MARCH 30, 2020

BUILDING RESILIENCE IN THE FACE OF CLIMATE CHANGE WITHIN TRADITIONAL RAIN-FED AGRICULTURAL AND PASTORAL SYSTEMS IN SUDAN

CLIMATE RATIONALE REPORT

Additional Information on changes in observed and projected climate, including evidence of impacts on crop yields

Introduction

This report provides a summary of key climate indices for Sudan that establish the climate rationale for the project.

Figure 1: Map of Sudan showing target sates(Marked red-target localities in each state)

Figure 1 shows the map of Sudan with the target states for project activities as well as the locations of target sites within each state. Table 1 below shows the corresponding weather station used in the analysis below for each target state.

Table 1: List of weather stations corresponding to each target state for project activities.

Weather Station	Target State
El Geneina	West Darfur-Central Darfur-East Darfur
EL Nuhod	West Kordofan
Kadogli	South Kordofan
Port Sudan	Red Sea
Khartoum	Khartoum
Kassala	Kassala
Dongola	Northern State

<u>Changes in observed climate</u>

The main climate factors affecting crops in Sudan are:

- Rainfall extreme variability (onset, duration, cessation and intensity);
- Unpredictable periods of droughts;
- Changes in temperature and high rates of ET and loss of soil moisture;
- Short growing season;
- Ecological and natural resources degradation.

Seven weather stations representing different regions of Sudan were analysed for trends in climate extremes using the Climpact2 software[1]. Daily data for rainfall, minimum and maximum temperature for each of the seven weather stations (Table 2 below) were analysed for the period 1990-2019 (30 years).

Table 2: Position (latitude, longitude and altitude) of the seven weather stations with available daily data 1990-2019.

Station	Longitude (decimal degrees)	Latitude (decimal degrees)	Altitude (m)
El Geneina	22.45	13.483	805
El Nuhod	28.433	12.7	564
Kadugli	29.717	11.0	499
Kassala	36.4	15.467	500
Port Sudan	37.233	19.433	138
Khartoum	32.549	15.6	380
Dongola	30.483	19.167	226

Changes in total annual rainfall are mixed (Figure 1) with mostly negative trends during MAM and SON and mostly positive trends during JJA (main rainfall season). This leads to slightly positive trends on average during the whole year.

[1] https://climpact-sci.org/get-started/

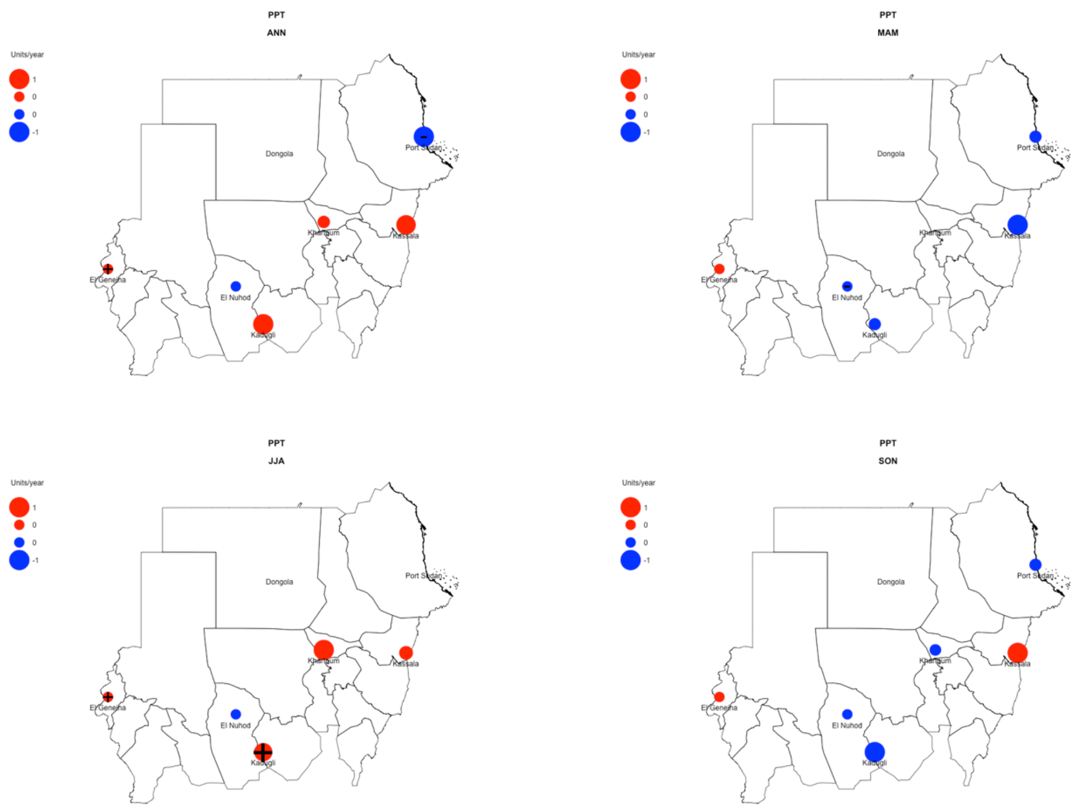


Figure 2: Trends in total rainfall for annual (ANN), March-May (MAM), June-August (JJA) and September-November (SON) – red +ve, blue -ve (zero trend not shown). Trends +ve/-ve at the 90% confidence level shown by +/-.

Trends in ET0 are shown in Figure 2 and are mostly positive during DJF but mostly negative during JJA, with more mixed trends during MAM and SON. This leads to similar patterns in rainfall-ET0 (P-ET0) as shown in Figure 3; trends are mostly negative during DJF and positive during JJA.

