Vol. 13(31), pp. 1577-1590, 2 August, 2018
DOI: 10.5897/AJAR2018.13365
Article Number: 3AC65CC57989
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Rainfall variability and its implications for agricultural production in Gedarif State, Eastern Sudan

Lotfie A. Yousif[1], Abdelrahman A. Khatir[2], Faisal M. El-Hag[3], Ahmed M. Abdelkarim[4], Hussain S. Adam[5], Abdelhadi A. Wahab[6], Yasunori Kurosaki[7] and Imad-eldin A. Ali-Babiker[3,7*]

[1]Gedarif Research Station, Agricultural Research Corporation (ARC), Gedarif, Sudan.
[2]El Obied Research Station, Agricultural Research Corporation (ARC), El Obied, Sudan.
[3]Dry Lands Research Center (DLRC), Agricultural Research Corporation (ARC), Soba, Khartoum, Sudan.
[4]Sudan Meteorological Authority (SMA), Khartoum, Sudan.
[5]Water Management and Irrigation Institute, University of Gezira, Wad-Medani, Sudan.
[6]College of Graduate Studies, Desert and Arid Zones Sciences Program, Arabian Gulf University, Manama, Bahrain.
[7]Arid Land Research Center (ALRC), Tottori University, Tottori, Japan.

Received 3 July, 2018; Accepted 27 July, 2018

Rainfed agriculture is practiced in the central clay plains of Sudan and is affected by the high rainfall variability in time and space within and between seasons. This study focused on analyzing rainfall variability and trend using a 30-year record (1985-2014) of seven meteorological stations at the major agricultural production areas in Gedarif state in eastern Sudan. Yearly rainfall has relatively low variability compared to monthly variability. According to annual rainfall totals, it was possible to classify stations into two groups; one with annual rainfall more than 600 mm and the second with rainfall ranging between 500 to 600 mm. In both groups, the majority of rainfall (60%) occurred during July and August. Trends of rainfall were inconsistent and the cropping season extended from June to September. Farmers in areas having high rainfall and extended growing season (group I) could grow suitable crops and varieties and their appropriate management practices should be implemented. In areas of low rainfall and short growing seasons (group II), farmers could grow crops of short maturing varieties and water harvesting techniques. There is a need for research activities that examine rainfall trends and how agricultural practices might adapt accordingly.

Key words: Rainfall, variability, trend, sorghum yield, Gedarif, Sudan.

INTRODUCTION

The rainfall as the most important hydrological variable significantly affects agriculture in dry land areas. Agricultural production is one of the main pillars of the Sudanese economy as it provides food for most of the country's citizens and raw materials for local industries besides its contribution to the export market. The contribution of agricultural sector to gross domestic product (GDP) is about 30.6% (Central Bank of Sudan, 2013). In Sudan, agriculture is divided into irrigated and rainfed sectors. The latter represents about 92% of the total cultivated area in the Sudan (18.7 million ha) (Federal Ministry of Agriculture and Irrigation, 2015). Rainfed agriculture is practiced in the central clay plains of Sudan in three climatic zones; dry, semi-dry and semi-humid zones (Adam, 2008). It is mainly practiced in Gedarif, Blue Nile, White Nile and Southern Kordofan states. Although these areas differ in the amount and distribution of rainfall, the crops grown and their associated management practices are more or less similar. Sorghum (*Sorghum bicolor* L.), the main staple food crop in Sudan, is mainly produced under rainfed conditions. Farah et al. (1996) studied the effect of climate and cultural practices on rainfed agricultural production in Sudan. Their results showed sorghum yields declined over the years. They also presented a strong association between rainfall distribution over time and crop yields.

Rainfed agriculture in Gedarif state is one of the most important Sudan areas; comprising of both traditional and mechanized farming practices. Mechanized rainfed farming in Gedarif state started in the mid-1940s. Since that time, it has witnessed a substantial expansion in area and by early sixties constituted around 30% of total sorghum area in Sudan (Ahmed, 1994). However, average Sorghum yields have declined from 0.7 t/ha during the period 1970-1979 to 0.36 t/ha in recent ten years (Ministry of Agriculture, 2011). The expansion in sorghum cultivated area is considered as compensation for the declining yields over years (Farah et al., 1996).

Several studies worldwide have shown that productivity of rainfed agriculture is a function of climate and cultural practices, with more emphasis on climatic variables. Mertz et al. (2009) suggested that high vulnerability of rain fed sector coupled with limited adaptation options have direct effects on production. Frequency and dry spells length are the major factors affecting yield (Rockström et al., 2002). On other hand, changes within season lead to changes in growing and maturation periods of crops (Dong et al., 2009). Rawhani et al. (2011) studied the climate variability and crop production in Tanzania. They found that climate variability reduced yields by 4.2, 7.2 and 7.6% for maize, sorghum and rice, respectively.

Generally, climatic factors, especially rainfall plays an essential role in the success of agricultural production in rainfed areas for the following reasons:

1) Rain is the main source of water for crops; hence it determines types of grown crops and their yields.
2) Rain determines the start and the end of the season (growing season length); consequently, it affects selection of varieties and scheduling of field operations.
3) Rain determines the available working days for machinery; through its effect on soil moisture content, thus, it affects the type and size of machinery to be used.
4) Variability of rainfall from season to season and during the season affects the whole farm planning and management.

Therefore, it is imperative to maximize the efficiency of rainwater use. Although it is difficult to predict rainfall in advance, because it varies in place and time of occurrence, analysis of rainfall records can help to understand rainfall patterns and trends; hence better rainwater management. Rainfall data analysis, such as; rain variability and trends will help to furnish information for policy and decision makers as well as farmers to develop and implement their plans. Moreover, it helps researchers to orient their research activities toward more suitable adaptation technologies to achieve sustainable agricultural productivity under the changing climate.

The main objective of this research was to analyze rainfall records from seven stations in Gedarif state over the 30-year period from 1985 to 2014. The specific objectives are to assess the monthly and annual rainfall variability, and to study trends of rainfall over this 30-year period.

MATERIALS AND METHODS

Description of study area

Gedarif State lies in the Eastern part of Sudan between latitudes 12.67º and 15.75º N and longitudes 33.57º and 37.0º E, covering 71,000 km^2 (Figure 1). The State stretches from North to South through three climatic zones; dry, semi- dry and semi-humid zones (Adam, 2008). The soil is heavy cracking clay (Vertisols), characterized by shrinking when dry and swelling when moistened. The daily mean temperature reaches 33.4°C in May and drops to 26.3°C in January. The relative humidity varies from 22% in March to 71% in August (Sudan Meteorological Authority, 2010). Rainfall is always in the summer and most rainfall events occur within the period June to October; resulting in a short-single growing season. About three million hectares are cultivated annually in Gedarif State. About 85% of this area is cropped by sorghum, the staple food crop. Seven stations were selected which are located and scattered in the major rainfed agricultural production areas of Gedarif State as shown in Figure 1. These stations are Gadambalia, Gedarif, Alhoory, Douka, Alhawaata, Umseenat and Samsam. The elevation of these stations is 505, 600, 540, 443,637, 467 and 480 m above sea level, respectively. All the stations are located in very flat extended areas with no significant topographic or forests lactated between them.

Data collection

To achieve the objectives of this study, rainfall data were obtained from Mechanized Farming Corporation (MFC) records. Monthly (April to October) rainfall data were obtained from the seven stations over a 30-year period (1985 to 2014). Moreover, data on sorghum cropped and harvested area (ha), total production (ton) and grain yield (kg/ha) were obtained from the records of Ministry of

*Corresponding author. E-mail: imadaa@gmail.com.

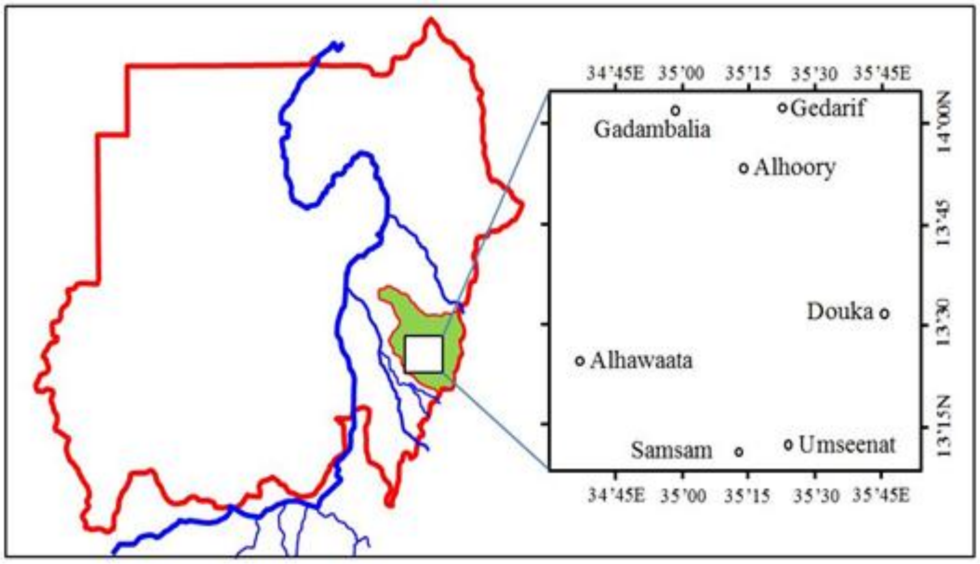


Figure 1. Sudan map showing Gedarif State (Green) and the studied area with the 7 Stations.

