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## Research Article

# ASSESSMENT OF RAINFALL SEASONALITY, CONCENTRATION AND EROSIVITY INDICES FOR THREE DIFFERENT CLIMATIC ZONES IN SUDAN.

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**ABSTRACT**

This study was based on rainfall meteorological data (1960-2010) from three meteorological stations namely: Dongola, Khartoum and Al-damazine represented different climatic zones of Sudan, hyper-arid, arid and semi-arid respectively. The main objectives of this study conducted in the targeted areas to show data on rainfall indices such as, seasonality (SI), concentration (PCI) and erosivity (MFI), beside investigation the changes in annually and monthly rainfall, also comparing the total rain gauge in two temporal periods 1960-1984 and rain gauge 1985-2009. In addition to generate empirical relationship between rainfall and erosivity (MFI) index. The data subjected to statistical analysis by using SPSS and regression done by "Excel, 2000". The results showed that the variation due to month was much higher than the annually. The monthly coefficient of variation for three meteorological stations, Dongola, Khartoum and Al-damazine were 1.3, 1.1 and 1.04 fold that measured annually. The highest contribution of the monthly rainfall in the three meteorological stations during 1960-2010 recorded in July and Aug. whereas absolutely lowest contribution of the monthly rainfall in Aldamazin, Khartoum and Dongola recorded in Dec. Annual overall means of the three meteorological stations significantly decreased in following order: Aldamazine> Khartoum> Dongola. The results revealed that Dongola, Khartoum and Aldamazine stations, the seasonality index accounted about 0.85, 0.99 and 0.90 mm respectively, so seasonality index in studied areas can be described as markedly seasonal with a long drier season. PCI in studied areas can be described as highly seasonal in Khartoum and Aldamazine but in Dongola gave irregular pattern of PCI. MFI in studied areas can be described as very low, low and high for Dongola, Khartoum and Aldamazine respectively. According to this finding the susceptibility of water erosion can flow the same order. The results for Dongola and Khartoum stations showed that the total rain gauge in two successive periods 1960-1984 (first period) and 1985-2009 (second period), decreased from first period to second by 30.2% and 11.9% respectively, but Aldamazin station gave very meager increasing accounted about 0.35. Eventually, since MFI for Dongola area gave higher correlation coefficient with annual total rainfall and the differences not exceeds plus or minus 4.5, thus it is recommended to predict MFI using the following equation: Y = -0.0003x3+0.0268x2+0.2958x+0.7752.

***Keywords:*** Dongola, Khartoum, Al – Damazine, Climatic zones, seasonality, concentration, erosivity, rain gauge and correlation coefficient.

## INTRODUCTION

As matter of fact the rainfall as climatic element is the most complex and high variability with temporal and spatial levels. Even in the absence of changes in the overall rainfall amount, but the rainfall distribution through the year may reflect noticed changes (Sumner *et al., 2001*). Changes leading to important impacts on the severity and timing of erosive rainfall, which seriously affect the agricultural and socio-economic activities (Diodato and Bellocchi, 2009). Torrential and high rainfall events make the soil highly susceptible to erosion (Jebari *et al., 2008*), resulting intensifying and increasing the flow of sediment into rivers, increases pollutants affecting the fresh water quality through reaching the water supply systems (Munka *et al., 2007*). This issue takes high importance in the context of climate change (Angulo-Martı´nez and Beguerı´a, 2009). The assessment of wind erosion and specify of areas falling under this risk plays a vital role in creating appropriate adaptation and mitigation strategies for the protection of soil and water resources and crop management practices, particularly in arid areas (Joshua, 1976; Bayramin *et al., 2006*; De Luis *et al.,2009*). Several research has been conducted on climate in Sudan e.g. (Abdelwahab and Mustafa, 2015; Alzubair and Abdelwahab, 2021; Adam and Abdalla, 2008; Mohamed and Mohamed, 2010; Mohamed, 2012; Abuzaid and Abdelwahab, 2018; Elagib and Mansell, 2000a). The rainfall characteristics are essential for understanding, its variability in time and space and development of methods for estimating the risks due to erosion (Apaydin *et al., 2006*; Jebari *et al., 2008*; De Luis *et al., 2009*). Generation of analyzing meteorological data is essential for designing soil erosion control methods, particularly in arid lands. Furthermore, very little attention was given to meteorological data analysis in Sudan till now, so it is necessary to carry out studies in all climate elements particularly in arid lands to avoid its negative impacts. The present study was undertaken to achieve the following objectives:

1. To generate broad–base quantitative data on rainfall changes and trends happening in seasonality (SI), concentration (PCI) and erosivity (MFI) indices for three different climatic zones of Sudan, and compared between them, that may help in designing soil erosion control projects.
2. To investigate and illustrate the changes in annual rainfall and monthly rainfall in the study areas, using rainfall measurements during the period 1960-2010.
3. To show the trends of rainfall by compare the total rain gauge in two temporal periods 1960-1984 and rain gauge 1985-2009.

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4. To generate empirical relationship between rainfall and erosivity (MFI) index, that derived from regression analysis, in order to determine the susceptibility of water erosion in the study area.

