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**Research Article**

# 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 in Gadarif State. The study ultilized secondary data covering 1970-2014. The data analyzed using Bias Correction and Spatial Downscaling (BCSD) and Representative Concentration Pathways (RCPs). The important results that an increasing trend of temperature indicating the evidence of existance of climate change.The a drop in crop yield associated with an increase in maximum and minimum temperatures. There are two scenarios based on greenhouse gas concentration in the atmosphere during 2020-2100. The results of best scenario assumed an RCP of 2.6 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, and the results of worst one assumed an RCP of 8.5 predicted 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 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.



## INTRODUCTION

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 refereed 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.

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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 $CO_2$ in the atmosphere under changed climatic conditions might act as an aerial fertilizer and enhancs 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.

Rainfall supports the overwhelming majorty of agricultural activites in Sudan (Ministry of Enviroment and Physical Development, 2007) that constitute the main economic sector of the country. In 2010 about 80 % of labour force is employed in the rural areas (Robinson, 2011). Almost all of the cultivated land (92%) is under a rain-fed machanized and traditional system producing sorghum the primary staple food in the country (Ministry of Agriculture 2008). These features make rain-fed agriculture the core for food security production, and important source for the 8.8 million individuals, about 22% of 43 million Sudanese, suffering from undernourishment (FAO, 2011).

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$^{O}$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).

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).

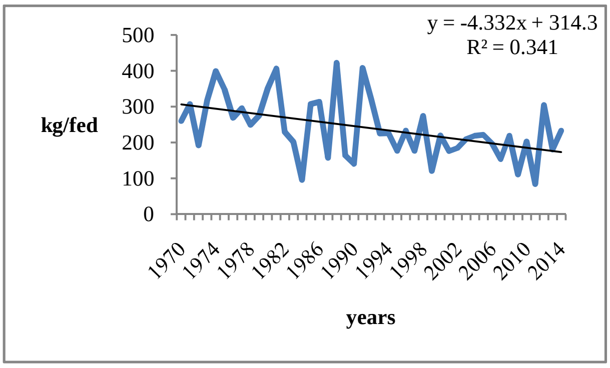


**Figure 1** The productivity of sorghum crop in Gadarif state during 1970-2014.
Source: Ministry of agriculture & Foresty, Gadarif State (2014).

## 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 21$^{st}$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 21$^{st}$ 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.

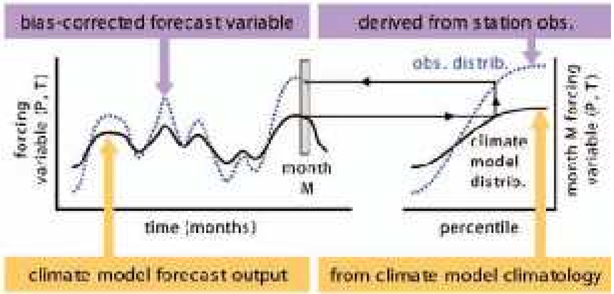


**Figure 2** Graphical representation of BCSD method

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 21$^{st}$ 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/m$^2$, respectively.

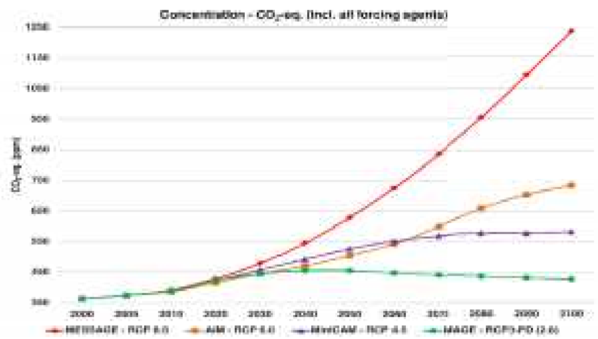


**Figure 3** Show all forcing agents' atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to four RCPs

## RESULTS OF STUDY

According to Table (1) and Figure (4) covered the period from 1941-2014. The obsrevation of the frequency distribution and increasing of rainfall at rate of 0.487 mm/year during the periods showed that during 1941-2014 ,the average of rainfall was about 600 mm. During 1971-1980 recorded the high average of rainfall was about 638.4 mm. 1981-1990 recorded high variation 26.5%, which indicated the fluctuation of rainfall. Table shows that the indictors of maximum and minumum rainfall had increased, espacially during the last ten yaers, which led to the dumping or flooding of the crops and drop in production. In general, indicate existance of an increasing trend of rainfall during those years in Gadarif State, with evidance of climate change.