Agriculture and Irrigation in Gedarif State for the period from 1985 to 2013.

Data analyses

In order to summarize data set and check its quality, a box and whisker plot was constructed from median, lower and upper quartiles, lower and upper extremes, and the mean is marked in it for each month for all stations. The changes in rainfall distribution were analyzed using statistic indicators such as average, percentage and coefficient of variation were used to analyze the monthly and total rainfall data for each station. In addition, anomalies for the total annual rainfall calculated as its departure from the long-term average values for the period 1985 to 2014 at each station. The monthly rainfall anomalies were also calculated for each month (June, July, August and September) separately and its departure from each month long-term average values for the same period (1985-2014).

Changes in rainfall distribution

Deviations of the total annual rainfall from average values at each station was obtained and plotted with their corresponding years to show changes in annual rainfall distribution. Point maps were created for these stations in *ArcGIS* software (ESRI, 2008) using their coordinates and annual rainfall data. Rainfall data in stations were interpolated to cover the entire study area; the results were continuous maps. The maps are based on the inverse distance weighted (IDW) interpolation which determines cell values using a linearly weighted combination of a set of sample points (stations). This method assumes that the variable being mapped decreases in influence with distance from its sampled location. To better visualize these rainfall data, the continuous maps were categorized into 50 mm isohyets.

Rainfall trends

To determine rainfall trends, the annual rainfall totals of each station for the 30 years were divided into three groups: (1985 - 1994), (1995 - 2004) and (2005 - 2014). The average of each ten years was calculated. The same procedure was used for monthly rainfall data. To analyze trends in rainfall data, regression coefficients were produced in image format. Simple linear regression modelling was applied to extract the regression parameters. Following Fuller (1998), time (in years) was defined as the independent variable and the rainfall data values as the dependent variable. The resulting individual linear regressions consisting of correlation coefficients and regression slope values indicate the strength and magnitude of the calculated trends (Eckert et al., 2015). The regression slopes of all pixel locations were thus categorized into negative trend", "positive trend" and "no trend" categories and then mapped accordingly.

RESULTS AND DISCUSSION

The box and whisker plots (Figure 2) indicated that there are generally viewer outliers. However, most of the months showed slightly positively skewed. In all stations, July and August showed large dispersion (IQR), while June and September was much less in dispersion. Some stations showed small dispersion in May. All stations showed no dispersions in April and October.

The analysis of rainfall data showed that the majority of rainfall (60%) occurred during July and August throughout all stations. The high amounts of rains during July and August adversely affect the necessary cultural practices such as plowing, sowing and weeding operations. This is because of the inherent limitations of Vertisols which are largely related to soil moisture. Generally, these soils have a narrow range of soil moisture within which mechanical operations can be conducted. A recent study indicated that a soil moisture content between 28.3 and 33.1% results in poor tillage (Yousif et al., 2012). The same study showed that more than 39.4% soil moisture

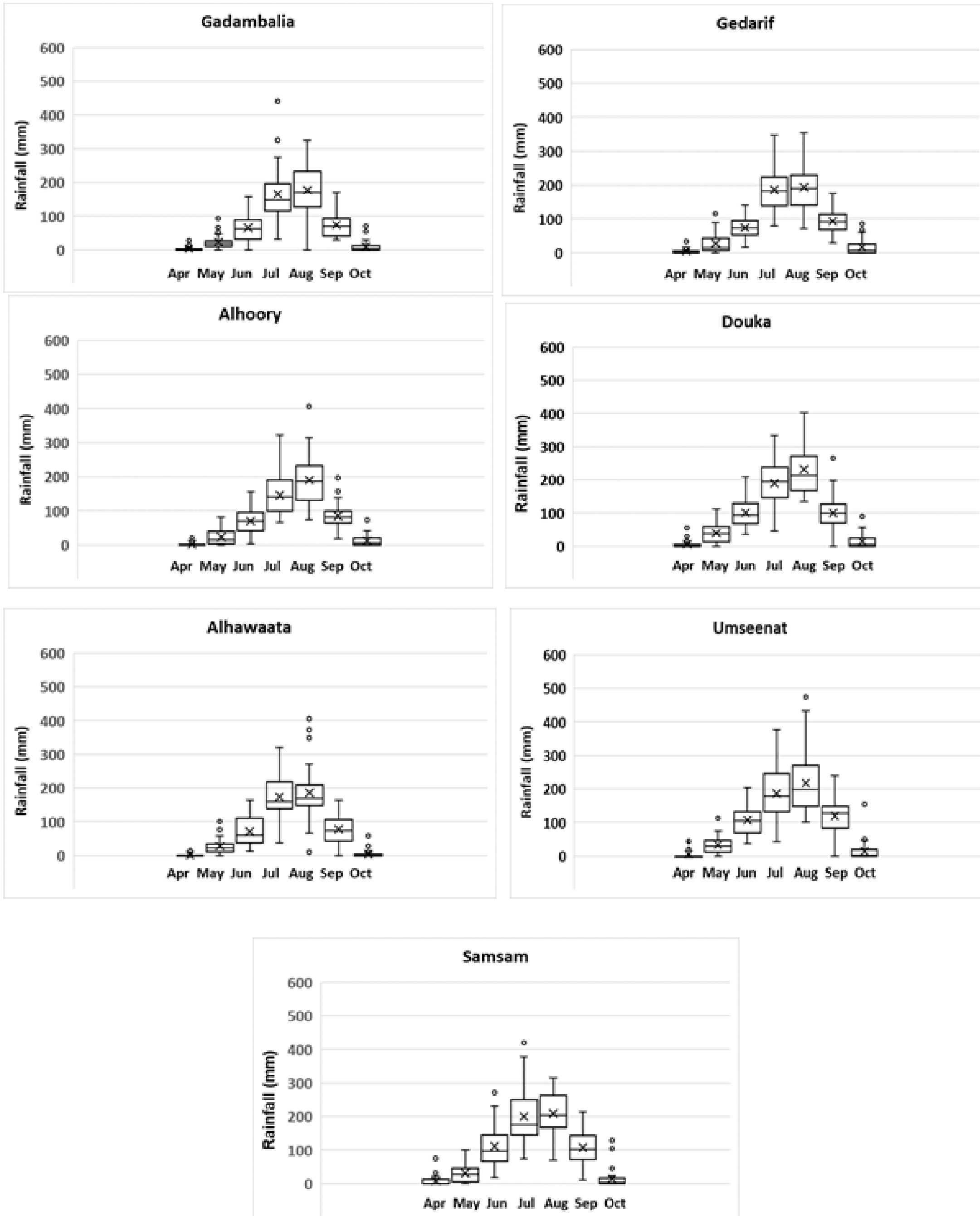


Figure 2. Monthly rainfall box and whisker plot for seven stations in Gedarif State for period from 1985 to 2014.

makes the soil unworkable. Due to the very low hydraulic conductivity of the soil, when high rainfall happens continuously during July and August, flooding occurs which may lead to severe crop damage.

Both June and September received half of the amount of rainfall that fell in July and August. Less rainfall (10%) occurred in April, May and October. Monthly rainfall distribution analysis can help in selecting and scheduling farm operations; for example to avoid water logging during seedling stage and water shortage during flowering stage of certain crops.

There are differences in the average total rainfall over the 30 years amongst the stations (Figure 3). Umseenat, Samsam and Douka stations hadthe highest and same average rainfall (683-684 mm); however, Alhawaata, Alhoory and Gadambalia stations had the lowest one