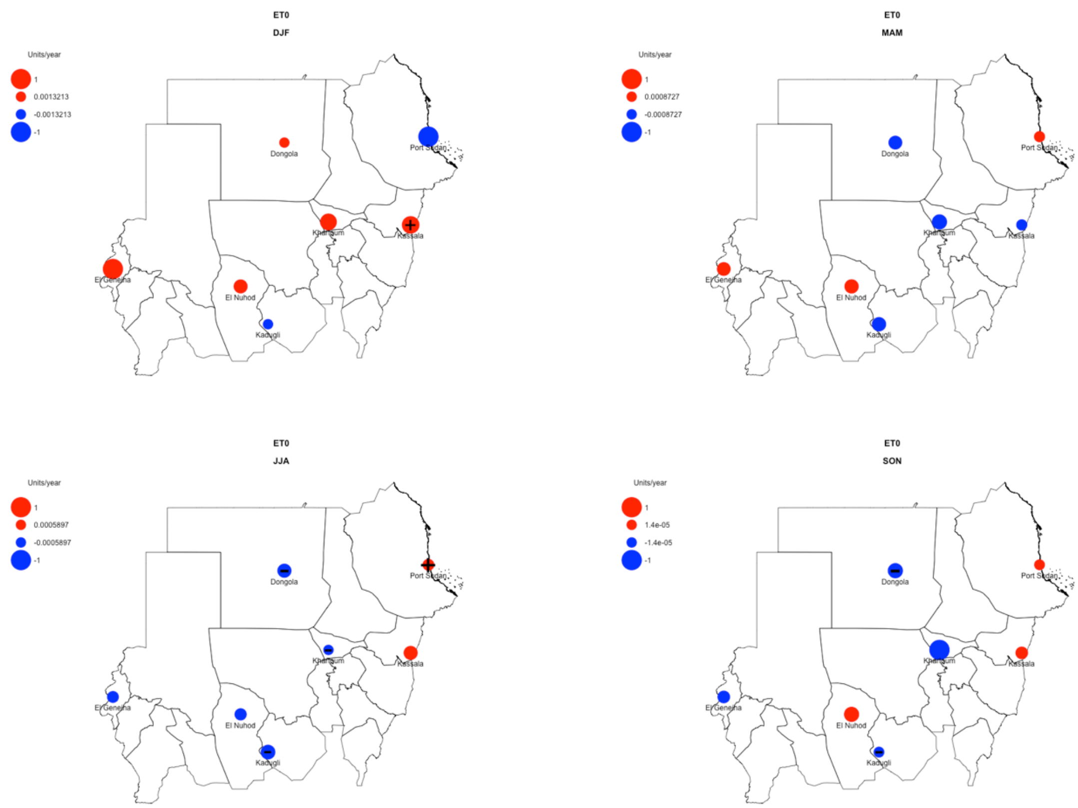


Figure 3: Trends in potential evapotranspiration (ET0) for annual (ANN), March-May (MAM), June-August (JJA) and September-November (SON) – red +ve, blue -ve (zero trend not shown). Trends +ve/-ve at the 90% confidence level shown by +/-.

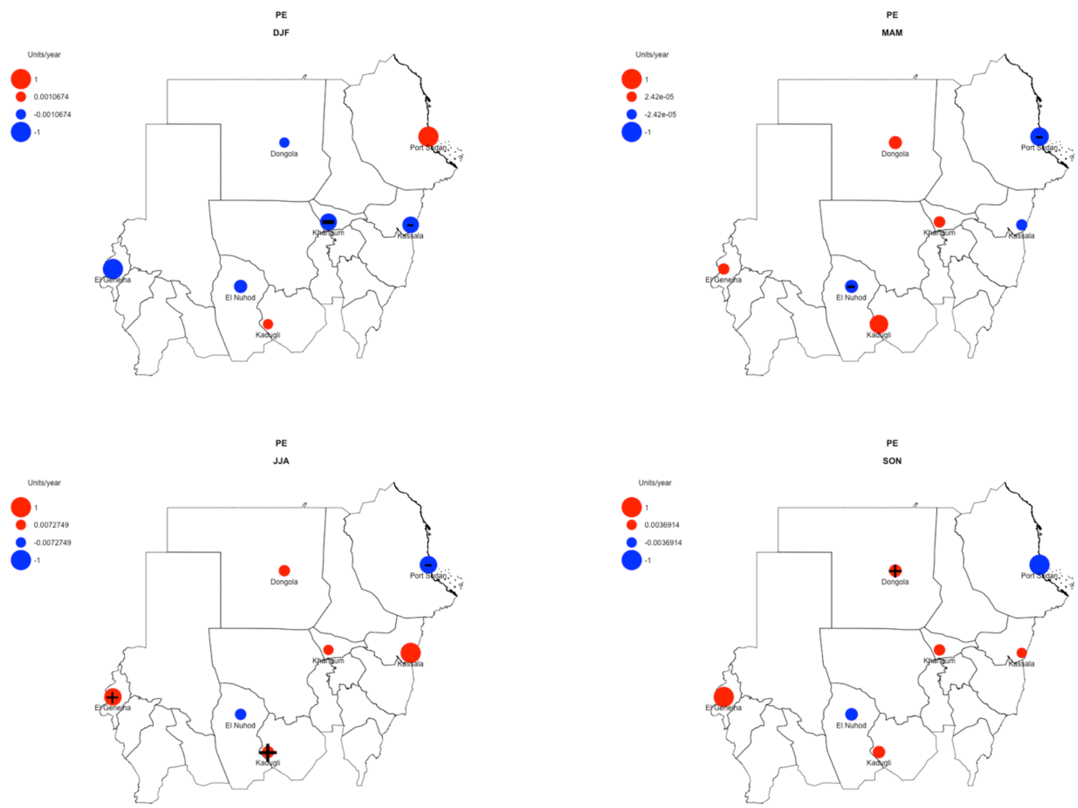


Figure 4: Trends in rainfall -potential evapotranspiration (P-ET0) for annual (ANN), March-May (MAM), June-August (JJA) and September-November (SON) – red +ve, blue -ve (zero trend not shown). Trends +ve/-ve at the 90% confidence level shown by +/-.