## MATERIALS AND METHODS

### Study area

Three meteorological stations were selected in this study, falling in three different climatic zones, namely: Dongola (hyper-arid), Khartoum (arid) and Al-damazine (semi-arid).

**Dongola area (Northern State).**

Dongola area is located in northern state of the country, which lies between latitudes 17˚ 45' 19˚ 15' N and longitude 30˚15'-32˚ 00' E. The occupaied an area of approximately 348697 km$^2$ *with* three meteorological stations in the state, located at Wadi Halfa, Dongolla and Karima. The climate predominant in the state can describe as desert (hyper-arid), typical continental, with two seasons, a hot summer from April to September and cold winter from October to March. The relative humidity is low, the highest evaporation recorded in May and the lowest in January; the maximum duration of sunshine is 11.9 hours in June and the lowest duration is 9.8 hours in December and the highest vapor pressure occurs in August and the lowest occur in February (Abuzaid, 2009). *Generally the rain* increases from effectively zero at the extreme northern border with Egypt to south. The average total annual rainfalls are 3, 18 and 37.7mm in Wadi Halfa, Dongolla and Karima respectively. Rainfall is very low falling in August. The highest mean maximum temperature recorded is 43.1˚C in Dongolla, while the absolute maximum is 49˚C in Wadi Halfa. The mean minimum recorded temperature 8.3˚C and absolute minimum is 1$^o$C both recorded in Wadi Halfa (Abuzaid, 2009).

**Khartoum area (Khartoum State).**

The study was conducted in the Khartoum state, which is affected by desertification processes. Khartoum state is characterized by an arid climate with two distinct season winter and summer (Kevie, 1973). During the hot summer months (April to July) the temperature ranges from 27 to 39 $^o$C. During the winter months (December-February), the mean daily minimum and maximum temperatures range from 18-27$^o$C (Lieth, 1999). Period extended from July to September temperature are moderated by rains totaling 155 mm, which reflects to an increase in humidity (Eltayeb, 2003).

**Aldamazine area (Blue Nile State).**

The Blue Nile State is located at the southeastern part of the Sudan in the semi wet zone. It lies between latitudes 9$^o$ 30' N and 12 $^o$ 30' N and longitudes 35$^o$ 30' E and 33$^o$ 50' E., with a total area of 40000 km$^2$ (UNDP, 2010). It is bordered by Ethiopia from the east and southeast, South Sudan from the west and south and Sinnar State from the north. The capital is Aldamazine with the distance of 550 Km. from Khartoum. It lies in the fertile woodland savannah belt of eastern Sudan, and receives significant rainfall through much of the year. It is characterized by vast clay plains, the Ingessana Mountains and the Blue Nile River flowing northwest from the Ethiopian highlands. There is a huge land for cultivation in both mechanized and traditional rain fed sectors, huge potential for fishing grounds, seasonal streams traversing the state fertile land along the banks of Blue Nile River, which are suitable for vegetable and fruit production and great number of livestock. The total population of Blue Nile State is about 832112, out of which 421758 are males and 410354 are females with an annual growth rate of 3%. The climate is typical of the high rainfall Woodland Savannah. The average rainfall between 750 – 1200, it start at May reaches peak at August and ends in October. The relative annual humidity is between 60 – 65% and the average annual temperature range between 35-40$^o$ C. (Meteorology Office, Aldamazine, 2017). Three different climatic zones under study are presented in figure (1).


**Fig.1.** Location of the study area

## Data and Analysis

Three meteorological stations were selected in this study to represent three States namely: Northern, Khartoum and Blue Nile States. The locations of the rainfall data points are, Dongola, Khartoum and Al-damazine. These stations were selected to detect on reliability, continuity and availability of long-term data for the regions and assess seasonality (SI), concentration (PCI) and erosivity (MFI) indices by using rainfall measurements during the period 1960-2010. No missing data exist in the time-series. This study uses the index designed by Walsh and Lawler (1981) to assess the aspect of rainfall seasonality as:

$$SI = \frac{1}{R}\sum_{n=1}^{12}\left|X_n - \frac{R}{12}\right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where $X_n$ = rainfall of month n and R= annual rainfall. The index has been used by several researchers (Bello, 1998; Sumner *et al*., 2001; Livada and Asimakopoulos, 2005; Pryor and Schoof, 2008). The index varies from zero, if all the months have equal rainfall, to 1.83 if all the rainfall occurs in a single month. A qualitative classification of degrees of seasonality is suggested as very equable (SI<0.19), equable but with a definite wetter season (0.20-0.39), rather seasonal with a short drier season (0.40-0.59), seasonal (0.60-0.79), markedly seasonal with a long drier season (0.80-0.99), most rain in 3 months or less (1.00-1.19) and extreme seasonality (almost all rain in 1–2 months) where SI≥1.20. Furthermore seasonality (SI) also may be estimated by concentration index (PCI), suggested by Oliver (1980) as follows:

$$PCI = 100 \times \sum_{n=1}^{12}\left(\frac{x_n^2}{R^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The PCI description categories set as follows: (PCI=8.3–10), moderately seasonal (PCI=10–15), seasonal (PCI=15–20), highly seasonal (PCI=20–50) and irregular (PCI=50–100). This index was utilized by Apaydin *et al.,* (2006). The last index assesses the effect of erosion by rainfall which modified by Arnoldus (1980), recognized by MFI expressed as follows:

$$MFI = \sum_{n=1}^{12}\left(\frac{x_n^2}{R}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

