and temperature sub-period analysis

The period of this study was from 1981 to 2010, it divided into three decades and analyzed the different between each sub-period on rainfall and temperature by cumbering deferent means using Duncan Multiple Range (DMR) at P≥0.05. The results showed that in rainfall there is no significant different between the three sub-period in all station except in Elobied station where (P = 0.041) and the sub-period (1990- 99) recorded the highest value (391.8 mm) followed by sub-period (2000-2010) (Table 5). In temperature there were significant deference between the three sub-period in Kassala, Eldouim and Elfasher stations. Where in Kassala station (P=0.022) the highest mean temperature value recorded in sub-period (2000-2010) equal 30.43 °C. In Eldouim station (P=0.036) the highest mean temperature value recorded also in sub-period (2000-2010) equal 30.02 °C, while Elfasher station recorded the highest mean temperature value in sub-period (1990 -1999) equal 30.02 with highly significant different (P) value equal (0.001) (Table 5). It is notice that Elobied station is the only one with significant difference between sub-periods in rainfall, but had no significant difference in temperature. This result confirms the negative relationship between rainfall and temperature.

Table 5. Rainfall and temperature time series analysis

Station	Period	Rainfall			Temperature		
		Mean	SE+	Sig.	Mean	SE+	Sig.
Kassala	1980-89 1990-99 2000-10	223.90 248.58 231.68	30.36 28.78 29.19	0.833	29.85^{b} 29.95^{b} 30.43^{a}	0.169 0.130 0.141	0.022^{*}
Wadmedni	1980-89 1990-99 2000-10	262.01 292.12 304.71	29.52 28.86 23.26	0.535	28.98 28.49 29.44	0.098 0.146 0.102	0.420
Eldouim	1980-89 1990-99 2000-10	212.54 281.57 239.55	24.20 26.42 15.45	0.111	29.61^{ab} 29.34^{b} 30.02^{a}	0.137 0.253 0.109	0.036^{*}
Elobied	1980-89 1990-99 2000-10	263.26^{c} 391.83^{a} 389.43^{ab}	24.89 36.29 51.16	0.041^{*}	27.69 27.51 28.08	0.174 0.452 0.151`	0.386
Elfasher	1980-89 1990-99 2000-10	160.67 228.86 195.48	17.71 21.90 20.90	0.076	25.82^{c} 29.47^{a} 27.20^{b}	0.292 0.209 0.141	0.001^{***}

*Means in the same litter followed by the same litter are not significant different according to Duncan Multiple Range at $P \geq 0.05$

3. 7. Aridity Index (AI)

Having demonstrated the changes in climatic conditions and patterns, it is useful to consider the possible changes in the aridity conditions also. According to the UNEP the highest aridity index values were obtained in July and August as during these months the area receives its highest rainfall [19]. Aridity can be equates with a deficiency of rainy days and ground moisture. In this study the Aridity Index in five stations for time period (1981-2010) has been computed using De Martonne (1926), which depend on rainfall and temperature data.

The results illustrated the variability of the Aridity Index in the five stations where the highest edge was very clear in Elobied which reached maximum value (11.11) recorded in 2007, on other hand, the lowest edge was in Eldouim with value only (0.86) recorded in 1983, where there were rapprochement between other stations (Figure 10). Also results showed that minimum aridity index values were found during June and October, when the rainfall is low and evapotranspiration is high (Figure 10).

From Figure (11) and Table (6) it can be concluded that the annual aridity index is increasing with time at Wadmedni, Eldouim, Elobied and Elfasher with no significant evidence, where Kassala showed decreasing trend not significantly. In Wadmedni and Elobied about 36% of points is above the semi-arid line which indicated that there are improvements in aridity conditions in these two areas. [11] according to analyzed of long-term data (1941-2004) cited that "There is a significant decreasing trend of the annual aridity index at Wad Medani and Shambat, indicating that there are intensifying arid conditions across the northern part of Butana area".

