Spatio-temporal Analysis of Rainfall Variability Using Statistical and IDW Interpolation Methods in Sudan (1970—2018)

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***Abstract*- Background**: Timely analyzing rainfall variability is an important in the economic and environmental conservation mainly in Arid and Semi-arid zones, like Sudan. In arid environments people exclusively depend on seasonal rainfall in their livelihoods. So, whenever life depends on the seasonal rainfall effectiveness, the authorized meteorological information should be guided the policy of seasonal activities. **Objective**: The aim of this paper is to detect the rainfall variability across the Sudan through analyzing long-term rainfall records. **Methods**: the annual Spatio-temporal data of long term (1970-2018) of the Sudan Meteorological Agency in Khartoum was used. Nine stations were selected for this study present the geographical divisions of the country. Statistical analysis parameters are processed using SPSS program. In addition, IDW a spatial statistics method analyzed the continues surface prediction over the study area in ArcGIS environment. **Results**: the results of this paper are of two folds: Statistical analysis shows increasing trend in annual average rainfall variability from (85.7) in the northern and eastern States to (438.4) mm in central and southern ones. Also, the rainfall peak and intensity during rainy months (July-August and September) detected significant variation from North to the South. The coefficient of variation shows different indictors range from (18.6) indicates high amount of rainfall to (87.7) for less rainfall amount areas. IDW maps generated continues surfaces that give a guide of the variability between observed values for different areas.

Index Terms- Rainfall Variability Seasonal Rainfall rainfall effectiveness SPSS IDW Dry land

I. Introduction

Climate change is among the most pressing environmental development challenges globally (UNCTAD/WTO, 2007). The dry lands cover 40% of the world's landmass, and are seen by many to be the areas at greatest risk from climate change due to their low, variable and unpredictable rainfall patterns. By understanding more about climatic variability, we can help dryland economies reach their true potential (IIED,2015). Climate variability (rainfall and temperature) in the last three decades have met by high order attention at the level of developed countries leaderships. This explains the seriousness of the climate change trends in precipitation and temperature worldwide. The significant effects of the temporal changes in rainfall can be increased in areas characterized by Arid and Semi-arid ecosystems. Sudan has a recognizable Spatio-temporal variability in the rainfall aggregates during the recent decades from north to south. Climate change or variability is a junction where all disciplines show their collaborations alternatingly. Climate news tell the truth about the global condition, in terms of the impacts upon the quality of life and call for resilient systems.

Rainfall is the agent that supports life with many relational attributes such as weather and hydrology. The Lack in water leads to imbalance that causes water stress, scarcity and inaccessibility. The temporal and spatial distribution characteristic of rainfall depend on the availability of its occurrence. Water deficits in fragile areas no longer sustain the water balances for normal mode of living, and completely associated with rainfall change. Natural mean rainfall may decrease down to less than 100 mm/year during drought regime. Change in rainfall in term of spatial distribution can be observed through meteorological stations that basically installed in main cities.

The relationship between annual amount of rainfall and some of the economic and human activities give the important of studying the rainfall variability. Any change of any gradient in the annual rainfall generate an alarm to socio-economic settings of the traditional societies. Not only agricultural farming, but water supply sustainability that exclusively depends on the rain water harvesting during rainy season. These associated with the hydrological and agricultural drought occurred in Sudan during 1980s and 1990s that consolidated the importance of analyzing rainfall variability.

The study of rainfall variability is one of the climate change critical issue showed its significant during the last three decades in Sudan. There is strong and positive relationship between the natural precipitation and agricultural sector areas in the Sudan. 80% of the agriculture depend on the seasonal rainfall classified as rain-fed cultivation. Measuring and monitoring Spatio-temporal rainfall variability becomes a guide to the agricultural sustainability.

II. Research Topic Statement:

Smallholder farmers in Sub-Saharan Africa(SSA) are not only dealing with decreased production from land degradation, but are also impacted heavily by climate variability (Jeremy et al; 2016).

Different agricultural authorities and farmer's communities mainly in traditional areas, need information regarding the rainfall prediction. The significant of the up to date rainfall information becomes as crucial as one of the drought adaptation mechanism in drought vulnerable areas. Sudan rural areas experienced severe and high droughts frequency that generated new thinking in crop rotation systems. The main problem identified this paper is to ensure the significant of the rainfall variability across Sudan's States. Rainfall analysis is a priority in all Sudanese socio-economic and one of the development determinants. Meteorological reports are only for official routines and little can be produced for the State's solving climatic problems.

The main aim of this study are emerged from the trends during the past three decades, local climate change, and the accelerating crops failure. So, the situation needs some kind of investigation from different fields. Two of the main objectives can be stated: analysis of long-term rain data to detect Spatio-temporal variability over the Sudan, and to generate continuous surfaces of rainfall prediction from observed rainfall values using one of the geo-statistical approach in ArcGIS environment.

