ASSESSING THE ECONOMIC IMPACT OF CLIMATE CHANGE (MAXIMUM AND MINIMUM TEMPERATURE) ON PRODUCTIVITY OF SORGHUM CROP IN GADARIF STATE, SUDAN

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ABSTRACT
This paper was prepared to estimate the current and projected relationship between climate change (temperature) and variability and the productivity of sorghum under rainfed mechanized farming system in Gadarif State. The study utilized secondary data covering the period 1970-2014. The data analyzed using descriptive analysis, Bias Correction and Spatial Downscaling (BCSD) and Representative Concentration Pathways (RCPs). The most important results revealed that an increasing trend of temperature indicating the evidence of existence of climate change in the State. The results also showed a drop in crop yield associated with an increase in maximum and minimum level of temperatures. As with respect to projection of future temperature and yield, two scenarios based on greenhouse gas concentration in the atmosphere for the period 2020-2100 were used. The best scenario assumed an RCP of 2.6 and the worst one assumed an RCP of 8.5. The results of best scenario predicted an expected increase yearly in maximum and minimum temperatures at rate of 0.015°C and 0.010°C respectively; and consequent decrease in crop yield at rate of 1.121 kg/fed/year in case of maximum temperature; and at rate of 0.618 kg/fed/year in case of minimum temperature. The result of the worst scenario predicted an expected yearly increase in maximum and minimum temperatures at 0.074°C and 0.081°C respectively, with consequent decline in crop yield at a rate of 5.235 kg/fed/year associated with maximum temperature and at rate of 4.844 kg/fed/year associated with minimum temperature. The effect of increase greenhouse gas concentration in future leads to increase maximum and minimum temperatures and decrease yield of sorghum in Gadarif State.

KEY WORDS
Greenhouse gas; scenario; bias correction and spatial downscaling; representative concentration pathways.

Climate change is an important environmental issue at the moment, being a disaster cosmic phenomenon. It is associated directly with impacts on various vital sectors, including agriculture, water, energy, health, transport and other sectors. The findings of the Intergovernmental Panel on Climate Change (IPCC,2007) have shown that climate change is already imposing strong impacts on human societies and the natural world, and is expected to do so for decades to come.

United Nations Framework Convention on Climate Change (UNFCCC, 2007) predicted that billions of people, particularly those in developing countries, would face shortages of water and food and greater risks to health and life as a result of climate change over the next decades.

The UNFCCC also referred to the IPCC prediction that even with a temperature rise of 1- 2.5°C, serious effects including reduced crop yields in tropical areas would lead to increased risks of hunger. Moreover, there is evidence that geographical regions with an arid and semi-arid climate could be sensitive to even insignificant changes in climatic characteristics. The climate change is expected to result in higher temperatures and rainfall levels. Whereas, higher expected temperature might lower the yields, the higher rainfall could enhance the growing period of crops. At the same time, the higher concentration of CO₂ in the atmosphere under changed climatic conditions might act as an aerial fertilizer and

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enhances crop yields. All these factors have to be taken into consideration while examining the climate change impact on agriculture.

Houghton et al. (1996) stated that scientific evidence indicates that due to increased concentration of greenhouse gases in the atmosphere, the climate conditions of the Earth is changing; temperature is increasing and the amount and distribution of rainfall is being altered. A scenario of simulated results indicated that greenhouse gas emissions could rise by 25-90 % by 2030 relative to 2000; the Earth could warm by 3°C by the present century.

Sorghum is the main staple food for most of the Sudanese people of the rural areas of Sudan. Sorghum crop is characterized by the ability to grow and adapt in different productive environments. The most important environmental factors affecting the productivity of sorghum are the maximum and minimum temperatures (15-35°C), and the moisture available during the process of germination and vegetative growth. It is known that sorghum crop squeamish excess water limit (drowning) as well as a sharp drop in humidity (thirst), especially in the whimsical flowering and fruiting. (ARC, 2012)

\[ y = -4.332x + 314.3 \]
\[ R^2 = 0.341 \]

![Graph showing productivity of sorghum crop in Gadarif state during 1970-2014](image)

Source: Ministry of agriculture & Forestry, Gadarif State (2014)

Figure 1 – The productivity of sorghum crop in Gadarif state during 1970-2014

Gadarif State is the major agricultural rainfed state in Sudan, producing about 40% of sorghum Sudan. Historically, is the first State which introduced agricultural mechanization in the Sudan in the forties. Currently, Gadarif State cultivates about seven million feddans about sixth of the cultivated area in Sudan, and more than 50% of the cultivated area under rainfed sector. Gadarif is the largest producing area of sorghum in Sudan. The main problem facing sorghum production in Gadarif area is the decline in the productivity during time (Fig.1).

