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Impact of Climate Variability and Change on Sorghum Yield in Gedaref State, Sudan

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Abstract

Climate variability has become a major constraint to agricultural productivity in Sudan, particularly in rain-fed regions such as Gedaref State. This study analyzes the impacts of temperature and rainfall variability on sorghum yield using long-term climate data (1961-2014) and sorghum production records (1970-2007). Mann-Kendall trend tests, correlation, and multiple regression analyses were applied to assess climate-yield relationships. The FAO AquaCrop model was used to project future yield changes under changing climate conditions. Results revealed significant increases in maximum and minimum temperatures ($p < 0.001$) and a slight, insignificant decline in rainfall. Sorghum yield was positively correlated with rainfall ($r = 0.59$) and negatively correlated with maximum ($r = -0.34$) and minimum ($r = -0.31$) temperatures. Regression results indicated that climatic variables explained about 30% of yield variability ($p = 0.02$). AquaCrop simulations suggested that by 2046, rainfall may decrease by 33% and temperature rise by 2.4˚C, leading to a 39.9% yield decline. The findings highlight the vulnerability of rain-fed sorghum to climate variability and emphasize the need for adaptation measures to safeguard food security and rural livelihoods in Sudan.

Subject Areas

Environmental Sciences

Keywords

Climate Variability, Sorghum Yield, AquaCrop Model, Gedaref, Sudan, Rain-Fed Agriculture

1. Introduction

Agriculture remains central to Sudan's economy, employing most of the population and contributing nearly 40% to the national GDP [1]. Sorghum is one of the country's most important cereal crops, providing both food and income for rural households. In Gedaref State, sorghum dominates rain-fed farming systems that rely heavily on seasonal rainfall. However, increasing temperatures and rainfall variability in recent decades have threatened agricultural production [2] [3].

Studies from the Sahel and Horn of Africa regions have similarly shown that warming trends and erratic rainfall adversely affect crop yields [4]-[6]. Yet, few studies have quantified these effects for Gedaref. This study fills that gap by assessing long-term climate variability, examining its relationship with sorghum yield, and projecting future impacts using the AquaCrop model.

2. Materials and Methods

2.1. Study Area

Gedaref State is located in eastern Sudan between latitudes 13˚N - 15˚N and longitudes 33˚E - 36˚E. The area has a semi-arid climate with one rainy season (June-October), characterized by annual rainfall ranging from 500 to 800 mm, and mean temperatures between 25˚C and 35˚C. Soils are predominantly clay, supporting extensive sorghum cultivation under rain-fed systems. See **Figure 1**.