III. Previous Related Studies:

The nature of rainfall variability over Africa on time scales of decadal to millennia is the topic studied by Nicholson et al. (2000). In 2007 Earls and Dixon studied spatial interpolation of rainfall data. They evaluated spatial interpolation techniques for interpreting 2Km OneRain data into 30m resolution using ArcGIS spatial Analyst. De Toffol et al. (2008) wrote about extreme rainfall intensities frequency. They analyzed the trends in rainfall patterns relevant to urban drainage system. They used intensities over 15 minutes, 30 minutes, 1 hour, 2 hours, and 24 hours as indicators due to their relevance for different sewer system parts and divisions. In 2009 Bitsuamk et al. introduced a paper showed the interaction between rain and wind. Their study titled application of a full-scale testing facility for assessing wind-driven-rain intrusion. Their emphasis as mentioned has been placed on generating a wind field with a proper boundary layer profile and turbulence characteristics. Analysis of highly accurate rainfall intensity measurements from a field site as is the paper published by Lanza, et al. (2010). They used both catching and non-catching type gauges in relation with suitable tolerance limits obtained as a combination of the estimated uncertainty of the reference intensity and the WMO accuracy limits for rainfall intensity measurements. Chen and Liu (2012) published a paper about spatial rainfall distribution using IDW in the middle of Taiwan. They used long time series rainfall data for 46 rainfall stations between 1981 and 2010. They concluded that the optimal parameters for IDW in interpolating rainfall data have a radius of influence up to 10-30 km in most cases. Alqudah et al. (2013) investigated rainfall estimation from radar measurements using neural network. They used this method to represent the nonlinear relationship between radar measurements and rainfall rate. In (2013) also, Degre et al. discussed in their paper different method for spatial interpolation of rainfall data for optimal hydrology and hydrological modeling at watershed scale. In their review, they concluded that the success of spatial interpolation varies according to the type of model chosen. Patle and Libany (2014) analyzed the seasonal and annual rainfall trends to climate variability in Northeast region of India. They examined the impact of climate change on rainfall using trend analysis techniques. Similar to the existing paper in Spatio-temporal approach, and in 2015 Ahamed et al. studied precipitation trends over time using Mnn-kendal and Seapman's rho Tests in Swat River Basin, Pakistan. They investigated precipitation variability across 15 stations over a 51-year period (1961-2011). Muhammed et al. (2016) in their study about extreme analysis of rainfall indices in Peninsular Malaysia showed that extra rainfall events are the main cause of flooding. They examined seven extreme rainfall indices. Chen et al. in 2017 published an article about the comparision of spatial interpolation schemes for rainfall data and application in Hydrological modeling. One of their methods used is the IDW interpolation method. Saini et al. (2020) published a paper about the advanced rainfall trends analysis. They analyzed 117 (1901-2017) time series over west plain and Hill climatic region of India. They used rainfall grid dataset for the analysis of rainfall trends on monthly, seasonal, and decadal time scales.

IV. Methodology:

4-1 Study area:

This paper analyzes the Spatio-temporal rainfall variation in Sudan. The time series for this study from 1970-2018 was used for detailed analysis. The observed data represent the whole Sudan based on authorized stations. The nine stations used in this paper are the best in their observed records over the period 1970-2018. across the Sudan. The States of the country share some of the climate characteristics basically, dry summer and likely annual rainfall duration Table (1). Two stations, in particular Atbra and Port Sudan are deviated from the other stations rainfall characteristics. The distribution of the meteorological stations over the Sudan seems to be widely scattered found exclusively in the main cities. The meteorological stations are important for the evaluation of the climate variability of Sudan. Recently, the country has experienced drought, and floods that have great economic and environmental consequences. In 2020 rain storm water caused high risk level flood in Khartoum and other cities over the country, indicated the lack in meteorological analysis and annual reports. We can introduce the meteorological stations starting with the Khartoum, which is the capital city of the Sudan, Port Sudan is the capital city of Eastern State and the main sea port of the country at the Red sea. ElObeid is the capital city of the North Kordofan State and the biggest world Gum Arabic market. ElGadarief is the capital city of ElGadarief State and the main Sudan's cereals producer. Atbra is the capital city of the Northern State, while Kosti is the capital city of White Nile State. Gadugly is the capital city of Southern Kordofan State, while ElFasher and ElGenina are both capital cities of North and Southern Darfur respectively.

Table (1): Main Meteorological Stations in Sudan

s	Stations	Longitude	latitude.	Elevation (m)	State
1	**El-Obeid**	30.2167	13.1833	650	N. Kordofan
2	**ElFasher**	25.35	13.63	700	N. Darfur
3	**Khartoum**	32.5598	15.5006	382	Khartoum
4	**Kosti**	32.66	13.17	380	White Nile
5	**Atbra**	33.9833	17.7167	360	Northern
6	**Port Sudan**	37.2164	19.6158	2	Eastern
7	**ElGadarief**	35.3833	14.03	580	ElGadarief
8	**ElGenina**	22.44	13.45	800	S. Darfur
9	**Gadugly**	29.7	11.01	499	S. Kordofan

Source: Based on Sudan's Base map organized by researchers (2010)

4-2 Rainfall Data and Methods:

The process of data preparation performed through a number of stages prior it entered for processing using IDW and other statistical processes. The process of data tabulation and organization was done in the excel program with the definition of the coordinates for each meteorological station, and then the data was exported to ArcMap (version 10.8), and converted to shape file. All rain gauge stations in Sudan are operated by meteorological office in Khartoum the only authorized body for reliable data. The seasonal Spatio-temporal data obtained from this office in Khartoum. The time-series extends from 1970 to 2018 (48 years) for analyzing variation in rainfall trends of long-term monthly rainfall data of the nine stations represent geographically all the country. The nine main meteorological stations are used over the Sudan's area 1.865.813 km**2** plotted in Fig (1). The locations of these stations are basically located at the Airports in the main cities of the States. The summation of the monthly rainfall values generated the annual rainfall amount per station.

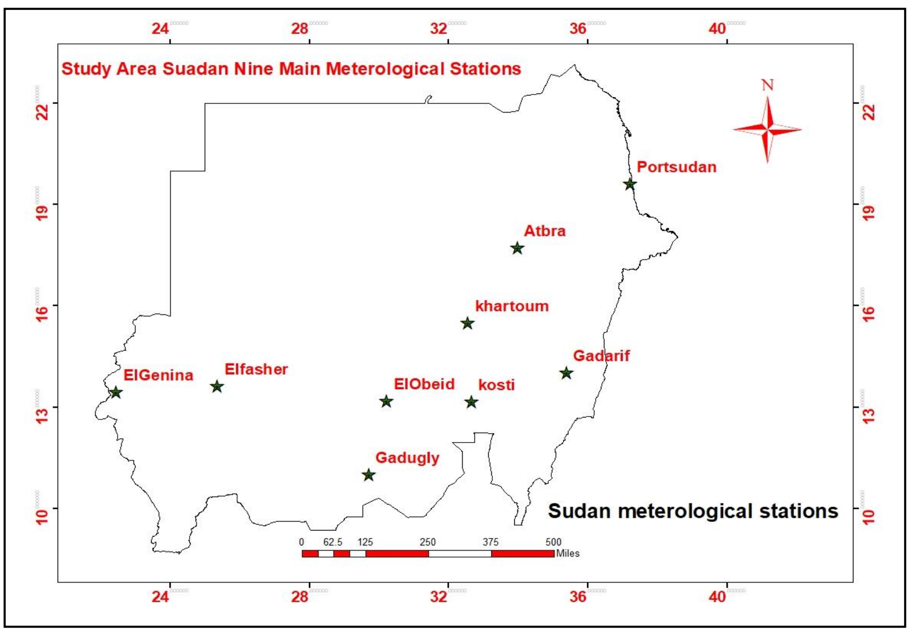


Fig (1): locations of meteorological stations at Sudan country (2020)
Source: Converted into shape file using Arc GIS 10.8

4-3 Methods of Analysis:

The main methods used for analysis are; IDW, central tendency, and dispersion statistical approaches. IDW performed in the Arc map 10.8 environment, while descriptive parameters are analyzed using Excel and Spss programs. The periodical rainfall analysis was assessed by applying 10 year accumulated rainfalls, represented by five periods (1970s, 1980s, 1990s, and 2000s).