High MFI values mean a greater severity while lower values indicate very light severity of rainfall. The erosivity categories of MFI organized as very low (MFI=0–60), low (MFI=60–90), moderate (MFI=90–120), high (MFI=120–160) and very high (MFI>160). This index calculation gave valuable in determing the erosive potential of rainfall by providing information on the long-term variability (Oduro-Afriyie, 1996; Apaydin *et al.,* 2006; Bayramin *et al.,* 2006; Munka *et al*., 2007; De Luis *et al*., 2009). The station data includes rainless observations in some years (14 years for Dongola), so the results value which generated in equations (1)-(3) is zero in these cases. Thus, no values have been calculated because of corresponding division by zero in those rainless years.

### Statistical analysis

All the time-series of monthly, maximum monthly and annual rainfalls and SI, PCI and MFI, for the period 1960-2010 have been investigated for their direction of trends by using the Statistical Package for the Social Sciences (SPSS). Analysis of variance and separation of means were undertaken according to Gomez and Gomez (1984). The test was applied on the SI, PCI and MFI series for the common data period with the rainless years being excluded. Simple regression analysis (Little and Jackson, 1975) was made by "Excel 2000".

# RESULTS AND DISCUSSIONS

## Results

### Monthly and annually rainfall in study areas, during the period 1960-2010

### Dongola station

Table 1 shows the statistical parameters for monthly rainfall (mm) at three meteorological stations extended from 1960-2010. The mean values of months ranged from 0 mm(Nov.& Dec.) to 273.9 mm(Aug.) with a mean of 10.7 mm a standard deviation (STD) of 2.8 mm and a coefficient of variation (CV) of 409.3%. The mean annually data ranged from 0 mm (14years) to 68 mm in the year of 1994 with a mean of 10.7 mm a STD of 33.5 and a CV of 314%. The variation due to month was much higher than the annually. The monthly coefficient of variation was 1.3 fold that measured annually. Some months gave the highest means of rainfall, these months are June, July, August and September. So, that can be considered as effective months and presented in table 2. The mean of rainfall by the Aug. month significantly greater than that produced by Sept. However, Aug. was not significantly different from that generated by Jun and July months, as well as Sept. with June and July. Statistically, main effects of month were in the following significant order: (Aug.> Sept.>) = July = June; the equal sign indicates that there was no significant effect (table.2).

### Khartoum station

Table 1 shows the main effect of month. Mean values of months ranged from 0 mm (Feb.& Dec.) to 3006 mm(Aug.) with a mean of 134.6 mm a STD of 13.3 mm and a CV of 265.7%. The mean annually data ranged from 0 mm to 301 mm in the year of 1988 with a mean of 134.6 mm a STD of 321.7 and a CV of 239%. The variation due to month was much higher than the annually, the monthly coefficient of variation was 1.1 fold that measured annually. Table 2. Shows that the mean of rainfall recorded by the Aug. month was significantly greater than June, July and Sept. Whereas there was significance differs between June and July but there was no significant observed between latest months and Sept. month. Statistically, main effects of month were in the following significant order: Aug.>(July >June)=Sept.; the equal sign indicates that there was no significant effect.

### Al-damazine station

Table (1) shows the main effect of month, values of months ranged from 0 mm (Jan.) to 9139 mm (July.) with a mean of 702.6 mm a STD of 26.8 mm and a CV of 175.3%. The mean annually data ranged from 0 mm to 1041 mm in the year of 1980 with a mean of 702.6 mm a STD of 1178 and a CV of 168%. The variation due to month was much higher than the annually, the monthly coefficient of variation was 1.04 fold that measured annually. Annual overall means of the three meteorological stations significantly decreased in following order: Aldamazine> Khartoum> Dongola. The highest contribution of the monthly rainfall in the three meteorological stations during 1960-2010 recorded in July and Aug. as follows: Aldamazine 9139 mm (July), 8941 mm (Aug.) > Khartoum 1796 mm (July), 3006 mm (Aug.) > Dongola 161.3 mm (July), 274mm (Aug.). For the lowest contribution of the monthly rainfall in Aldamazin and Khartoum recorded in Jan., Feb. and Dec. Regarding to Dongola all months seems to be equal with very meager differs except June, July and August. Figures 2 &3 showed annual and monthly rainfall for three meteorological stations. Table (2). Shows that mean of rainfall of both July and August were significantly higher than June and Sept., whereas there was significant difference between them. On the other hand, there was no significant difference between June and Sept. Statistically, main effects of month were in the following significant order: Aug.=July > June=Sept.; the equal sign indicates that there was no significant effect.