To investigate the impacts of changes in other rainfall characteristics, extreme indices (see examples in Table 2) were calculated for each year between 1990 and 2019 for each of the stations in Table 1 using Climpact software[2]. Trends were calculated for the period using standard linear regression routines using the R software.

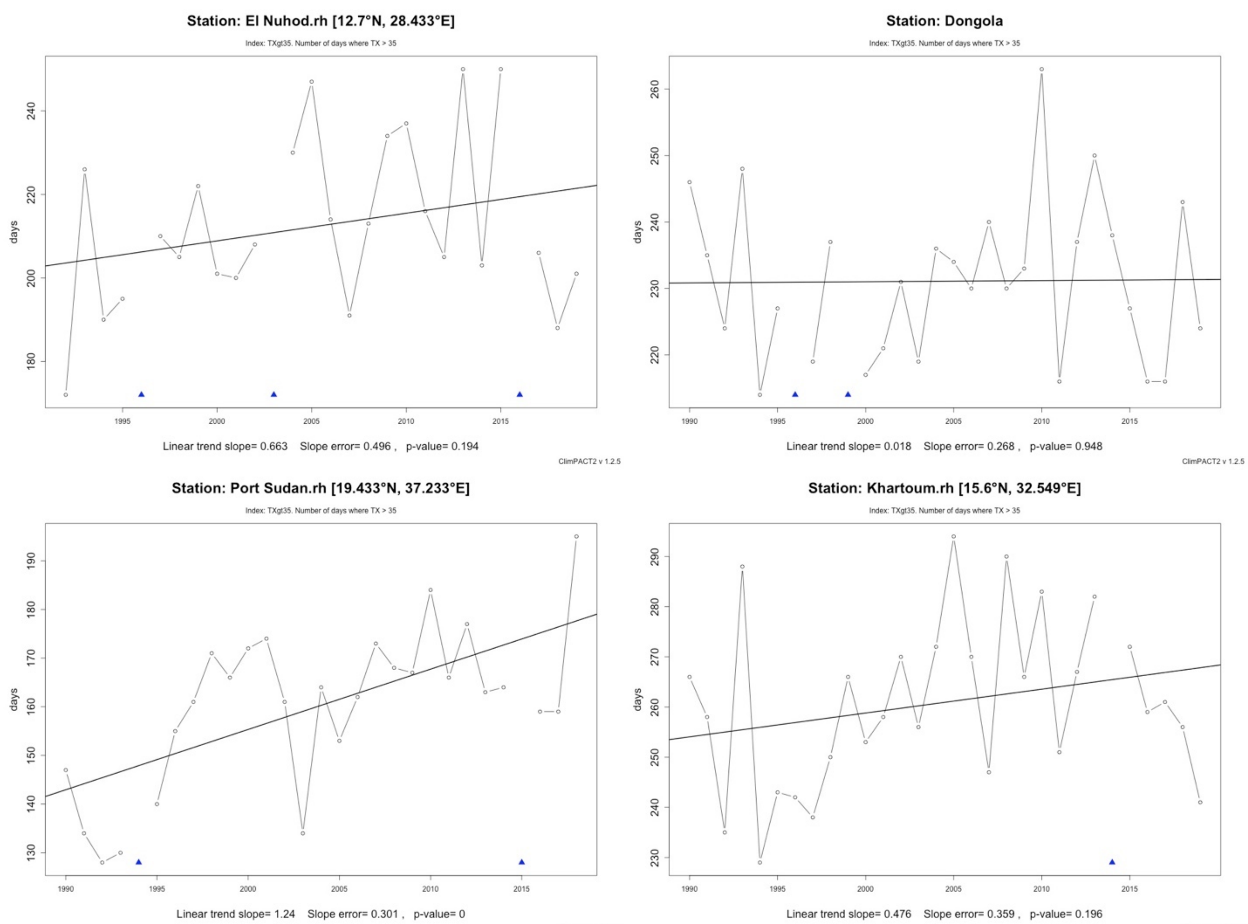
Table 3: Sample of extreme climate indices analysed using Climpact*, 1990-2019*

№	Indices	Name	Definition	Unit
1	FD	Frost days	Annual count when daily minimum temperature < $0^{O}C$	Days
2	SU	Summer days	Annual count when daily maximum > $25^{O}C$	Days
3	GSL	Growing season length	Annual count between first span of at least 6 days with daily mean temperature >5ºC and first span after July 1 of 6 days with daily mean temperature TM<5ºC	Days
4	Txx	Maximum of daily maximum temperature	Monthly maximum of daily maximum temperature	^{O}C
5	Tnn	Minimum of daily minimum temperature	Monthly minimum of daily minimum temperature	^{O}C
6	WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when daily maximum temperture >90th percentile	Days
7	CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days when daily minimum temperture <10th percentile	Days

[2] https://climpact-sci.org/

8	RX1day	Maximum 1-day precipitation	Monthly maximum 1-day precipitation	mm
9	RX5day	Maximum 5-day precipitation	Monthly maximum 1-day precipitation	mm
10	CDD	Consecutive dry days	Maximum length of dry spell: maximum number of consecutive days with daily precipitation <1mm	Days
11	CWD	Consecutive wet days	Maximum length of wet spell: maximum number of consecutive days with daily precipitation P>1mm	Days
12	SPEI3/6/12	Standardised precipitation evapotranspiration Index	Measure of "drought" using the Standardised precipitation evapotranspiration Index on time scales of 3, 6 and 12 months	Dimensionless

Here we focus on the main climate indices that impact crop yields in Sudan: i) Maximum temperatures greater than 35 ºC (which cause damages to sorghum and millet during the growing period); ii) shortened rainfall seasons which do not allow crops to reach maturity and which are inversely proportional to the length of the dry season (CDD); and iii) drought indices (SPEI) which measure rainfall – evapotranspiration for 3 month and longer periods.



