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Impacts of Rainfall and Temperature on Sorghum (*Sorghum biocolor*) and Millet (*Pennisetum glaucum*) Yield in Arid Zone of the Sudan 1981-2010

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ABSTRACT

The fundamental goal of this work was to investigate the impact of rainfall and temperature on sorghum and millet yield in the arid zone in Sudan. Therefore the study had pivoted in two axis: climate characteristics and trends and impacts of climate on crops yield. Five focal points (Kassala, Wadmedni, Eldouim, Elobied and Elfasher) were selected to represent the whole zone. The climate data of monthly rainfall, minimum and maximum air temperature were obtained from Sudan Metrological Authority. Other climatic factors were calculated and estimated from temperature and rainfall data. Using rainfall, temperature, potential evapotranspiration, cumulative rainfall departure, effective rainfall, aridity index and standardized precipitation index for the period (1980 – 2010). Generally the trend of annual mean air temperature, annual rainfall, potential evapotranspiration, effective rainfall, cumulative rainfall departure, rainfall coefficient of variance, annual aridity index and standardized precipitation index had been increased during the period from 1980 to 2010 with statistically significant evidences ($p \leq 0.05$). Correlations between long-term sorghum yield and climatic factors analysis showed that there were positive significant correlation between sorghum yield and aridity index in Gezira and Elobied. Also, in Elobied negative significant correlation between Sorghum yield and air temperature, potential evapotranspiration. Where in Elfasher there were positive significant correlation between sorghum yield and rainfall, cumulative rainfall departure, effective rainfall, aridity index and standardized precipitation index. Correlations between long-term millet yield and climatic factors showed that in Elobied station there were positive significant correlation between millet yield and rainfall, effective rainfall, aridity index and standardized precipitation index. Where in Elfasher there were negative significant correlation between millet yield and potential evapotranspiration. Using multiple regression model where the climatic factors with sorghum and millet yield; the results showed there were significant regression

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equation model in three stations (Wadmedni, Elobied and Elfasher) and in two stations (Elobied and Elfasher), respectively.

Keyword**:** Rainfall, temperature, sorghum, millet yield, correlation, *Sorghum biocolor*, *Pennisetum glaucum*

1. INTRODUCTION

Sudanese economy depends largely on agriculture, about 70 % of the population of the country work in agriculture and 90 % of them lives in rural areas [1]. Almost of the irrigated areas in the Sudan, which are estimated as 1.68 ha (about 4 million feddans) fall in the arid and semi-arid tropical zones, in which 76% of the human population lives [2]. These areas are most vulnerable to climate change, which affects the agriculture productivity, flora and fauna. Most of the national Sudanese agriculture projects are sited in these two zones. Therefore it is very important to study the effect of climate change on these areas.

The climatic zones of the Sudan have been identified according to the classification reported by [3], using Sylianinov parameter as follows: desert, semi-desert, arid, semi-arid, semi-humid, humid and very humid. On the other hand, the UNSO classification in 1997 the aridity zones of the Sudan are as follows :hyper-arid, arid, semi-arid dry, sub-humid and moist humid. Beside that there are other classifications of climatic zones in Sudan. Arid and semi-arid areas in Sudan are located between latitude 10° to 15° north and longitude from 20° to 35° west, with annual rainfall about between 250 to 350 (mm/year) in arid region and (350 – 550 mm/year) in semi-arid [4]. The yield under arid_and semi-arid regions of Sudan is highly dependent on the amount of rainfall and its distribution, the physical properties of the soil and the weather during the different stages of growth of plants [5].

Mean annual temperatures vary between 26 °C and 32 °C across the country, except for the elevated points of Jebel Marra in the West (22.6 °C), and the Red Sea mountains (22.8 °C). Annual rainfall in Sudan varies from close to zero near the border with Egypt, to about 200 mm around the capital Khartoum and reach to 700mm at Eldamazin. Declining and uncertain rainfall makes life very difficult for traditional farmers and herders and severely affects their Livelihoods [6]. Sorghum and millet are the main crops that represent Sudanese food security where about 85% of the population depend on these tow crops. Total area under sorghum reached 10 million feddans about 63.6 % of which is rainfed and 35 % irrigated and only 1.4 % by floods, sorghum is one of the dominant food crops in the Sudan [7]. Around 93% of millet crop is produced by the traditional rainfed sector, of which 66 %t and 24 % come from Darfur and Kordofan, respectively [8].

A number of studies on the impact of climate change on crop yields have previously been carried out in the West African region. Notable among them include that by [9], who reported that the percentage change in grain yield will be higher under climate change weather conditions. Other studies by [10], reported that, we have attempted to perform a consistent assessment of climate change impacts on crop yields in West Africa by accounting for uncertainties in future climate scenarios. The adverse role of higher temperature on crop yield is a robust result, irrespective of rainfall changes, and seems to be modulated across millet and sorghum varieties and across regions in West Africa. [11] stated the results of the analysis confirm the claim that sorghum and millets are indeed climate-resilient and do not respond to changes in climatic parameters. This study suggests to calculate rainfall and temperature data and estimate other climatic factors such as potential evapotranspiration (ETp), cumulative rainfall departure (CRD), effective rainfall (RF_{effect}), aridity index (AI) and standardized precipitation index (SPI) for the period (1980 – 2010); as a parameters to explore the climate variability and climate change on sorghum and millet yield in five selected stations (Kassala, Wadmedani, Eldouim, Elobied and Elfasher) represent the whole region.

2. MATERIAL AND METHODS

2. 1. Study areas

Five meteorological stations were used as focal points, to represent the whole arid zone in Sudan. Kassala, Wad Medani, Eldouim, El- obied and Elfasher meteorological stations were selected according to their suitable geographical location.

2. 2. Data collection

The climate data of the mentioned stations was obtained from the Sudan Meteorological Authority (SMA). Meteorological observations of monthly temperature (maximum, minimum air temperature) and rainfall, for a period from 1981 to 2010 were used to obtain the objectives of this study. According to available data five stations (Kassala-Wadmedani-Eldouim-Elobied-Elfasher) were obtained for sorghum yield, where only three stations (Eldouim-Elobied-Elfasher) were obtained for millet yield. Take in consideration the agricultural sectors, the sorghum yield data were obtained from traditional sector for Gezira (Wadmedani), North Kordofan (Elobied) and North Darfur (Elfasher), where mechanized rain-fed sector for White Nile (Eldouim) and Kassala. In the other hand millet yield data obtained from traditional rain-fed sector for White Nile state (Eldouim), North Kordofan (Elobied) and North Darfur (Elfasher). Individual missing data for a given month were filled in from the neighboring values, as described by [12], taking the average of the three preceding and the three following years records for that specific month.

