Rainfall Variability in the Sahel: A study from Sudan (1970-2010)

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Abstract- This article focuses on studying and analyzing rainfall variability in the Sahel area with a case study from Sudan. The main objective of the article is to analysis the rainfall variation over both space and time during the last four decades. The data for rainfall variability was collected from five meteorological stations namely, Elobied, EnNuhud, Elfashir, Nyala, and Elginaina for the period 1970-2010 including four strong Elnino events. The descriptive and statistical analytical methods, the mean, standard deviation, coefficient of variation and Geographical Information System (GIS) have been used for data analysis. The results show that rainfall is highly fluctuated and varied over both space and time indicating a real variation in annual average rainfall values. the coefficient of variation ranges between 0.22 to 0.37 and the standard deviation ranges between 76 to 127.6 which are presented in GIS formats. Results also show a successive decade of small rainfall variatbility followed by a decade of high rainfall variability. Two positive and four negative anomalies have been found during the period 1970-2010.

Index Terms- Sahel, Anomalies, Elobied, Elfashir, EnNuhud, Elginaina, rainfall, fluctuation, Variability, GIS

I. INTRODUCTION

Rainfall is one of the major climatic elements that affect the traditional producers, especially traditional farmers livelihood. It plays a major role in the environment and socioeconomic conditions of the Sudan. Rainfall aspect is vital for both present and future rational utilization of the economic and human resources (Abdalla 1992). Many studies for example (Bewket, 2009) focused on the relation between inter-annual and seasonal variability of rainfall with the fluctuation in production of cereals. Rainfall variation, fluctuation and condition have a crucial role in determining the success of rainfed production specially in the study area which is a part of the Sahelian zone. Rainfall variability is also one of the climate indications denoting the trends of changes within the earth's environment that can affect the natural set up. Cimate records suggest that preceipitation patterns have already shifted in the 20th century (christophre *et al*., 2005). Climate variability and change profoundly influence social and natural events throughtout the world. Seasonal to inter-annual rainfall fluctuations strongly affect the success of agriculture and the abandonce of water resources (Adnan, 2009). The internal variability in the rainfall system can be recognized as a form of schock, meaning that the current state of rainfall reflects consequences upon the human life. The variability involves changes in the average state of rains over durations ranging from decades to millions of years. Rainfall variability means the degree to which rainfall amounts vary across an area or through time. There are two types of rainfall variability (spatial and temporal). The temporal variability means the variation of rainfall amounts at a given location across a time interval, which is important in understanding climate change.

Contradictory reports were found about the nature of rainfalls in the Sahel zone for example, le Compte *et a*l., 1994 reported that the year 1994 was the wettest year during the last twenty five years. Simulatenously, Tucker (1995) suggested that the year 1994 was a relatively dry year) in the Sahel . These contradictions statements were also confirmed by the study conducted by (Nicholson *et al*., 1996) who reported that the year 1994 barely exceeded the long term rainfall mean in the Sahel zone. This contradiction can be attributed to the operational definitions of the Sahel concept and its geographical domain and, therefore, greatly affect the analysis. The interannual variability of rainfall over Africa, specially in the Sahel has been tackled by many authors for example Nicholson, 1994, and Nicholson *et. el.,* 1996. In west Africa there has been a pattern of continued aridity since the late 1960s (Nicholson *et. al.,* 1999). However, some recovery occurred in most eastern sector during the 1990s with rainfall in some years being near or just above the long-term mean (Nicholson *et. al.,* 1999). As such, this article aims at analyzing temporal and spatial rainfall variability in centeral and western Sudan as a part of the Sahelian zone using quantitive methods along with Geographical Information System (GIS) analysis techniques and presentation formats.