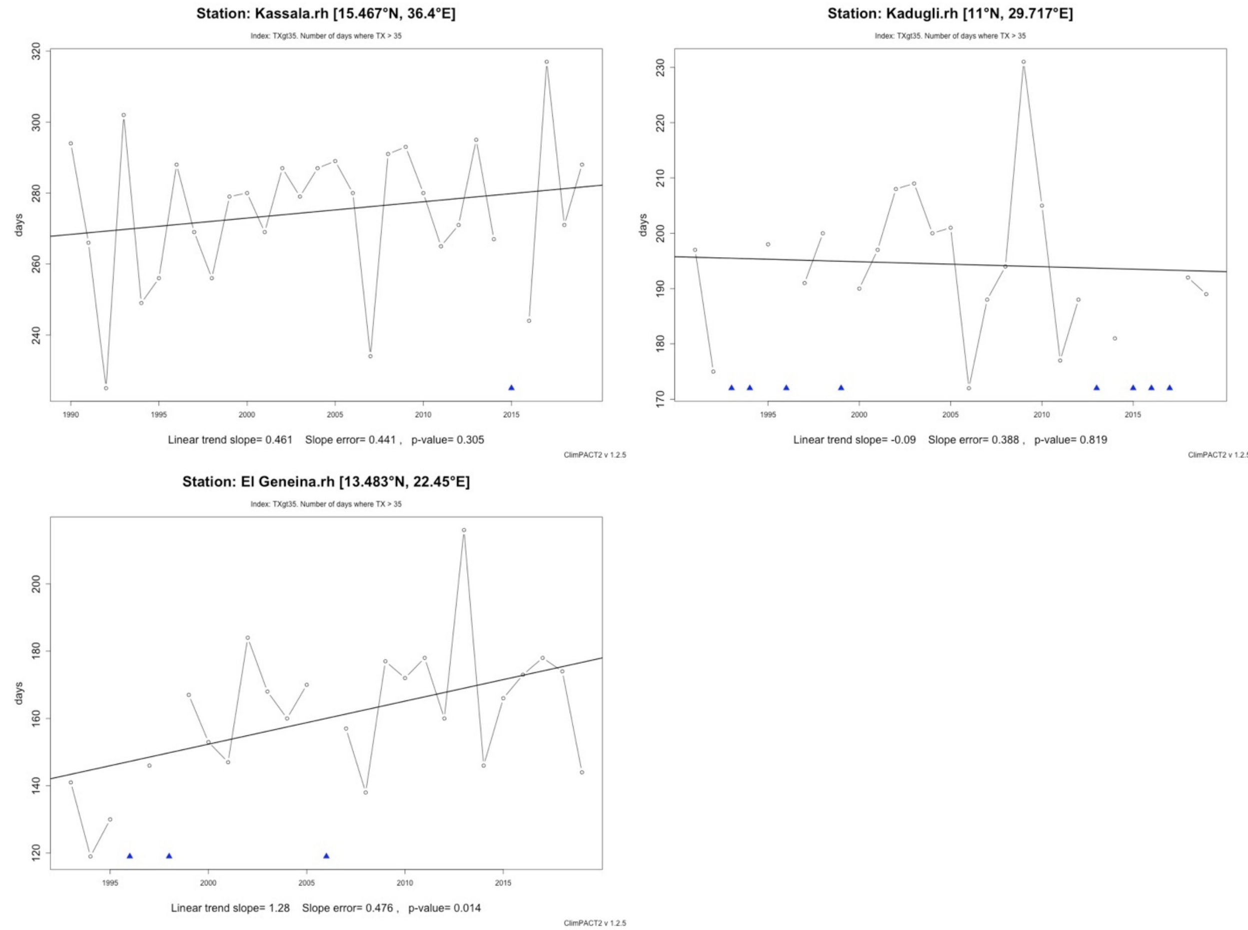
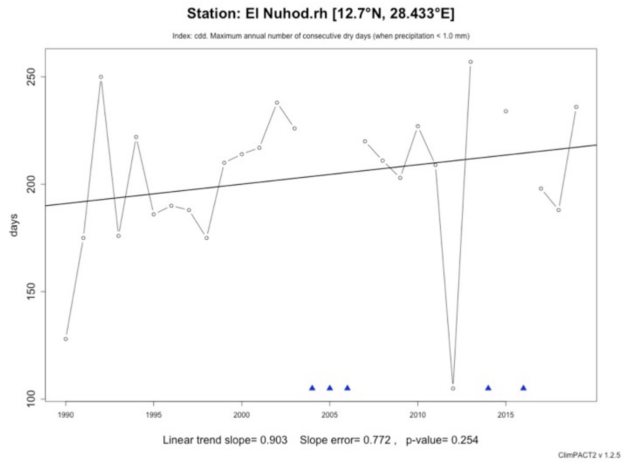
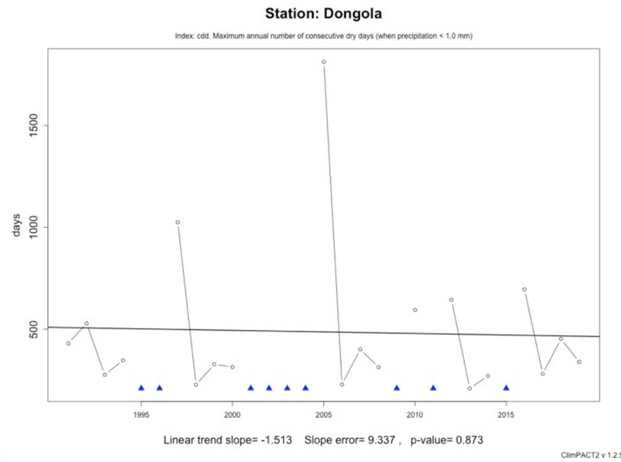
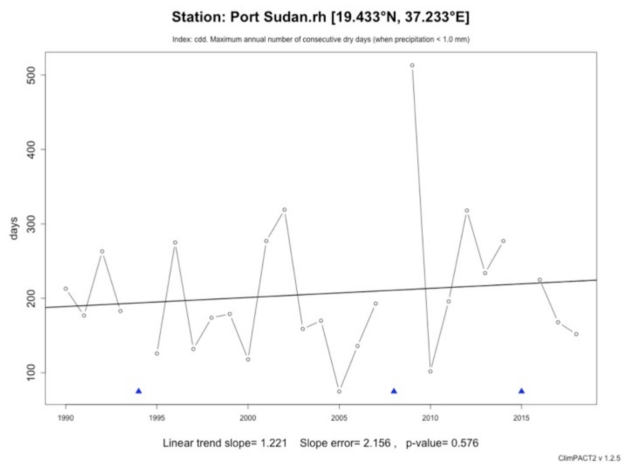