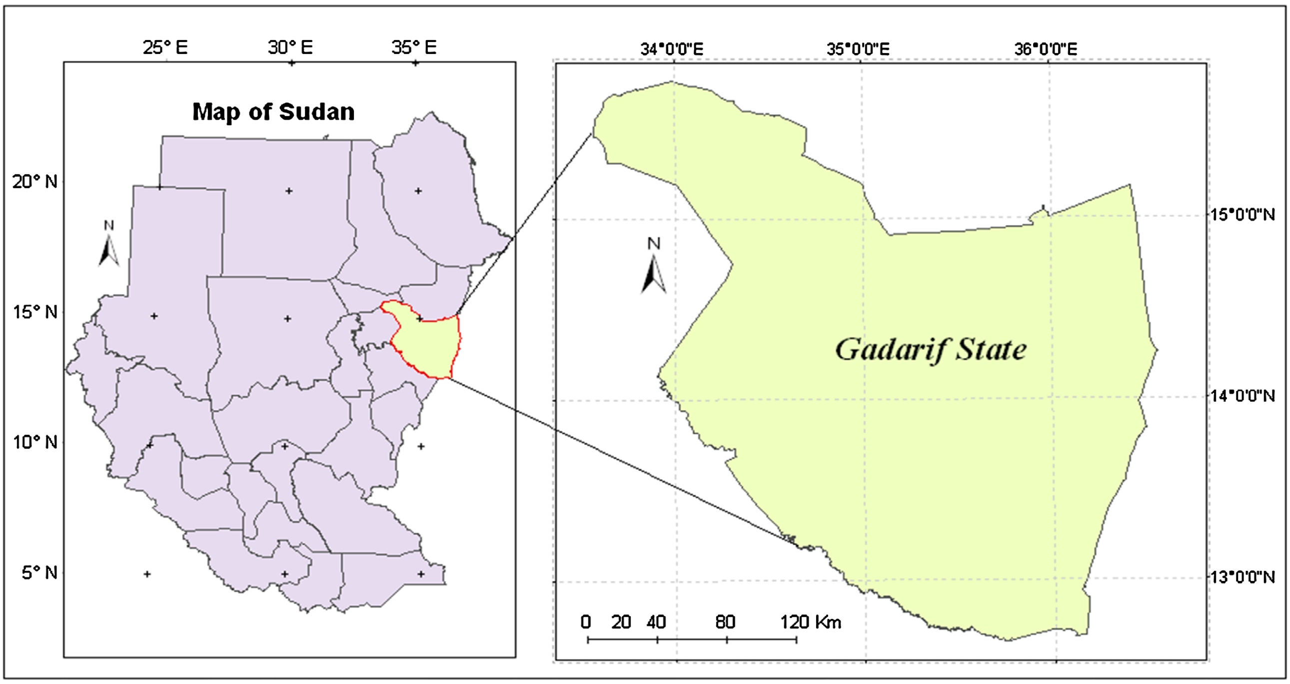

Figure 1. Map of Gedaref State, Sudan, showing the study area.

2.2. Data Sources

Monthly rainfall, maximum and minimum temperatures, and potential evapotranspiration (1961-2014) were obtained from the Sudan Meteorological Authority. Sorghum yield data (1970-2007) were obtained from the Ministry of Agriculture and Forests. Climate projections for 2017-2046 were derived from the NCC-

CORDEX regional model, driven by the HadGEM2-ES Global Climate Model (GCM) under the RCP 4.5 scenario, which represents a medium stabilization pathway.

2.3. Analytical Methods

Trends in temperature and rainfall were analyzed using the Mann-Kendall test and Sen's slope estimator. The coefficient of variation (CV) was used to assess interannual variability. Pearson correlation and multiple regression analyses determined the relationships between sorghum yield and climate variables. The FAO AquaCrop model [7] was used to simulate yield response under observed and projected climate conditions. The model was calibrated ($R^2 = 0.82$, RMSE = 0.41 t/ha) with historical yield data and validated through observed-simulated comparison.

3. Results and Discussion

3.1. Climate Trends

Both maximum and minimum temperatures and evapotranspiration increased significantly during the study period ($p < 0.001$). Rainfall showed high variability but a weak, statistically insignificant decline. These results are consistent with regional patterns of increasing temperature and rainfall variability observed across the Sahel and East Africa [3] [8]. See **Figure 2**.