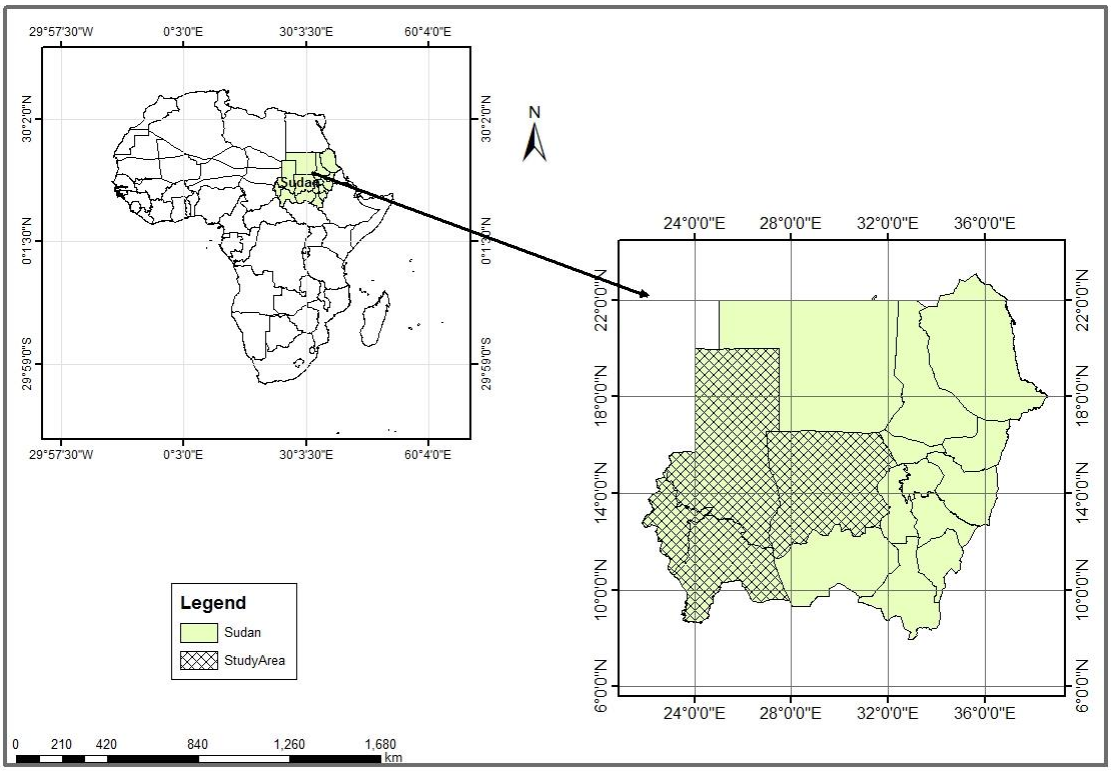
1.2 Materials and Methods

This section provides a short description of the geographical and environmental characteristics of the study area while focusing on the nature of the material and information used in the analysis and the tools and methods utilized for the collection of such information.

1.2.1 Geographical and Environmental Charactaristics of the Study Area

The study area is a part of the Sahelian zone lies between longitude (32^0 - $22^{0/}$ E) and latitude (10^0 - 20^0 N) as presented in Map 1. This area charactarised by vulnerable environment, high rainfall variability, high water deficiency, frequent rainfall failure,prolonged drought, as in 1984 and 1991 and rainfall varies over both space and time (Dano, 1980, El-Jaili 1995, Egemi 1995, Elfaig 1996, Elfaig 2002). The rainy months in this area extended from July to October (the month when it has at

least 10% of the annual rainfall (Eltom, 1975, Musa 1986, Abdalla 1992).



Map 1: Location of the Study Area

1.2.2 Rainfall Variability Data

The data related to rainfall variability has been collected from Elobied, EnNuhud, Nyala, Elfashir and Elgenaina meteorological stations for the last four decades 1970-2010 (Table 1).