**Table (1). Statistical parameters for monthly rainfall (mm) at three meteorological stations extended from 1960-2010.**

| Station | Statistical parameters | Month | | | | | | | | | | | | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan. | Feb. | Mar. | Apr. | May | Jun | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. | |
| Dongola (Hyper arid) | Sum | 7.4 | 2.9 | 1.3 | 2.0 | 20 | 61.8 | 161.3 | 274 | 9.0 | 12.8 | 0.0 | 0.0 | 545.4 |
| | $\bar{x}$ | 0.15 | 0.06 | 0.03 | 0.04 | 0.39 | 1.2 | 3.2 | 5.4 | 0.18 | 0.25 | 0.0 | 0.0 | 10.7 |
| | Min. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0.0 | 0.0 |
| | Max. | 6.2 | 1.5 | 1.0 | 2.0 | 12.4 | 61 | 49.6 | 49 | 4.4 | 7 | 0.0 | 0.0 | 68 |
| | STD | 0.88 | 0.28 | 0.15 | 0.28 | 1.9 | 8.5 | 8.5 | 10.8 | 0.65 | 1.3 | 0.0 | 0.0 | 33.5 |
| | CV (%) | 607.2 | 500.2 | 570.4 | 714.1 | 474.6 | 704.8 | 267.3 | 200.8 | 370.8 | 502.2 | 0.0 | 0.0 | 314% |
| Khartoum (Arid) | Sum | 0.6 | 0.0 | 3.6 | 27 | 243 | 270 | 1796 | 3006 | 1105 | 319 | 22 | 0.0 | 6863 |
| | $\bar{x}$ | 0.01 | 0.0 | 0.1 | 0.5 | 4.8 | 5.3 | 35 | 59 | 22 | 6 | 0.4 | 0.0 | 134.6 |
| | Min. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Max. | 0.6 | 0.0 | 1.6 | 13 | 33 | 47 | 204 | 301 | 100 | 52 | 22 | 0.0 | 301 |
| | STD | 0.1 | 0.0 | 0.3 | 2.4 | 8 | 10 | 38 | 60 | 26 | 11 | 3 | 0.0 | 321.7 |
| | CV (%) | 714 | 0.0 | 431 | 463 | 164 | 198 | 108 | 102 | 118 | 176 | 714 | 0.0 | 239% |
| Aldamazine (Semi arid) | Sum | 0 | 4 | 110.8 | 636.8 | 2217 | 5904 | 9139 | 8941 | 6610 | 2123 | 139.7 | 8.8 | 35834 |
| | $\bar{x}$ | 0.0 | 0.08 | 2.2 | 12.5 | 43.5 | 115.8 | 179.2 | 175.3 | 129.6 | 41.6 | 2.7 | 0.17 | 702.6 |
| | Min. | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.1 | 64.2 | 88.6 | 45.7 | 1.7 | 0.0 | 0.0 | 0.0 |
| | Max. | 0.0 | 4 | 38.3 | 81.5 | 108.6 | 267.7 | 457.3 | 278.8 | 261 | 176 | 24.7 | 3.3 | 1041 |
| | STD | 0.0 | 0.56 | 6.8 | 20.5 | 29.0 | 53.7 | 71.5 | 48.6 | 53.7 | 30.7 | 5.8 | 0.70 | 1178 |
| | CV (%) | 0.0 | 714.1 | 311.2 | 163.9 | 66.6 | 46.4 | 40.0 | 27.7 | 41.4 | 73.8 | 212.3 | 406.7 | 168% |

**Table (2). Statistical analysis of effective months for three meteorological stations during three periods 1960 -1976, 1977-1993 and 1994 -2010.**

| Effective months | Means of three meteorological stations | | |
|---|---|---|---|
| | Dongola | Khartoum | Aldamazine |
| **June** | 20.6ab | 88.5c | 1968.1a |
| **July** | 53.8ab | 613.2b | 3046.2a |
| **August** | 89.3a | 1013a | 2980.3b |
| **September** | 3.0b | 368.2bc | 2203.4b |
| **S.E +** | 23.4 | 97.5 | 102.3 |
| **CV (%)** | 97.4 | 32.4 | 6.9 |

- Each data point is a mean of three data points (1960 -1976, 1977-1993 and 1994 -2010).
- Means followed by the same letters are not significantly different from each other at the 0.05 level by Duncan Multiple Range Test.