4-3-1 Statistical Methods:

Monthly rainfall time series from June to November for 47 seasons were analyzed. General trends of the rainfall and the comparison between ten years' periods and rainfall deviation from the mean indicated that rainfall variability characterizes the rainfall in the study area. In addition, rainfall over time graphs were made for all nine stations in order to visualize the data time series. Central tendency and dispersion statistical parameters were applied to calculate the main descriptive statistics for the rainfall during the period of the study. Means, max., min., mode, median, standard deviation, and coefficient variation are interpreted.

4-3-2 GIS Spatial Statistical Method IDW:

Identification of spatial rainfall variability in Sudan and its extremes characteristics analyzed using spatial interpolation. IDW spatial statistic method applied to analyze many different rainfall parameters. Total of the rainfall, mean deviations, annual averages, and periodical behavior of rainfall per station processed via IDW functionalities that generated interpretable recults.

V. Results and Discussion:

Geographically, studying the rainfall trend in the Sudan is of great important. The two trends of rainfall distribution can be viewed: States located further west received considerable rainfall with little variations during rainy seasons having average of 438.4 mm during the period 1970-2018. States located further North received less amount of rainfall as compared with the rest, having average of 87.7 mm during the target period. The actual totals of rainfall also have some significant variations from spatial perspectives. A long-term data (1970-2018) indicated the general trend of the data to increase or decrease within the overall average.

Many analysis includes primary general statistical parameter computation including the average, standard deviation, max., min values, and coefficient of variation. Table (2) organized the statistical parameters for the 48 years from 1970 to 2018, while Fig (2) presents the isohyet rainfall analysis over the 48-year period from 1970-2018 that also indicated the spatial variations in annual rainfall amount.

Table (2): Main statistical parameters of the rainfall analysis (1970-2018

Stations	**average**	**median**	**Sd**	**Max.**	**Min.**	**Co-var**
ElObeid	354.68	344.1	118.84	735.5	161.7	**33.51**
Elfasher	201.57	183.2	70.40	361.5	72.7	**34.92**
khartoum	117.35	109.7	65.48	415.5	4.4	**55.80**
kosti	339.95	335.1	108.13	602.1	12.84	**31.81**
Atbra	53.38	50.50	44.93	239.70	0.00	84.16
Portsudan	68.20	60.5	59.80	281	0	**87.69**
Gadarif	608.42	602.8	120.56	872.6	322	**19.81**
ElGenina	446.03	450.6	131.99	870.2	124.4	**29.59**
Gadugly	678.00	666.3	125.95	990.8	468.8	**18.58**

The table (2) explains that the standard deviation also varied between 44.93 mm and 131.99 mm, based on the nature of the low and high average indicates that the high standard deviation value describes the higher average rainfall and the vis versa.

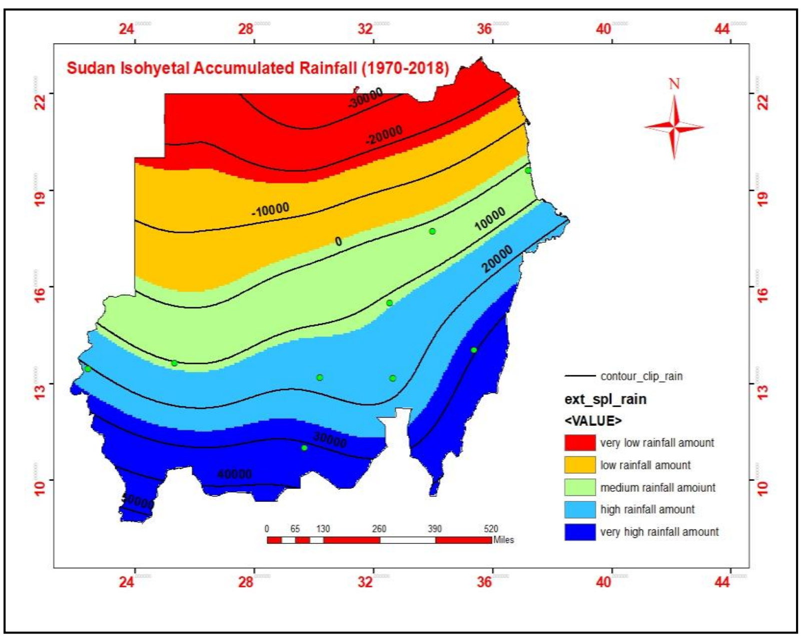


Fig (2): Accumulated rainfall isohyet (1970-2018)
Sources: Based on Khartoum meteorological data (2021)

The rainfall isohyet generated from the total rainfall accumulated during 48 years (1970-2018) showed significant variation. The extreme northern parts (16 – 22 degrees) represent the most critical variability in rainfall. The high amount of rainfall increases southward, while the central parts of the country have medium level of rainfall.

5-1 Rainfall Average Analysis:

Comparing the computed mean annual rainfall in the corresponding stations, we found that the mean varied from station to another affected by the geographical location. From the east the average is about 75.5 mm, to the north is about 45.3 mm, in the central is about 354.6 mm and the highest in the southern and further western States is about 411.4 mm. The overall average of the Sudan is about 438.4 mm. There are three stations that their averages beyond the line of approaching the overall average in particular, Atbra, Port Sudan, and Khartoum. So, increasing mean annual rainfall trends were observed in the Gadarif, ElGenina, and Gadugly States at the southern, western, and central Sudan.