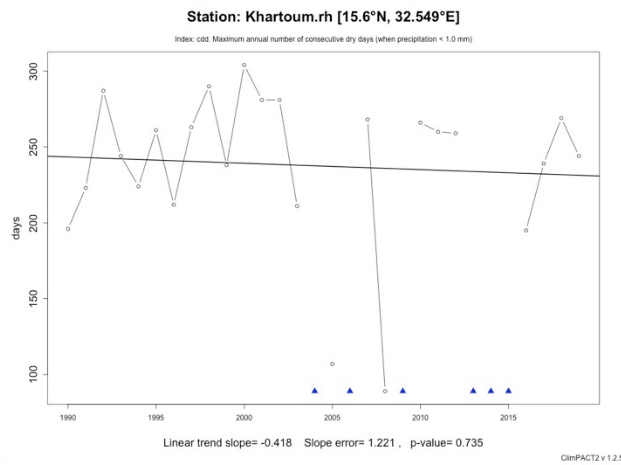
Figure 5: Trends in the number of days during the year when Tx > 35 C.

Figure 5 shows trends in number of days when maximum temperatures are greater than 35 ºC at all 7 weather stations. Trends have been positive i.e. increasing risks at all but 2 of the stations (Dongola and Kadugli.


Station: El Nuhod.rh [12.7°N, 28.433°E]
Index: cdd. Maximum annual number of consecutive dry days (when precipitation < 1.0 mm)
days
Linear trend slope= 0.903 Slope error= 0.772 , p-value= 0.254
ClimPACT2 v 1.2.5


Station: Dongola
Index: cdd. Maximum annual number of consecutive dry days (when precipitation < 1.0 mm)
days
Linear trend slope= -1.513 Slope error= 9.337 , p-value= 0.873
ClimPACT2 v 1.2.5


Station: Port Sudan.rh [19.433°N, 37.233°E]
Index: cdd. Maximum annual number of consecutive dry days (when precipitation < 1.0 mm)
days
Linear trend slope= 1.221 Slope error= 2.156 , p-value= 0.576
ClimPACT2 v 1.2.5


Station: Khartoum.rh [15.6°N, 32.549°E]
Index: cdd. Maximum annual number of consecutive dry days (when precipitation < 1.0 mm)
days
Linear trend slope= -0.418 Slope error= 1.221 , p-value= 0.735
ClimPACT2 v 1.2.5