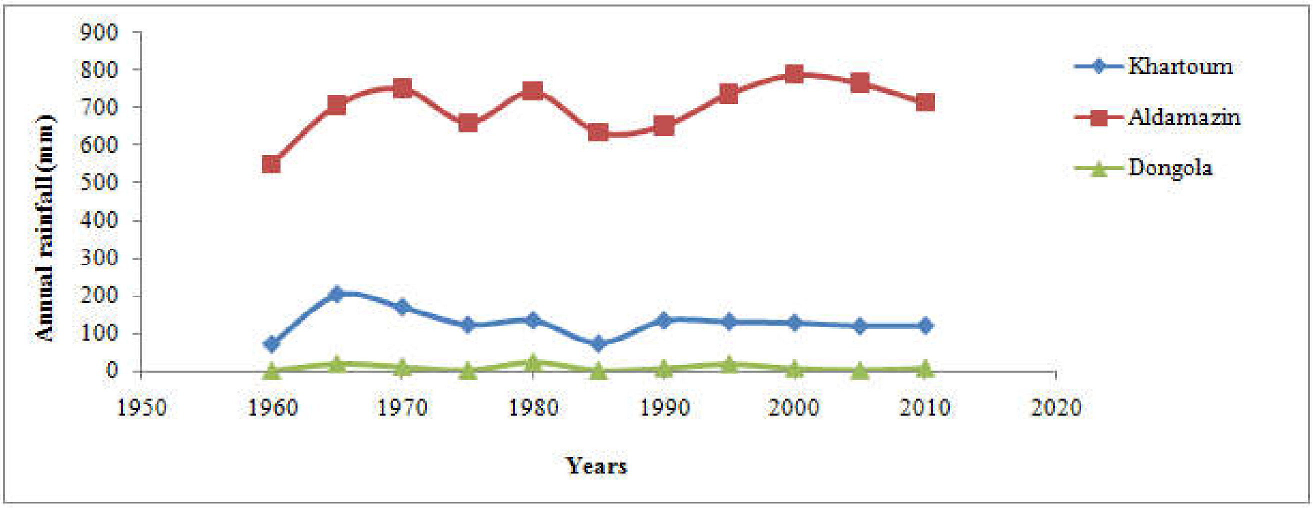


**Fig. 2.** Changes in annual rainfall expressed as 5 years running means

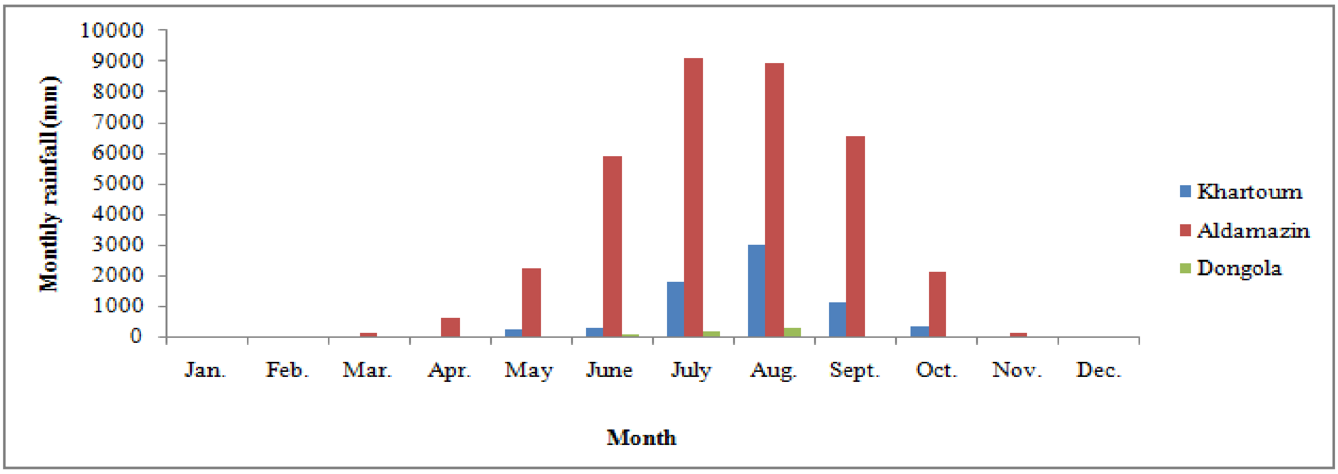


**Fig.3.** Monthly total of rainfall (mm) for three meteorological stations during 1960-2010

### Changes of the rainfall during two periods 1960-1984 and 1985-2009

The total rain gauge from 1960-2009 for the three meteorological stations decreased in the following order Aldamazin (35834 mm) > Khartoum (6791.8 mm) > Dongola (552.4 mm), with a mean accounted 702.6, 133.2 and 10.8 mm for Aldamazin, Khartoum and Dongola stations respectively. Table (3) shows the total rain gauge in two targeted periods 1960-1984 (first period) and 1985-2009 (second period). For Dongola and Khartoum stations the rain decreased from first period to second by 30.2% and 11.9% respectively, but Aldamazin station gave very meager increasing accounted about 0.35. According to these findings there is attendance to increasing aridity in Dongola and Khartoum areas. Referring to Aldamazine station there is no changes in rain status in two studied periods

**Table (3). Rain gauge reading for two studied periods 1960-1984 and 1985-2009**

| Station | Rain gauge 1960-1984 (mm) | Rain gauge 1985-2009 (mm) | Total rain gauge 1960-2009 (mm) | Increase (mm) | Decrease (mm) | Percentage (%) |
|---|---|---|---|---|---|---|
| **Dongola** | 316.7 | 220.9 | 552.4 | - | -95.8 | 30.2 |
| **Khartoum** | 3570 | 3144.7 | 6791.8 | - | -425.3 | 11.9 |
| **Aldamazine** | 17525.2 | 17587 | 35834 | +61.8 | | 0.35 |