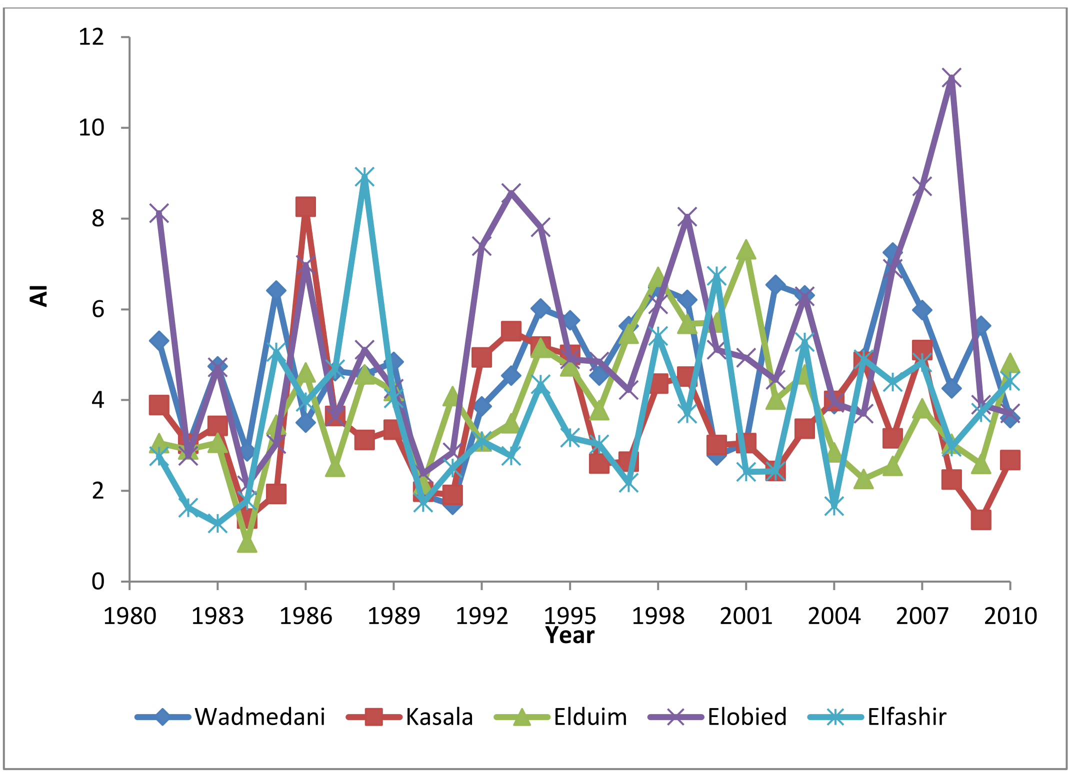

Figure 10. Annual mean Aridity Index (AI) of the stations (Kassala-Wadmedni- Eldouim-Elobied- Elfasher in period 1981-2010 (Data from SMA)

Table 6. Trends in inter–Aridity Index (AI) of variance and their Significance levels (p = 0.05)

Station	Trend	Sig.
Kassala	- 0.014	0.656 ns
Wadmedni	+ 0.046	0.134 ns

Eldouim	+ 0.034	0.258 ns
Elobied	+ 0.064	0.172 ns
Elfasher	+0.034	0.350 ns

ns = not significant; * = significant

3. 8. Standardized Precipitation Index (SPI)

The results illustrated the variability of the Standardized Precipitation Index (SPI) in five stations where the highest edge was very clear in Elobied which reached maximum value (2.82) recorded at 2007, on other hand, the lowest edge was in Eldouim with value only (-2.59) recorded at 1983 where there were rapprochement between other stations Figure (11). This results are typical to (AI) results in time and place, Justification of this finding is rainfall amount which recorded the highest value (during all the period) in Elobied (735.5 mm) at 2007, where the lowest value recorded in Eldouim (51.5) at 1983. Figure (11) showed the relation between monthly rainfall and SPI where the maximum SPI occurrence in the rainy moths especially in August.