Fluctuating trends in mean annual rainfall over the Sudan have been detected. Fig (3) shows classification of the average into five classes showed that it ranges from 36.62 to 632.9 mm. class one labeled very low average rainfall areas when the average ranges between 210.7 to 366 mm, while class two classified as low average rainfall areas when it ranges between 210.7 to 307.7 mm. The medium average rainfall showed in class three ranges between 307.8 to 361.8 mm, while the fourth and fifth classes classified as high and very high average rainfall areas has an average ranges between 361.8 to 458.8 and 458.9 to 632.9 respectively. An annual average greater than 350 mm rainfall indicates good rainy season, while an average exceeds 450 mm examines as rainfall of high extremes. On the other hand, the annual amount less than 200 mm rainfall explains the bad rainy seasons and gives symptoms of drought emergences.

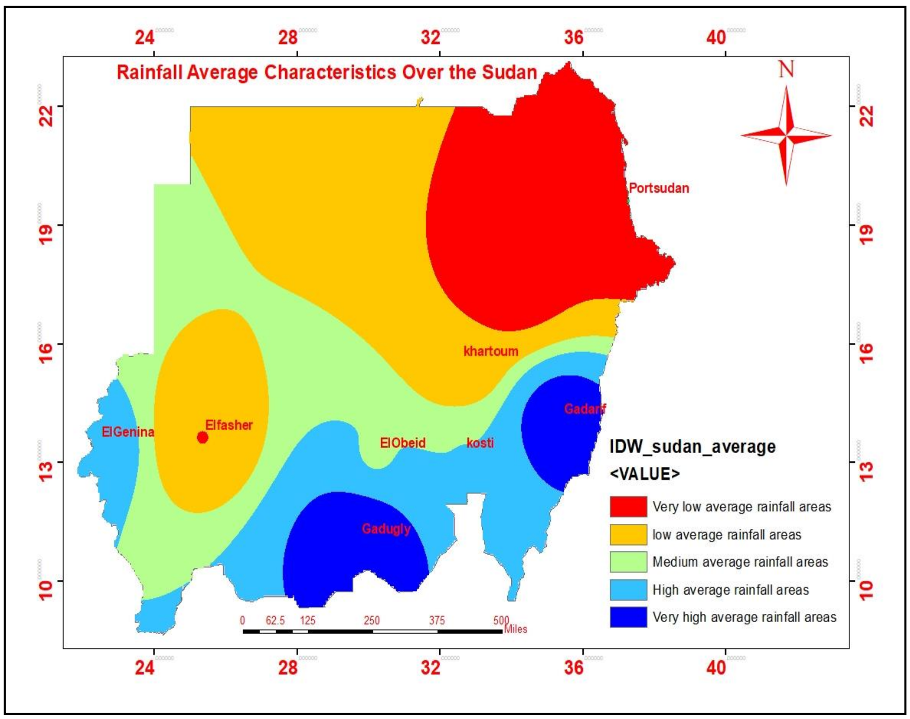


Fig (3): IDW Rainfall average analysis
Source: Based on Arc map 10.8 processing (2021)

5-2 Rainfall Spatio-Temporal accumulation analysis:

The most important part of the rainfall variability is to examine the temporal variation across the large geographical extent. The information generates by the temporal variability analysis, being of high value for many other sectors. Records of rainfall obtained from nine stations concern annual precipitation amounts over 48 years for this study, showed a significant result. Measuring and monitoring temporal variability give a guide that can be used as an indicator for valuing water of rainfall in the area. Temporal variation detects extreme high and low values among the studied stations Fig (4). The high extreme values may indicate no problem for farmers, but may generates flood risk in urban areas. The low extreme value presents the real problem as the effectiveness of the rain cannot sustain the seasonal activities such as rain-fed cultivation. During seasons 1988, 1995, 1999, 2007, 2008, and 2012 the Sudan experienced too much rainfall (high extremes) mainly in Khartoum, Gadugly, ElGadarief, Kosti, ElObeid, ElGenina, States with annual amount of 415.5, 990.8, 872.6, 602.1, 735, and 870.2 respectively. On the other hand, the 1984 season across the country was recorded the low extreme rainfall in all stations Fig (5). From the figure we can compare between the variation in amount precipitated in this year. Table (3) shows the total amount precipitated during the 48-year periods per each stations and the percentages from the overall amount accumulated in the nine stations during 1970-2018.

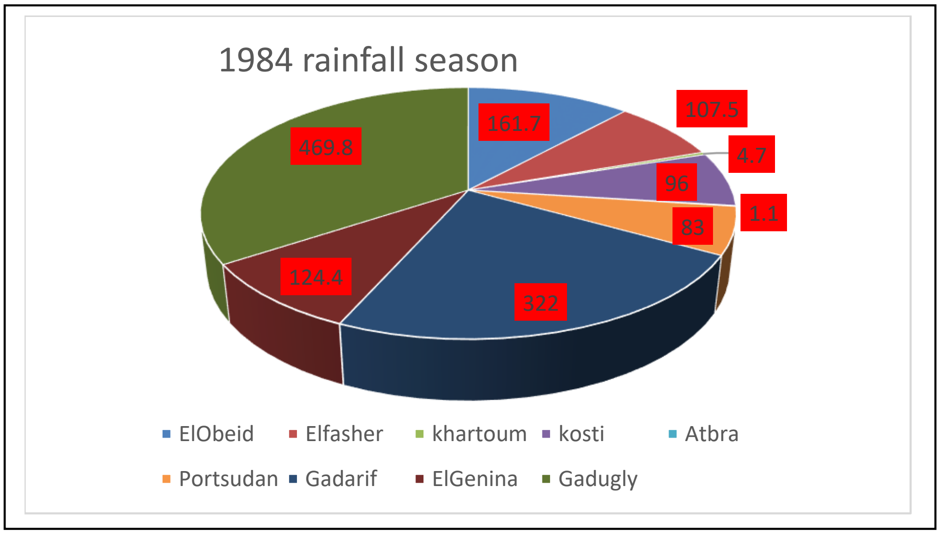
Table (3): Total amount precipitated during 1970-2018s

station	amount	%	average
ElObeid	17379.5	12.75%	354.7
Elfasher	10263	7.53%	209.4
khartoum	5750	4.22%	228.1
kosti	17757.84	13.03%	362.4
Atbra	2347.1	1.72%	47.9
Portsudan	1791.63	1.31%	36.6
Gadarif	29442.1	21.60%	600.9
ElGenina	20571.1	15.09%	419.8
Gadugly	31018.8	22.75%	633.0
	136321.07		321.42

Source: Based on Khartoum meteorological data (2021)

Another interpretation using class interval value classified the rainfall into five classes. The rainfall amount between 1000 and 8000 mm per station classified as a very low rainfall, while low, medium, high, and very high refer to classes that the rainfall amount is between (8-13), (13-16), (16-22), and (22-31) thousands/station in mm.