### Rainfall indices seasonality (SI), concentration (PCI) and erosivity (MFI) in three meteorological stations for the study period (1960-2010)

### Seasonality Index (SI)

Table 4 shows the SI in three meteorological stations. The values of SI for Dongola, Khartoum and Al-damazine meteorological stations ranged from 0 to 6.1 mm with a mean of 0.85 mm, a standard deviation (STD) of 1.3 mm and a coefficient of variation (CV) of 154.9%, ranged from 0.08 to 14.2 mm with a mean of 0.99 mm, a STD of 2.6 mm and a CV of 264.7% and ranged from 0.86 to 0.94 mm with a mean of 0.90 mm, a STD of 0.02 mm and a CV of 1.7%, respectively. For Dongola, Khartoum and Al-damazine stations, the seasonality index accounted about 0.85, 0.99 and 0.90 mm respectively, so seasonality index in studied areas can be described as markedly seasonal with a long drier season.

### Precipitation Concentration Index (PCI)

Table 4 shows the PCI in three meteorological stations. The values of SI for Dongola, Khartoum and Al-damazine meteorological stations ranged from 0 to 100 mm with a mean of 63 mm, a STD of 42.3 mm and a CV of 67.2%, ranged from 21.1 to 74.6 mm with a mean of 45.4 mm, a STD of 14.5 mm and a CV of 31.9% and ranged from 14.6 to 27.9 mm with a mean of 22.2 mm, a STD of 2.9 mm and a CV of 12.9%, respectively. For Dongola, Khartoum and Al-damazine stations, the PCI accounted about 63, 45.4 and 22.2 mm respectively. Precipitation Concentration Index (PCI) in studied areas can be described as highly seasonal in Khartoum and Aldamazine but in Dongola gave irregular pattern of PCI.

### Erosivity (MFI)

Erosivity (MFI) in three meteorological stations was shown in table (4). The values of MFI for Dongola, Khartoum and Al-damazine meteorological stations ranged from 0 to 51.3 mm with a mean of 8.9 mm, a STD of 12.6 mm and a CV of 153.2, ranged from 2.2 to 236.3 mm with a mean of 61 mm, a STD of 47.9 mm and a CV of 78.6% and ranged from 96.9 to 290.5 mm with a mean of 155.8 mm, a STD of 31.5 mm and a CV of 20.2%, respectively. For Dongola, Khartoum and Al-damazine stations, the MFI accounted about 8.9, 61 and 155.8 mm respectively. Erosivity (MFI) in studied areas can be described as very low, low and high for Dongola, Khartoum and Al-damazine respectively. According to this finding the susceptibility of water erosion can flow the same order.

**Table (4). Statistical parameters of SI, PCI and MFI in three meteorological stations for the study period (1960-2010)**

| Station | Rainfall indices | Min. | Max. | Mean | STD | CV (%) | Description |
|---|---|---|---|---|---|---|---|
| Dongola | SI | 0 | 6.1 | 0.85 | 1.3 | 154.9 | Markedly seasonal with a long drier season |
| | PCI | 0 | 100 | 63 | 42.3 | 67.2 | Irregular |
| | MFI | 0 | 51.3 | 8.9 | 13.6 | 153.2 | Very low |
| Khartoum | SI | 0.08 | 14.2 | 0.99 | 2.6 | 264.7 | markedly seasonal with a long drier season |
| | PCI | 21.1 | 74.6 | 45.4 | 14.5 | 31.9 | Highly seasonal |
| | MFI | 2.2 | 236.3 | 61 | 47.9 | 78.6 | Low |
| Aldamazine | SI | 0.86 | 0.94 | 0.90 | 0.02 | 1.7 | Markedly seasonal with a long drier season |
| | PCI | 14.6 | 27.9 | 22.2 | 2.9 | 12.9 | Highly seasonal |
| | MFI | 97 | 290.5 | 155.8 | 31.5 | 20.2 | High |

**The relationship between rainfall intensity and erosivity (MFI)**

The relationship between rainfall intensity (RI) and erosivity (MFI) for Dongola, Khartoum and Aldamazine, in sequence depicted in Figs. 4,5 and 6. In general, the relationship was gave strong correlation. Fig.(4). Shows a highly significant ($p<0.001$, $R=0.977$) cubic, increase of rainfall intensity with increase in erosivity (MFI). Rainfall intensity accounted for about 95% of the variability of the MFI. Fig.5. Shows a highly significant ($p<0.001$, $R=0.885$) squire, increase of rainfall intensity with increase in erosivity (MFI). Rainfall intensity accounted for about 78% of the variability of the MFI. Fig.(6). Shows a highly significant ($p<0.001$, $R=0.779$) squire, increase of rainfall intensity with increase in erosivity (MFI). Rainfall intensity accounted for about 61% of the variability of the MFI. Regression analysis between rainfall intensity and MFI data is presented in Table 5.