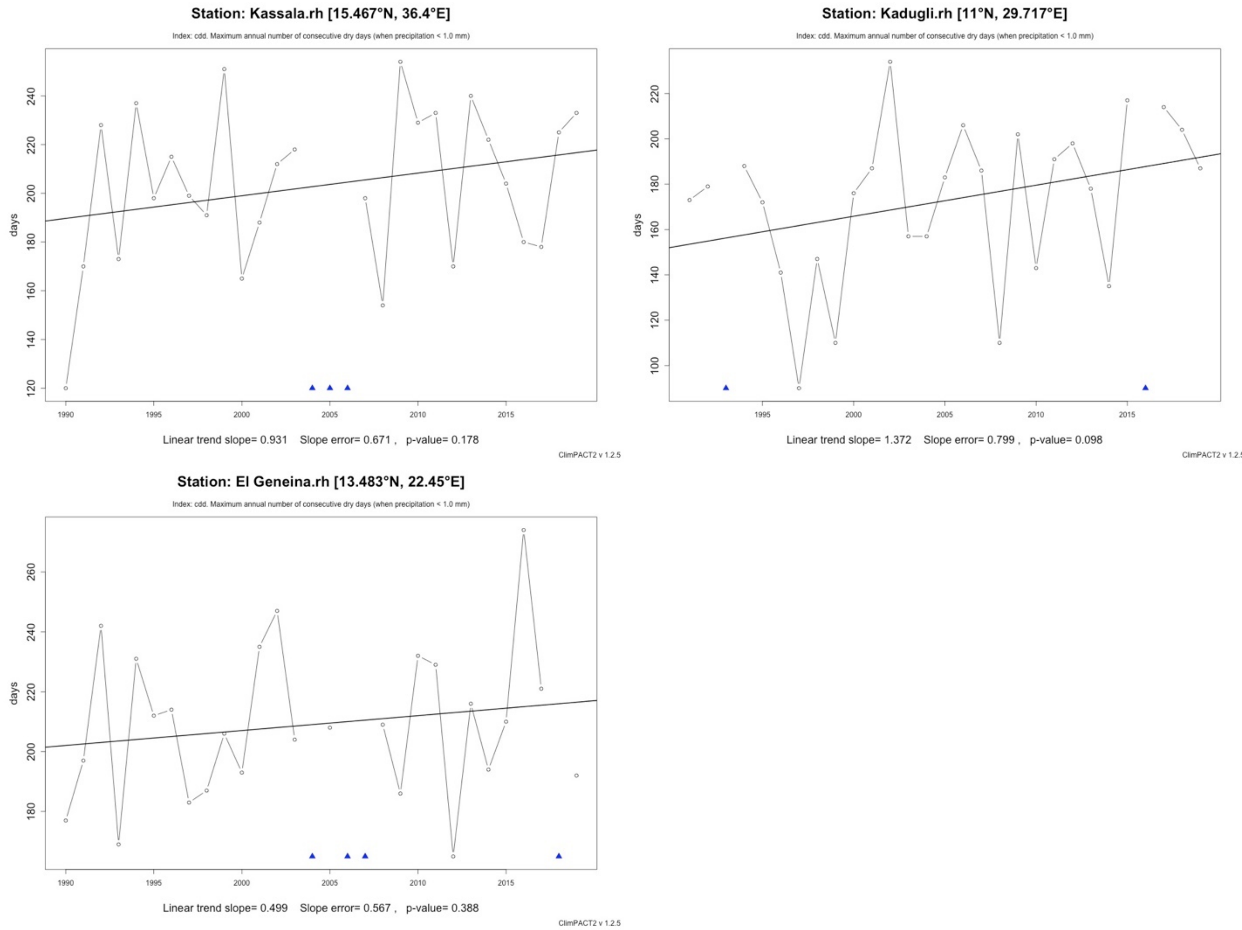
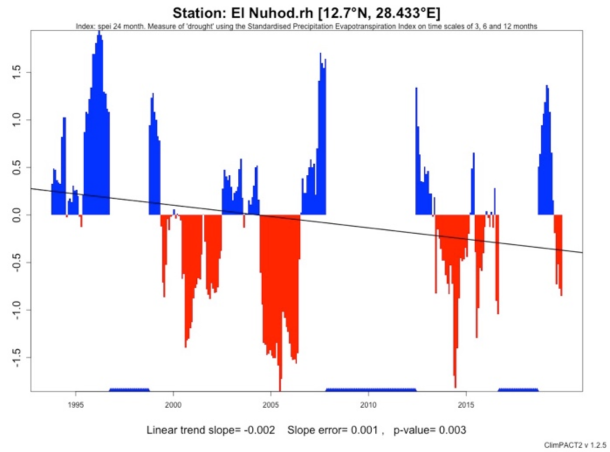
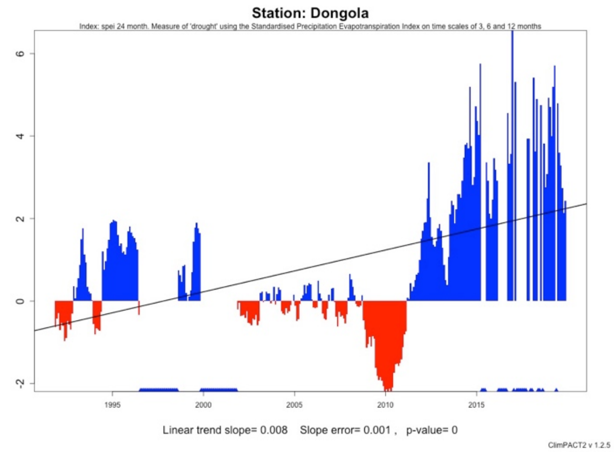
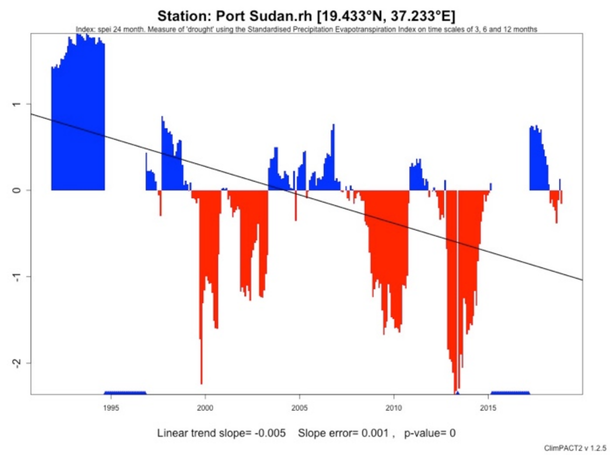


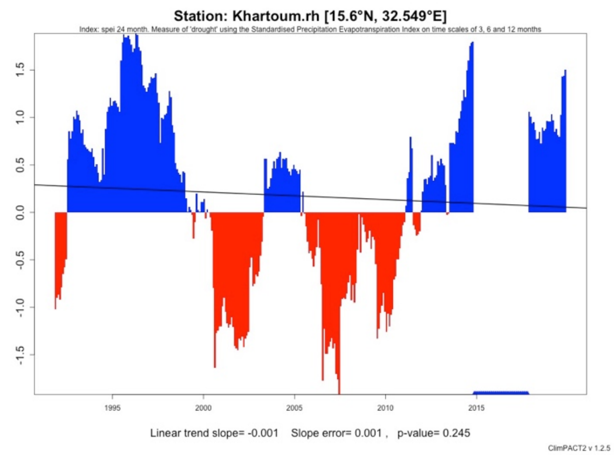
Figure 6: Trends in the maximum number of consecutive dry days (length of the dry season).