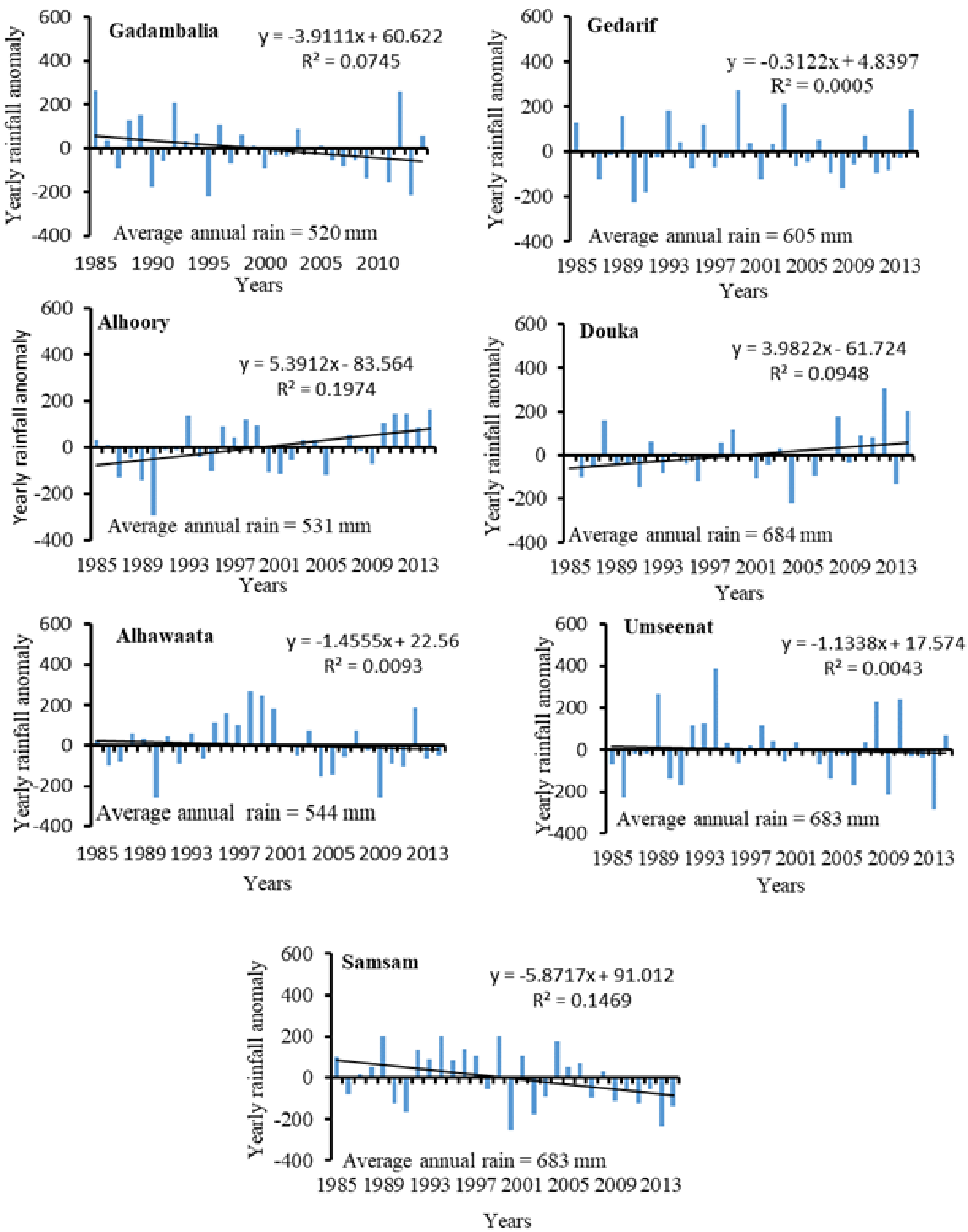


Figure 3. Yearly total rainfall anomalies at seven stations in Gedarif State for period from 1985 to 2014.

(520-544 mm), while Gedarif station had about 600 mm. There is a relationship between longitude and rainfall (that is more rain in the south than north). Figure 3 also shows the variability in annual rainfall in Gedarif State. The deviation of annual rainfall from the overall average rainfall at each station.

The coefficient of variation (C.V.) for yearly total rain fall at all stations was not high and was ranging between 17 and 24%. In contrast, C.V. for monthly rainfall varied; in July and August, it ranged between 29 and 49% and in April and October it is very high ranging between 137 and 260%. C.V. use allows for the comparison of the variability of rainfall between locations which have different average annual rainfall.

Generally, the monthly C.V. increases when the rainfall decreases. However, it is worth noting that similar monthly C.V. was found for stations recording different rainfall totals. For example, the C.V. at Umseenat and Gedarif in June was the same (41%) but the same stations had different rainfall; 107 mm and 74 mm respectively. These results are in concur with the findings of Tilahun (2006) who found that rainfall was a highly variable factor in comparison with other meteorological parameters in arid and semi-arid regions of Ethiopia.

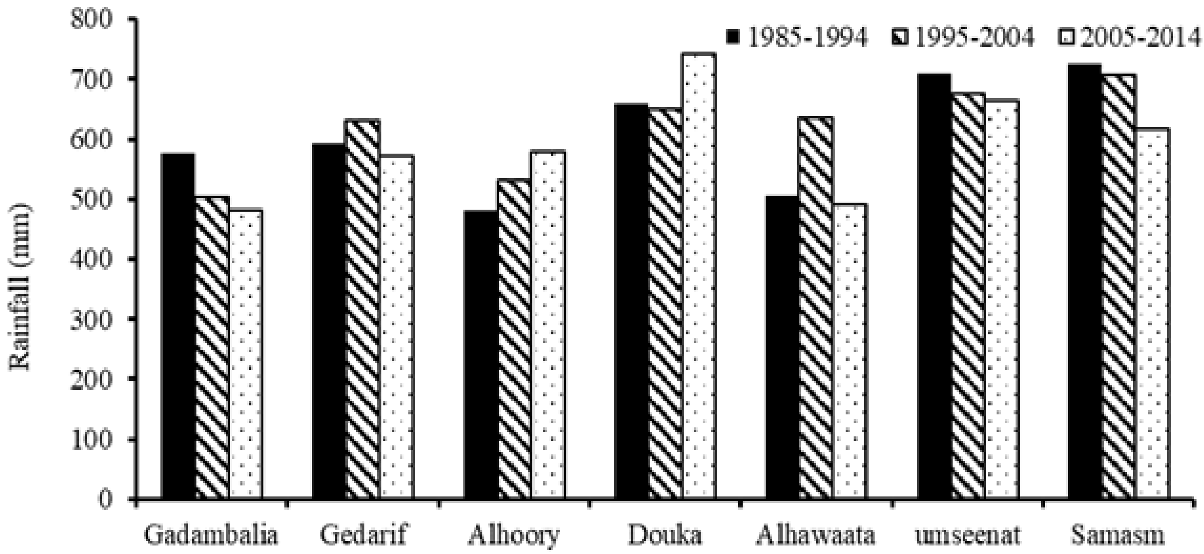


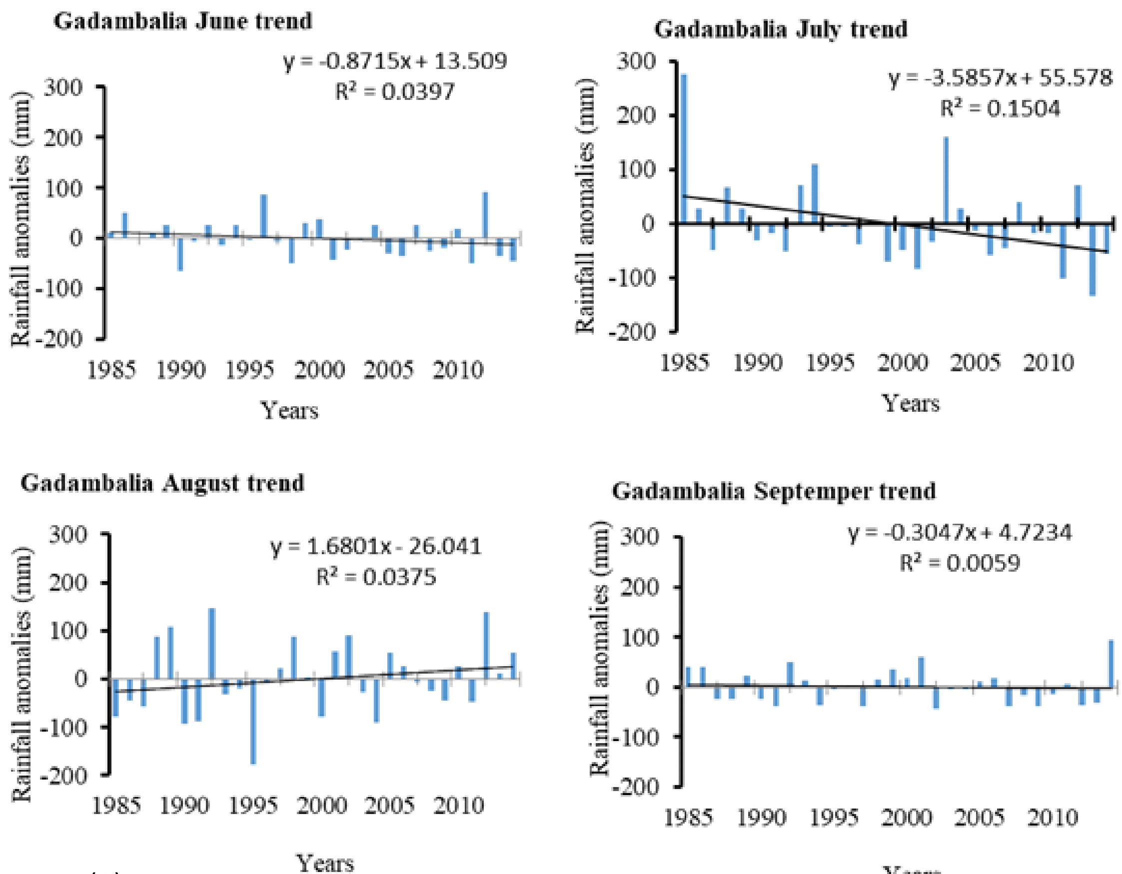
Figure 4. Total annual rainfall (mm) each ten years (1985 to 2014) at seven stations in Gedarif State.

Similarly, Adam (2008) mentions that the ecology of any region is not only dependent on how much rainfall falls but also on how it is distributed in time and space within and between seasons. This agrees with the fact that drier conditions mean even greater rainfall variability (Batisani and Yarnal, 2010). Total rainfall trends at Umseenat, Samsam and Gadambalia stations reflected a decrease in average rainfall in 10-year periods from 1985 to 2014 (Figure 4), whereas at Alhoory and Douka there was an increase trend. At Alhawaata and Gedarif stations, no steady trend between the three periods was similarly observed.