**MATERIALS AND METHOD OF RESEARCH**

Bias Correction and Spatial Downscaling (BCSD). The algorithm for BCSD method was originally designed to process monthly data. The method assumes that the model biases in both present and future climate simulations follow the same pattern. In order to perform the BCSD for the model simulations of 21st-century climate, three data sets are needed – observed climatic data, a given General Circulation Model (GCM) outputs for the same time period, and the model's 21st century climate prediction.

The bias correction algorithm is based on the first and second datasets. First, both the OBS data and the model output for the present climate are regridded to a common resolution (2°x2° for GCMs and 0.5°x0.5° for (RCMs) Regional Climate Models. At each grid cell, Cumulative Distribution Function (CDF) curves are then generated for both the model climate
a dobs data respectively, by plotting the sorted values versus the rank probabilities. The CDFs for both the model and OBS data are then related through probability threshold to define the quintile map, which is then used for bias removal from the 3rd data set. This Process, which is graphically described in Figure 2, is done on a location specific and time-specific basis.

![Figure 2 – Graphical representation of BCSD method](image)

Specifically for each data point from the 3rd dataset (i.e., for each data from the future prediction), its corresponding percentile is determined based on the climate model CDF. The observed data corresponding to the same percentile is identified and accepted as the bias corrected model prediction. The result of bias-correction is an adjusted model output that is statistically consistent with observations. Before applying the bias correction to model simulation of 21st century temperature, the future trend is first set aside, and will be added back later to the bias corrected dataset. Bias corrected model output reflects the same relative changes in mean, variance and other statistical moments as the raw model output. The procedure has been repeated for each grid point of the domain.

The next step is to perform the spatial downscaling to translate the bias-corrected model outputs to 1/8°x1/8° from 2°x2° for GCMs and from 0.5°x0.5° for RCMs. The spatial downscaling is conducted on climate factors. First, the spatially distributed value of observed mean is defined as the “observational datum”. A factor is then defined comparing the observational datum and adjusted model data. The factor value for temperature is the adjusted model data minus observational datum for each coarse grid cell, and for precipitation, the factor value is the ratio of adjusted model data to observational datum. These coarse resolution factors are interpolated to 1/8° resolution using the SYMAP algorithm (Shepard, 1984) and the interpolated factors are then applied to the OBS mean at 1/8° resolution in order to produce the downscaled model simulations. This method is based on the assumption that the topographic and the climatic features determining the fine-scale distribution of large-scale climate will remain unchanged in the future periods.

For the impact analysis in many sectors, climate data are required at daily temporal scale. However, the BCSD method, as it was originally developed to process the monthly data, is not completely suitable to perform the bias correction of daily data, especially for precipitation. In models, it rains every day at lower rain intensity, while in observed dataset, there are many zero precipitation days and the rain intensity is larger during the rainy days. That creates an inconsistency between the CDFs of model and observed dataset for daily precipitation. In order to address this problem in this study, a modification was made in the CDF of model precipitation data. If P is the probability threshold of having zero precipitation days in the observed climatology, the values of any model precipitation having probability threshold lower than P, were set to zero. As such, the CDFs of both model and observed data were made consistent. One drawback, however, is that many drizzling days is set to no-rain days which lead to slight underestimate of the rain amount.
Representative Concentration Pathways (RCPs). Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000.

The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values +2.6, +4.5, +6.0, and +8.5 W/m², respectively.

RESULTS OF STUDY

According to Table (1 and 2) the average of maximum and minimum temperature increased during the whole period it was record 37°C and 21.7°C respectively.