Fig (4): Temporal Variation in Rainfall Amount (1970-2018)
Source: Based on Khartoum meteorological data (2021)



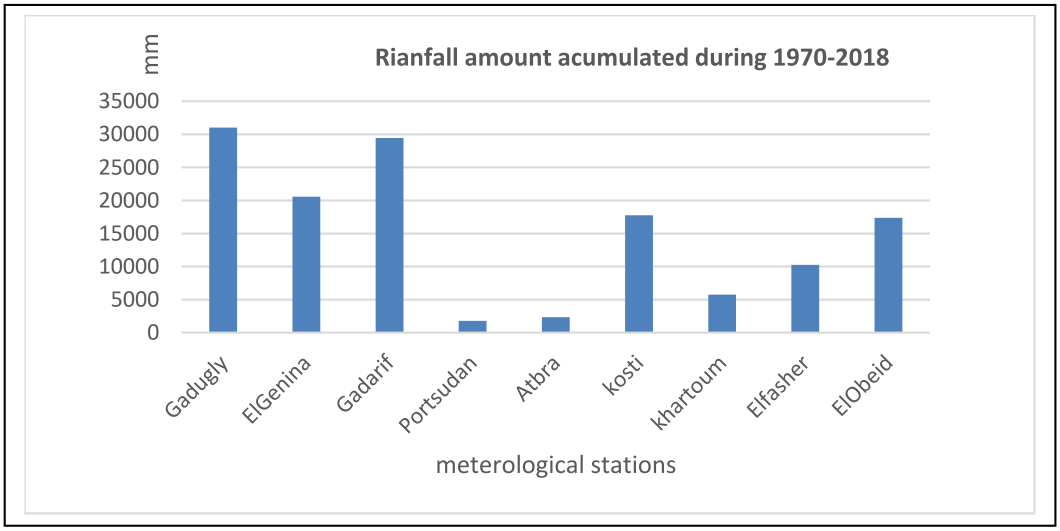


Fig (5): Total 1984 compared seasonal rainfall amount
Source: Based on Khartoum meteorological data (2021)

The average of the 1984 season of the overall total of rains that were observed over the Sudan is equal to (152.24) mm for a period of 48 years. When comparing this average with the average in the previous and next season, we detected the clear difference, as it was calculated to be 241.17 mm in 1983, and 305.17 mm in 1985. The surface distribution of the rainfall across the Sudan during the period from 1970 to 2018 is analyzed. Overall amount per station was computed and processed in Arc map 10.8 to generated the continuous surface variation analysis Fig (6). From the figure we can interpret Atbra and Port Sudan as deviated stations showed less amount presented the fifth class in red color. The other stations to some extent were apparently have nearly significant trend.

Based on the nine stations records, rainfall totals over the 48 years fluctuated in their amounts. From the figure Gadugly and Genina show the highest amount trend in annual rainfalls accumulation across the Sudan from 1970-2018. The percentage of the variation in rain amount to the overall rains that recorded based on its monthly accumulation during the period 1970 to 2018, can be classified into four categories. The first category (1%> 5%) is represented by three stations (Atbara, Port Sudan and Khartoum), the second category (5%> 10%) is represented by one station, which is El Fasher, and the third category (> 20% 10%) is represented by three stations (El Abyad, Kosti, and El Geneina), and the fourth category (> 20%) that represented by the Gedaref and Kadugli stations**.**

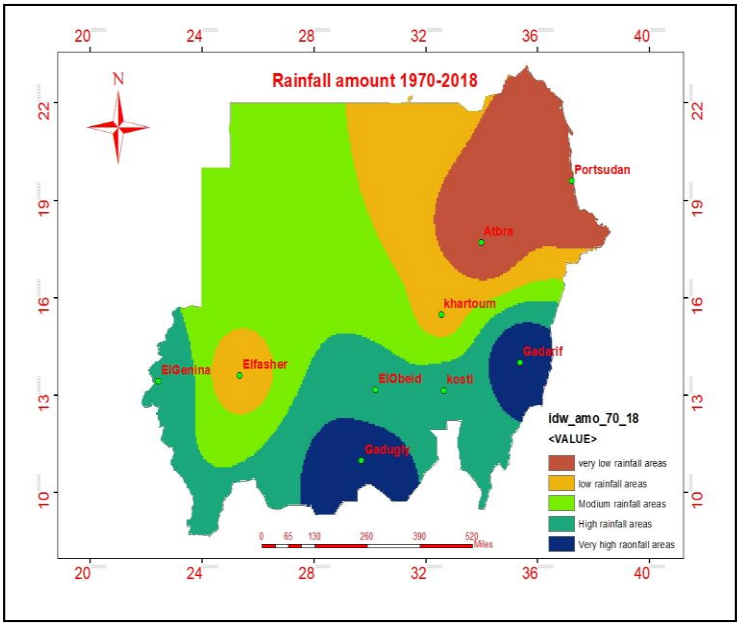


Fig (6): IDW rainfall amount continues surface prediction 1970-2018
Source: Based on ArcGIS 10.8 processing

5-3 Analysis of Mean Deviation:

This feature of seasonal rainfall average deviation gives a good trend in the meteorological analysis when categorized drier and wet seasons of rainfall. One of the guidance for detecting rainfall variability is the mean deviation variability that calculated by subtracting each periodical amount from the overall average of each station during 1970-2018. This deviation of the overall amount of the rain accumulated per station to the overall stations' average of the amount recorded during the same period were analyzed using descriptive statistics. The above average recorded values yield positive subtracted results, while the below average values determine negative subtracted results, Fig (7). The anomalies identified a combine of positives and negatives that present the trend of increasing and decreasing in an annual rainfall amount. At the level of stations, negative anomalies can be detected from the analysis of the Atbra and Port Sudan rainfall data. Fig (8) presented the output of the IDW analysis showing the continuous surface of anomalies deviated from the overall mean.

