CLIMATE CHANGE IMPACT ON IRRIGATION WATER REQUIREMENT AND CROP WATER PRODUCTIVITY OF RICE

By

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THESIS

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Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Climate change is a universal process observed since ancient times and is expected to accelerate in the coming years (IPCC, 2021). Climate change severely threatens global food security, poverty alleviation, and sustainable development (Birkmann *et al.*, 2022). Agriculture is affected directly by changes in temperature, precipitation, and carbon dioxide concentrations, and indirectly by changes in soil moisture and water availability. Thus, agricultural productivity is vulnerable to climate change (Mendelsohn, 2014). Hence, a study was conducted to investigate the impacts of climate change on Irrigation Water Requirements (IWR) and Crop Water Productivity (CWP) of rice in Pattambi, Kerala.

The study analyzed observed climate data from 1991-2022 and future projected climate data from 2025-2095. The variability and trend of climate parameters were analyzed using descriptive statistics, the Mann-Kendall test, and Sen's slope estimator. The future climate projections, based on SSP2 4.5 and SSP5 8.5 scenarios, were sourced from four Global Climate Models (GCMs): MPI-ESM 1-2-HR, ACCESS-ESM 1-5, MPI-ESM 1-2-LR, and INM-CM-5-0. Among these, the model INM-CM 5-0 displayed good agreement with RMSE, R^2, SD, and MAE values in the acceptable range. The CROPWAT 8.0 model was used to find ET_o, ET_c, and irrigation requirements. The AquaCrop model was calibrated and validated for Viruppu and Mundakan rice, to simulate the yield. Irrigation requirements and water productivity of rice were estimated for the present and future periods. To mitigate the climate change impacts, two adaptation strategies were evaluated by the AquaCrop model for the rice crop.

The annual mean rainfall across the months showed significant variability, with the highest mean rainfall observed in July at 580.22 mm, followed by June (558.08 mm) and August (399.59 mm). The standard deviation (SD) and coefficient of variation (CV%) highlighted the variability in rainfall distribution, with the highest CV% seen in January (346.55%), February (166.07%), and March (131.47%), indicating extreme fluctuations during these months. In contrast, June had the lowest CV of 31.29%, indicating more consistent rainfall during the monsoon season. The maximum and minimum temperatures were relatively stable throughout the year. The highest variability in maximum temperature was observed in May, with a CV of 4.10%, while the lowest was in January, with a CV of 1.30%. For minimum temperature, the highest variability was in December (9.01%), and the lowest was in June (3.63%), demonstrating a more consistent temperature pattern compared to rainfall fluctuations. The trend analysis revealed, statistically significant increasing trends in both minimum and maximum temperatures, particularly for March and April, where the trends were significant at the 5% level. Similarly, rainfall exhibited marginally significant upward trends during April and September, with significance at the 10% level, indicating climate change impacts that may influence regional water resources and agricultural planning.

The impact studies using future climate data obtained from GCMs will not be operational without proper bias correction. Hence, the future downloaded data was bias-corrected by the linear scaling method for temperature, and power transformation for precipitation using the CMhyd tool. The application of bias correction significantly improved the accuracy of the INM-CM 5-0 climate model predictions for the study area. After bias correction, the RMSE and R^2 values for maximum temperature (2.45, 0.75), minimum temperature (1.50, 0.52), and rainfall (4.80, 0.85) were found acceptable, indicating a better alignment with observed data demonstrating an enhanced correlation between the model-derived and observed values.