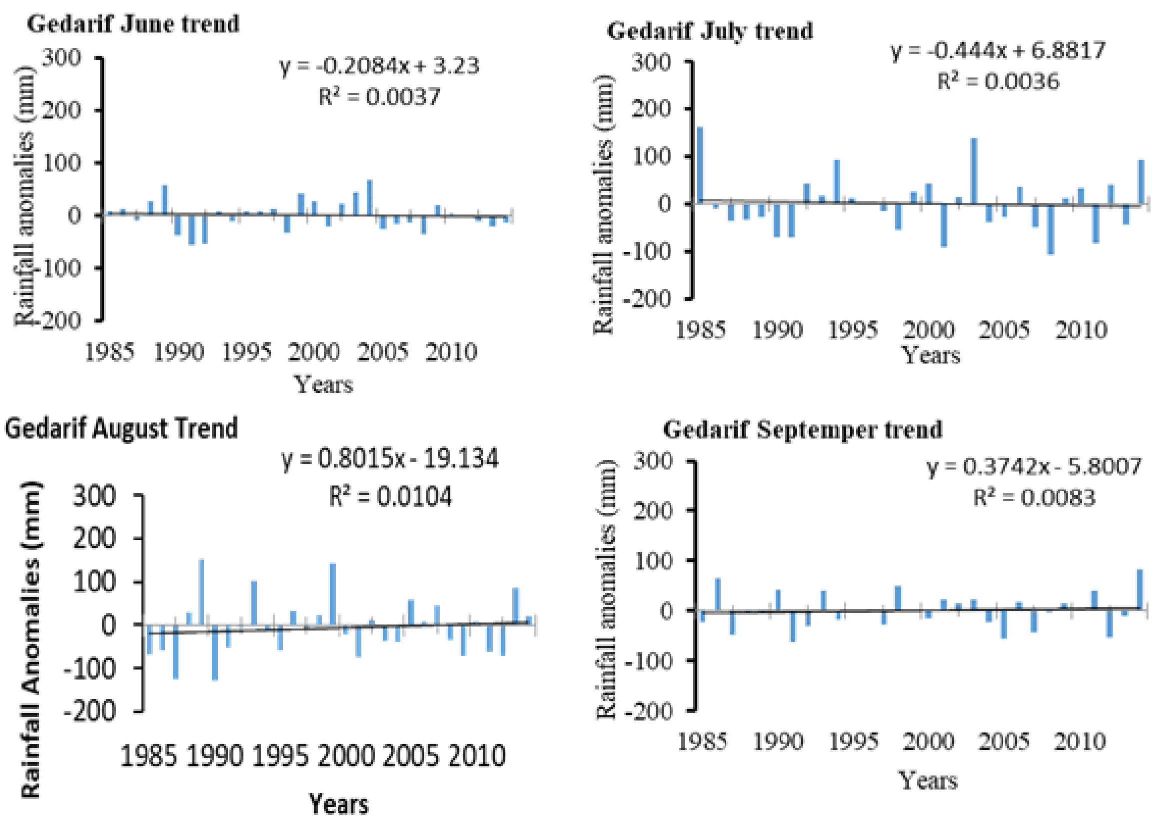
The monthly rainfall anomalies (June, July, August and September) at the seven stations during the period 1985-2014 are shown in Figure 5a to g. Four stations (Gadambalia, Gedarif, Alhoory, and Douka) showed no changes in the rainfall trend in June. On the other hand, three stations (Alhawaata, Umseenat and Samsam) those located more to south expiated slight rainfall decrease trend in June. For July, all the stations, except Alhoory and Douka, showed varied decreasing trend in rainfall. In contrast, for August, all the stations, except Samsam, showed perceptible increases in the rainfall whereas for September all the stations exhibited slight to noticeable increases in the rainfall. Although the rainfall variability during the same month among different years was very high, but there is the general trend that rainfall decreases at the beginning of the season (June-July) and increase towards the end of the season (September). Increasing trends in monthly rainfall were observed in July in Alhoory, August in Gedarif, and September in Douka as well as Alhoory (Figure 6). However, a decreasing trend of rainfall was seen in June in Gadambalia and July in Umseenat, Samsam and Gadambalia stations, August in Samsam, and October in Gedarif and Gadambalia. On the other side, some months showed unstable trends in rainfall such as June in Umseenat, Douka and Alhoory as well as July in Douka. Farah et al. (1996) suggest that good distribution of rainfall during the growing season is a stronger determinant of crop yield than the total annual rainfall.

These results have implications on timing of land preparation and planting crops. Huho (2011) reported similar trends in the March-April-May rainfall season in Kenya, as the beginning of the season showed gradual decline in rainfall amounts while towards the end of the season showed increased monthly rainfall totals. Under such situations, farmers commence sowing later when rainfall was certain. This cautiousness by farmers favor the shifts in planting dates from late June and early July to late July and early August due to the changing rainfall patterns in order to avoid the cost repeated sowing in occasions when July rainfall delayed. These results imply that short to medium maturing varieties of field crops, which have lower crop water requirements, and their associated management practices are required for the near future.

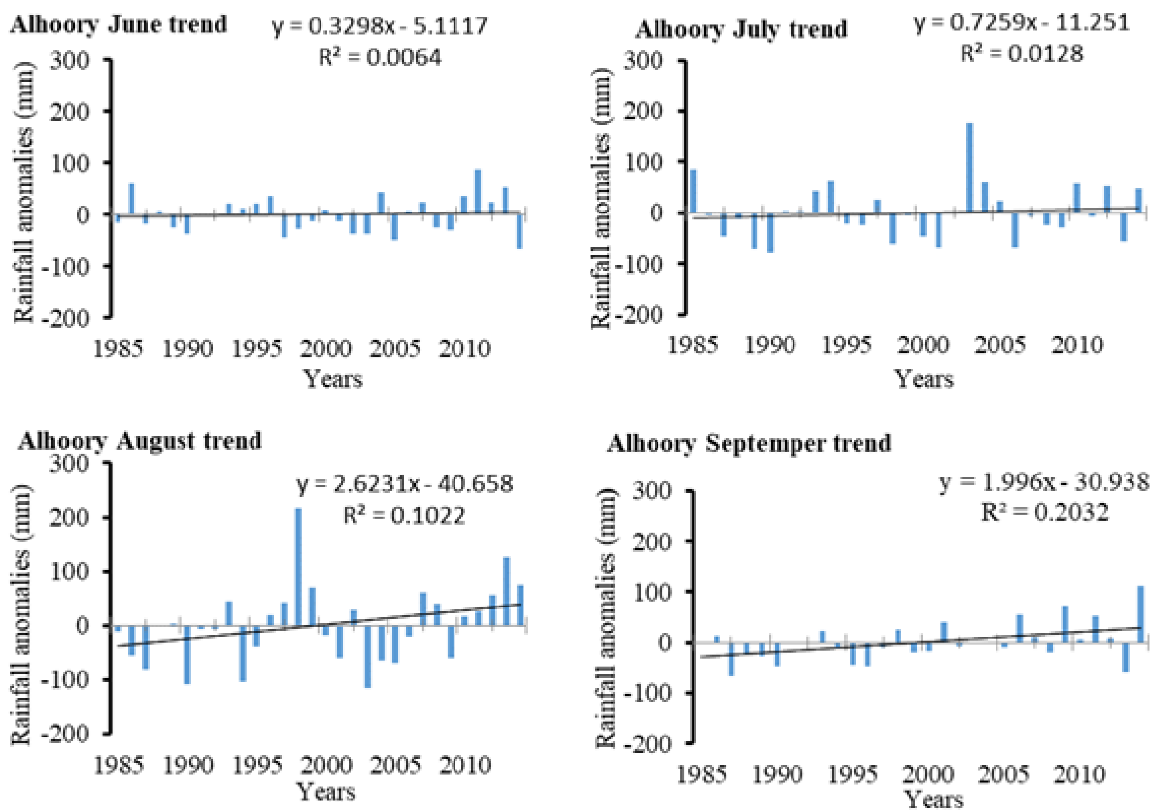
The result of mapping trends in rainfall distribution across the study area over the whole study period is shown in Figure 7. The areas of Alhoory and Douka showed a positive trend in rainfall distribution, whereas Gadambalia, Samsam and to some extent Umseenat showed a negative trend. On the other hand, in Gedarif and Alhawaata rainfall distribution was unstable and reflects no trend. A previous study showed a declining trend in mean annual rainfall throughout Sudan during the period 1952 to 1992 except for Gedarif where it remained unchanged (Mohamed, 1998). A recent study in Butana region, part of which lies in northern Gedarif State, showed that rainfall isohyets have moved


Gadambalia June trend
y = -0.8715x + 13.509
R² = 0.0397
Rainfall anomalies (mm)
Years
Gadambalia July trend
y = -3.5857x + 55.578
R² = 0.1504
Rainfall anomalies (mm)
Years
Gadambalia August trend
y = 1.6801x - 26.041
R² = 0.0375
Rainfall anomalies (mm)
Years
Gadambalia Septemper trend
y = -0.3047x + 4.7234
R² = 0.0059
Rainfall anomalies (mm)
Years