2. 3. Analysis of climate data

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

2. 4. Effective rainfall

The definition of effective rainfall is the fraction of rainfall, that is effectively intercepted by the vegetation or stored in the root zone and used by the plant soil system for evaporation [13]. FAO/ AGLM was determined the coefficient of the linear empirical formula for different arid and sub humid climates as following equations:

$R_{eff} = 0.6\ P_{tot} - 10$ …………….. For: (P_{tot} less than 70 mm) ………………………….(1)

$R_{eff} = 0.8\ P_{tot} - 24$ …………….. For: (P_{tot} more than 70 mm)…………………......…..(2)

where:

R_{eff} : Effective rainfall

P_{tot} : Total rainfall

2. 5. Cumulative Rainfall Departure (CRD)

The cumulative rainfall departure (CRD) from normal rainfall is a concept used by hydrologists to characterize rainfall trends. There are a number of empirical formula to estimated cumulative rainfall departure, in this study **[14]** formula had been used as follows:

$$CRD = CRD_{i-1} + RF_i - C \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where:

CRD = cumulative rainfall departure

I = ith month

RF = amount of rainfall (mm)

C = long-term average rainfall (mm)

2. 6. Aridity Index (AI)

Aridity is the continuous occurrence of rainfall below an arbitrary but very low threshold. It should be noted that aridity can be considered on seasonal or monthly basis **[15]**. Aridity is defined as the more or less repetitive climate condition, which is characterized by a lack of water [16]. The De Martonne formula (1926) aridity index is used to evaluate the monthly aridity index as follow:

$$\mathrm{AI} = \left[\frac{\mathrm{P}}{\mathrm{T}+10} + \frac{12\,\mathrm{p}}{(\mathrm{t}+10)}\right] /2 \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where:

P : is the mean annual precipitation in mm

T : is mean annual temperature in ºC

p :the precipitation of the direst month in mm

t :the mean temperature of the direst month in ºC.

2. 7. Standardized Precipitation Index to identify drought (SPI)

The standardized precipitation index (SPI) is a tool which was developed primarily for defining and monitoring drought [17]. In this study the following formula was obtained to identify SPI values:

$$SPI = \frac{\mathrm{M_m} - \mathrm{M_a}}{SD\pm_a} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where:

M_m Monthly mean of rainfall

M_a Annual mean of rainfall

$SD \pm_a$ Standard deviation of annual rainfall

Indicates of SPI is helpful in monitoring the development and relief of a drought. [18] suggested the SPI classification scale (Table 1).

Table 1. Standardized precipitation index (SPI) classification scale

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

3. RESULTS AND DISCUSSION

3. 1. General climate trend in the study area

The general climatic trend in the study area illustrated in Table (2) showed that there were increasing in most of climate factors in the five stations. In Kassala station all factors increased among the time except aridity index which showed non significant decrease with time. The significant increased obtained in mean annual temperature and potential evapotranspiration (ETp) with $P \leq 0.05$ value (0.004) for all stations. In Wadmedni station all climatic factors were increased among the time where temperature, ETp and CRD showed statistical significant with $P \leq 0.05$ value (0.045) (0.043) and (0.039), respectively. In Eldouim station all climatic factors increased along the time where only mean annual temperature showed statistical significant with $P \leq 0.05$ value (0.037). In Elobied station all climatic factors increased along the time where mean annual rainfall, CRD, effective rainfall, rainfall coefficient of variance (CV) and SPI showed statistical significant with $P \leq 0.05$ value (0.022), (0.001), (0.022), (0.022) and (0.020), respectively. In Elfasher station all factors increased along the time except potential evapotranspiration (ETp) which showed decreasing trend with highly significant evidence where $P \leq 0.05$ value (0.000^{**}), also the significant increased obtained in mean annual temperature and cumulative rainfall departure (CRD) with $P \leq 0.05$ value (0.000^{**}) and (0.047), respectively.

The mentioned results explained that during the period from 1980 to 2010 mean annual air temperature have statistical significant increasing in the four out of five stations in this study. While annual rainfall have statistical significant in just Elobied station which was the only station recorded not significant increasing of mean air temperature. These results may justify the opposite relationship between rainfall and temperature. cumulative rainfall departure (CRD) and potential evapotranspiration (ETp) have statistical significant in three stations, where aridity index (AI) has no statistical significant in all stations. These results provide indictors that the climate trend gets drier by increasing mean air temperature and ETp, on the other hand, indications of climate improvement by increasing CRD among the time.

These findings agree with [19] who cited temperatures in Sudan have increased by more than 1.0 degree Celsius (°C) across much of central and southern Sudan. As with rainfall, these changes can be visualized as expansions of hot (and in this case dry) areas, as maps of anticipated changes, or as time series. Over the past 30 years, central and southern Sudan have been among the most rapidly warming locations on the globe, with station temperatures increasing as much as 0.4 °C per decade. Also [20] cited That "Anomalies trends of mean annual temperature and rainfall almost show a rise in temperature and a decline in rainfall in most parts of Sudan during the last three decades of the twentieth century. Droughts are becoming more frequent and severe, and since the early 1970s, the country has been subjected to a series of drought shocks, the most notable are in 1984/85 and 1990.

Table 2. General climatic factors trend in Kassala-Wadmedni-Eldouim-Elobied and Elfasher stations in period 1981-2010.

Climate Factors	**Analysis**	**Kassala**	**Wadmedni**	**Eldouim**	**Elobied**	**Elfasher**
Rainfall	Trend R^2 Sig.	+ 0.309 0.001 0.874^{ns}	+ 2.515 0.067 0.167^{ns}	+ 1.612 0.036 0.314^{ns}	+ 6.317 0.173 0.022 *	+ 2.268 0.086 0.115^{ns}
Temperature	Trend R^2 Sig.	+ 0.030 0.265 0.004^{**}	+ 0.022 0.136 0.045^{*}	+ 0.026 0.146 0.037^{*}	+ 0.020 0.037 0.311^{ns}	+ 0.064 0.398 0.000^{***}
Etp	Trend R^2 Sig.	+ 0.289 0.248 0.004^{**}	+ 0.210 0.138 0.043^{*}	+ 0.237 0.105 0.081^{ns}	+ 0.141 0.018 0.482^{ns}	- 4.059 0.727 0.000^{***}
CRD	Trend R^2 Sig.	+ 1.162 0.006 0.680^{ns}	+ 5.350 0.144 0.039 *	+ 2.841 0.048 0.245^{ns}	+ 13.61 0.323 0.001*	+ 4.446 0.134 0.047*
$RF_{effective}$	Trend R^2 Sign	+ 0.248 0.001 0.874^{ns}	+ 2.012 0.067 0.167^{ns}	+ 1.290 0.036 0.314^{ns}	+ 5.054 0.173 0.022^{*}	+ 1.815 0.085 0.115^{ns}
Rainfall CV	Trend R^2 Sign	+ 0.577 0.003 0.770^{ns}	+ 2.658 0.083 0.123^{ns}	+ 1.841 0.046 0.254^{ns}	+ 6.332 0.173 0.022^{*}	+ 2.281 0.086 0.115^{ns}

AI	Trend	-0.014	+ 0.046	+ 0.035	+ 0.064	+ 0.033
	R^2	0.007	0.078	0.046	0.066	0.031
	Sig.	0.656^{ns}	0.134^{ns}	0.258^{ns}	0.172^{ns}	0.352^{ns}
SPI	Trend	+ 0.003	+ 0.029	+ 0.022	+ 0.048	+ 0.035
	R^2	0.001	0.067	0.036	0.179	0.093
	Sig.	0.874^{ns}	0.167^{ns}	0.314^{ns}	0.020^{*}	0.102^{ns}

3. 2. Impacts of climate factors on sorghum

In this study, according to available data, traditional sector data were obtained for Gezira, North Kordofan and North Darfur, where mechanized rainfed for Eldouim and in Kassala irrigated sector. Figures (1,2,3,4 and 5) showed Long-term sorghum yield and harvested areas in the five stations, it is clear that there were increasing in yield in Kassala, White Nile state (Eldouim) and North Darfur state (Elfasher) with statistical significantly in Kassala and Eldouim where ($P\geq0.05$) equal 0.003 and 0.042, respectively. In the other hand there decreasing in yield in Gezira and Elobied with no statistical evidence. The percentage of (harvested / cultivated) area was 90.2% in Kassala, 72.6% in Gezira, 79.3% in Eldouim, 67.4 in Elobied and 60.4 in Elfasher. Table (3) showed the correlations between long-term sorghum yield, rainfall, temperature, potential evapotranspiration, cumulative rainfall departure, effective rainfall, aridity index and standardized precipitation index in the five stations using Pearson test value. The results showed that there were correlation between long-term average sorghum yield and (AI) in Gezira with significant different ($P\geq0.05$) equal 0.024. Where in Elobied the significantly correlation between long-term average sorghum yield and annual temperature, (ETp) and (AI) with ($P\geq0.05$) values (0.036), (0.045) and (0.009), respectively. In Elfasher most of the climatic factors had highly significant correlation with sorghum yield, such as rainfall, CRD, RFeffe, AI and SPI with ($P\geq0.05$) values (0.001), (0.000), (0.001), (0.010) and (0.000), respectively.