From Figures (12, 13, 14, 15 and 16) and Table (7) it can be concluded that the annual Standardized Precipitation Index (SPI) is increasing with time at the five stations without statistical significant in the five stations. There were an evidences of improvement of drought conditions in all focal points in the study area. About 70 % of the time period were classify as near normal in Kassala, Wadmedni, Eldouim and Elobied; where the percentage about 56% in Elfasher station.

Also, Figures (12, 13, 14, 15 and 16) illustrated that about 16 %of the points in graph fill in moderately wet zone for five stations and there were some points in severity wet zone for Kassala and Wadmedni and in extreme wet zone for Eldouim, Elobied and Elfasher. On the other hand, the severity dry zone conditions occurred in Kassala and Wadmedni at 1990 and in Elfasher at 1983, where extreme dry zone occurrence only one time in Eldouim at 1984.

Similar results reported by [20] " Analyzed of SPI in the period 1941-1970 for arid and semi-arid region in Sudan, it was clear that the wet conditions occurrence at several years lying in the extremely and severely wet classes. Most of the drought cases were mild and only one case was severe for June-August.

On the other hand, the wet cases were overwhelmingly mild and very rarely moderate". [11] according to analyzed of long-term data (1941-2004) from five stations in arid and semi-arid (Wadmedni, Shambat, New Halfa, Elgadaref) cited that " SPI analysis showed that throughout the Butana region the severe drought has occurred during 1984, 1990, 1991, while the drought during 1972, 1983 and 2000 affected only some parts of the area".

Also, [20] cited that according to analysis of time series of the standardized precipitation index (SPI) for the arid and semi-arid areas (using data from 13 stations distributed in hole region) of Sudan during the period 1941-2010 the results showed that drought has become more probable during the recent four decades, it recurs at shorter time intervals between drought spell.

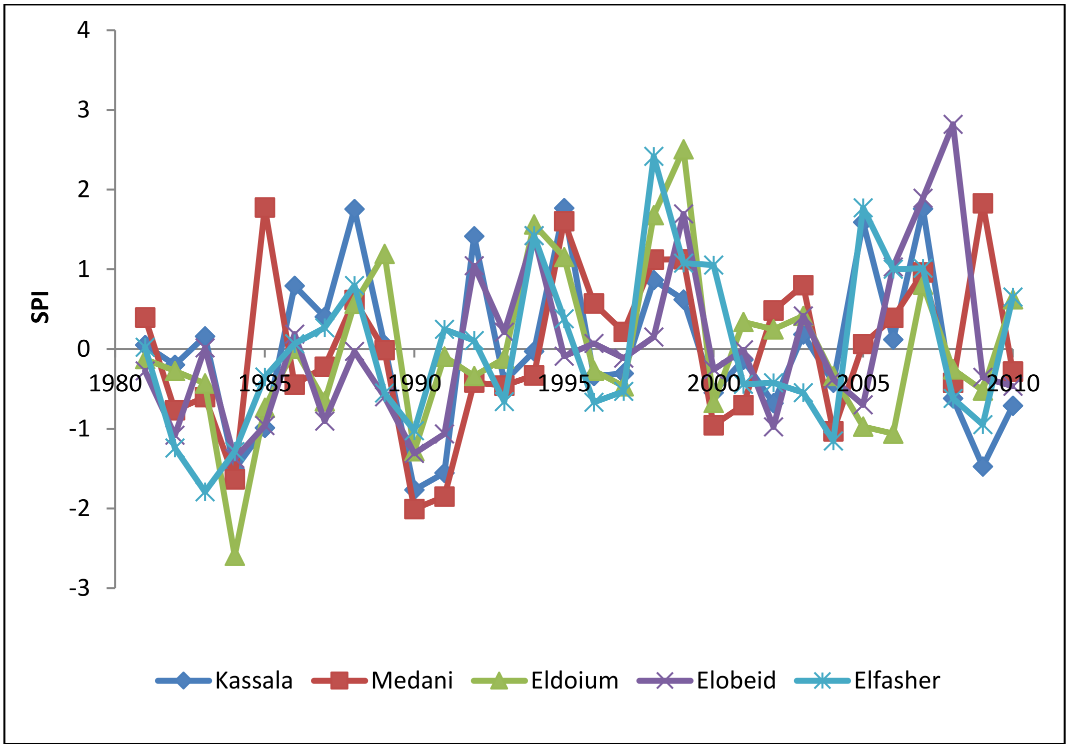

Figure 11. Annual mean Standardized Precipitation Index (SPI) of the stations (Kassala-Wadmedni- Eldouim-Elobied- Elfasher in period 1981-2010 (Data from SMA)