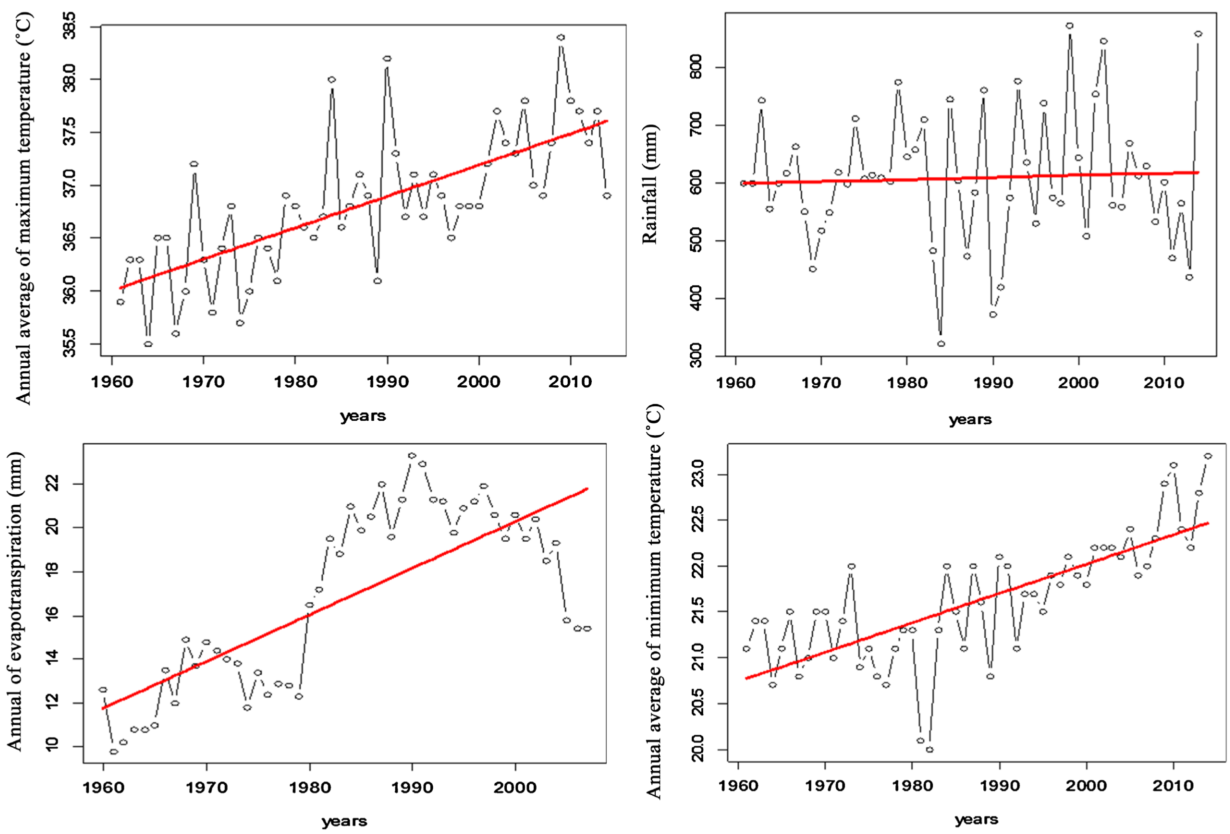

Figure 2. Historical data trend analysis of rainfall, evapotranspiration and temperature, Gadaref area (1961-2014).

3.2. Relationship between Climate and Sorghum Yield

Sorghum yield was positively correlated with rainfall (r = 0.59) and negatively correlated with maximum temperature (r = −0.34) and minimum temperature (r = −0.31), see Table 1. The multiple regression model indicated that climatic factors explained 30% of yield variability (p = 0.02). See Table 1.

Table 1. Correlation coefficients between sorghum yield and climatic variables.

Variables	Correlation Coefficient	T Calculated	T Tabulated	Relationship Description
Sorghum yield and rainfall	0.59	4.792	1.645	Significant
Sorghum yield and maximum temperature	−0.34	−2.371	1.645	Significant
Sorghum yield and minimum temperature	−0.31	−2.138	1.645	Significant
Sorghum yield and evapotranspiration	0.25	1.693	1.645	Significant

Rainfall remains the dominant factor determining yield variability in Gedaref. Reduced rainfall and increased temperature shorten the crop cycle and increase soil moisture stress. Physiologically, higher maximum temperatures during flowering can induce heat stress, reducing grain set, while higher minimum temperatures can increase nighttime respiration, reducing carbohydrate accumulation. Similar trends have been reported in other semi-arid regions of Sudan and East Africa [3] [5].

To contextualize the regression result (30% of explained variance), non-climatic factors such as soil fertility degradation, limited fertilizer use, pest infestations, and policy constraints likely account for much of the unexplained yield variability.