Table 1: Rainfall data of the study area (1970-2010)

	Meteorolgical Stations				
year	Elobeid	EnNahud	Nyala	Elfashir	Elgenaina
1970	343.1	254.3	509	306.3	459.3
1971	245.7	334.8	386.4	255.9	514.3
1972	423.8	327.7	347.5	119.4	342.5
1973	256.9	299.1	362.4	199.5	213.8
1974	387	343.4	405.5	329	404.3
1975	377.2	274.6	412.9	190.5	349.9
1976	286.4	334.3	310.7	176.7	416.5
1977	317.6	186.9	333.3	183.4	533.4
1978	391.7	359.8	469.6	208.9	383.6
1979	423.8	219.8	318.3	169.9	471.2
1980	681	327	533.4	219	527.6
1981	494.4	296.3	339	197.2	348.1
1982	363.1	346	272.4	110.4	310.4
1983	321.2	339	325.2	72.1	241.3
1984	138.9	127	196.3	101.5	124.4

1985	320.9	219.2	347.4	171.6	419.7
1986	274.7	364.8	294.1	20.1	329.4
1987	318	271.8	248.5	214	238.1
1988	382.9	283.1	493.4	250.3	510.4
1989	350.9	277.5	422.7	151.7	334.4
1990	164.6	199.5	289	125	424.2
1991	322.2	258.2	413.5	112.6	420.4
1992	411.3	442.6	325.9	202.8	335.9
1993	281.9	378.7	319.7	150.2	408.2
1994	425.7	344.7	416.9	304.8	597
1995	517.2	337.7	293.7	221.1	661.5
1996	372	359.2	360.6	149.9	274.5
1997	474.7	329.4	396.3	159.1	472.6
1998	430.9	370.6	379.6	369.6	444.5
1999	347.8	581	430.7	269.5	559.2
2000	276.3	314.5	552.4	263.1	320.1
2001	351.6	292.5	324.9	165.2	492.2
2002	363.2	116.9	299.2	166.7	456.1
2003	335.8	355	626.1	143.3	652.8
2004	198.4	318	432.3	116.5	441.7
2005	403.3	237.5	487.3	317.2	635.1
2006	391.7	379	445.2	242.2	422.2
2007	777.7	557.7	459.3	281.7	527.4
2008	238.4	411.2	498	132	393.4
2009	306.6	321.2	302	130.1	475.1
2010	315.3	414.1	380.3	250	595.6

Source: Khartoum Meteorolgical Authority (2012)

1.2.3 Method of Data Analysis

In order to analyze the data related to the rainfall variability several methods were adopted and applied. These Include:
Quantitative methods which imply the mean, standard deviation (SD) and coefficient of variation (CV). The coefficient of variation (CV), also known as "relative variability", equals the standard deviation divided by the mean. It can be expressed either as a fraction or a percent. These equations are used to calculate the long term rainfall variability as shown hereafter. These equations showed the variability factor in terms of percentage, specially the coefficient of variation.

$$\bar{X} = \frac{\sum X}{N} \quad \text{i.e} \quad \bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \qquad \text{Equation (1)}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(xi - \bar{X})^2}{n-1}} \qquad \text{Equation (2)}$$

σ = population standard deviation
X_i = value of sample (i)
$\bar{X}$ = mean of sample values
n = number of samples

$$Cv = \frac{\sqrt{\frac{\sum_{i=1}^{n}(xi - \frac{\sum_{i=1}^{n} Xi}{n})^2}{n-1}}}{\frac{\sum_{i=1}^{n} Xi}{n}} \qquad \text{Equation (3)}$$

Cv = is the Coefficient of variation in percent
X_i = is the value of sample (i)
n = is the number of samples
$\sum$ is ' the sum of'