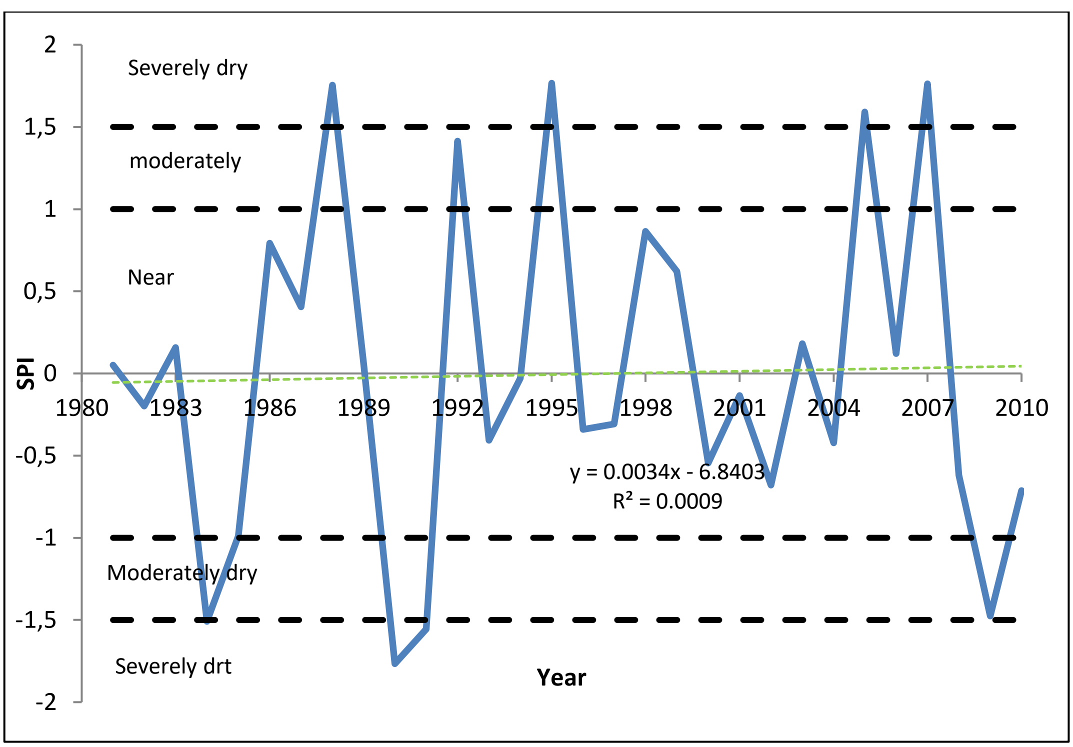

Figure 12. Standardized Precipitation Index trend in Kassala station in period 1981-2010