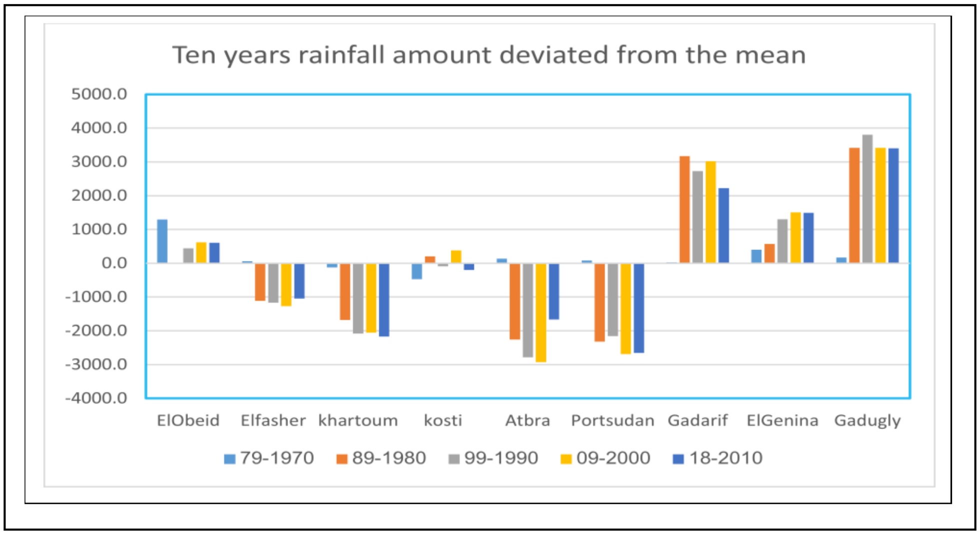


Fig (7): Overall Sudan's rainfall mean deviation (1970-2018)
Source: Based on Khartoum meteorological data

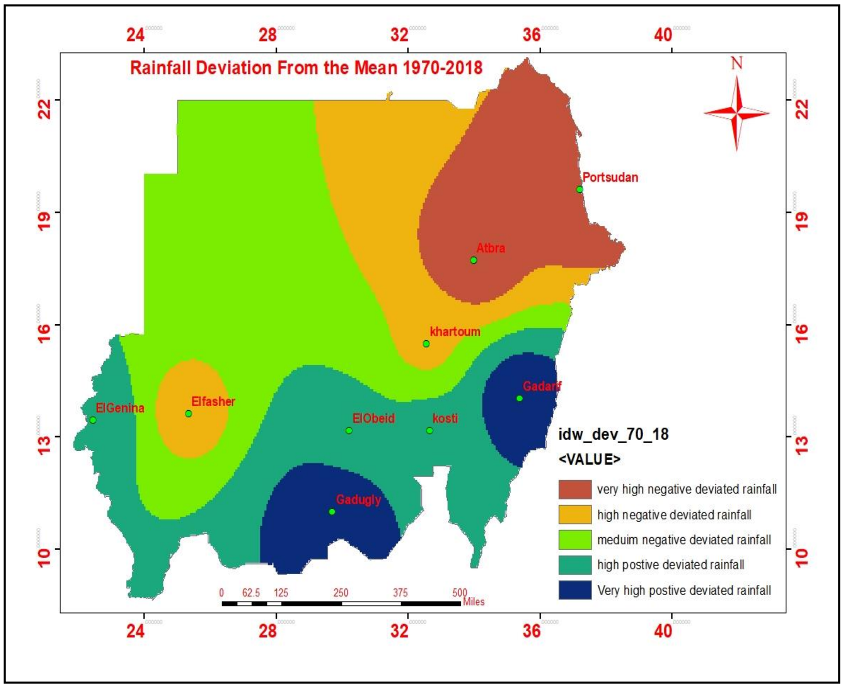


Fig (8): Rainfall deviation from the mean 1970-2018
Source: Based on ArcGIS 10.8 processing

Mean deviation result shows a good identical areal rainfall distribution variability. The States characterizes by very low, low, medium, high, and very high averages, also indicated the same trend of the rainfall accumulation analysis generated using IDW for predicting mean deviation. This validated the data and results obtained using other variables. The result presents in Fig (8) also, indicated that the very high negative anomalies can overlap with the areas of low and very low averages. These are Port Sudan and Atbra States. Medium negative anomalies indicated rainfalls deviated from total overall rainfall amount accumulated during the time series of this study. Moreover, the very high and high anomalies can match significantly areas of high and very high average such as Kagugly and Gadarif.

4-5 Patterns of Rainiest Months Analysis:

The rainiest months' trend was performed to evaluate peak and intensity of rainfall variability over the Sudan. The extent of rainfall across the Sudan is from June to end of October. The extensive rainfall indicated the peak of the rainfall occurred during August all over the country. In fact, the percentages vary from station to another based on the nature of the rainfall amount table (4). The rainfall amount precipitated during this month determines the successfulness or failure of the agricultural season in rural areas. The actual totals of rainfall during rainy months over the Sudan vary, based on the geographical location of the area.

Table (4): August versus rainiest months' percentage 1970-2018

station	**Rainiest total**	**August amount**	**%**	**Rainiest average**	**August average**
ElObeid	14253.00	6248.30	**43.84%**	290.88	127.52
Elfasher	8630.30	4304.10	**30.20%**	176.13	87.84
khartoum	4968.60	2532.90	**17.77%**	101.40	51.69
kosti	13610.73	5972.48	**41.90%**	277.77	121.89
Atbra	2556.60	1531.40	**10.74%**	52.18	31.25
Gadarif	23001.00	10114.60	**70.96%**	469.41	206.42
ElGenina	18925.10	8517.70	**59.76%**	386.23	173.83
Gadugly	20895.50	7583.80	**53.21%**	426.44	154.77

Source: **Based on Khartoum meteorological data (2021)**

Three groups can be identified to interpret the rainy months' events. The first group includes Gadugly and Genina stations that showed the most significant rainiest months during the temporal extent of the study above 350 mm in average. The second group characterizes by significant average of rainiest months' ranges between 200 and 350 mm, while the third group of less rainy events during these months includes Atbra, Khartoum, and Port Sudan with averages range between 50 and 200 mm.