1.2.4 GIS analytical methods (Inverse distance weighted interpolation)

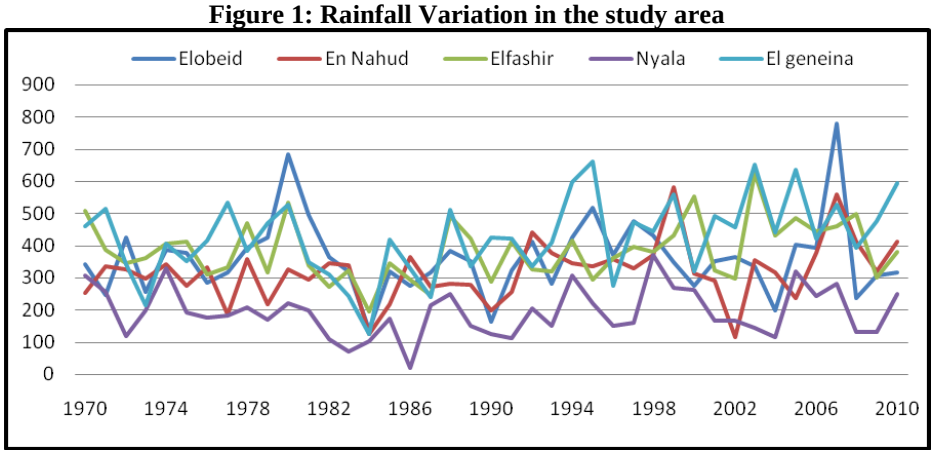
The Inverse Distance Weighted (IDW) interpolation is a Geostatistical method that determines cell values using a linearly weighted combination of a sample points. In this method we assume that the rainfall variability being mapped increases with distance from the measured meteorological site. This method is used because of the lack of the sufficient rainguages to cover the whole area. The method greatly depends on the coefficient of variation which was used by Chacón and Fernandez (2006) to study temporal variability of rainfall in the mountainous region of the Reventazón River basin, Costa Rica.

II. RESULTS AND DISCUSSION

2.1 General Rainfall Variabilty: Spatial and temporal Variation

Data on rainfall for the period 1970-2010 shows that rainfall was highly fluctuated and varied over both space and time. It shows that Elgenaina received high amount of rainfall with an average of 476.6 mm followed by Nyala (401.6mm) and EnNuhud (367mm) as shown in Figure 1.

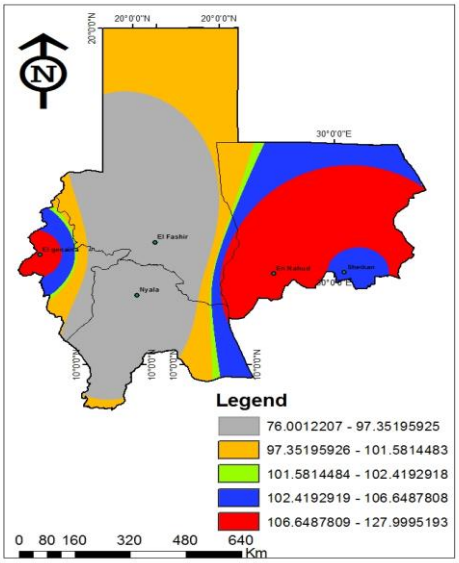
Figure 1: Rainfall Variation in the study area



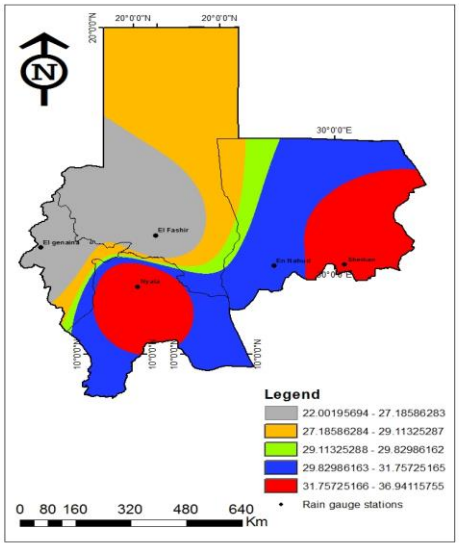
The data also shows high rainfall variability at Elfasir (CV = 0.37). High rainfall spatial variation on the study area clearly observed as shown in Table 2, Maps 2 and 3 and Figures 2:1-2:5. The differences in the maps can be explained by the fact that the standard deviation is largely affected by the extreme values where four strong Elnino events as well as frequent occurance of drought happened during this period .