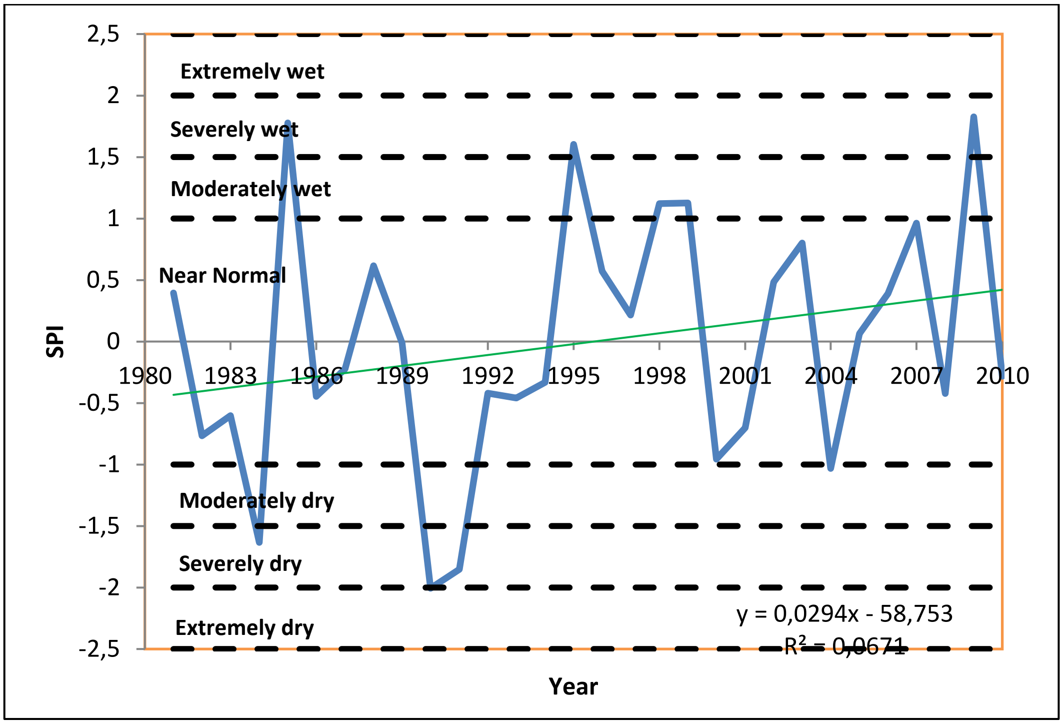

Figure 13. Standardized Precipitation Index trend in Wadmedani station in period 1981-2010

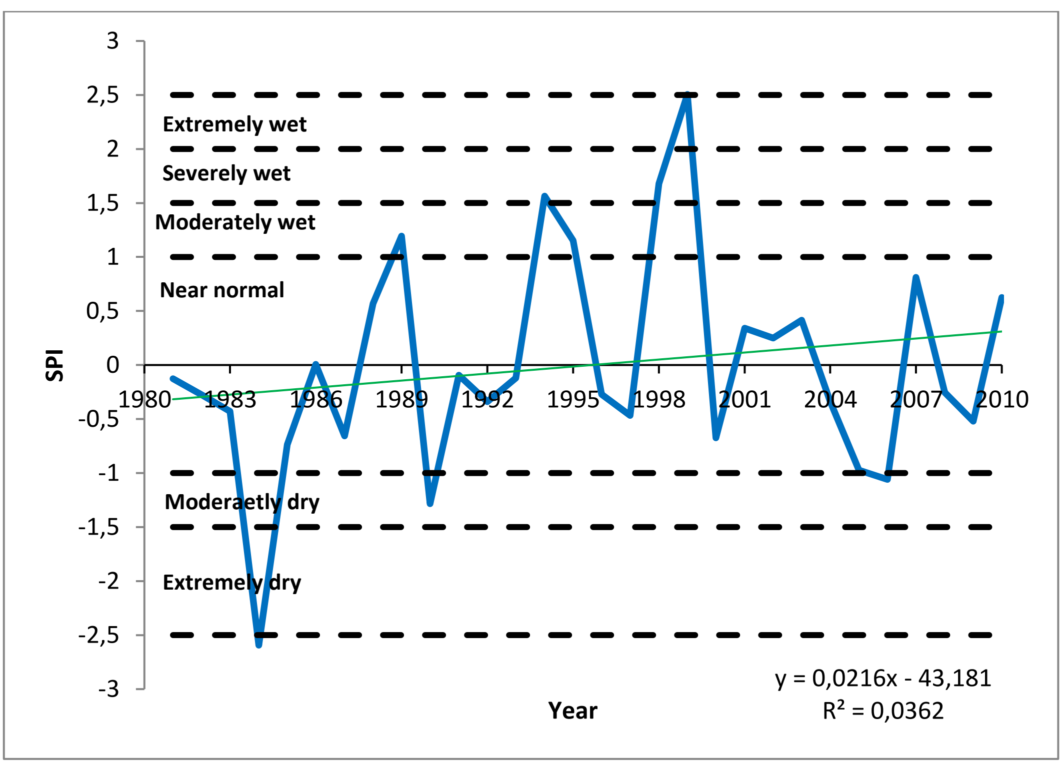

Figure 14. Standardized Precipitation Index trend in Eldouim station in period 1981-2010