Table 1 – Statistical indicators of maximum temperature (°C) in Gadarif state during 1970-2014

<table>
<thead>
<tr>
<th>Item</th>
<th>70-80</th>
<th>81-90</th>
<th>91-00</th>
<th>01-10</th>
<th>11-14</th>
<th>70-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (°C)</td>
<td>36.4</td>
<td>37</td>
<td>37</td>
<td>37.5</td>
<td>37.7</td>
<td>37</td>
</tr>
<tr>
<td>Std.Dev</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Coef of variation (%)</td>
<td>1.1</td>
<td>1.7</td>
<td>0.6</td>
<td>1.2</td>
<td>0.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Max(°C)</td>
<td>38.4</td>
<td>38.1</td>
<td>37.3</td>
<td>38.4</td>
<td>37.8</td>
<td>38.4</td>
</tr>
<tr>
<td>Min(°C)</td>
<td>35.7</td>
<td>36.1</td>
<td>36.5</td>
<td>36.9</td>
<td>37.5</td>
<td>35.7</td>
</tr>
</tbody>
</table>

Source: Sudan Meteorological Authority, annual reports (2014).

Table 2 – Statistical indicators of minimum temperature (°C) in Gadarif state during 1970-2014

<table>
<thead>
<tr>
<th>Item</th>
<th>70-80</th>
<th>81-90</th>
<th>91-00</th>
<th>01-10</th>
<th>11-14</th>
<th>70-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average (°C)</td>
<td>21.2</td>
<td>21.2</td>
<td>21.7</td>
<td>22.4</td>
<td>22.5</td>
<td>21.7</td>
</tr>
<tr>
<td>Std.Dev</td>
<td>0.4</td>
<td>0.7</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Coef of variation (%)</td>
<td>1.7</td>
<td>3.5</td>
<td>1.3</td>
<td>1.6</td>
<td>1</td>
<td>3.2</td>
</tr>
<tr>
<td>Max(°C)</td>
<td>22.0</td>
<td>22.0</td>
<td>22.1</td>
<td>23.1</td>
<td>22.8</td>
<td>23.1</td>
</tr>
<tr>
<td>Min(°C)</td>
<td>20.7</td>
<td>20.0</td>
<td>21.1</td>
<td>21.9</td>
<td>22.3</td>
<td>20</td>
</tr>
</tbody>
</table>

Source: Sudan Meteorological Authority, annual reports (2014).
The high and low maximum temperature falling between 38.4°C and 35.7°C, and the high and low minimum temperature record falling between 23.1°C and 20°C. Figure (4 and 5), the general trend of maximum and minimum temperatures revealed an increasing pattern during 1970-2014 at rate of 0.033 and 0.040 per year respectively.

Figure 4 – Maximum temperature in Gadarif State during 1970-2014

\[ y = 0.0333x + 36.209 \]
\[ R^2 = 0.5075 \]

Source: Sudan Meteorological Authority, annual reports (2014)

Figure 5 – Minimum temperature in Gadarif State during 1970-2014

\[ y = 0.0402x + 20.778 \]
\[ R^2 = 0.5909 \]

Source: Sudan Meteorological Authority, annual reports (2014)

Prediction of yield in Gadarif State during 2020-2100. As can be seen from Figure (6), the predicted yield from RCP2.6 scenario, with maximum temperature as main predictor for period from 2020 to 2100, followed a downward trend in the first 30 years at rate -1.121 kg/fed/year, while its trend remained with no significant change for the rest period, except for its high variability in the latter two decades. The RCP8.5 scenario with the same predictor showed a dramatic downward yield trend at rate of -5.235 kg/fed/year with below normal yield starting around 2055.

Figure (7) shows the projected yield of RCP2.6 scenario by means of minimum temperature as a predictor for period from 2020 to 2100. A slight downward trend during the first 30 years at rate of -0.618 kg/fed/year would occur while a stable one would continue through the rest of the period. However, an increased variability can be seen from around the
2050. The RCP8.5 scenario shows a dramatic downward yield with a below normal yield starting nearby 2055 and would continue to wards the rest of the time frame. The trend would decrease at a rate of -4.844 kg/fed/year and it would be similar in both minimum and maximum temperatures projections.