3.3. Projected Future Changes

AquaCrop simulations projected that by 2046, rainfall may decrease by 33% while temperatures rise by 2.4˚C (mainly driven by a significant increase in minimum temperatures) (see Table 2), resulting in an estimated 39.9% reduction in sorghum yield compared to the baseline period (see Figure 3).

Table 2. AquaCrop simulation results showing projected yield changes.

Variables	Average of Observed Data	Average of Future Data (2046)	Change	Percentage Change
Rainfall (mm)	612.43	409.97	−202.46	−33.0%
Maximum temperature (˚C)	36.71	36.73	+0.02	+0.05%
Minimum temperature (˚C)	21.36	23.75	+2.39	+11.2%
Sorghum yield (simulated)		—	↓	−39.9%

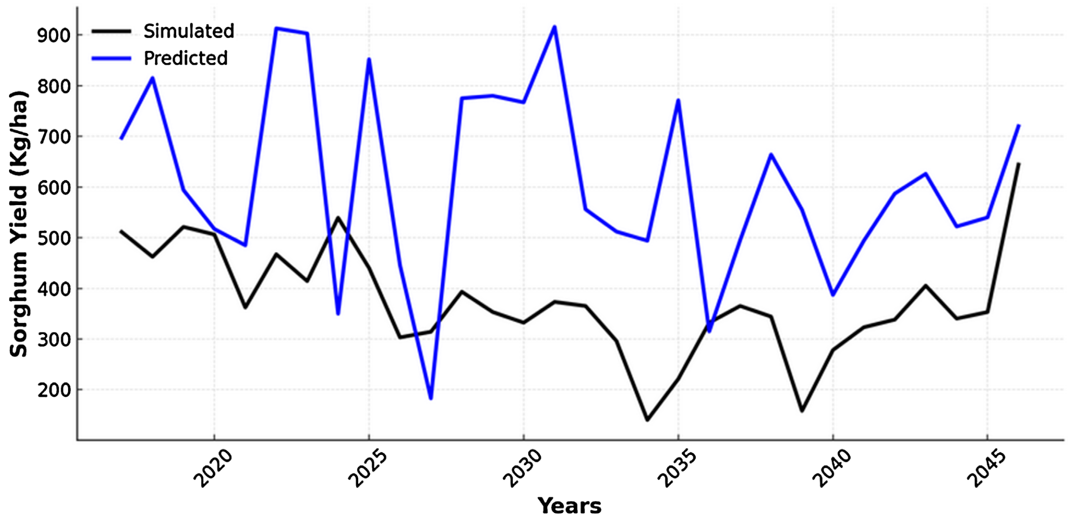

Figure 3. Simulated sorghum yield decline under future climate scenarios.

3.4. Policy Implications

The results of this study underline the urgent need for climate-resilient agricultural strategies in Gedaref State. Policymakers should prioritize:

- Promotion of drought-tolerant sorghum varieties and climate-smart farming practices.
- Investment in small-scale irrigation and water harvesting systems to reduce dependence on erratic rainfall.
- Enhancement of agricultural extension services and farmer capacity building on climate risk management.
- Integration of seasonal climate forecasting into local agricultural planning.
- Supportive policies that encourage sustainable soil management and access to inputs (fertilisers, seeds, technology).

These measures will help strengthen rural livelihoods and ensure food security under changing climate conditions.

4. Conclusion

This study demonstrates that climate variability—especially increased temperature and reduced rainfall—significantly influences sorghum yields in Gedaref State. Climate factors accounted for roughly one-third of observed yield variability. Future projections suggest potential yield declines of about 40% by mid-century, posing a major threat to food security. Policy responses should focus on promoting climate-smart agriculture, water conservation, and resilient crop varieties to sustain productivity in rain-fed systems.

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Author's Contribution

The author, Noah Adam Hudo, designed the study, collected and analyzed data, conducted modelling, interpreted results, and prepared the manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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