Table (4) showed multiple regression model using all climatic factors (dependant variable) with sorghum yield (independent variable) in the five stations. It is clear that there were no statistically significant except in Elfasher stations. When used the climatic factors which have statistically significant (as dependant variable), three regression model equations were obtained in Gezira, Elobied and Elfasher (Table 5). In Gezira (AI) is the dependant variable with ($P\geq0.05$) value 0.024, where in Elobied the dependant variables were AI, ETp and temperature with ($P\geq0.05$) value 0.041 and in Elfasher the dependant variables SPI, CRD, AI and rainfall with ($P\geq0.05$) value 0.003. Similar results reported by [21] who cited that according to analysis of time series of the standardized precipitation index (SPI) for the arid and semi-arid areas of Sudan during the period 1941-2010 the results showed that there is a highly significant relationship between the drought SPIs and crop yield of sorghum and millet during the early-to-mid growing calendar.

Also, [22] cited that the productivity of local crops in Sub-Saharan in Africa (SSA) is directly affected by m+any aspects of climate change such as average temperature increase, change in rainfall amount and patterns, change in climate variability and extreme events, rising atmospheric concentration of CO_2. Also [23] reported that in the whole of north Sudan, reduction in sorghum yields are expected, this result confirmed by [24] who cited that the projected sorghum and millet yields in Sudan indicate that by 2060 production in these regions will be reduced by more than 75%.

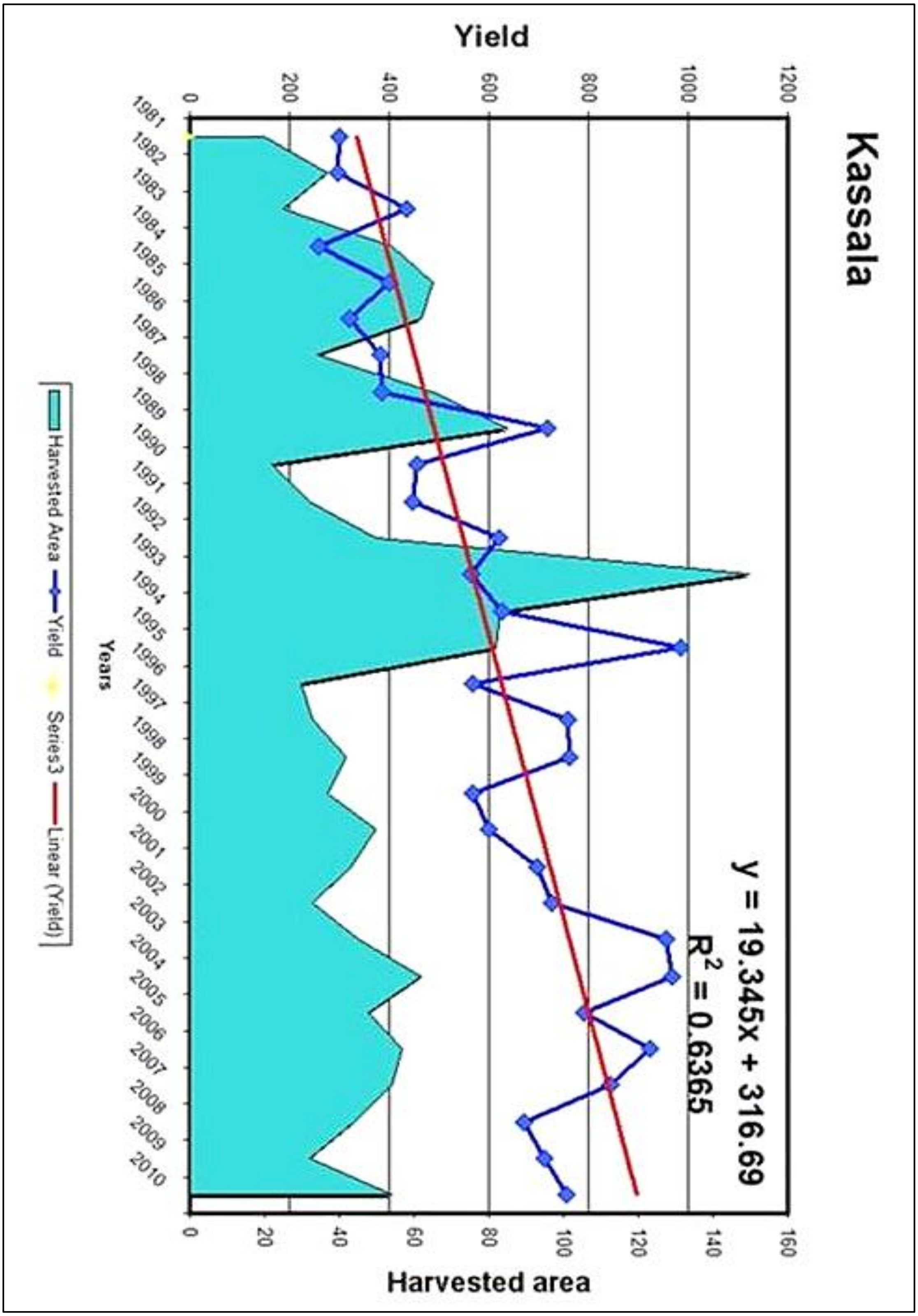

Figure 1. Long-term sorghum yield and harvested areas in Kassala, during period 1981-2010