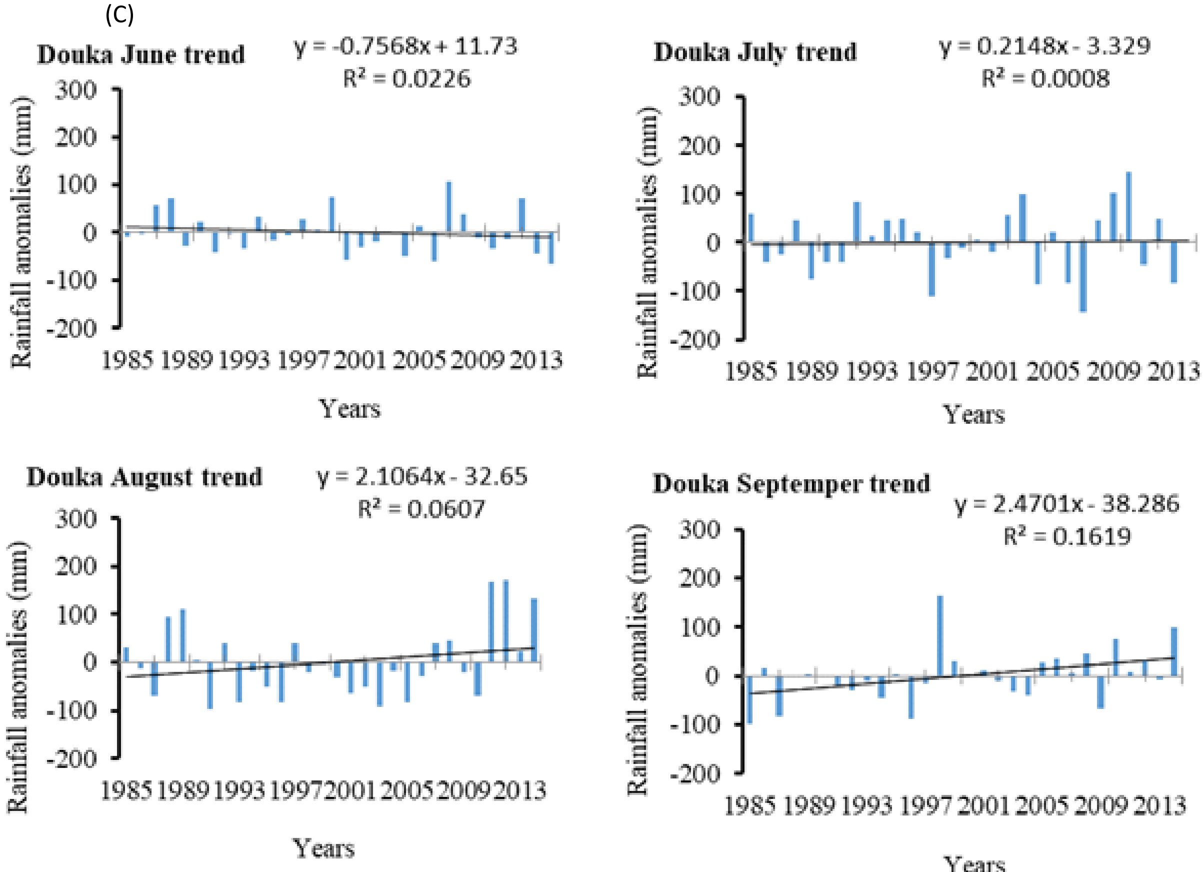
(A)


Gedarif June trend
y = -0.2084x + 3.23
R² = 0.0037
Rainfall anomalies (mm)
Years
Gedarif July trend
y = -0.444x + 6.8817
R² = 0.0036
Rainfall anomalies (mm)
Years
Gedarif August Trend
y = 0.8015x - 19.134
R² = 0.0104
Rainfall Anomalies (mm)
Years
Gedarif Septemper trend
y = 0.3742x - 5.8007
R² = 0.0083
Rainfall anomalies (mm)
Years

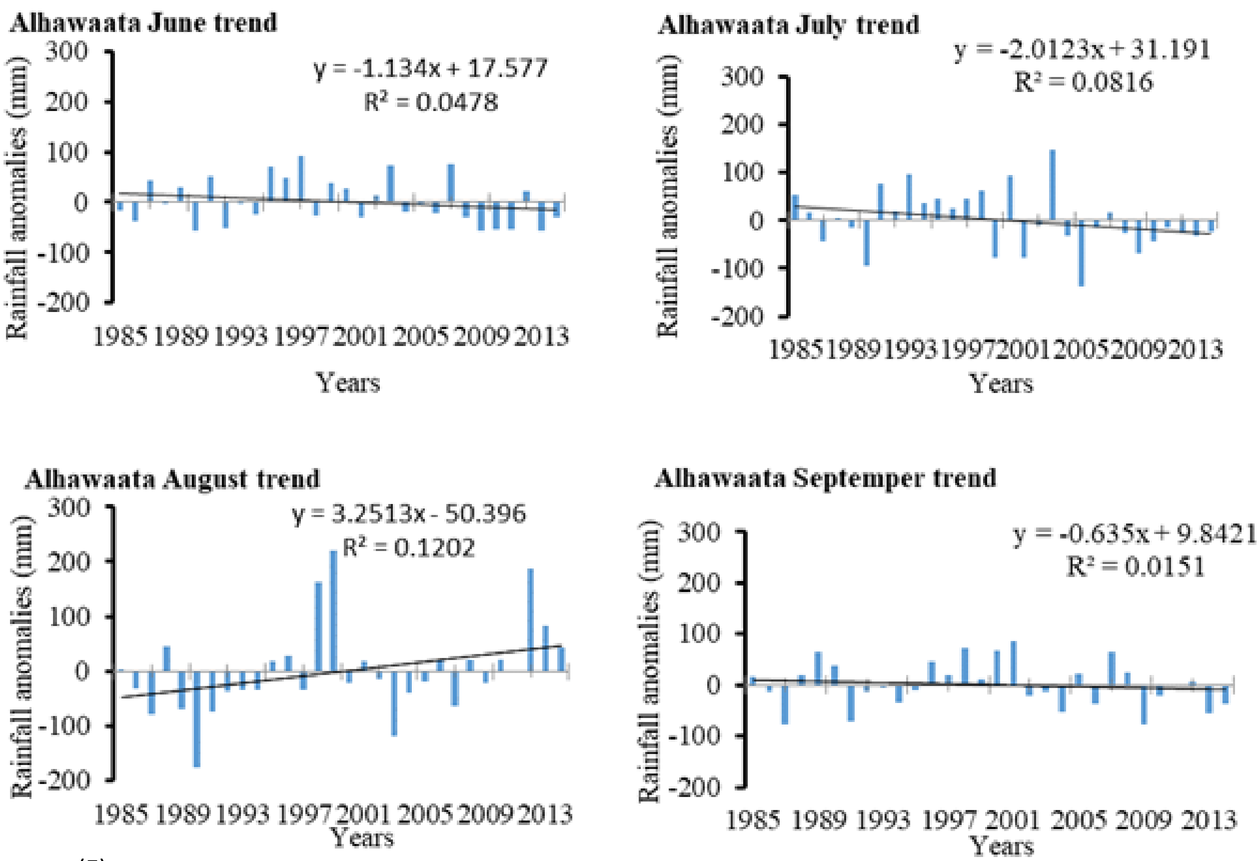
(B)


Alhoory June trend
y = 0.3298x - 5.1117
R² = 0.0064
Alhoory July trend
y = 0.7259x - 11.251
R² = 0.0128
Alhoory August trend
y = 2.6231x - 40.658
R² = 0.1022
Alhoory Septemper trend
y = 1.996x - 30.938
R² = 0.2032
Rainfall anomalies (mm)
Years
300
200
100
0
-100
-200
1985 1990 1995 2000 2005 2010

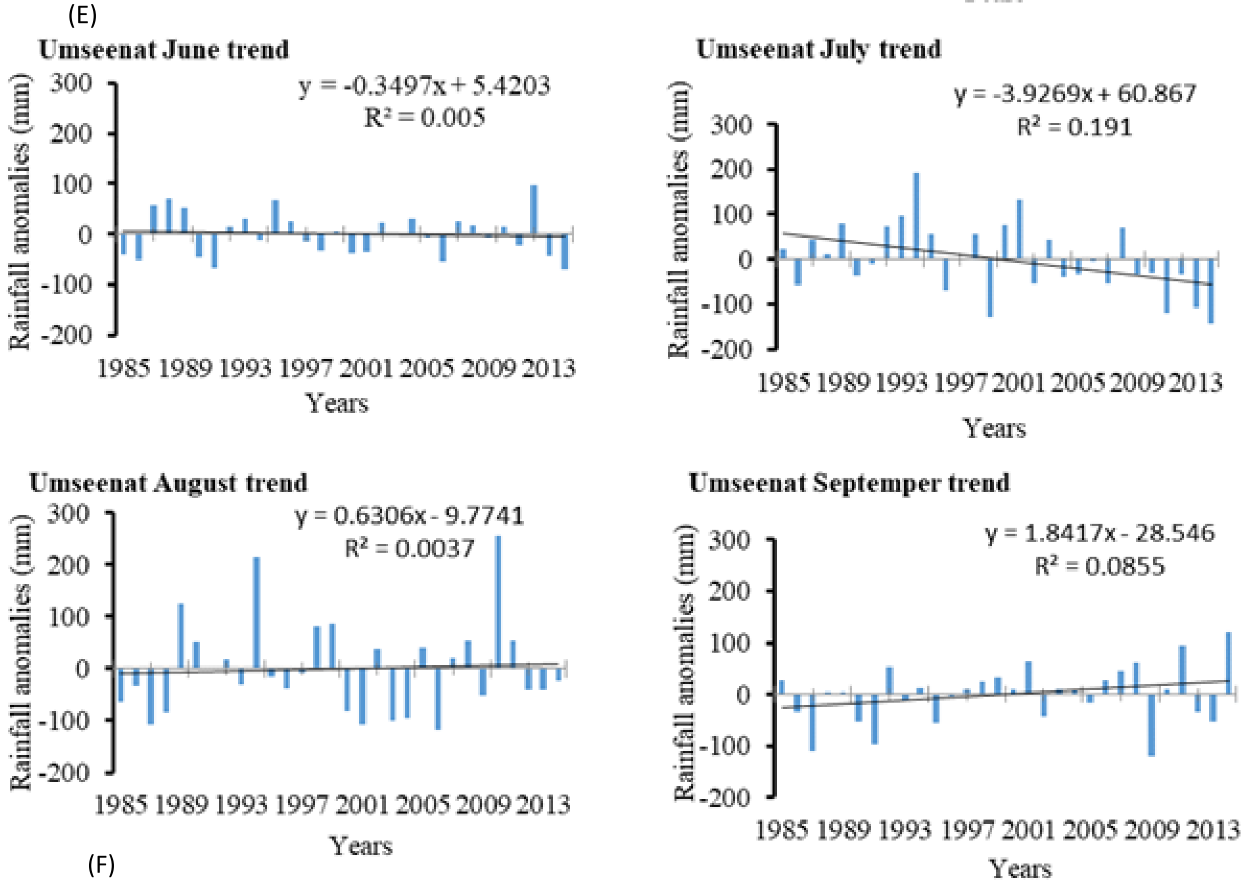
(C)


