Abstract

Over the past decade, global greenhouse gas emissions have reached record highs, threatening water, food, and energy security. Rising temperatures, uncertain precipitation patterns, and increased extreme events jeopardize water availability and food productivity. The 2015 Paris Agreement set an ambitious target to limit the global temperature increase to well below 2°C, with an ideal goal of 1.5°C compared to pre-industrial levels. Achieving this requires understanding regional climate change impacts, as responses vary based on local climatic, ecological, and social factors. Developing regions like India and Africa are especially vulnerable due to high populations, dependence on climate-sensitive sectors, and limited adaptive capacity. Within countries, climate change responses also differ, with Central India, for example, being more vulnerable than other regions.

The Mahanadi Basin in Chhattisgarh, a major rice-growing area in Central India, faces significant risks from climate change due to its reliance on rainfed agriculture and lack of irrigation infrastructure, with 80% of the population dependent on this sector. Understanding regional climate change impacts is crucial for food security in such areas. Most existing impact studies use process-based simulations with General Circulation Models (GCMs), but this approach is associated with several challenges and is highly uncertain. This is because most of the studies are based on limited and low-resolution regional information, earlier Coupled Model Inter-comparison Project Phase (CMIP) versions, and inappropriate selection of GCMs that fail to represent the physical processes and lead to large uncertainties. Additionally, the standard uncertainty reducing approaches, like bias adjustment and historically constrained inputs, are based on the assumption of stationarity, which is not valid under non-stationary climate conditions, leading to unreliable hydrological projections. Recent studies suggest that specific global warming-based assessments, such as 1.5ºC, may reduce regional projection uncertainties. However, the regional responses to such warming levels remain unclear, and no studies have yet provided a comprehensive assessment of the impacts on critical agricultural systems at a specific global warming level.

This research focuses on the challenges and uncertainties of regional climate-impact studies and provides a comprehensive analysis of the climate-hydrology-agriculture-economic responses to a 1.5°C global warming scenario in the Mahanadi Basin of Chhattisgarh. The study begins with an evaluation of 29 CMIP6 climate models for their ability to represent regional

monsoon characteristics and extreme climate indices critical for rice productivity. Eight models with significant biases were discarded and the remaining 21 models were used as an input in the agro-hydrological Soil and Water Assessment Tool (SWAT) model for future hydrological and agricultural simulations. The SWAT model was calibrated and validated using multisource datasets, demonstrating satisfactory performance.

The research then investigates the propagation of climate biases from global-scale climate variables to regional hydrological projections, highlighting non-stationary biases that challenge the reliability of regional projections. It emphasizes that commonly used uncertainty reducing approaches might not be feasible, particularly under extreme scenarios. Under such circumstances, impact assessments based on specific global warming levels (e.g., 1.5°C) are essential for reliable regional projections.

The study then evaluates the impact of 1.5°C global warming on critical climate and hydrological variables (e.g., precipitation, temperatures, surface runoff) as well as water availability for rainfed (green water) and irrigated (blue water) agriculture. Results suggest significant regional uncertainties, with reductions in precipitation, runoff, green water, and blue water by 5-15%, 10-35%, 12-1%, and 40-10%, respectively. The decrease in blue water is more pronounced than green water, stressing the need to improve rainfed rice productivity and irrigation efficiency.

Furthermore, the implications of 1.5°C global warming on rice yield were analyzed for two emission scenarios (SSP2-4.5 and SSP5-8.5), using SWAT-based simulations for both rainfed and irrigated conditions. The findings show that rice yields under rainfed conditions may change by -15% to -2% (SSP2-4.5) and -15% to +2% (SSP5-8.5), while irrigated yields could change by 1% to 9% (SSP2-4.5) and -2% to 8% (SSP5-8.5). Economic losses due to these yield changes were also estimated, with water stress and flash droughts playing a dominant role under SSP2-4.5, while heat stress and rising night temperatures were more significant under SSP5-8.5.

This study highlights the vulnerability of the region to water scarcity and productivity losses under 1.5°C of warming and emphasizes the urgency of developing adaptive strategies. It also provides a framework for understanding the complex interactions between climate, hydrology, agriculture, and economics in a 1.5°C warmer world.