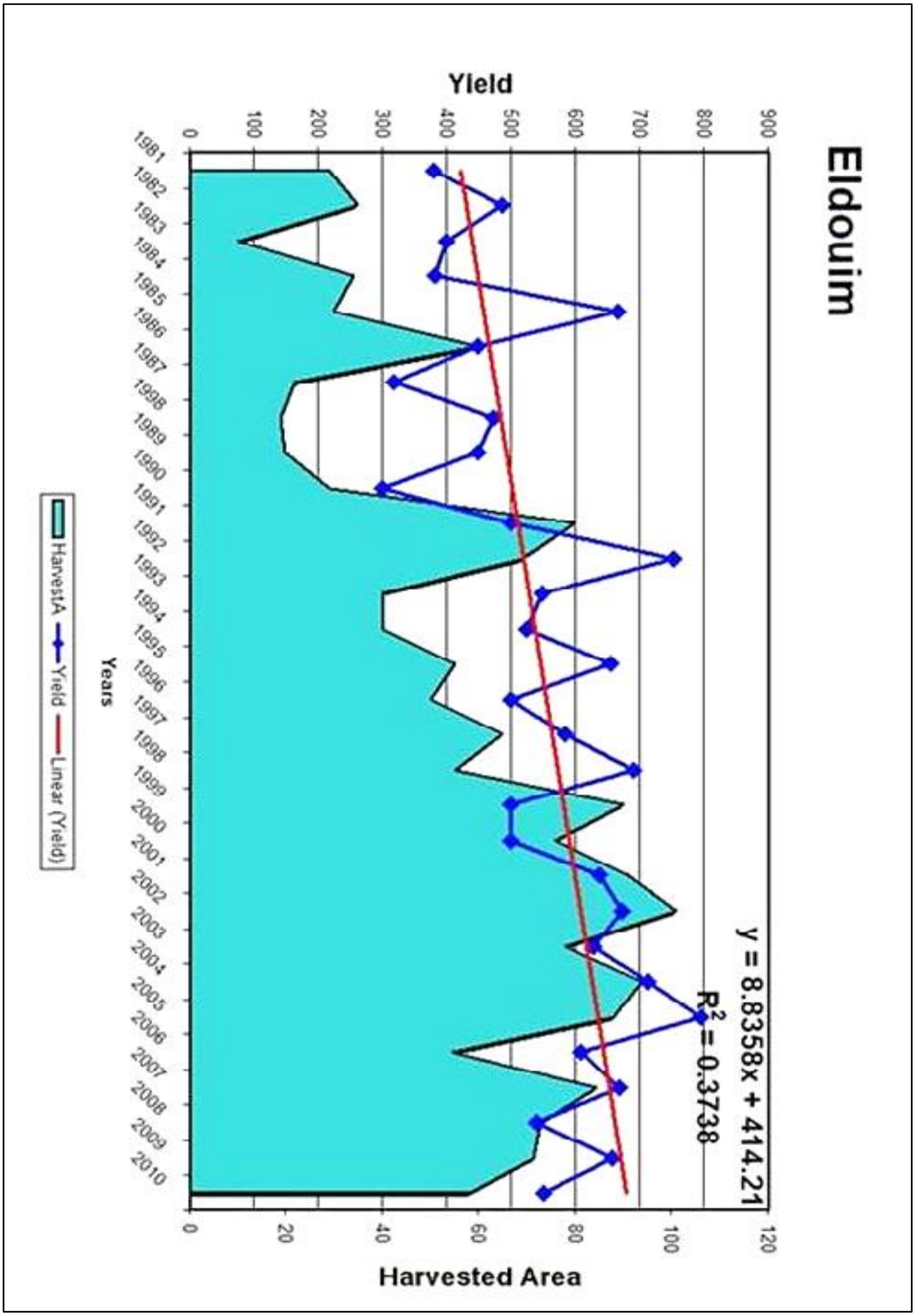

Figure 2. Long-term sorghum yield and harvested areas in White Nile state (Eldouim), during period 1981-2010

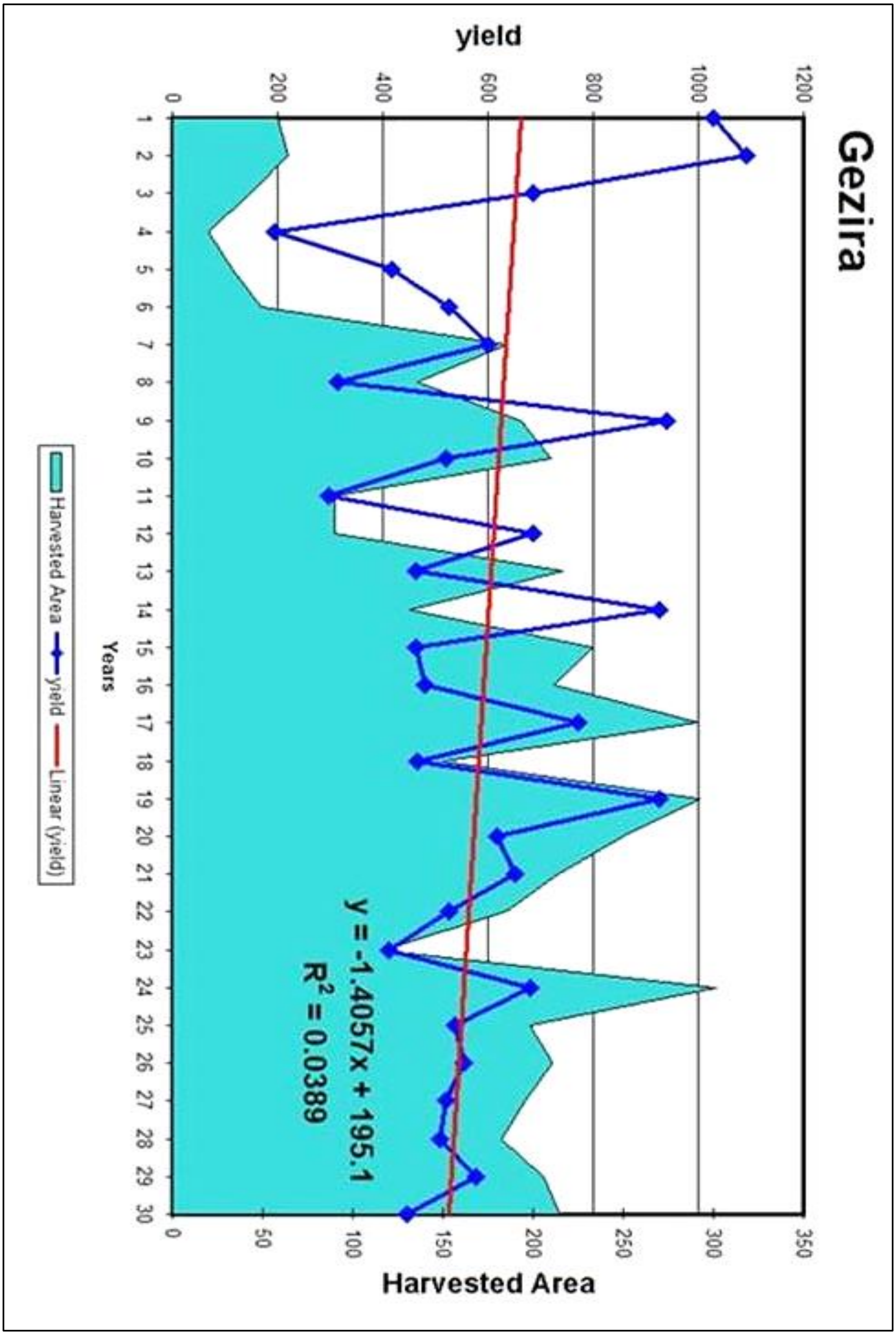

Figure 3. Long-term sorghum yield and harvested areas in Gezira (Wadmedni), during period 1981-2010