**Table (5). Equations of the trend lines showing the relationship between RI and MFI in three meteorological stations**

| Station | Type of equation | a | b | c | d | R | $R^2$ |
|---|---|---|---|---|---|---|---|
| **Dongola** | Cubic | -0.0003 | 0.0268 | 0.2958 | 0.7752 | 0.9771 | 0.9548 |
| **Khartoum** | Squire | 0.0009 | 0.2351 | 9.5447 | - | 0.8854 | 0.7840 |
| **Aldamazine** | Squire | 0.0004 | 0.3151 | 195.94 | - | 0.7789 | 0.6068 |

*Cubic: $Y= ax^3+bx^2+cx+d$, Squire: $ax^2+bx+d$. Level of significance: R (0.05) = 0.2761; R (0.01) = 0.3577; R (0.001) = 0.4476

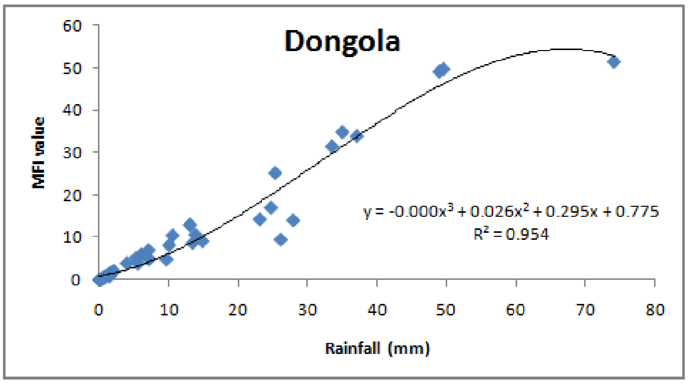


**Fig.4.** Total annually rainfall versus total annually MFI for Dongola station

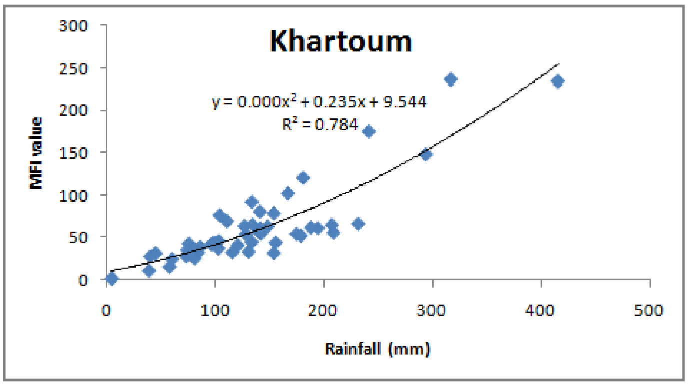


**Fig.5.** Total annually rainfall versus total annually MFI for Khartoum station

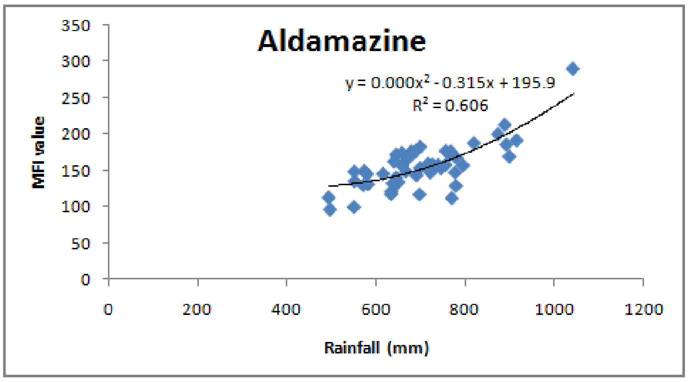


**Fig.6.** Total annually rainfall versus total annually MFI for Aldamazine station

The equation that generated between annual rainfall data and erosivity (MFI) of Dongola gave the highest correlation coefficient when compared to that produced of Khartoum and Aldamazine. So the MFI values can be calculated, with differences not exceeds plus or minus 4.5, by the following equation:

$Y= -0.0003x^3+0.0268x^2+0.2958x+0.7752$ Where, Y is the MFI, and x is the total rain gauge.