Table 2: Rainfall Indicators and Dispersion in the Study Area

Period	Meteorological stations	Maximum amount	Minimum amount	Mean	STD	CV
1970-2010	Eobied	777.7	138.9	348.5	104.9	.30
	En Nuhud	581	127	367	127.6	.35
	Elfashir	369.6	20.1	203.5	76	.37
	Nyala	626.1	196.3	401.6	90.2	.23
	Elgenaina	661.5	124.4	476.6	108.9	.22



Map2: Rainfall Variablity shown by deviation (1970-2010)



Map2: Rainfall Variablity shown by Coefficient of variation (1970-2010)

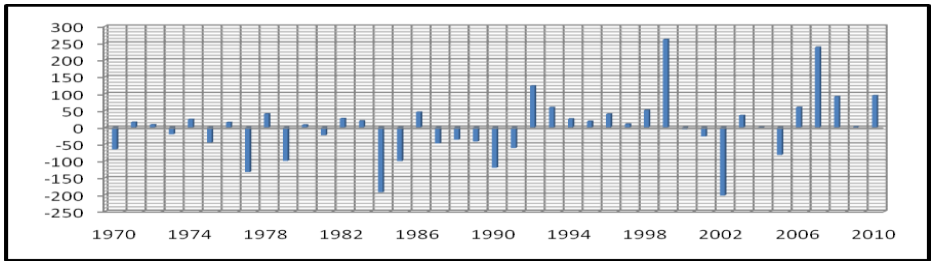


Figure 2.1: Rainfall Anomalies and Deviation in Elobied

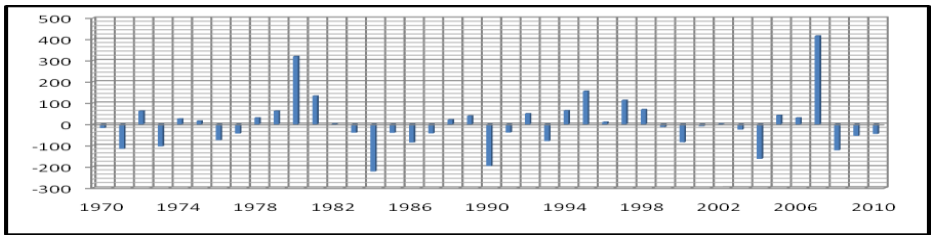


Figure 2.2: Rainfall Anomalies and Deviation in EnNuhud

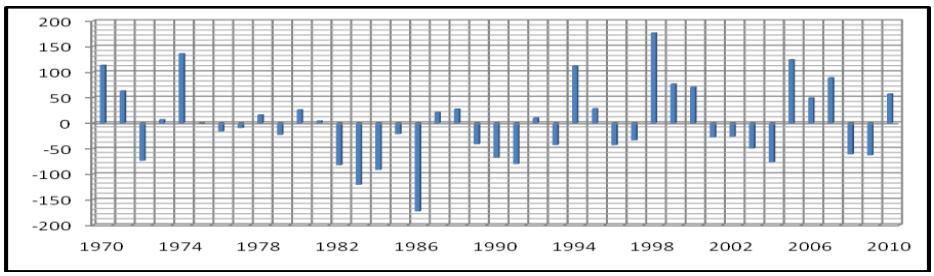


Figure 2.3: Rainfall Anomalies and Deviation in Elfashir

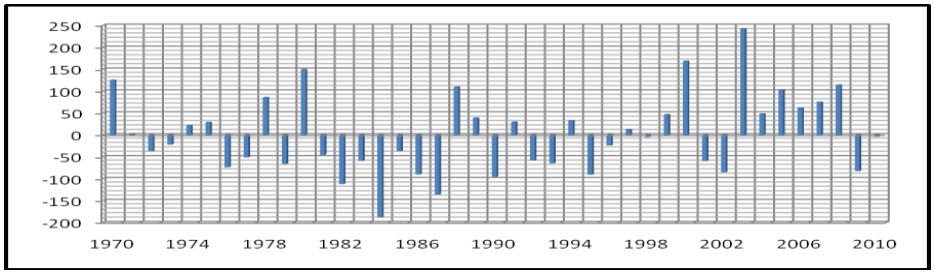


Figure 2.4: Rainfall Anomalies and Deviation in Elgenaina

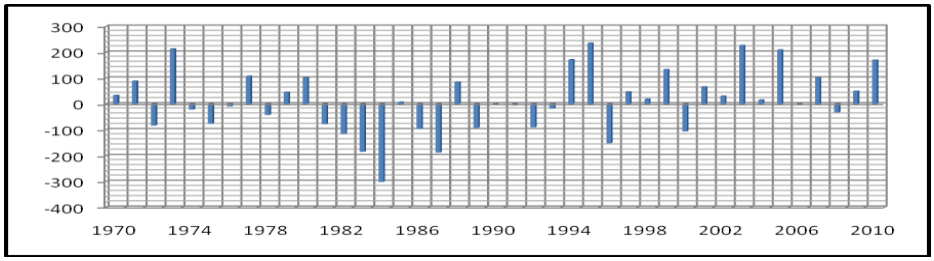


Figure 2.5: Rainfall Anomalies and Deviation in Nyala

2.2 Spatial and Temporal Rainfall Variability: Decades Intervals

The data for temporal and spatial rainfall variability for every decade shows enormous variation and fluctuation in rainfall over both space and time as shown in Table 3 and Figures 3.1-3.4. For example in Nyala area (South Darfur). The study shows that a decade of of small rainfall variability (CV = 0.15) followed by a decade of high rainfall variability (CV = 0.34) during the last four decades.

Table 3: Rainfall variability idicators in the Study Area: Decades Intervals