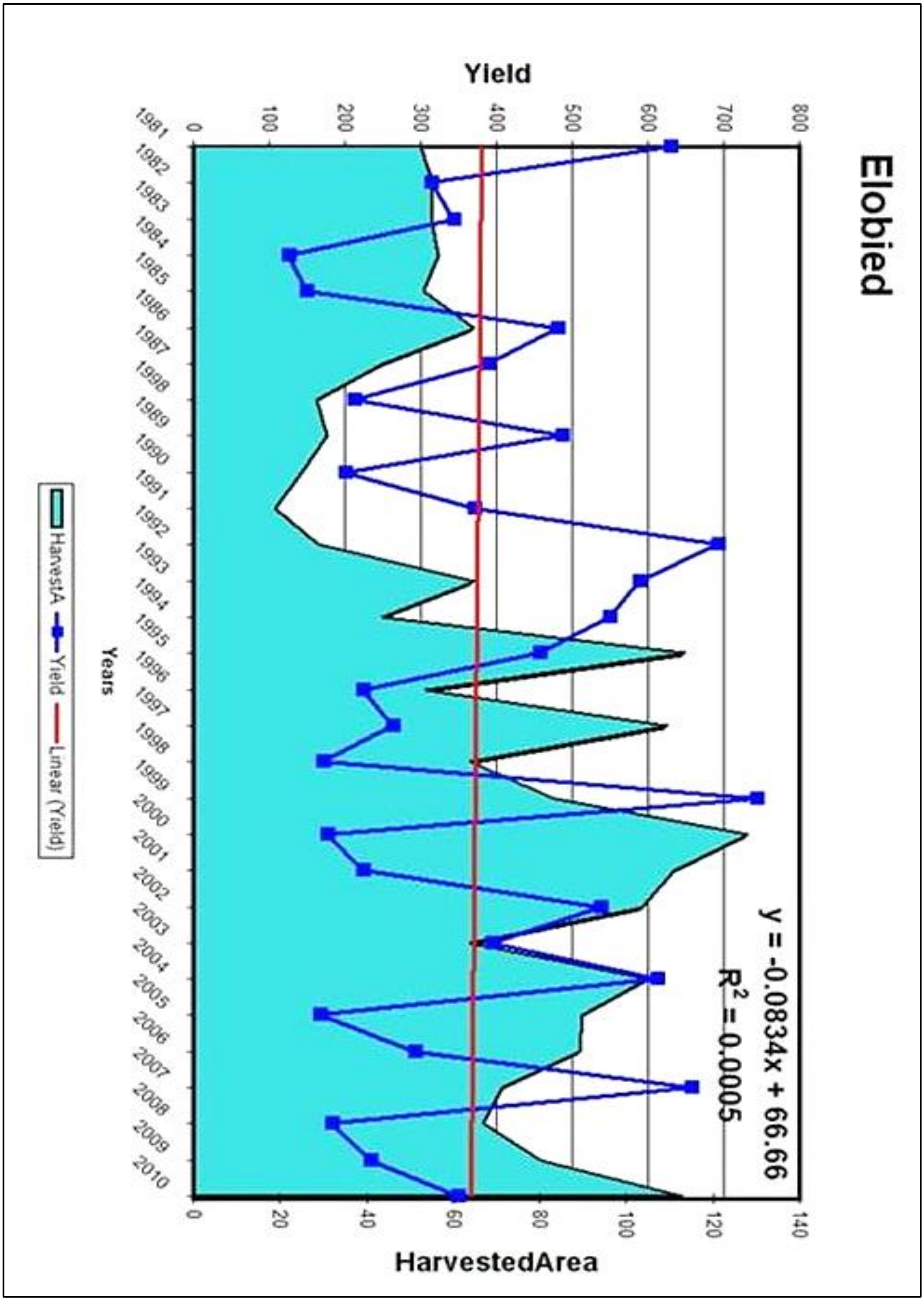

Figure 4. Long-term sorghum yield and harvested areas in North Kordofan (Elobied), during period 1981-2010

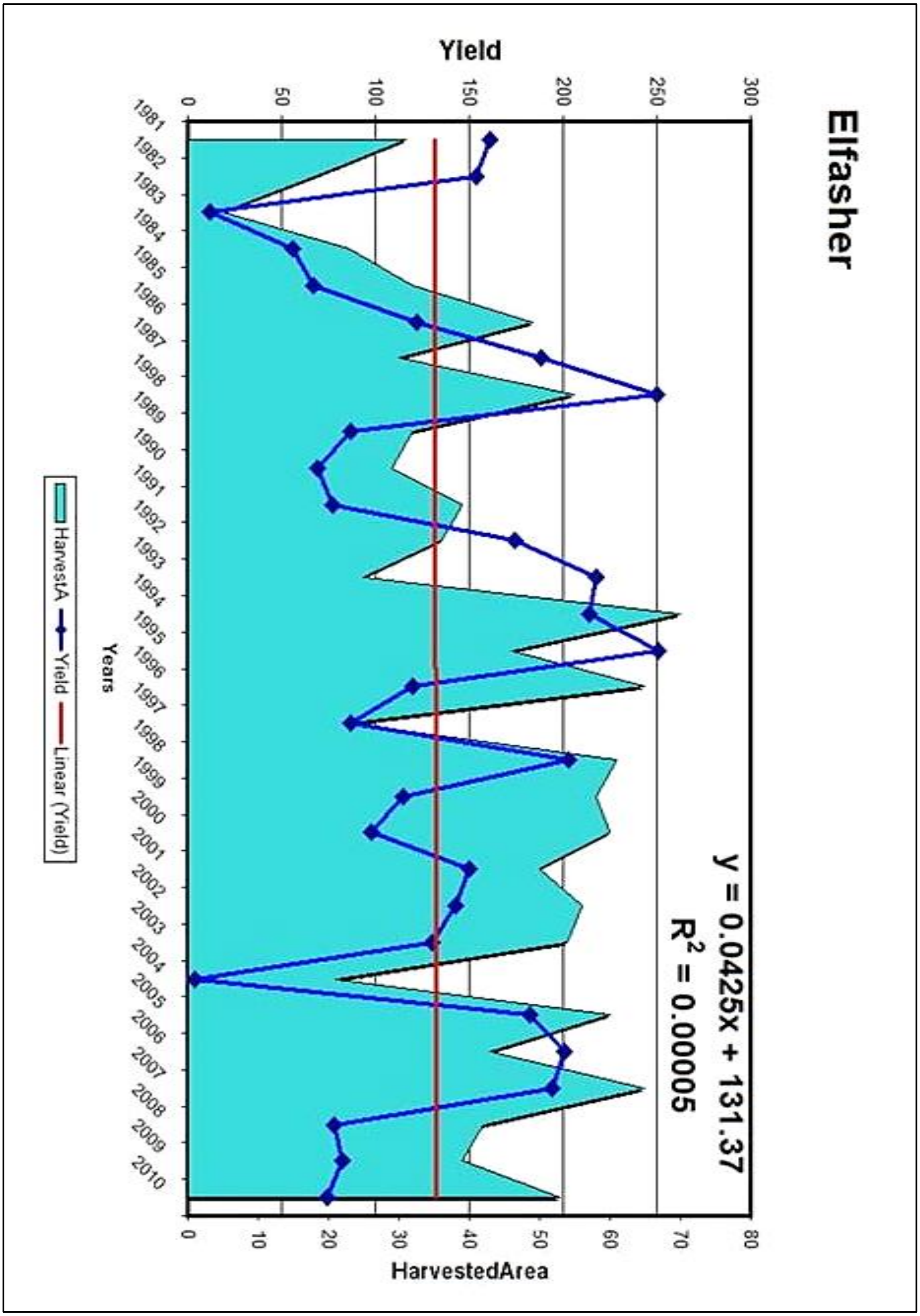

Figure 5. Long-term sorghum yield and harvested areas in North Darfur (Elfasher) During period 1981-2010

Table 3. Correlations between long-term sorghum yield, rainfall, temperature, potential evapotranspiration (ETp), cumulative rainfall departure (CRD), effective rainfall, aridity index and standardized precipitation index (SPI) using Pearson test value