A particular feature of the rainfall during rainy season was the high percentage of August fall all over the Sudan's meteorological stations, table (4). The northern States recorded less rainfall during the August month indicated their rainfall efficiency characteristics. The States that showed high amount of rainfall during the month of August are ElGadarief, ElGenina, Gadugly, and ElObeid where the amount showed 70.96%, 59.76, 53.21, and 43.84 from the total rainiest months recorded in the stations respectively. Fig (9) represents the comparison between total amount of rainfall accumulated during rainiest months (July, August, and September) and the share of the August month rainfall.

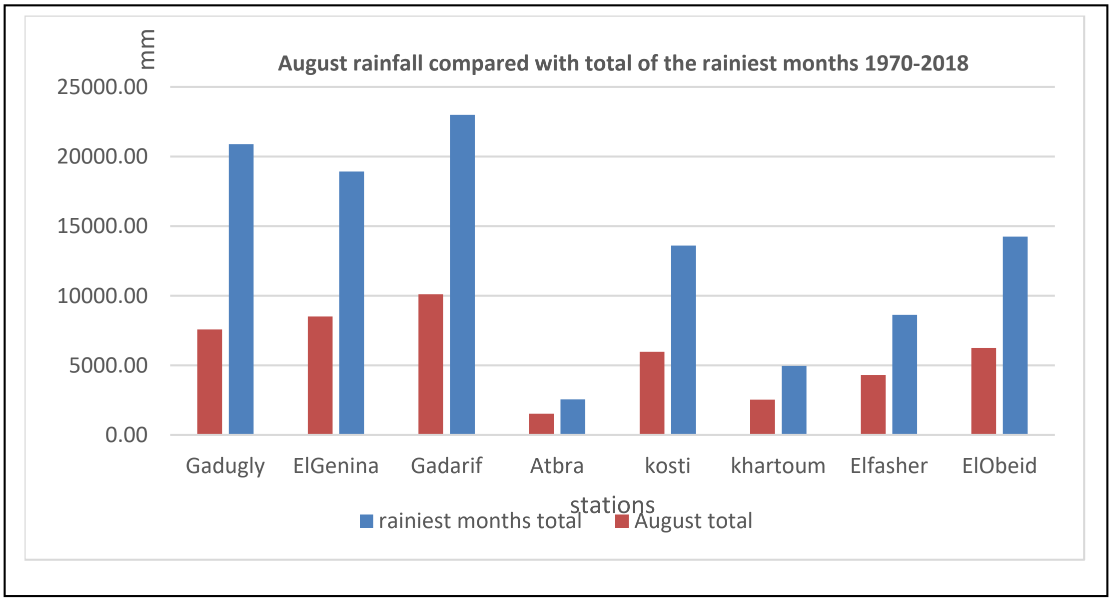


Fig (9): The rainiest months versus August rainfall 1970-2018
Source: Based on Khartoum meteorological data (2021)

5-6 Periodical rainfall analysis:

The good verification analysis can be realized through the analysis of the ten-years rainfall variability. The comparison between the five maps generated show that there are variations in rainfall amount received over the Sudan. Port Sudan and Atbra States as usual recognized by the less amount of the rainfalls received during all the five periods. In both States, 1970s and 1980s witnessed the very critical below average rainfall compared with the rest of the stations. It is periodical analysis that shows the total amount of rainfall for each ten years' aggregation. The aggregate of each ten years' rainfall amount was interpolated using the IDW for analyzing variability. Generally, the 1970s had witnessed an unprecedented decline of rainfall between States, with sharp critical in the Northern and Eastern areas. The 1980s also witnessed severe drought that caused hydrological and agricultural drought all over the country. Statistics show that the periodical analysis indicated rank of the periods. Fig (10) show the variability of rainfall among stations during the period 1970-2018, while Fig (11) displays the results that showed continuous surfaces predicted variations of five periods (1970s,1980s,1990,2000-2009, and 2010-2018). From all generated maps for each 10-year period, the results indicated some kind of significant variations.