Sorghum productivity trend analysis showed three distinct performance under three levels of rainfall. The relationship between sorghum yield and dry rainfall years indicated a decreasing trend at 4.9 kg/fed/year. This reflect considerable negative effect of rainfall quantities and distribution upon sorghum crop yields during dry period Figure (5).

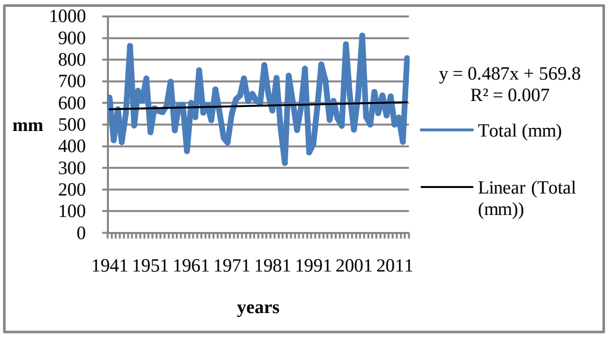


**Figure 4** Performance of rainfall (mm/year) in Gadarif State during 1941-2014

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

The relationship between sorghum yield and normal rainfall had also indicated a drop at 3.39 kg/fed/year Figure (6). The sharp drop in crop yield is even more during the wet rainfall seasons. From Figure (7) the drop took place at a rate of 11.37 kg/fed/year. In general, the decline in sorghum crop yield is influenced, in addition to rainfall performances, by other factors such as continued mono-cropping, and poor land prepartion due to land compactness.

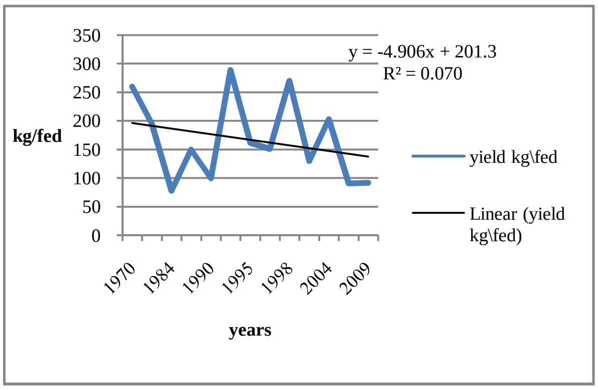


**Figure 5** The performance of sorghum yield in dry rainfall years in Gadarif State during 1970- 2014

Source: Sudan Meteorological Authority and Ministry of agriculture (Gadarif State)

***Prediction of rainfall in Gadarif State***

Both climate change scenarios RCP2.6 and RCP8.5 Figure (8) projected that, future rainfall trend of Gadarif State would be decreasing steadily at rates of 0.865 mm/year and 0.554 mm/year, resrpectively. The rate would be lower when using the RCP 8.5.However, the variability might be high with many extreme values which might be serious.

**Table 1** Statistical indicators of rainfall (mm) in Gadarif State during 1941-2014

| Item | 41-50 | 51-60 | 61-70 | 71-80 | 81-90 | 91-00 | 01-10 | 11-14 | 41-14 |
|---|---|---|---|---|---|---|---|---|---|
| Average (mm) | 593.4 | 547.5 | 562.4 | 638.4 | 560.2 | 612.5 | 606.2 | 564.9 | 587.4 |
| Std.Dev | 134.3 | 88.4 | 98.2 | 63.2 | 148.8 | 139.2 | 123.3 | 168.6 | 118.1 |
| Co.variation% | 22.6 | 16.1 | 17.5 | 9.9 | 26.5 | 22.7 | 20.3 | 29.8 | 20.1 |
| Max (mm) | 863.2 | 697.9 | 751.3 | 774.9 | 758.9 | 870.4 | 910.7 | 807.8 | 910.7 |
| Min (mm) | 418.1 | 377.3 | 417.8 | 549.1 | 322 | 410.1 | 476.5 | 420 | 322 |