Station	**Co-relation with yield**	**Rainfall**	**Temp.**	**ETp**	**CRD**	**Effective Rainfall**	**Aridity Index**	**SPI**
Kassala	Pearson Test Sig.	0.26 0.16	0.16 0.39	0.17 0.39	0.24 0.19	0.26 0.16	0.09 0.63	0.26 0.16
Wadmedni	Pearson Test Sig.	0.33 0.070	0.049 0.797	-0.049 0.799	- 0.295 0.114	0.336 0.070	0.410 0.024*	- 0.336 0.069
Eldouim	Pearson Test Sig.	-0.19 0.31	-0.013 0.95	-0.018 0.924	- 0.017 0.931	0.016 0.933	0.215 0.224	0.190 0.315
Elobied	Pearson Test Sig.	0.33 0.06	- 0.38 0.036*	- 0.36 0.045*	0.215 0.254	- 0.337 0.069	0.467 0.009**	0.349 0.058
Elfasher	Pearson Test Sig.	0.593 0.001**	-0.012 0.949	-0.002 0.993	0.616 0.000**	0.593 0.001**	0.464 0.010*	0.599 0.000**

Table 4. Multiple regression model using all climatic factors (dependent) with sorghum yield (independent) in the five stations.

Station	**R**	**R^2**	**Adjusted R^2**	**S.E**	**Regression Model Equation**	**Model Sig.**
Kassala	0.49	0.25	0.09	203.63	$Y_{yield} = -9301.98 + 1.46 X_{RF} + 2.72 X_{Temp} + 21.04 X_{ETp} + 0.035 X_{CRD} + 1.46 X_{RFeffec} + 6.34 X_{AI} + 130.66 X_{SPI}$	0.206^{ns}
Wadmedni	0.44	0.19	0.03	191.61	$Y_{yield} = -5600.5 + 181.57 X_{Temp} - 24.53 X_{ETp} + 0.227 X_{CRD} + 5.81 X_{RF} - 17.37 X_{SPI}$	0.345^{ns}
Eldouim	0.41	0.16	- 0.05	130.19	$Y_{yield} = -382.82 - 0.324 X_{RF} - 63.75 X_{Temp} - 6.23 X_{ETp} - 2.44 X_{CRD} + 2.02 X_{RFeffec} + 9.3 X_{AI} + 52.88 X_{SPI}$	0.593^{ns}
Elobied	0.59	0.35	0.18	29.25	$Y_{yield} = 119.76 + 0.82 X_{RF} - 29.98 X_{Temp} - 2.25 X_{ETp} + 0.025 X_{CRD} - 1.08 X_{RFeffec} + 10.83 X_{AI} + 106.79 X_{SPI}$	0.096^{ns}
Elfasher	0.74	0.54	0.42	50.19	$Y_{yield} = -970.52 + 0.58 X_{RF} - 21.12 X_{Temp} + 0.84 X_{ETp} + 0.45 X_{CRD} + 0.29 X_{RFeffec} + 4.26 X_{AI} + 10.42 X_{SPI}$	0.007^{**}

Table 5. Multiple regression model using the climatic factors that have statistical effect according to Pearson test (dependent) with Sorghum yield (independent) in the Elobied and Elfasher stations

Station	**R**	**R^2**	**Adjusted R^2**	**S.E**	**Regression Model Equation**	**Model Sig.**
Wadmedni	0.41	0.16	0.13	180.71	$Y_{yield} = 448.11 + 54.88X_{AI}$	0.024
Elobied	0.52	0.27	0.18	29.24	$Y_{yield} = -205.76 + 5.72X_{AI} - 32.12X_{Temp} - 2.53X_{Etp}$	0.041
Elfasher	0.65	0.42	0.33	54.41	$Y_{yield} = 178.88 + 52.61X_{SPI} + 0.22X_{CRD} + 0.54X_{RF} + 4.35X_{AI}$	0.003

3. 3. Impacts of climate factors on millet

In this study according to available data, traditional sector data were obtained for White Nile state (Eldouim), North Kordofan and North Darfur. Figures (6, 7 and 8) showed Long-term millet yield and harvested areas in the three stations, it is clear that there were increasing in yield in White Nile state (Eldouim) without statistical significant. In the other hand there decreasing in yield in North Kordofan (Elobied) and North Darfur (Elfasher) with statistical significant in Elfasher area where ($P \geq 0.05$) equal 0.042. It is clear that the trends of harvested area are typical to trend of yield in the three stations. The percentage of (harvested / cultivated) area was 76.4 % in Eldouim, 56.9 % in Elobied and 56.3 % in Elfasher, these percentages are low especially in Elobied and Elfasher area. Table (6) showed the correlations between long-term millet yield, rainfall, temperature, potential evapotranspiration (ETp), cumulative rainfall departure (CRD), effective rainfall, aridity index and standardized precipitation index (SPI) in the three stations using Pearson test value. The results showed that there were correlation between long-term average millet yield and annual rainfall, effective rainfall, (AI) and (SPI) in North Kordofan (Elobied) with ($P \geq 0.05$) values (0.021), (0.022), (0.005) and (0.019), respectively. Also in Elfasher there were significant negative correlation between long-term average Millet yield and (ETp) with ($P \geq 0.05$) values (0.027).

Table (7) showed multiple regression model using all climatic factors (dependable variables) with millet yield (independable variable) in the three stations, it is clear that there were no statistically significant in the three stations. When used the climatic factors which have statistically significant according to Pearson test (as dependable variable), two regression model equations were obtained in Elobied and Elfasher (Table 8). In Elobied the regression model equation contain AI, SPI and effective rainfall were the dependable variables with ($P \geq 0.05$) value 0.047, where in Elfasher the equation contain only ETp factor as dependable variable with ($P \geq 0.05$) value 0.027. Similar results reported by [22] who cited that according to analysis of time series of the standardized precipitation index (SPI) for the arid and semi-arid areas of Sudan during the period 1941-2010 the results showed that there is a highly significant relationship between the drought SPIs and crop yield of sorghum and millet during the early-to-mid growing calendar. Also [22], [23]and [25] had similar studies of the correlation between climatic factors and millet yield in arid semi-arid region in different countries in Africa and all of them confirmed the strong statistical relationship.

Table 6. Correlations between long-term millet yield, rainfall, temperature, potential evapotranspiration (ETp), cumulative rainfall departure (CRD), effective rainfall, aridity index and standardized precipitation index (SPI) using Pearson test value.

Station	**Co-relation with yield**	**Rainfall**	**Temp.**	**Etp**	**CRD**	**Effective Rainfall**	**Aridity Index**	**SPI**
Eldouim	PearsonTest Sig.	0.277 0.139	- 0.281 0.122	- 0.321 0.083	0.277 0.138	0.302 0.105	0.120 0.527	0.276 0.139
Elobied	PearsonTest Sig.	0.420 0.021*	- 0.293 0.116	- 0.289 0.121	0.295 0.113	0.420 0.022*	0.498 0.005*	0.425 0.019*
Elfasher	PearsonTest Sig.	0.125 0.511	- 0.274 0.142	- 0.403 0.027*	- 0.033 0.861	0.125 0.511	0.095 0.616	0.119 0.533

Table 7. Multiple regression model using all climatic factors (dependent) with total Millet yield (independent) in the Eldouim, Elobied and Elfasher stations.

