Abstract

Managing water resources effectively and maintaining environmental flows in rivers are essential for mitigating climate change and anthropogenic impacts on river ecosystems. With limited studies in this direction, this study was carried out in the Rushikulya River Basin (~7013 km²), located in Eastern India. Firstly, the surface water resources were assessed using the SWAT model while the groundwater resources were estimated separately using Central Ground Water Board guidelines. The SWAT model was calibrated and validated with observed streamflow (2000–2016). The model was employed to analyze spatiotemporal variations in water balance components and assess climate change impacts under Shared Socioeconomic Pathways (SSP 245 and SSP 585) scenarios for the near-future (2025–2041) and mid-future (2042–2058) periods. Additionally, the environmental flow (e-flow) of the data-scarce and regulated river reaches was estimated using a framework integrating hydrological modeling with optimization models with subsequent evaluations of the ecological flow sustainability. Finally, a multi-objective optimization (MOO) model was developed to find tradeoffs between maximizing agricultural profit and minimizing unmet water demands across all sectors which was solved by Non-dominated Sorting Genetic Algorithm-II (NSGA-II) for a 'normal' year. The MOO was also solved under the above four 'future climate change' and three 'irrigation management' scenarios: Alternate Wetting and Drying (AWD), Sprinklers, and a combination of AWD and Sprinklers. Analysis of the results indicates that the annual surface runoff, water yield, baseflow, and potential groundwater recharge exhibit higher fluctuations (CV: 30-40%) than the annual soil moisture and evapotranspiration (CV: 3-5%). Future climate projections indicate changes in annual rainfall (1.04–1.06 times increase; 0.96 times decrease under SSP 245) and annual temperature (1–3°C rise). Streamflow will decline annually by 0.80–0.95 times, with 1.01–5.39 times increases in winter and early monsoon, and 0.03–0.87 times reductions during summer and monsoon. Groundwater resources vary significantly, with Dynamic Groundwater Reserves (DGWR) ranging from 16.64–104.32 MCM and Static Groundwater Reserves (SGWR) from 0.001–239.22 MCM. The pre-impact streamflow revealed significant hydrologic alterations with a 35–50% decline in post-impact streamflow and 2-3 times reduced flow peaks. Further, the future climate scenarios revealed frequent EFE violations with lower resilience of the altered river reaches. The multi-objective optimization modeling results show that in 'normal' year, net profits range from Rs. 12.34 to 2.50 billion, with unmet demand fractions ranging from 6.9 to 9.5. Future climate change scenarios increase unmet demand by 20-72%, with marginal changes in net profit (±1%). Adopting efficient irrigation practices can enhance net agricultural profit by 1-17% and reduce unmet water demands by 3-41%. The findings of this study can be useful for policymakers and water managers for optimal resource allocation as well as for mitigating human-induced detrimental impacts on the riverine ecosystem.

Keywords: *Water resources availability; SWAT; Dynamic groundwater reserve; Environmental flow; Environmental flow envelope; Multi-objective optimization model; Non-dominated sorting genetic algorithm; Climate change scenarios; Shared socio-economic pathways; Water management scenarios; Regulated river basin; Rushikulya river basin.*