Douka June trend
y = -0.7568x + 11.73
R² = 0.0226
Douka July trend
y = 0.2148x - 3.329
R² = 0.0008
Douka August trend
y = 2.1064x - 32.65
R² = 0.0607
Douka Septemper trend
y = 2.4701x - 38.286
R² = 0.1619
Rainfall anomalies (mm)
Years
300
200
100
0
-100
-200
1985 1989 1993 1997 2001 2005 2009 2013

(D)


Alhawaata June trend
y = -1.134x + 17.577
R² = 0.0478
Rainfall anomalies (mm)
Years
Alhawaata July trend
y = -2.0123x + 31.191
R² = 0.0816
Rainfall anomalies (mm)
Years
Alhawaata August trend
y = 3.2513x - 50.396
R² = 0.1202
Rainfall anomalies (mm)
Years
Alhawaata Septemper trend
y = -0.635x + 9.8421
R² = 0.0151
Rainfall anomalies (mm)
Years

(E)


Umseenat June trend
y = -0.3497x + 5.4203
R² = 0.005
Rainfall anomalies (mm)
Years
Umseenat July trend
y = -3.9269x + 60.867
R² = 0.191
Rainfall anomalies (mm)
Years
Umseenat August trend
y = 0.6306x - 9.7741
R² = 0.0037
Rainfall anomalies (mm)
Years
Umseenat Septemper trend
y = 1.8417x - 28.546
R² = 0.0855
Rainfall anomalies (mm)
Years

(F)

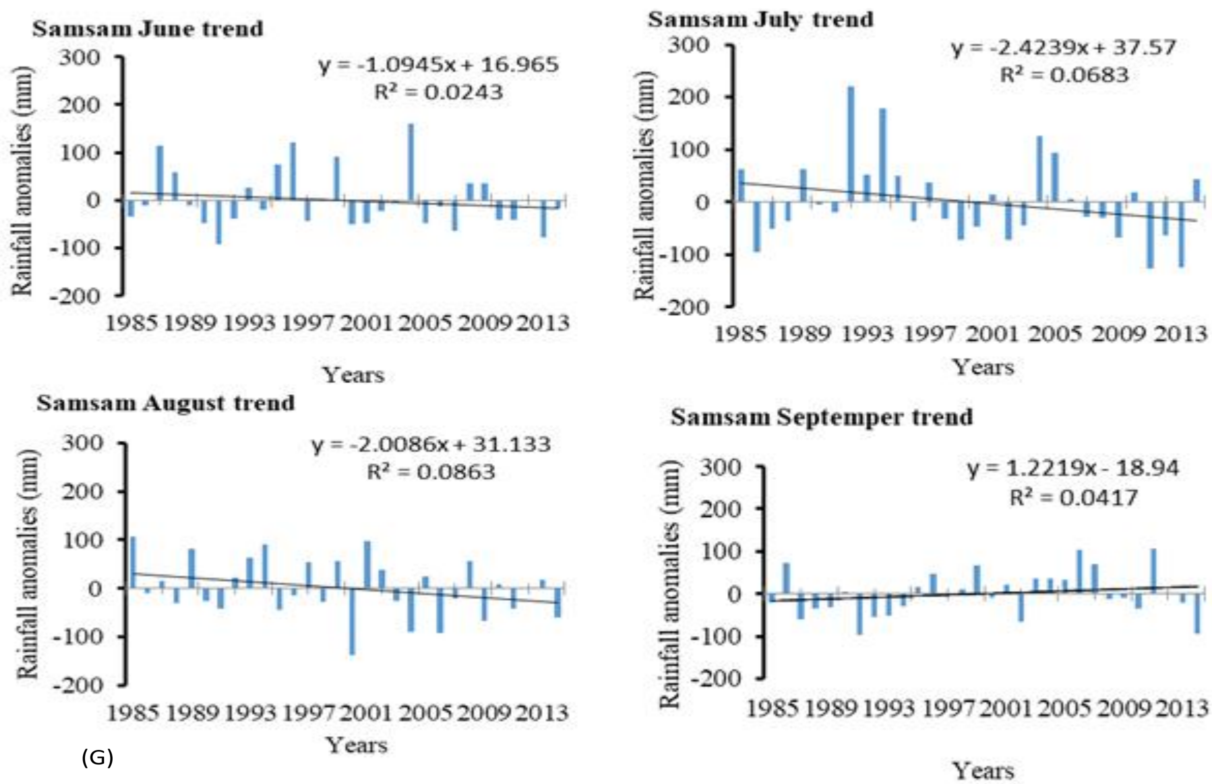


Figure 5. (a) Monthly rainfall anomalies (June to September) for Gadamballia station for period from 1985 to 2014, (b) Monthly rainfall anomalies (June to September) for Gedarif station for period from 1985 to 2014, (c) Monthly rainfall anomalies (June to September) for Alhoory station for period from 1985 to 2014, (d) Monthly rainfall anomalies (June to September) for Douka station for period from 1985 to 2014, (e) Monthly rainfall anomalies (June to September) for Allhawaata station for period from 1985 to 2014, (f) Monthly rainfall anomalies (June to September) for Umseenat station for period from 1985 to 2014, (g) Monthly rainfall anomalies (June to September) for Samsam station for period from 1985 to 2014.

northward in recent years (Magboul et al., 2015).

Rainfall distribution linear regression slope values for trends derived from the 7 stations rainfall data every 10 years is shown in Figure 8. For the first period (1985 - 1994), the 600 mm Isohyets almost divide the area into two equal halves (Figure 8a); one half to the south-east including Douka, Samsam and Umseenat, was favored with higher rainfall (650-700 mm). The other half was around Alhoory and Alhawaata with lower rainfall (550 mm). Rainfall distribution during the second period (1995 - 2004) shows a decrease in total rainfall amounts; the 700 mm isohyet was no longer seen on the image (Figure 8b). It was also noted that areas receiving rainfall below 550 mm were larger in the second period. The third period (2005 - 2014) witnessed greater variation in rainfall distribution. In the southeastern part (around Douka), rainfall was higher than 700 mm, whereas in the western part, more areas were received rainfall below550 mm (Figure 8c).

Rainfall variability in Gedarif State may increase the risk and uncertainty in crop production; because climate change is one of the main drivers of the inter-annual variation in vegetation activity (Zhou et al., 2001; Schimel et al., 2001). Recent studies (IFPRI, 2009) indicated that by 2050 in sub-Saharan Africa, yields of food crops will decline by up to 22% as a result of climate change. The results can serve to help researchers to tailor their research plans to cope with the anticipated rainfall amounts in each area. It is clear from the results that there is higher rainfall in southern areas than in northern areas. As rainfall amounts and distribution determine the selection of the crops grown, the crop varieties in northern areas must therefore be more drought tolerant than those grown in southern areas.