Period	Meteorological stations	Minimum amount	Maximum amount	Mean	STD	CV
1970-1979	Eobied	245.2	423.8	345.3	68.9	.20
	En Nuhud	186.9	359.8	293.7	66	.22
	Elfashir	119.4	306.3	214	64.6	.30
	Nyala	310.7	509	385.6	65.2	.17
	Elgenaina	213.8	533.4	408.9	94.1	.23
1980-1989	Eobied	138.9	681	364.6	142.4	.39
	En Nuhud	127	364.8	324.9	116.6	.36
	Elfashir	20.1	250.3	287	130.2	.45
	Nyala	196.3	533.4	332.3	112.2	.34
	Elgenaina	124.4	527.6	299	129.5	.43
1990-1999	Eobied	164.6	517.2	374.8	102	.27
	En Nuhud	199.5	581	360.2	102.2	.28
	Elfashir	112.6	369.6	206.5	105.5	.51
	Nyala	289	430.7	362.6	52.7	.15
	Elgenaina	274.5	661.5	459.8	119.2	.26
2000-2010	Eobied	198.4	777.7	291.5	159.4	.55
	En Nuhud	116.9	557.7	297.5	136.1	.46
	Elfashir	130.1	317.2	315	144.8	.46
	Nyala	302	626.1	401.2	133.6	.33
	Elgenaina	320.1	652.8	364.4	149	.41

In Elginana (West Darfur) similar situation was also found where small rainfall variation was reported. The CV ranges between 0.23-0.26 for the periods 1970-1979 and 1990-1999, respectively. Meanwhile great variation and fluctuation in rainfall was found for the period 1980-1989 and 2000-2010 where the CV range between 0.41-0.43. In Elfashir (north Darfur) a tendency of increasing in rainfall variability is a general feature of rainfall charactaristics in that area. High rainfall variability was reported during the period 1970-1979

and 1990-1999 for both Elobied (CV ranged between 0.39-0.55) and EnNuhud (CV ranged between 0.36-0.46).