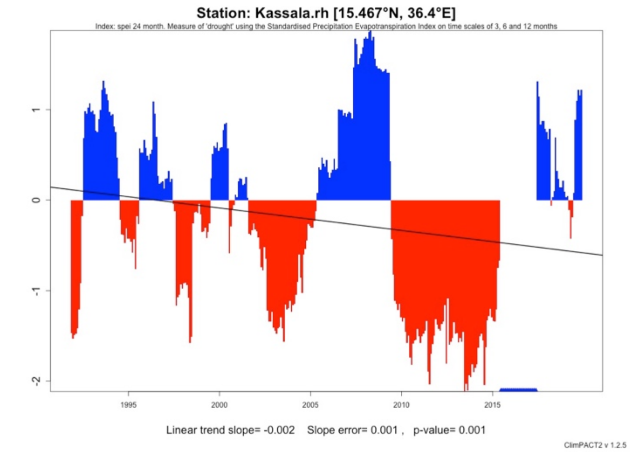
Figure 6 shows that the maximum number of consecutive dry days (length of the dry season) has been increasing at all stations except Khartoum (note that Dongola is so dry that the values for CDD are more than a year in many cases, invalidating its use as a metric in this environment. This suggests that the dry season has been getting longer and consequently the wet season shorter in most locations.

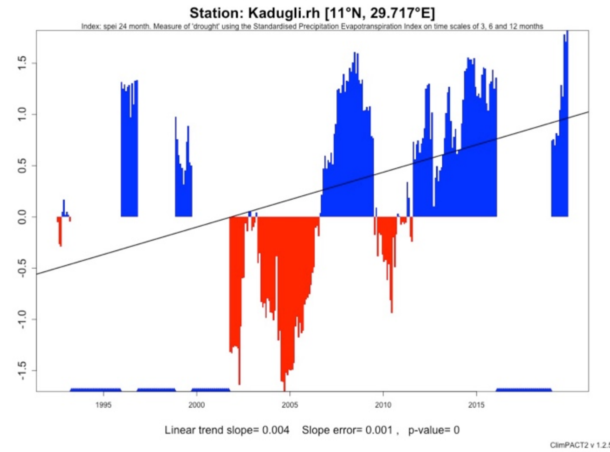

Station: El Nuhod.rh [12.7°N, 28.433°E]
Index: spei 24 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
Linear trend slope= -0.002 Slope error= 0.001 , p-value= 0.003
ClimPACT2 v 1.2.5


Station: Dongola
Index: spei 24 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
Linear trend slope= 0.008 Slope error= 0.001 , p-value= 0
ClimPACT2 v 1.2.5


Station: Port Sudan.rh [19.433°N, 37.233°E]
Index: spei 24 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
Linear trend slope= -0.005 Slope error= 0.001 , p-value= 0
ClimPACT2 v 1.2.5


Station: Khartoum.rh [15.6°N, 32.549°E]
Index: spei 24 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
Linear trend slope= -0.001 Slope error= 0.001 , p-value= 0.245
ClimPACT2 v 1.2.5





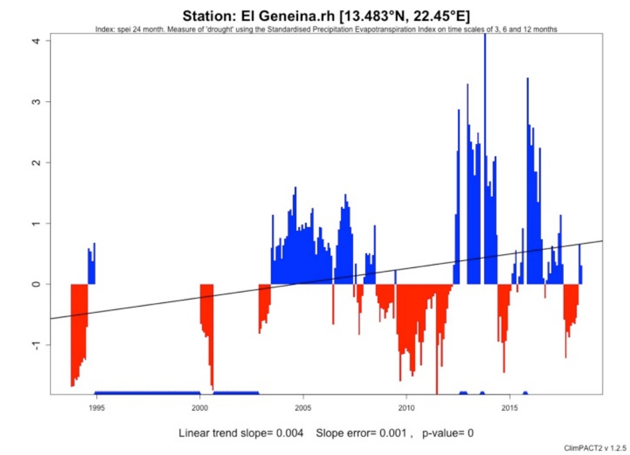


Figure 7: Trends in SPEI over 24 months.

Figure 7 shows that besides Khartoum which indicates no trend, half the stations indicate significant -ve trends in SPEI over 24 months. This is consistent with the seasonal differences in P-ET0 shown in figure 4.

Overall the most consistent trends (between stations) of aspects of climate affecting crops are for shorter rainfall seasons and for more days with high daily maximum temperatures.

Climate impacts on crops

Grain sorghum (*Sorghum bicolor* L. Moench) is the main staple crop with high acreage in Sudan. It ranks first in terms of both area and volume of crop production and is sown all over Sudan in both the irrigated and the rain-fed sectors. Recent studies (2016) indicate a strong correlation between sorghum yields and climate parameters (see Table 4 below).

Table 4: Correlation between sorghum yield and climate parameters. Source: Hudo, N.A. (2016) assessing the impact of climate variability and change on sorghum yield over Gadaref area in Sudan, MSc, Thesis,2016

Parameters	**Correlation coefficient**	**Relationship description**

Sorghum yield and rainfall	0.59	Significant
Sorghum yield and maximum temperature	-0.34	Significant
Sorghum yield and minimum temperature	-0.31	Significant

Comparison of the average productivity (kg/ha) of the main crops in the target states with those of the international, regional, national traditional rain-fed sector and record yields are shown in Table 5.