Station	**R**	**R^2**	**Adjusted R^2**	**S.E**	**Regression Model Equation**	**Model Sig.**
Eldouim	0.46	0.22	0.02	44.11	$Y_{yield} = 1650.37 + 43.13\, X_{Temp} - 5.96\, X_{ETp} - 0.72\, X_{CRD} + 0.77\, X_{RFeffec} - 3.92\, X_{AI} + 7.23\, X_{SPI}$	0.404^{ns}
Elobied	0.52	0.27	0.08	16.71	$Y_{yield} = 3.99 - 8.01\, X_{Temp} + 0.66\, X_{ETp} - 0.009\, X_{CRD} + 0.26\, X_{RFeffec} + 4.66\, X_{AI} + 23.7\, X_{SPI}$	0.242^{ns}
Elfasher	0.47	0.23	0.02	90.26	$Y_{yield} = -429.21 - 3.82\, X_{Temp} - 0.94\, X_{ETp} - 0.06\, X_{CRD} + 1.41\, X_{RFeffec} - 1.39\, X_{AI} - 47.43\, X_{SPI}$	0.377^{ns}

Table 8. Multiple regression model using the climatic factors that have statistical effect according to Pearson test (dependent) with millet yield (independent) in the Kassala Elobied and Elfasher stations

Station	**R**	**R^2**	**Adjusted R^2**	**S.E**	**Regression Model Equation**	**Model Sig.**
Elobied	0.51	0.26	0.17	15.86	$Y_{yield} = 67.65 + 4.88\, X_{AI} + 22.81\, X_{SPI} + 0.23\, X_{RFeffec}$	0.047
Elfasher	0.40	0.16	0.13	85.21	$Y_{yield} = -328.75 - X_{Etp}$	0.027

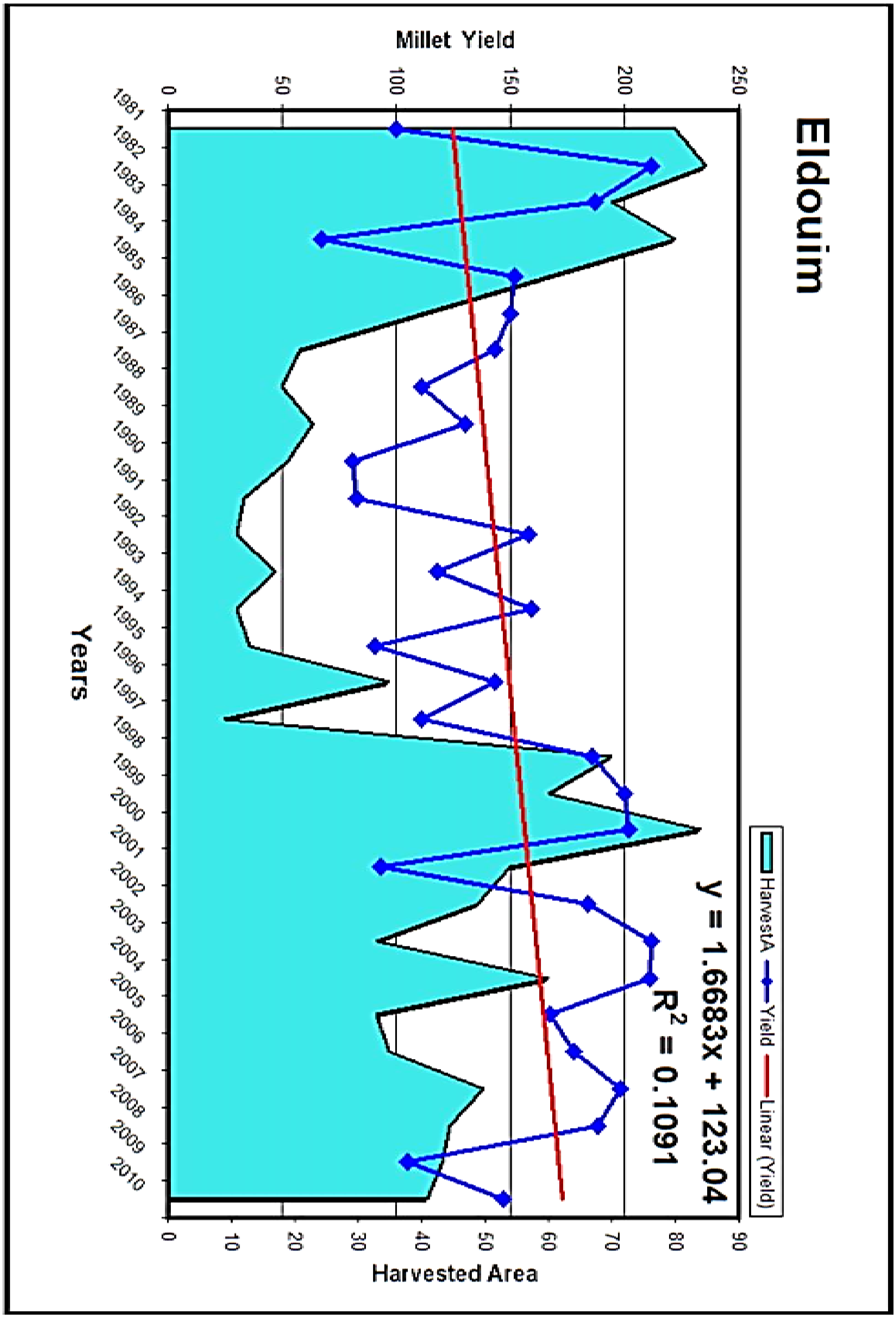

Figure 6. Long-term millet yield and harvested areas in White Nile state (Eldouim), during period 1981-2010