The future climate projections for the study area indicated a significant rise in maximum and minimum temperatures and precipitation under SSP2 4.5 and SSP5 8.5 scenarios. By the 2030s, maximum temperatures (T_{max}) were expected to rise by 0.6°C and 0.66°C under SSP2 4.5 and SSP5 8.5, respectively, compared to the baseline of 32.29°C. By the 2050s, T_{max} was expected to increase by 0.84°C under SSP2 4.5 and 1.3°C under SSP5 8.5. The highest rise was expected during the 2080s, with T_{max} projected to reach 33.18°C (+0.89°C) under SSP2 4.5 and 34.26°C (+1.97°C) under SSP5 8.5. Similarly, minimum temperatures (T_{min}) were expected to rise by 0.57°C in the 2030s, 0.85°C in the 2050s, and by 1.2°C during the 2080s under SSP2 4.5. A higher increase under SSP5 8.5, where T_{min} was projected to rise by 0.67°C, 1.48°C, and 2.46°C by the 2030s, 2050s, and 2080s, respectively, compared to the baseline of 22.88°C. Precipitation was expected to increase significantly, particularly under SSP5 8.5, where precipitation was projected to rise by 96.19 mm in the 2030s, 159.3 mm in the 2050s, and 415.57 mm by the 2080s, compared to the baseline of 218.28 mm, indicating considerable variability in rainfall patterns in future climate projections.

Calibration and validation of the AquaCrop model showed good agreement between observed and simulated yields. For the Virippu season, the calibration and validation yielded RMSE of 0.3527, MAE of 0.069, CV of 13.97%, NSE of 0.99, and degree of agreement (d) of 0.984. For the Mundakan season, the same were 0.3728, 0.076, 10.26%, 0.97, and 0.74, respectively indicating the model's accuracy and reliability in simulating rice yield under different seasonal conditions.

Future projections of IWR indicated a remarkable rise in water demand both in the Virippu (1st crop) and Mundakan (2nd crop) seasons. For the Virippu season, the baseline IWR was 1029 mm. The projected IWR under SSP2 4.5 showed an increase of 37.99%, 34.02%, and 42.63% by 2035s, 2055s, and 2085s, respectively. Under SSP5 8.5, it was expected to increase by 30.84%, 12.78%, and 37.97% for 2035s, 2055s, and 2085s, respectively. For the Mundakan season, baseline IWR of 1322.4 mm was projected to increase by 2.78% for 2035s, 4.20% for 2055s, and 3.22% for 2085s under SSP2 4.5. Under SSP5 8.5, the IWR was expected to increase by 1.36%, 11.65%, and 4.21% for the same time horizon respectively.

Yield projections showed declines across all time periods. The Mundakan season, with a baseline yield of 4.06 *t*/ha, showed a reduction of -43.35%, -51.72%, and -60.59% by 2035s, 2055s, and 2085s, respectively, under SSP2 4.5 projections. Under SSP5 8.5, yields were projected to decrease by -5.42%, -34.73%, and -42.12% for the same period. The Virippu season, with a baseline yield of 3.05 *t*/ha, showed yield reductions of 66.56% by 2035s, 67.54% by 2055s, and 77.38% by 2085s under SSP2 4.5 projections. SSP5 8.5 showed declines of 68.52% by 2035s, 81.97% by 2055s, and 80.98% by 2085s.

Hence, CWP also showed significant declines in both seasons. The Mundakan season, with a baseline CWP of 10.70 *t*/m³, showed reductions of 50.91% by 2035s, 58.18% by 2055s, and 66.36% by 2085s under SSP2 4.5. Under SSP5 8.5, CWP is projected to decrease by 9.09% for 2035s, 43.64% for 2055s, and 46.36% for 2085s. The Virippu season, with a baseline CWP of 10.33 t/m³, showed reductions of 81.16%, 80.19%, and 87.92% by 2035s, 2055s, and 2085s, respectively, under SSP2 4.5. The SSP5 8.5 projections showed declines of 83.09%, 87.92%, and 90.82% by 2035s, 2055s, and 2085s, respectively. These findings suggested that adaptation strategies, such as improved irrigation management, adjusting the planting date, water conservation practices, and adopting climate-resilient rice varieties, etc. will be essential to cope up with increasing water demands and declining crop water productivity in the future.