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

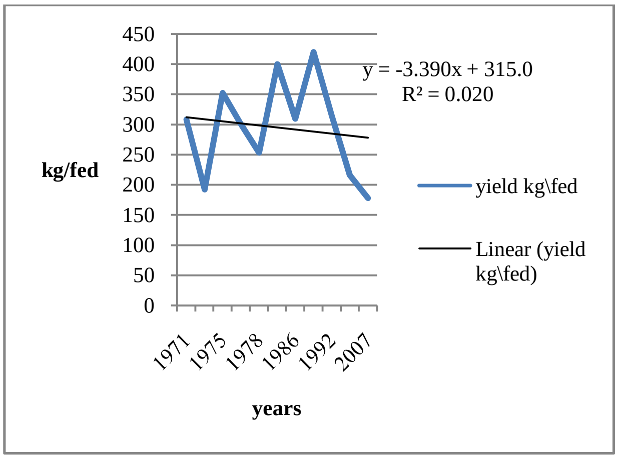


**Figure 6** The performance of sorghum yield in normal rainfall years in Gadarif State during 1970- 2014

Source: Sudan Meteorological Authority and Ministry of agriculture (Gadarif State)

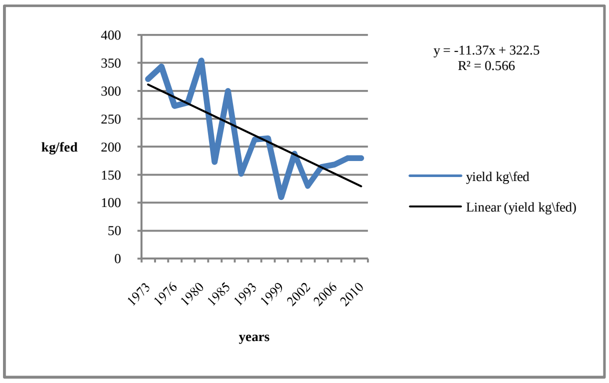


**Figure 7** The performance of sorghum yield in wet rainfall years in Gadarif State during 1970- 2014

Source: Sudan Meteorological Authority and Ministry of agriculture (Gadarif State)