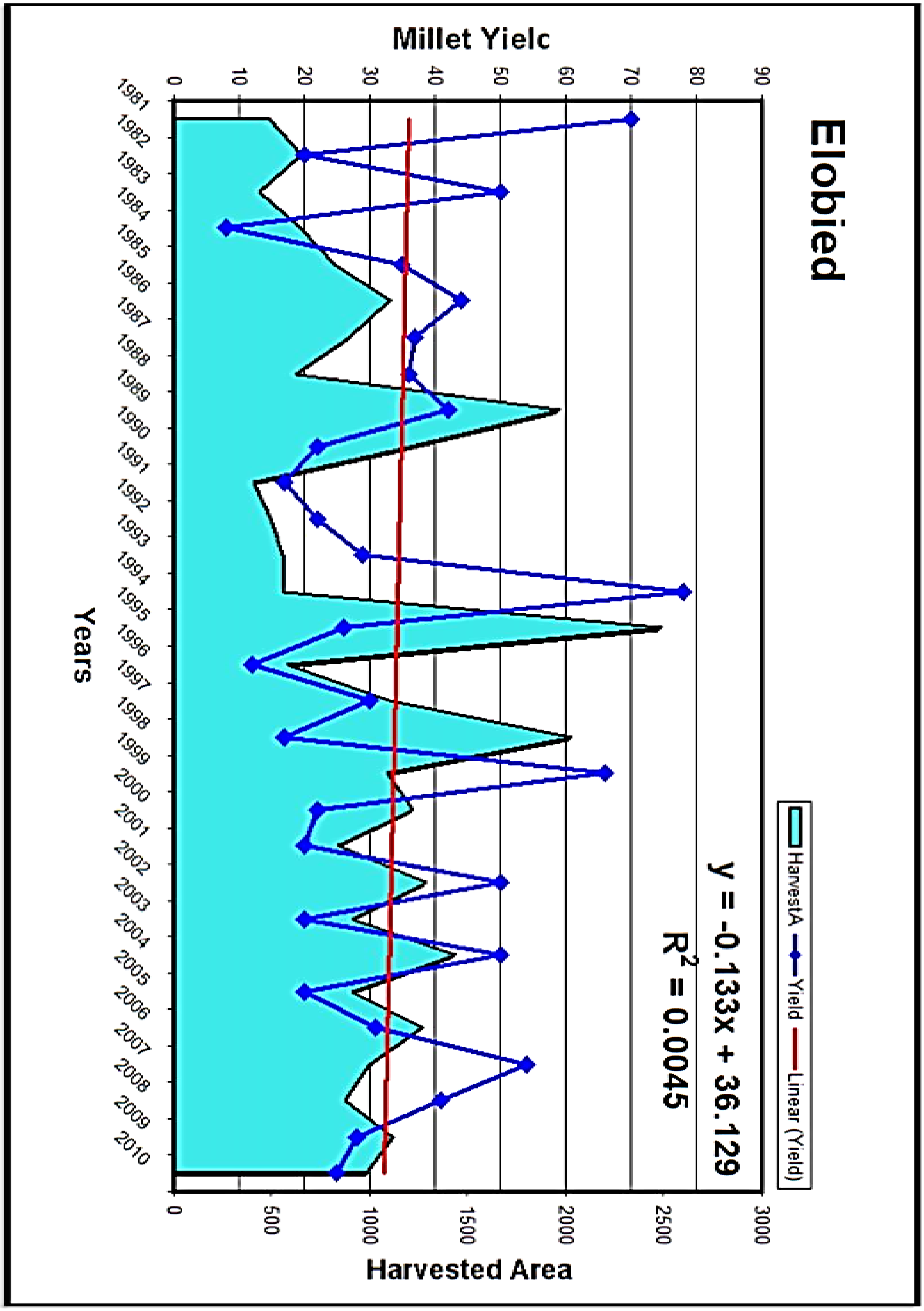

Figure 7. Long-term millet yield and harvested areas in North Kordofan (Elobied) during period 1981-2010

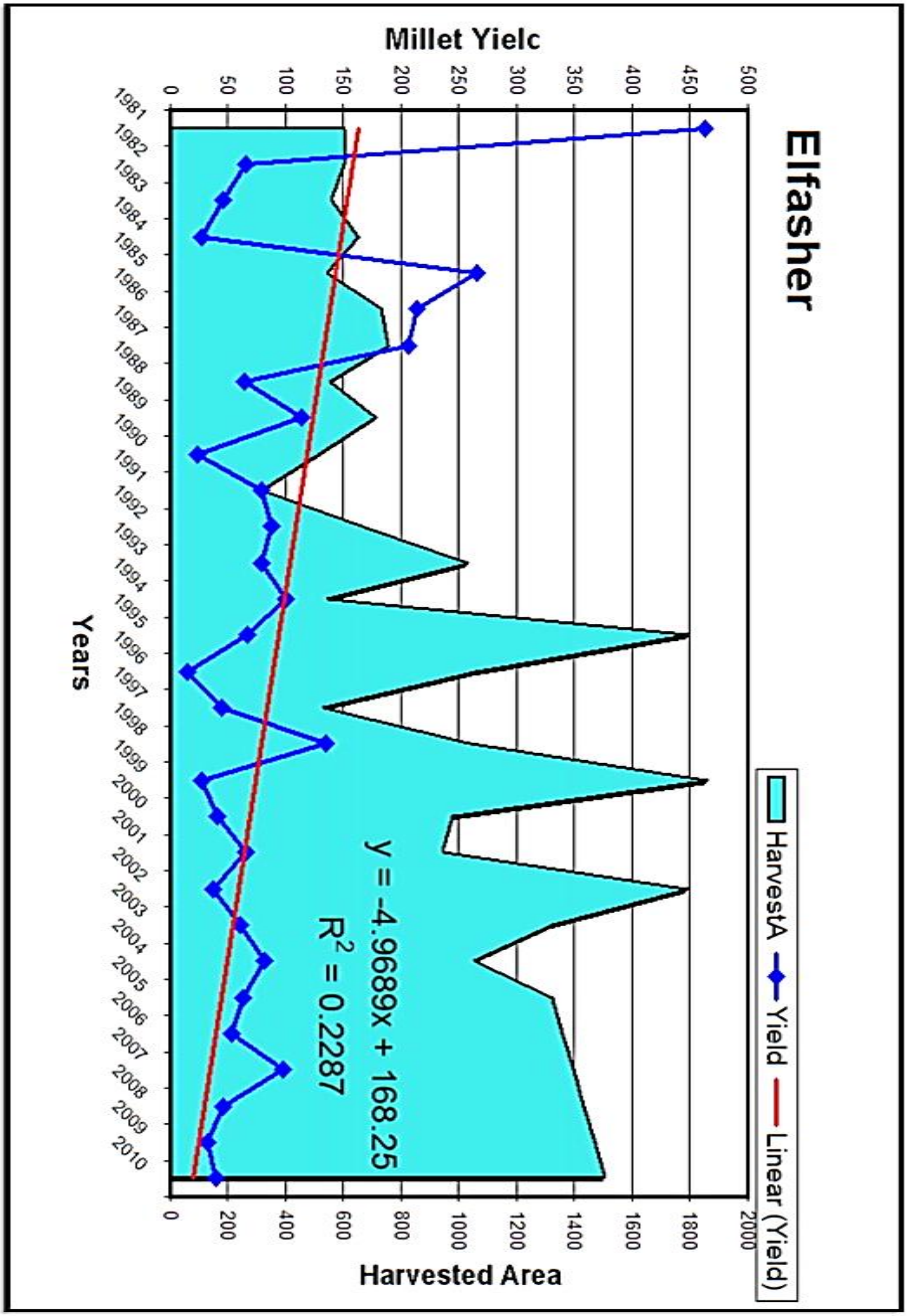

Figure 8. Long-term millet yield and harvested areas in North Darfur (Elfasher), during period 1981-2010

4. CONCLUSIONS

In this study five focal points had selected (Kassala, Gezira, Eldouim, Elobied and Elfasher) to represent the arid zone in Sudan.The study had pivoted in two axis: climate characteristics and trends and impacts of climate on Sorghum and Millet yield,. The results and findings of this study can be concluded as follow:

Generally the annual air temperature, annual rainfall, annual potential evapotranspiration (ETp), annual cumulative rainfall departure (CRD), annual effective rainfall (RFeffe), annual rainfall coefficient of variance (RFCV), annual aridity index (AI) and annual standardized precipitation index (SPI) had been increased during the period from 1980 to 2010 with statistically significant evidences in the all stations. Correlations between long-term sorghum yield and climatic factors analysis showed that there were positive significant correlation between sorghum yield and (AI) in Gezira and Elobied. Also in Elobied negative significant correlation sorghum yield and air temperature and (ETp). Where in Elfasher there were positive significant correlation between sorghum yield and rainfall, (CRD), (RFeffe), (AI) and (SPI). Correlations between long-term millet yield and climatic factors analysis showed that in Elobied station there were positive significant correlation between millet yield and rainfall, (RFeffe), (AI) and (SPI). Where in Elfasher there were negative significant correlation between millet yield and (ETp). Using multiple regression model where the climatic factors (dependent variables) with millet yield (independent variable); the results showed there were significant regression equation model in Elobied and Elfasher with ($p \leq 0.05$) values (0.047) and (0.027), respectively.

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