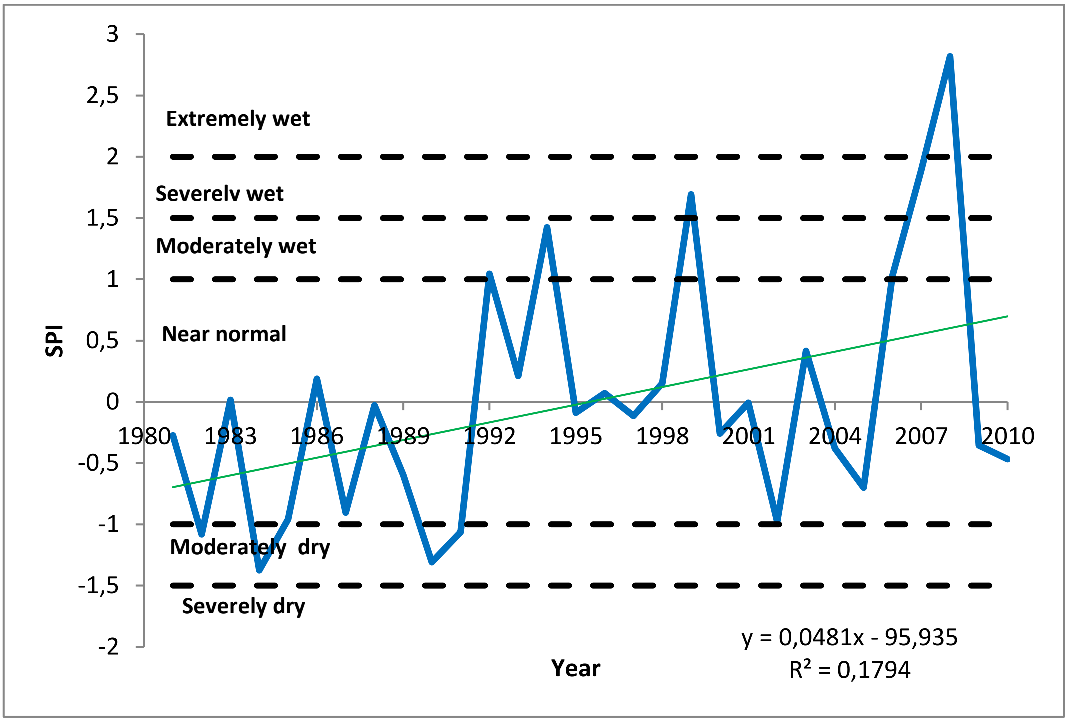

Figure 15. Standardized Precipitation Index trend in Elobied station in period 1981-2010