Table 1 shows that there is an increasing trend in total cropped area in Gedarif State during the periods 1985-1994, to 1995-2004 and 2005-2014. One reason for this expansion in cropped area is due to the fact that farmers cultivate sorghum in multiple locations in an effort to cope with the uncertinity of the rainfall in time and space. Another reason for the expansion in the total cropped area is that it is a response-measure to compensate for the declining yields which in turn are due to decreased rainfall as well as an increase in degraded lands (Farah et al., 1996). The results also show that crop yield is very low (Table 1) and declining over the 30 year period due

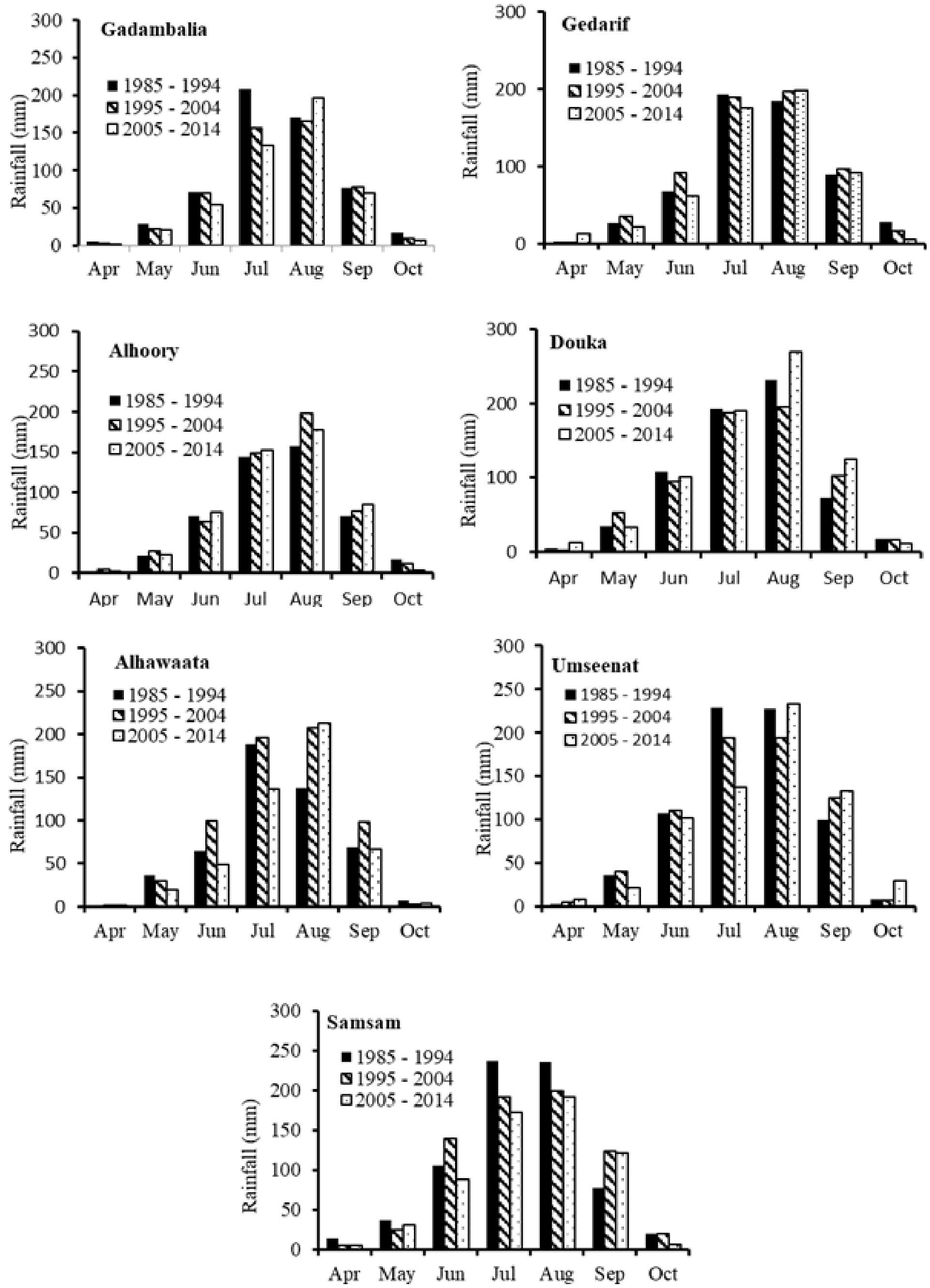


Figure 6. Average monthly rainfall each ten years at seven stations in Gedarif State during the years from 1985 to 2014.

to the delayed rains and therefore delayed sowing date coupled with lower rainfall amounts during the critical growing period (the grain filling and maturity stages during September and October).

Sorghum grain yield (kg/ha) in Gedarif State during the period from 1985 to 2014 fluctuated with years (Figure 9). Generally, this variability reflects the variability in annual rainfall for the seven studied stations. Figure 8 also shows a noticable declining trend in sorghum grain yield during the period. Ali Babiker et al. (2015), reported a similar declining trend in sorghum yield in Gedarif State during the period from 1979 to 2009. This may be due to negative (declining) trend in rainfall in Gadambalia, Samsam and Umseenat, which represent large production areas in Gedarif State. Ahmed (2011) studied climate change impacts on rainfed sorghum production and the length of growing season trends during the last 20 years (1991- 2010) in Gedarif area. His results also show a

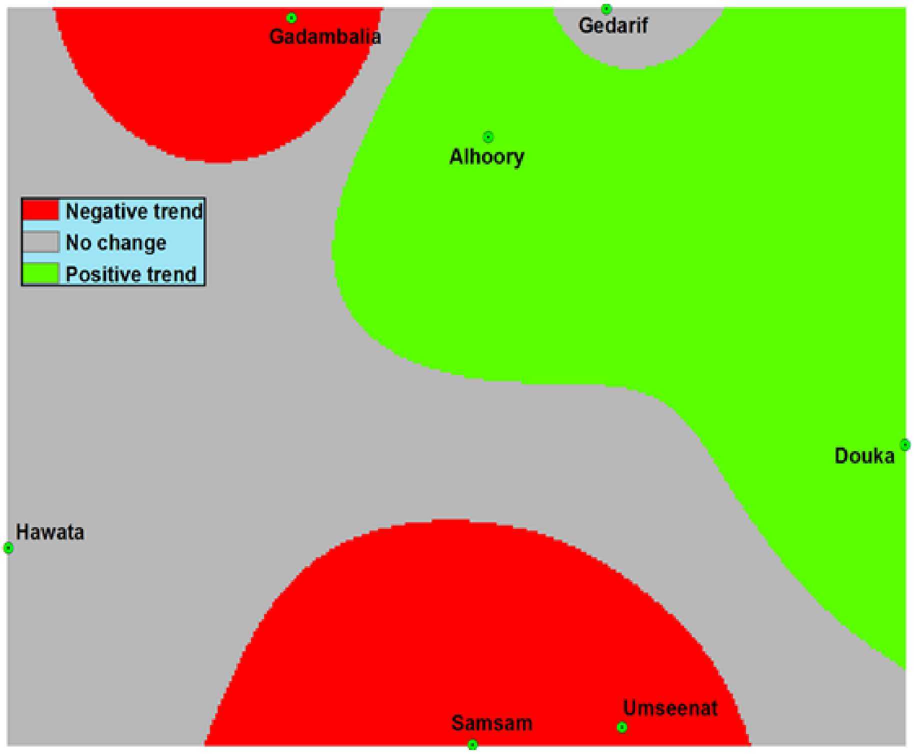


Figure 7. Linear regression slope values for trends derived from the 7 stations rainfall data (1985-2014).

decreasing trend in sorghum productivity, as well.

Conclusion

The results of this study and the above reviewed literature can shows that annual rainfall in the studied stations has relatively low variability compared to monthly variability. According to annual rainfall totals and for agricultural purposes it is possible to classify the stations into two groups; for example Umseenat, Samsam and Douka stations should be considered as one group (I) which have high annual rainfall more than 600 mm; while Alhawaata, Alhoory and Gadambalia stations could be considered as group (II) with annual rainfall ranging between 500 to 600 mm. The majority of rainfall at all the studied stations occurred during July and August supporting the adoption of suitable management practices to avoid water logging during seedling stage for example in areas of group I; and water shortage during flowering and maturity stages of crops for example in areas of group II. Trends of rainfall revealed that some areas, like Alhoory and Douka, showed positive trends in rainfall, whereas Gadambalia, Samsam and to some extent Umseenat showed negative rainfall trends. In Gedarif and Alhawaata, there was no definite rainfall trend. The different trends in rainfall across Gedarif State, might suggest that according to geographical area, different varieties of field crops (for example short to medium maturing varieties) and their associated management practices might be more appropriately applied. Crops of short maturing or drought resistant varieties and early sowing dates coupled with water harvesting techniques should be used in areas of short growing seasons for example areas under group II, to avoid the risk of crop failure whereas in areas of extended growing season for example areas under group I, suitable crops and varieties and their appropriate management practices should be implemented.

Further analysis of rainfall coupled with crop water requirements will be useful to predict crops yield. Also, studies on the effect of dry spells early in and during the growing season on crops yield are of great importance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Mechanized Farming Corporation in Gedarif State, Sudan for providing rainfall data of the seven stations in the studied area.