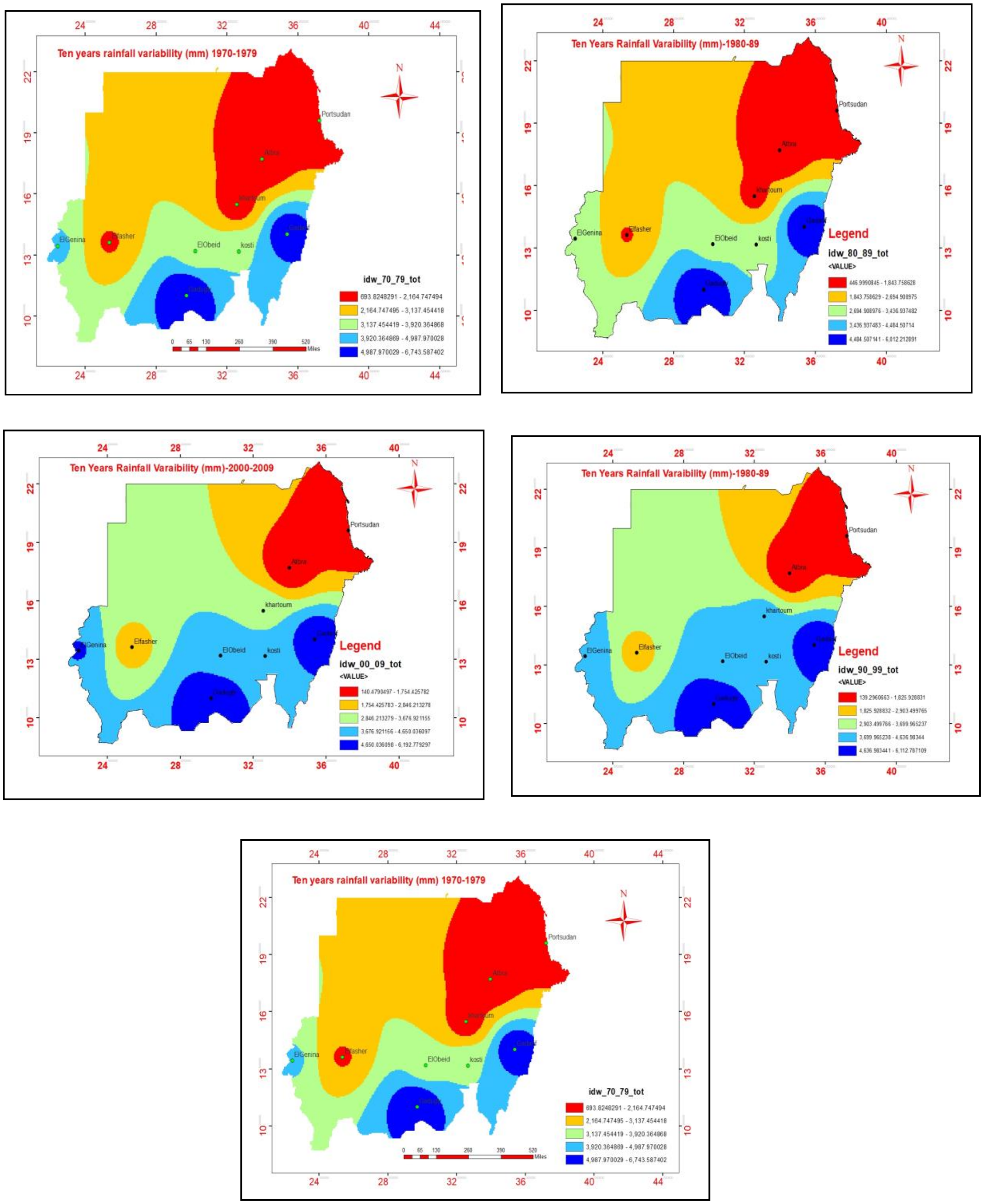


Fig (11): Ten Years Rainfall Variability Analysis
Source: Based on Arc GIS 10.8 processing

Variation in rainfall amount at State level has been the main cause of geographical location in the Sudan. The trend being represented by Khartoum, Port Sudan, and Atbra States, when most of the rainfall received is at extreme low compares with rest of the States.

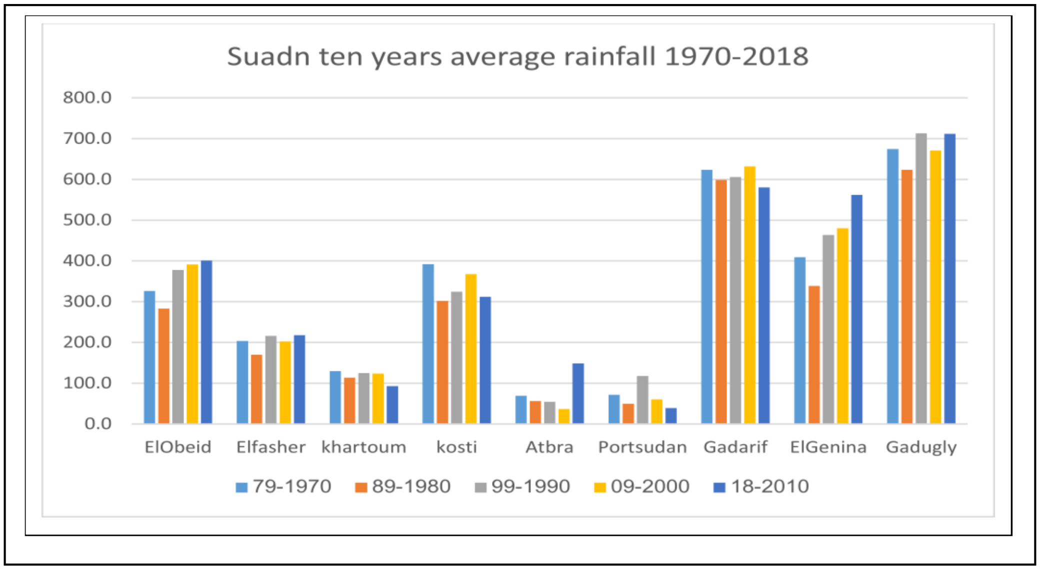


Fig (10): Sudan's Ten years' average rainfall 1970-2018
Source: **Based on Khartoum meteorological data (2021)**

VI. Discussion:

The main purpose of this study was to analyze the rainfall variability over the Sudan using GIS and Statistical methods. The study elaborated monthly and annually rainfall variability in Sudan over a 48-year (1970-2018). Rainfall trends of variability were interpreted as illustrated in figures, tables, and charts. The annual average rainfall over the Sudan showed considerable variations with standard deviation also varied from one station to another. The stations showed high standard deviation are ElGenina, Gadugly, ElGadarief, ElObeid, and Kosti with values of 131.99, 125.95, 120.56, 118.84, and 108.13 mm respectively.

Nine different meteorological stations were included in the study in order to analyze rainfall variability over the Sudan during the time series from 1970 to 2018. In addition, the complementary statistical analyses were also applied in association with nine different stations. IDW has been used as an effective approach detects the continues surfaces variation based on the observed values of the nine stations. All IDW maps generated seem to be in consistent with the origin data for the stations. The overall trend of rainfalls consistency found in all stations except Atbara, Khartoum and Port Sudan States. The distribution of the station is dispersal over the country and the distance between these station is not match the criteria for ideal meteorological representations.

Some of the Sudan's States are seem as being classified of low rainfall for environment sustainability. Insufficiently, the annual rainfall amount indicated critical low extremes during the rainy seasons such as in Dongla and Atbra in the northern fringes of the country. The rainfall characteristics of the Sudan with high coefficient of variation indicates the specificity of the extremes (low or high). The only station that vulnerable to the effect of the rainfall variability is the coastal Port Sudan the capital city of the Red Sea State. From the analysis we compare the low year rains with the less wetlands occurrence that depicted as the multi-year droughts emerged in the mid-1980s and continued to reoccur in high frequency during 1990s and 2000s.

VII. Conclusion:

This study concluded the monthly and annually rainfall variability in the Sudan meteorological stations over the period from 1970 to 2018. The coordinates of the nine stations were tabulated in excel sheet and converted into GIS formatting and then used for IDW application. Sudan's rainfall depends on the seasonal movement of the Intertropical Convergence Zone (ITCZ) that determines the seasonality of the monsoon rainfall all over the country. From the north towards the south, the annual rainfall increased in their frequency, amounts, and intensity. The average rainfall significantly varies from north to the south. The study analyzed the main clues that explain and interpret the rainfall variability in the context of climate change. The study depicts the signs of the variability trends of Sudan's meteorological stations, which have different interpretation in the rainfall general trends. The conclusive statement is that based on the 48-year study period, the Sudan characterizes by significant rainfall variation from the north to south and from west to east.

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