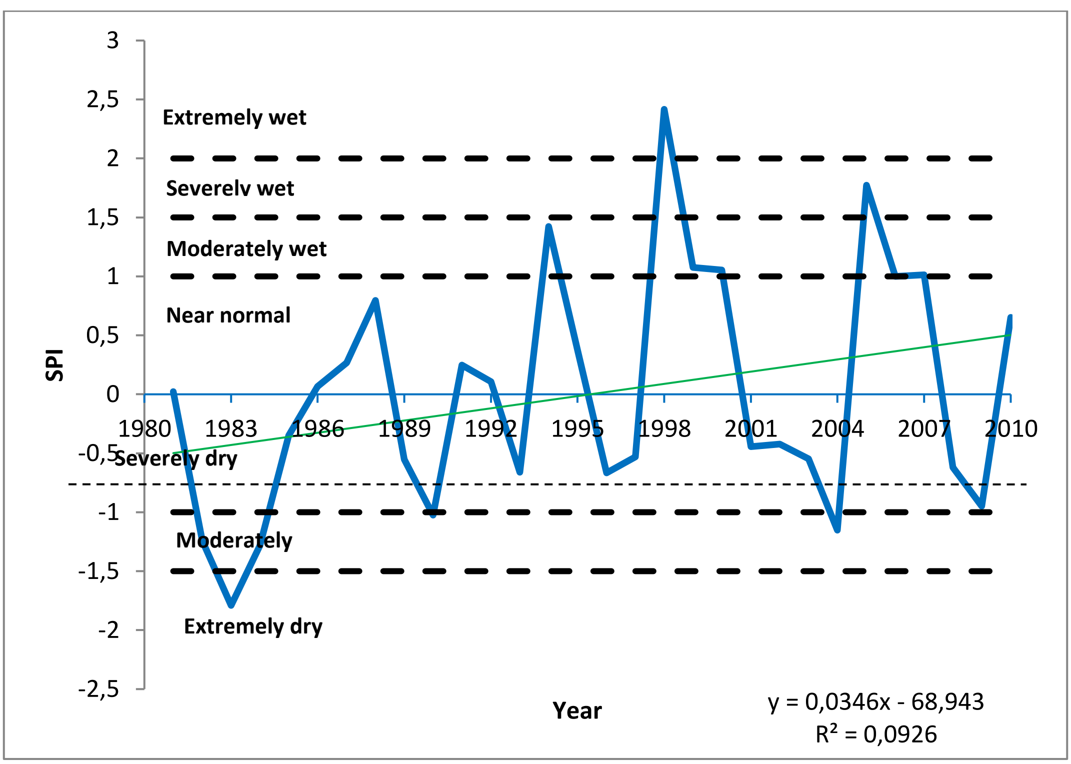

Figure 16. Standardized Precipitation Index trend in Elfasher station in period 1981-2010

Table 7. Trends in inter– Standardized Precipitation Index (SPI) of variance and their Significance levels (p = 0.05)

Station	Trend	Sig.
Kassala	+ 0.003	0.874^{ns}
Wadmedni	+ 0.029	0.167^{ns}
Eldouim	+ 0.021	0.314^{ns}
Elobied	+ 0.048	0.020^{*}
Elfasher	+ 0.035	0.102^{ns}

ns = not significant; * = significant

4. CONCLUSSION

The general climatic trend in the study area showed that there were increasing in most of climate factors in the five stations. In Kassala station all factors increased among the time except Aridity Index which showed non significant decrease with time. The significant increased obtained in mean annual temperature and Potential Evapotranspiration (ETp) with P≤0.05 value (0.004) for all five stations. In Wadmedni station all climatic factors were increased among the time where temperature, ETp and CRD showed statistical significant with P≤0.05 value(0.045), (0.043) and (0.039), respectively.

In Eldouim station all climatic factors increased along the time where only mean annual temperature showed statistical significant with P≤0.05 value (0.037). In Elobied station all climatic factors increased along the time where mean annual rainfall, CRD, effective rainfall, rainfall coefficient of variance (CV) and SPI showed statistical significant with P ≤ 0.05 value (0.022), (0.001), (0.022), (0.022) and (0.020), respectively. In Elfasher station all factors increased along the time except Potential Evapotranspiration (ETp) which showed decreasing trend with highly significant evidence where P≤0.05 value (0.000^{**}), also the significant increased obtained in mean annual temperature and Cumulative Rainfall Departure (CRD) with P≤0.05 value (0.000^{**}) and (0.047), respectively.

The mentioned results explained that during the period from 1981 to 2010 mean annual air temperature have statistical significant increasing in the four out of five stations in this study. While annual rainfall have statistical significant in just Elobied station which was the only station recorded not significant increasing of mean air temperature.

These results may justify the opposite relationship between rainfall and temperature. Cumulative Rainfall Departure (CRD) and Potential Evapotranspiration (ETp) have statistical significant in three stations, where Aridity Index (AI) has no statistical significant in all stations.

These results provide indicators that the climate trend gets drier by increasing mean air temperature and ETp, on the other hand, indications of climate improvement by increasing CRD among the time.

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