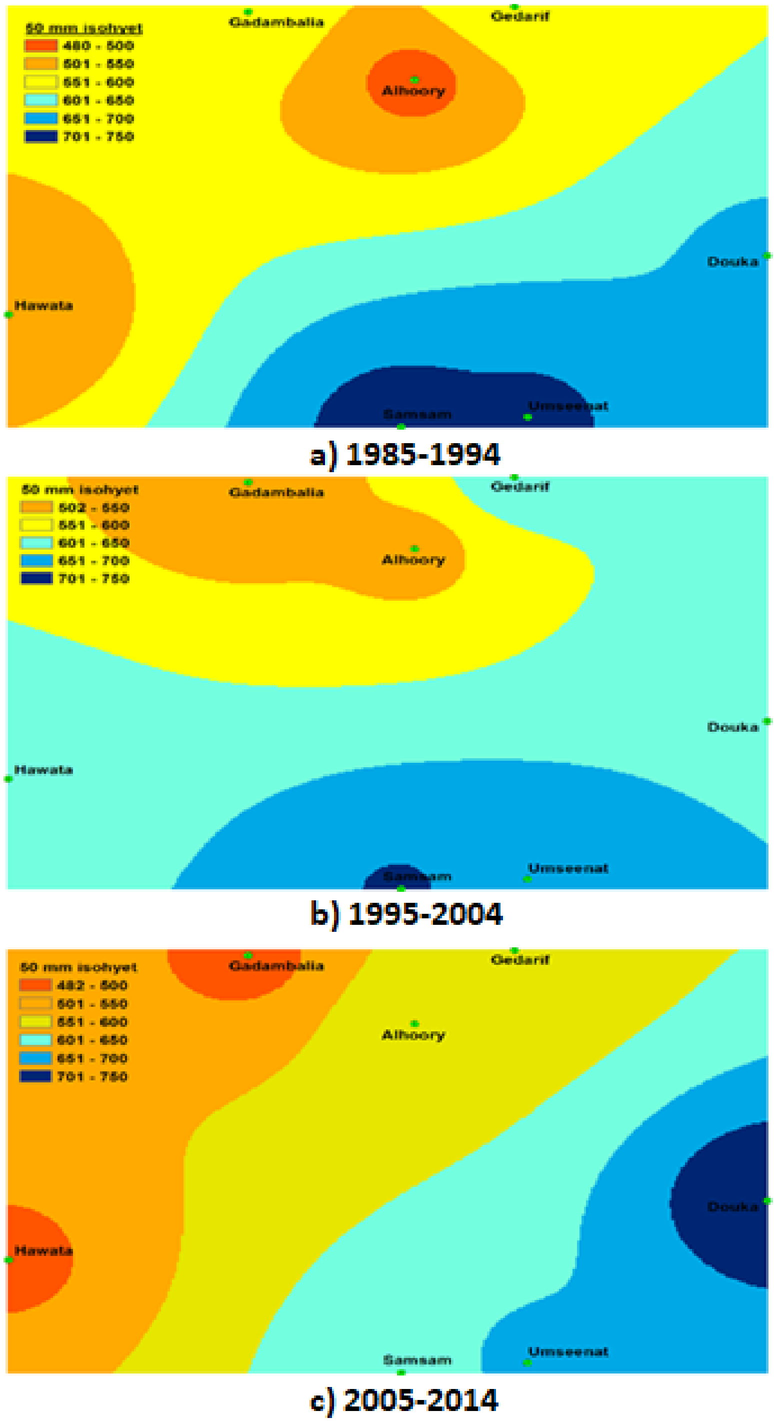


Figure 8. Linear regression slope values for trends derived from the 7 stations rainfall data every 10 years.

Table 1. Average sorghum cropped and harvested area, total production and grain yield in Gedarif State from 1985 to 2014.

Period	Cropped area millon (ha)	Harvested area million ha	Production million (ton)	Yield (ton/ha)
1985 - 1994	1.5	1.3	0.76	0.55
1995 - 2004	1.8	1.5	0.63	0.41
2005 - 2014	2.2	1.4	0.55	0.39

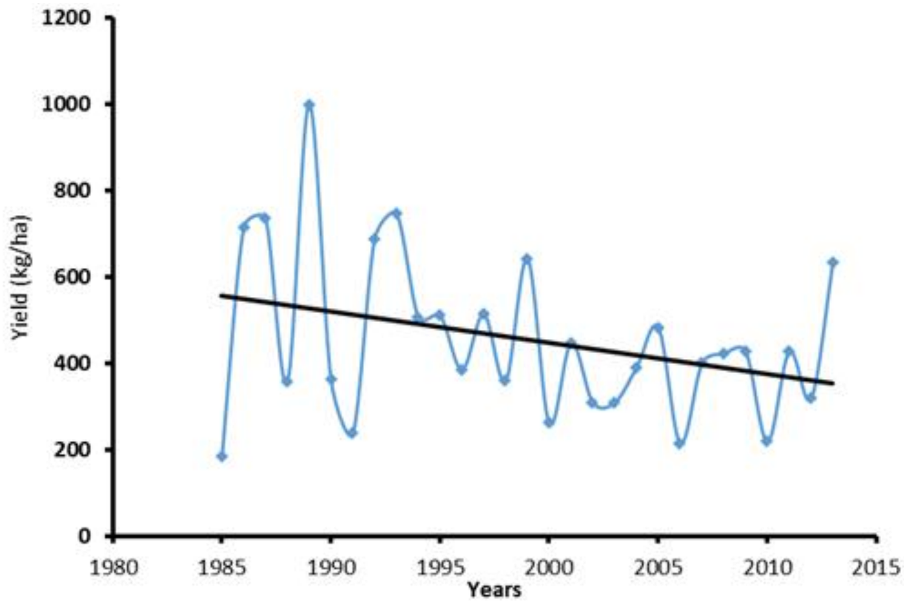


Figure 9. Sorghum yield (kg/ha) in Gedarif State during the period 1985 t0 2014.

REFERENCES

Adam HS (2008). Agroclimatology, Crop Water Requirement and Water Management; Gezira Printing and Publishing Co. LTD, Wad Medani, Sudan.

Ahmed KE (2011). Utilization of Crop Simulation Model ˝APSIM˝ in Investigating Climate Change Effects on Sorghum Yield in Gedarif Area. M.Sc. Thesis, Sudan Academy of Sciences.

Ahmed MAM (1994). Introducing New Technologies on Vertisols of Eastern Sudan: A Dynamic Programming Approach. Ph.D Thesis, Purdue University, USA.

Ali Babiker IA, El-Hag FAM, Abdelkarim AM, Abdalla AK (2015). Changing Climate and Farming Productivity in the Drylands of Eastern Sudan. Sudan Academy of Sciences Journal-Special Issue (Climate Change) 11(1):56-61.

Batisani N Yarnal B (2010). Rainfall variability and trends in semi-arid Botswana: Implications for climate change adaptation policy. Applied Geography 30:483-489.

Central Bank of Sudan (2013). Annual report No. 53 for the year 2013. Central Bank of Sudan, Government of Sudan.

Dong W, Jiang Y, Yang S (2009). Response of the starting dates and length of seasons in Mainland China to global warming. Climatic Change 99(1-2):81-91.

Eckert S, Hüsler F, Liniger H, Hodel F (2015). Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. Journal of Arid Environments 113:16-28.

ESRI (2008). ArcGIS software, version 9.3 User Manual. 380 New York Street, Redlands, CA 92373-8100, USA.

Farah SM, Ali IA, Inanaga S (1996). The Role of Climate and Cultural Practices on Land Degradation and Desertification with References to Rainfed Agriculture in the Sudan, Proceeding of the Fifth International Conference on Desert Development, Volume 1, Texas Tech University, August 12-17 1996.

Federal Ministry of Agriculture and Irrigation (2015). Annual National Agricultural Statistics Report by Administration of Planning and Agricultural Economics, Department of Agricultural Census, Khartoum, Sudan. Federal Ministry of Agriculture and Forestry, Government of Sudan.

Fuller DO (1998). Trends in NDVI time series and their relation to rangeland and crop production in Senegal, 1987- 1993. International Journal of Remote Sensing 19(10):2013-2018.

Huho JM (2011). Rain-fed Agriculture and Climate Change: An Analysis of the Most Appropriate Planting Dates in Central Division of Laikipia District, Kenya. International Journal of Current Research 3(4):172-182.

International Food Policy Research Institute (IFPRI) (2009). Climate change: impact on agriculture and costs of adaptation. International Food Policy Research Institute, Nairobi, Kenya.

Magboul AM, Elamin AEM, Ali-Babiker IA, Abdelmalik MA, Ibnoaf AA, El-Hag FM (2015). Assessment of Climate Change and Variability in Butana Region, Sudan. Journal of Natural Resources and Environmental Studies 3(1):1-8.

Mertz O, Halnaes K, Olesen JE, Rasmussen K (2009). Adaptation to Climate Change in Developing Countries. Environmental Management 43(5):743-752.

Ministry of Agriculture (2011). Ministry of Agriculture and Irrigation; Department of Agricultural Economics and Statistics, Gedarif state, Sudan. Ministry of Agriculture, State Government of Gedarif, Sudan.

Mohamed HA (1998). Rainfall in the Sudan: trend and agricultural implications. SUDAN Journal of Agricultural Research 1:45-48.

Rawhani P, Lobell DB, Linderman M, Ramankutty N (2011). Climate Variability and Crop Production in Tanzania, Agricultural and Forest Meteorology 151(4):449-460.

Rockström J, Barron J, Fox P (2002). Rainwater management for Increased Productivity among Smallholder Farmer in Drought. prone Environments. Physics and Chemistry of the Earth 27(11-22):949-959.

Schimel DS, House JI, Hibbard KA (2001). Recent patterns and mechanism of carbon exchange by terrestrial ecosystems. Nature 414:169-172.

Sudan Meteorological Authority (2010). Sudan Seasonal Monitor 5:1-6.

Tilahun K (2006). Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century, Journal of Arid Environments 64(3):474-487.

Yousif LA, Elhagwa AI, Awad Elkarim MI (2012). Effect of soil moisture contents on machinery performance in the clay soils of rainfed agriculture, eastern Sudan, Life Science International Journal 6(4):2690-2695.

Zhou LM, Tucker CJ, Kaufmann RK, Slayback D, Shabanov NV, Myneni RB (2001). Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. Journal of Geophysical Research 106(17):20069-20083.