Abstract

Rainfed agriculture plays a vital role in providing food and livelihoods globally. However, its production is adversely affected due to uncertainty in rainfall patterns which is increasing under the impact of climate change. Supplemental irrigation helps minimization of risk thus stabilizes the crop yield. Given that rice is a primarily grown crop in rainfed conditions and is the staple food of half the global population, it is under the pressure of increasing production due to the burgeoning population globally. Therefore, proper farming management such as balanced fertilization practices, irrigation etc are required. On the other hand, monocropping of cereal is a growing phenomenon among the farmers, due to known yield, reduced investment, prior knowledge of the activity calendar, insufficient irrigation and lower market risk resulting in a rice-fallow cultivation system. However, the introduction of pulses, oilseeds and vegetable crops during the fallow season is the key to providing better nutrition and improving household food security. Thus, irrigation water management is required for maximizing yield of these crops during the fallow season.

Climate change impact on global water resources varies spatially and temporally. Besides, many basins encounter difficulties in hydrological modeling due to limited information of hydro-climatological variables and their location specific unique hydrological pattern. Understanding the nutrient balance process and climate change impact in a rice-fallow cropping system is paramount for sustainable crop intensification in fallow lands of rain-shadowed areas. This study proposes a chance-constrained optimization model for optimal crop area planning of rabi crops for maximizing benefit considering the constraints of irrigation water availability, environmental flow requirement (EFR), farmers' choice, local food demand and the availability of residual soil nutrient after rice harvesting. The model is named as Irrigation-Food-Environment-EFR-Chance Constraint Programming (IFEC) model. Further, various modeling concepts and Artificial Neural Network (ANN) are devised for understanding climate change response to hydrological regime and crop water demand in such areas with potential socio-economic, demographic, and geographical factors. Performance of three temperature-based ET_0 (TET) models, namely FAO Penman Monteith, Blaney Criddle, Thornthwaite and Modified Penman was evaluated by comparing the result with the available Pan evaporation data of the study area and the model performing best was identified for estimating future seasonal irrigation demand under climate change. A Multilinear Regression (MLR) model was developed for future temperature projections using predictors from 3 GCM models. The model was calibrated using historical data and applied to forecast water demand for RCP Scenarios. Downscaling of precipitation by similar model was found to perform poorly in the study basin, as the basin is in a rain-shadowed area with complex topography. Therefore, a hybrid ANN model was established to identify and quantify the impacts of climate change on streamflow. For that, we identified two sets of potential predictors using Iterative Input Selection (IIS) by regression for ANN-Back Propagating model. The method directly regresses observed streamflow value based on the GCM variables without downscaling precipitation and temperature.

These modeling concepts were then applied to the rain-shadowed river basin Jamuna and its associated canal command area. Jamuna is a sub-tributary of Brahmaputra River, which is experiencing severe land degradation due to fallow agricultural lands. Thirteen villages were selected for soil and plant sample collection along with interviewing the farmers of corresponding villages about the farming practices. Rice-fallow and minimal irrigation water availability are the two major agricultural related concerns affecting crop diversification in the command area. Crop diversification not only leads to enhanced food security but also reduces crop water use as compared to single cropping of water-intensive cereal crops such as rice and wheat. Also, farmers' choice of summer rice cultivation indicated that area under this crop can be set to a specific percentage rather than cultivating the whole area to optimize water consumption. Simultaneously, crop area under vegetable crops can be increased to maximize farmer's profit. Further, to assess the stability of planned crop diversification, study was conducted for climate change impact analysis on the watershed hydrology and crop water demand for future period (2025-2100) as compared to the base period (2000-2012) along with demographic growth in the area. Findings suggested that, the demand of irrigation water in the command area increased up to 1% by the end of 21^{st} century. Annual average flow rate has been found to vary with time and scenarios. Maximum increase of as high as 33% is observed towards end of 21^{st} century. On the other hand, for some other scenarios, the flow rate decreases by 4% in mid future. Therefore, irrigation infrastructures and cropping plan need to be planned dynamically and in a more flexible manner to address such possible variation in future. The percentage change in winter flow rate is projected to increase as compared to the base period. This is a positive indication towards scope of enhancing winter crop. This, emphasizes the need for change in infrastructure along with irrigated area expansion associated with crop diversification under growing population. This type of future scenarios of crop water demand and hydrological changes projected by using future climate change scenarios and, demographic

conditions derived from the master plan of an irrigation project provide an opportunity to re-evaluate the irrigation project plan. Several adaptive strategies has also been suggested for increasing the efficiency of agricultural water use inside the command area. In addition, there is also a need for increasing yield per unit area of fallow lands by introducing higher crop yield variety. Also, rice planting period should be advanced by one month (June to September) to avail the maximum water availability in the river. The present situation of food production in eastern India is not sufficient, as they cannot fulfil the required food demand for people residing and depends on exported food. The continued use of amount of water from the current water utilization systems and cultivation practices, argues for an urgent need to shift towards scientific solutions that would then be seen as a rational approach to decision-making on a pragmatic evaluation of alternatives available. Finally, to obtain a sustainable irrigation planning, prevent phosphorus depletion and to limit nitrogen pollution within a permissible limit, the optimal crop area is planned considering the nutrient residues in soil after rice harvest.

The study has revealed that, optimal utilization of land, water and fertilizer in agricultural field not only help enhancing food production, but also help in sustainable use of water and land resources. In the context of climate change, sustainable use of water resources is extremely important. Faster rate of population growth in general demands crop intensification and this study has shown how proper crop area planning can enhance food security. Therefore, concerned authority should take steps to popularize such approaches of optimal crop planning through field implementation to realize real benefit of such study. Stakeholder engagement is crucial for bringing technically and socioeconomically feasible policies and regulations in the firm to achieve balanced water consumption per available water resources.