Figure 6 – Yield prediction according to maximum temperature as a predictor using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State

Figure 7 – Yield prediction according to minimum temperature as a predictor using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State

*Prediction of maximum temperature in Gadarif State during 2020-2100.* From Figure (8), maximum temperature projection for the period from 2020 to 2100 might be increasing rapidly when using RCP8.5 at rate of 0.074 °C/year. The increase could be slightly less in case of the RCP 2.6, at rate of 0.015 °C/year during the same period.

Figure (9) present a steady rise trend. The trend line of future temperature might continue to rise at rate of 0.015 °C/year. The highest temperature might reach 41 °C in 2086.
Figure 8 – Maximum temperature prediction using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State

\[ y = 0.0159x + 38.78 \]
\[ R^2 = 0.2622 \]

\[ y = 0.074x + 37.73 \]
\[ R^2 = 0.9372 \]

Figure 9 – Current and predicted future maximum temperature during 1970-2014 and 2020-2100 using RCP 2.6 scenario in Gadarif State

\[ y = 0.0159x + 37.988 \]
\[ R^2 = 0.2622 \]

Figure 10 – Current and projected future maximum temperature during 1970-2014 and 2020-2100 using RCP 8.5 scenario in Gadarif State

\[ y = 0.074x + 34.029 \]
\[ R^2 = 0.9372 \]
Figure (10) indicates a steady rise in future maximum temperature for current data recorded between 1970 and 2014, after which the projected maximum from RCP8.5 scenario would follow an increase giving an alarm. The trend would rising at rate of 0.074 °C/year and the future maximum temperature might reach 45 °C in 2100.

**Prediction of minimum temperature in Gadarif State.** A high difference occurs between the two scenarios (RCP2.6 and RCP8.5) projections for minimum temperatures for 2020 and 2100. The RCP 2.6 trend would have a slight increase when RCP8.5 would be at a higher rate dramatically increasing.

![Graph](image_url)

**Figure 11 – Minimum temperature prediction using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State**

![Graph](image_url)

**Figure 12 – Current and future projected minimum temperature during 1970-2014 and 2020-2100 using RCP 2.6 scenarios in Gadarif State**
A slight rise in current minimum temperature is seen, which a steady rising trend of rising trend of 0.010°C/year is predicted for the period 2020-2100 using RCP 2.6. The highest minimum temperature might occur 25°C in 2097.

Figure 13 – Current and future projected minimum temperature during 1970-2014 and 2020-210 using scenario RCP 8.5in Gadarif State

Figure (13) shows a steady rise in trend is witnessed on actual minimum temperature and a rapid increase in future minimum temperature at rate of 0.081°C/ year using RCP 8.5. The highest minimum temperature might occur at 30°C in 2099.

DISCUSSION

Climate change results from human activity including industrial production, cars exhausts and cutting down of trees. These types of activities increase the concentration of carbon dioxide, methane, nitrous oxide and other greenhouse gases in the atmosphere (IPCC, 2007). If the current trend continues, the temperature will increase by about one degree by the year 2030 and two degrees in the next century. This increase would probably have different effects in different regions. The impact on agricultural is likely to be negative affecting the poorest developing countries during the next fifty years. It would reduce the area of agricultural land and their productivity potential Sub-Saharan Africa, would which have hit areas due to the inability to cope with situation. The expected impact of climate changes on temperature would harm agricultural production. Climate change can alter those factors causing a serious threat to water availability and reduction in agricultural productivity. Climate change and variability phenomena are under investigation in Sudan. Available data indicate that continued increase in temperature levels during 1940-2014. The concurrent increase and fluctuations in sorghum productivity under rain fed system in Gadarif region may be caused by prevailing climate change and variability.

CONCLUSIONS

The general trend of temperatures revealed an increasing pattern about one degree centigrate during 1970-2014. Drop in crop yield has been associated with an increase in maximum and minimum temperatures, this situation requires the introduction of drought-resistant varieties. Increase greenhouse gas concentration in future lead to increase maximum and minimum temperatures and decrease yield of sorghum in Gadarif State.
REFERENCES

3. Intergovernmental Panel on Climate Change (IPCC)(2007). Fourth Assessment Report, Climate change-the physical science basis, Chapter 2 Changes in atmospheric constituents and radiative forcing, p. 208.