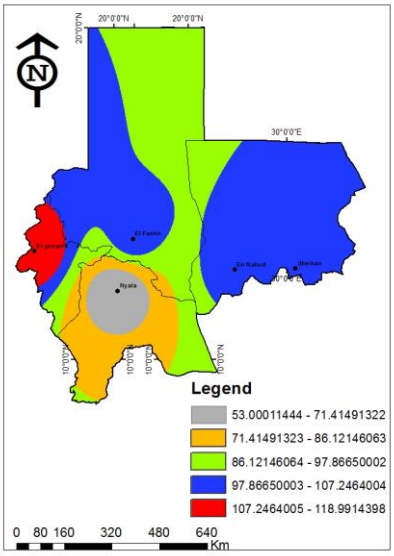


Fig.3.1: Rainfall Variability1970-197

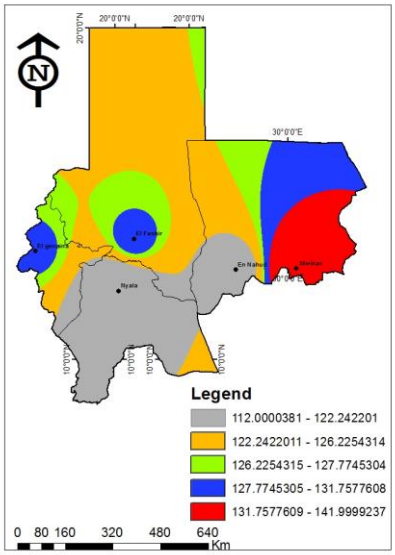


Fig. 3.2: Rainfall Variability 1980-1989

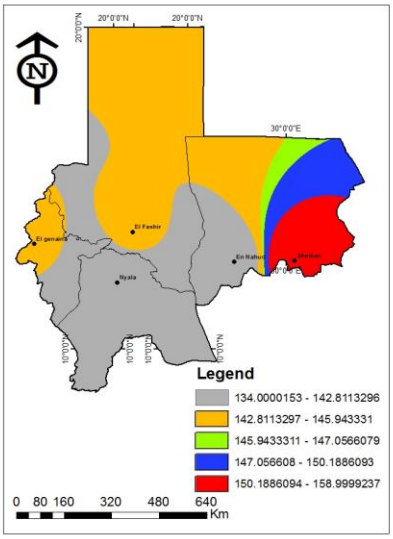


Fig.3.3:Rainfall Variability 1990-1999

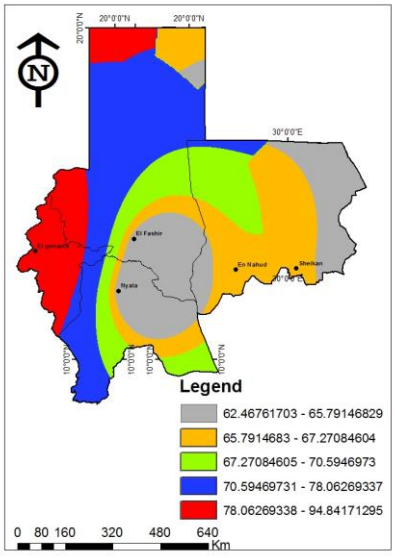


Fig.3.4:Rainfall Variability 2000-2010

III. CONCLUSIONS

Rainfall conditions during the period 1970-2010 were highly fluctuating in most of the years (45%) of the study period below the long-term rainfall average. Four extreme negative anomalies were found as in the years 1977, 1979, 1984 and 1990 which represent prolonged drought prevailed during that period. This means that rainfall amounts vary across the study area through time which is an important feature of the climate of the study area. Results also show that since 1988, the study area has recorded a series of good years, however, rainfall continues fluctuating and rainfall variability persists i.e inter-annual and intra-seasonal rainfall. A tendency of good and bad year occurs randomly. A successive decade of small rainfall variability followed by a decade of high rainfall variability was concluded in most parts of the study area. This characteristic of rainfall can't be explained neither by the presence of the two positive anomalies as in 1994 and 2007 nor by the presence of

four negative anomalies as in 1977, 1984,1990 and 2002. Such a phenomena can be explained in the context that there is a general trend of rainfall variation over both space and time that may indicate climatic change in this semi-arid area of the Sahelian zone which affect agricultural as well as pastoral sectors . These results are compatable with the theory of climatic school thought as mentioned by Dando (1980), Cox (1981) and Lamp (1982) that provides centurial long-term or short-term rainfall data to document a climatic transformation that considered climatic change and climatic elements, specially rainfall variability is e one of the major factor contributing to environmental degradation and famine in the Sahel zone.

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