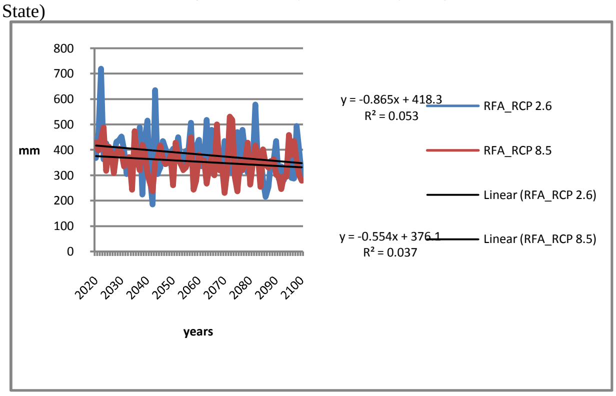


**Figure 8** Rainfall prediction using two scenarios RCP2.6 and RCP8.5 during 2020-2100 in Gadarif State

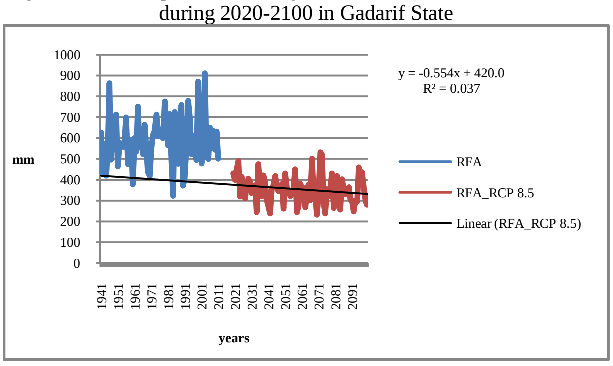


**Figure 9** Current and predicted rainfall during 1970-2014 and 2020-2100 using RCP 8.5 scenario in Gadarif State

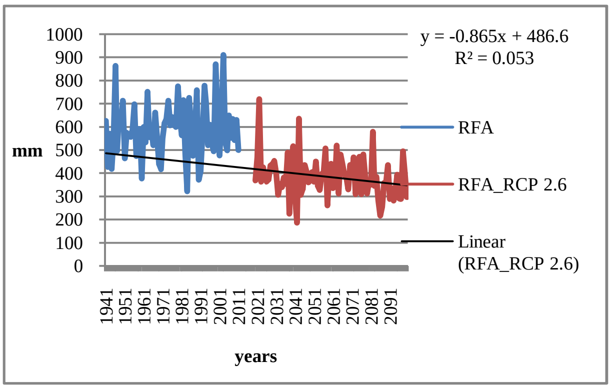


**Figure 10** Current and predicted rainfall during 1970-2014 and 2020-2100 using RCP 2.6 scenario in Gadarif State

Figure (9) and Figure (10), show different rainfall trend lines under RCP 2.6 and RCP 8.5.The trend of the actual rainfall recorded (1970 -2014) is increasing slightly, while that of the RCP2.6 future projected rainfall might be as lightly decreasing.

For RCP 8.5 trends of actual and predicted rainfall values are not following the same direction. The actual rainfall recorded from 1970 to 2014; has a slightly increasing trend, while the projected future rainfall would be a slightly decreasing.

***Prediction of yield in Gadarif State during 2020-2100***

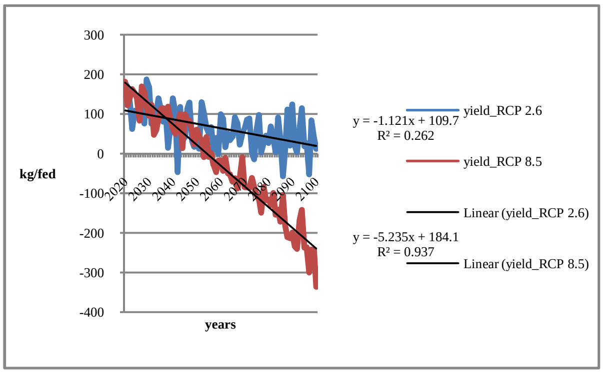


**Figure 11** Yield prediction according to maximum temperature as a predictor using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State

As can be seen from Figure (11), the predicted yield from RCP2.6 scenario 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.

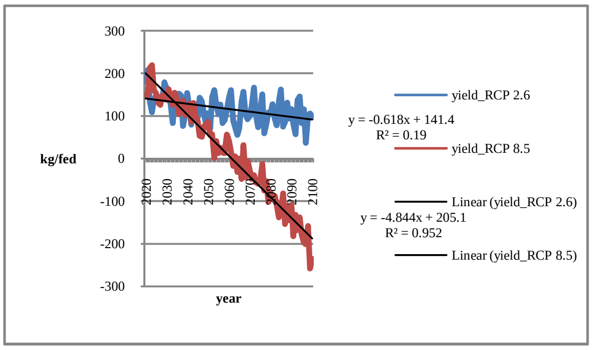


**Figure 12** Yield prediction according to minimum temperature as a predictor using two scenarios RCP 2.6 and RCP 8.5 during 2020-2100 in Gadarif State

The RCP8.5 scenario showed a dramatic downward yield trend at rate of -5.235 kg/fed/year with below normal yield starting around 2055.

Figure (12) 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.

## 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). 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 rainfall 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 rainfall is moving southwards, with recurrent droughts and flooding cycles. The data analysis in Gadarif region showed a continued increase in rainfall with fluctuations during 1940-2014. The concurrent decrease and fluctuations in sorghum productivity under rain fed system in Gadarif region may be caused by prevailing climate change and variability.

## CONCLUSION

The general trend of rainfall in Gadarif State revealed an incraesing pattern during 1941-2014. The dry and normal rainfall years were more favorable for keeping the level of sorghum crop yield more or less than the wet rainfall years. Increase greenhouse gas concentration in future lead to decrease rainfall and decrease productivity of sorghum in Gadarif State. This situation requires to introduce supplementary irrigation system and water harvesting to reduce the risks of inappropriate distribution of rainfall and enhance extension services to raise the awareness about green cover and uses to balance and conserve the environment for the present and future generation.

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