To mitigate the climate change impacts, two adaptation strategies were evaluated by the AquaCrop model for the rice crop. The first strategy involved shifting the transplanting dates by +/- 30 days in 10-day intervals. For the Virippu season, the original transplanting date of May 1st was adjusted, while for the Mundakan season, November 1st was modified. Adopting early transplanting dates, particularly on April 21st, in Virippu season would help to increase yields by 16.5% and 45.2% under both SSP2 4.5 and SSP5 8.5 scenarios of 2035s and reduce irrigation water requirements by 2.5 and 4.5%, while late transplanting in Virippu should be avoided due to significant yield reduction (9.8- 14.4%). During the Mundakan season, transplanting dates on Oct 12th, Nov 11th, and Nov 21st were found optimal due to increased yield (2- 9.8%) for 2035s, 2055s, and 2085s respectively. The second adaptation measure focused on changing irrigation methods from conventional practices to drip systems. Adopting drip irrigation resulted in a yield increase across all projected periods, though the yield increments were modest, ranging from 1.2 to 2.5%, depending on the scenario and time frame. For instance, under SSP2 4.5, yield increase was 2%, 1.5%, and 1.2% respectively for 2035s, 2055s, and 2085s. Under the SSP5 8.5 scenario, slightly higher yield gains of 2.5%, 2%, and 1.8% were observed for the same time periods. Though the yield increases from drip irrigation were not so large, the water savings potential of the drip system is substantial. These measures improved water use efficiency, supported sustainable rice cultivation, and enhanced resilience against future climate variability, particularly in the Pattambi region.

Hence the study concluded that:

1. Maximum and minimum temperatures, as well as rainfall, are expected to increase under SSP2 4.5 (+89°C, +1.2°C and +214.23cm) and SSP5 8.5 (+1.97 °C, +2.46 °C and +699.9cm) scenarios, with minimum temperatures rising more than the maximum temperatures.
2. Irrigation water requirements of rice are expected to increase for both Virippu (+42.63%) and Mundakan (11.65%) seasons under future climate scenarios, leading to reduced rice yields, particularly in Virippu (-81.97%) season, which will result in a decline in CWP (-90.82%) for both seasons, especially under SSP5 8.5.
3. Early transplanting dates, particularly around April 21st, will help to increase yields (+45.2%) and reduce irrigation water requirements (-1.48), while late transplanting should be avoided due to significant yield reduction (- 33.1%) in Virippu.
4. During the Mundakan season, transplanting dates on Oct 12th, Nov 11th, and Nov 21st were found optimal (increase in yield +9.8- 16.1%) for 2035s, 2055s, and 2085s, respectively.
5. Drip irrigation reduced water use by 20% and improved rice yields by 2.5%, enhancing crop water productivity and crop resilience under future climate conditions in both seasons
6. Hence, it is recommended to integrate water management strategies with drip irrigation to combat the adverse effects of climate change on rice.

Recommendations for Farmers

- Advancing rice transplanting from May 1st to April 21st boosts yield during Virippu, while shifting from Nov 1st to October 12th during 2035s and then to November 11th and 21st during 2055s and 2085s, respectively, enhances Mundakan yield under future climate scenarios.

- Adopting drip irrigation to the extent possible for rice is expected to enhance water use efficiency and grain yield and conserve water, supporting sustainable production under future climate scenarios.

Recommendations for Researchers

- Future studies should incorporate additional Global Climate Models (GCMs) and Regional Climate Models (RCMs) to evaluate a wider range of climate projections
- Researchers should explore additional bias correction methods to improve climate data accuracy and better predict irrigation water requirements and crop water productivity under future scenarios
- This study should also be extended to different rice-growing regions and expanded to include a variety of crops to ensure the findings apply to broader agricultural systems
- Future research should optimize drip and sprinkler irrigation under various climate scenarios and assess their efficiency across different crops and soils for greater water savings