Table 5: Average yields of main crops compared to world regions.

Region	**Sorghum**	**Millet**	**Sesame**	**Groundnut**
International	1570	790	405	959
Africa	871	619	362	762
World drylands	800	600	500	1299
Sudan traditional sector	690	380	186	543
North Kordofan	320	119	166	383
North Darfur	428	164	156	419
West Kordofan	459	280	179	547
West Darfur	800	583	286	869
South Kordofan	662	357	339	762
South Darfur	607	333	245	583
Central Darfur	621		275	753
East Darfur	530	366	-	628
Blue Nile	550	-	245	-
Kassala	428	-	238	-
Research (South Kordofan)	952	660	593	933
Records (International)	4003	1616	862	2899

Source: Osman A. K. and Mohamed ElFatih K. Ali.2010. Crop Production under Traditional Rain-Fed Agriculture. Proceedings of the National Symposium on: Sustainable Rain-Fed Agriculture in Sudan. Al-Sharga Hall, University of Khartoum, Khartoum, Sudan 17 –18 November 2009.Edited by Prof M A Mustafa. Published by: UNESCO Chair of Desertification Studies, University of Khartoum, January 2010. Updated by A K Osman.

However, there have been significant declines in observed yields of both Sorghum and Millet between 1971 and 2001 (see Figure 8). In part this is due to the increases in temperature seen above as well as reductions in the length of the growing season, which is the duration between the onset and end of significant rains. In Sudan rain-fed sector, practically planting is done on the date of onset of the effective rain (10mm and more), normally during the first week of July, with harvesting at the end of significant rains (practically, about late September/early October). The length of the growing period also influences the selection of crop variety (short / medium / late maturing).

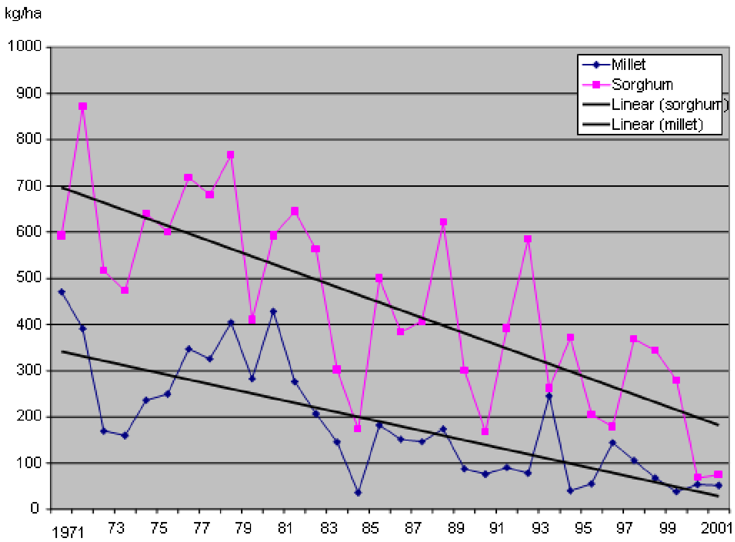


Figure 8: Trend of millet and sorghum productivity in the rain-fed sector in Sudan. Source :Ibrahim El-Dukheri et al 2011. Review of the Food Security and Natural Resource Situation in Sudan. DCG Report No.63.

In Sudan, the link between climate and livelihood is very strong, as more than 80 per cent of cultivated land is currently under rain fed agriculture and most of the population depends heavily on rain-fed agriculture and livelihoods are highly vulnerable to climate variability. This is important as further reductions in yields as a result of climate change are predicted (see Figure 9 below).

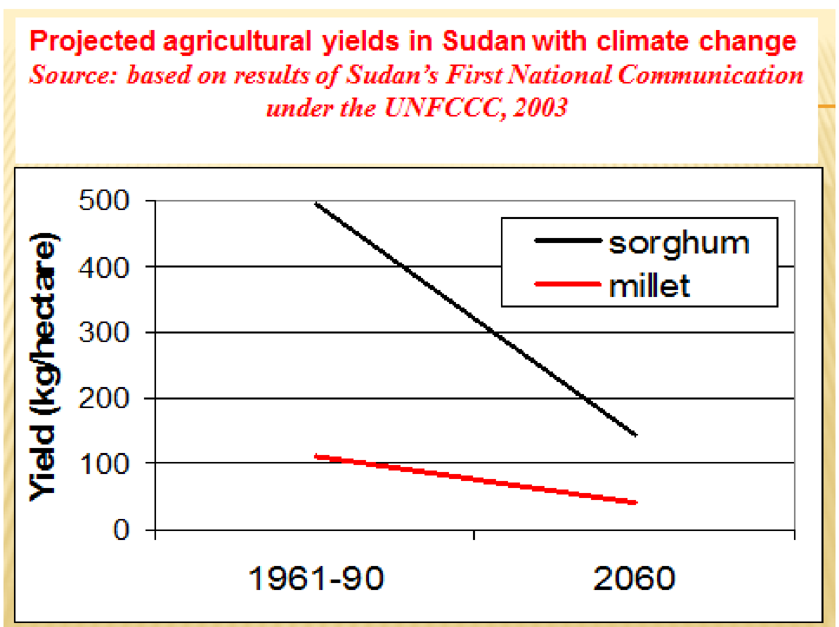


Figure 9: Projected sorghum and millet yields. Report: Sudan First National Communication under the UNFCCC, 2003