## DISCUSSIONS

As matter of fact the precipitation type in Sudan is summer precipitation and the rainfall intensity decreases from southern part of the country to northern part so, the amount of rainfall decreased coinciding with the same trend as expected in the following order: Aldamazine > Khartoum > Dongola. In autumn, the south and southwest winds (southerly winds) caused rainfall in vast area of the country, ultimately reaching the northern state (Dongola) without, or rare clouds that may resulted in 0 mm rainfall. Moreover the high contribution of months noticed in specific months namely: June, July, August and September. The highest contribution of the monthly rainfall in the three metrological stations during 1960-2010 recorded in July and Aug. as follows: Aldamazine 9139 mm (July), 8139 mm (Aug.) > Khartoum 1796 mm (July), 3005 mm (Aug.) > Dongola 161.3 mm (July), 273 mm (Aug.). For the lowest contribution of the monthly rainfall in Aldamazin and Khartoum recorded in Jan, Feb. and Dec. Regarding to Dongola all months seems to be equal with very meager differs except June, July and August. The overall means of months gave higher variability than annual. The monthly coefficient of variation for three meteorological stations, Dongola, Khartoum and Al-damazine were 1.3, 1.1 and 1.04 fold that measured annually. This fact may attribute to the high differences in the intensity amount of rainfall between months. The means rainfall of months ranged between zero (mm) to some thousands of (mm). In general, the overall means of months is higher than annual overall month, this finding recorded in othe studies dealt with intensity of wind erosion (Abelwahab, 2017). The results revealed that Dongola, Khartoum and Al-damazine stations, the seasonality index accounted about 0.85, 0.99 and 0.90 mm respectively, so seasonality index in studied areas can be described as markedly seasonal with a long drier season. PCI in studied areas can be described as highly seasonal in Khartoum and Al-damazine but in Dongola gave irregular pattern of PCI. MFI in studied areas can be described as very low, low and high for Dongola, Khartoum and Al-damazine respectively. According to this finding the susceptibility of water erosion can flow the same order. In Al-damazine noticed increasing rainfall seasonality and concentration would lead to high runoff and erosivity. This situation lead to make soil erosion prevention more difficult (Santibanez, 2006) The total rain gauge in two targeted periods 1960-1984 (first period) and 1985-2009 (second period). For Dongola and Khartoum stations the rain decreased from first period to second by 30.2% and 11.3% respectively, but Al-damazin station gave very meager increasing accounted about 0.35. According to these findings there is attendance to increasing aridity in Dongola and Khartoum areas. Referring to Al-damazin station there is no changes in rain status in two studied periods. This finding may interpreted as a strong evidence of climate change would lead to deteriorate natural resources generally and agriculture productivity especially, will result in food insecurity. So deteriorate will continue unless serious measure will take, through setup appropriate strategies for climate change adaptation. This finding agrees with (Bello, 1998). The equation that generated between annual rainfall data and erosivity (MFI) of Dongola gave the highest correlation coefficient when compared to that produced of Khartoum and Al-damazine. So the MFI values can be calculated, with standard error plus or minus 4.4 by the following equation:

$Y= -0.0003x^3+0.0268x^2+0.2958x+0.7752$, Where, Y is the MFI, and x is the total rain gauge.

# CONCLUSION AND RECOMMENDATIONS

## Conclusion

- Annual overall means of the three meteorological stations significantly decreased in following order: Al-damazine> Khartoum> Dongola.
- The overall coefficient variation generated by months was much higher than annual and the highest contribution of the monthly rainfall in the three meteorological stations during 1960-2010 recorded in July and Aug. as follows: Al-damazine 9139 mm (July), 8941 mm (Aug.) > Khartoum 1796 mm (July), 3006 mm (Aug.) > Dongola 161.3 mm (July), 274mm (Aug.). Whereas the lowest contribution of the monthly rainfall in Al-damazin and Khartoum recorded in Jan., Feb. and Dec. Regarding to Dongola all months seems to be equal with very meager differs.
- The total rain gauge in two targeted periods 1960-1984 (first period) and 1985-2009 (second period), for Dongola and Khartoum stations the rain decreased from first period to second by 30.2% and 11.9% respectively, but Al-damazin station gave very meager increasing accounted about 0.35.
- For Dongola, Khartoum and Al-damazine stations, the Seasonality Index (SI) accounted about 0.85, 0.99 and 0.90 mm respectively, so SI in studied areas can be described as markedly seasonal with a long drier season. Whereas Precipitation Concentration Index (PCI) accounted about 63, 45.4 and 22.2 mm respectively, so PCI in studied areas can be described as highly seasonal in Khartoum and Al-damazine but in Dongola gave irregular pattern of PCI. The erosivity index (MFI) accounted about 8.9, 61 and 155.8 mm respectively. MFI in studied areas can be described as very low, low and high for Dongola, Khartoum and Al-damazine respectively. According to this finding the susceptibility of water erosion can flow the same order.
- The equation that generated between annual rainfall data and erosivity (MFI) of Dongola gave the highest correlation coefficient when compared to that produced of Khartoum and Al-damazine. So the MFI values can be calculated, with differences not exceeds plus or minus 4.5, by the following equation:

  $Y= -0.0003x^3+0.0268x^2+0.2958x+0.7752$. Where, Y is the MFI, and x is the total rain gauge.

## Recommendations

- Laid upon the results of two targeted periods 1960-1984 (first period) and 1985-2009 (second period), showed that Dongola and Khartoum stations the rain decreased from first period to second by 30.2% and 11.3% respectively, but Al-damazin station gave very meager increasing accounted about 0.35. This finding can considered as alarming rate of aridity in Dongola and Khartoum areas. These results may be attributed to climate change, so serious measures must be done to avoid the impact of increasing this aridity on agriculture productivity and food insecurity.
- There is urgent need to adopt appropriate strategies for climate change adaptation, particularly in the areas where the aridity increased.
- Since MFI for Dongola area gave higher correlation coefficient and standard error plus or minus 4.4, with annual total rainfall, it is recommended to predict MFI using the following equation:
  $Y= -0.0003x^3+0.0268x^2+0.2958x+0.7752$. Where, Y is the MFI, and x is the total rain gauge.
- From the MFI results there is a high inherent risk of soil erosion by water in Al-damazine area, thus control projects of water erosion deserves top priority.

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