ABSTRACT

Ever-growing population, rapid industrialization and urbanization, and large-scale mismanagement of water resources have resulted in the escalation of water scarcity and environmental problems worldwide. The agricultural sector is the largest consumer of freshwater resources across the world including India and additional freshwater supply will be needed to fulfill the enhanced food requirements in coming decades. Formulation of robust land and water management strategies is a daunting task under data scarcity and uncertain future conditions. Thus, sustainable management of both surface water and groundwater resources is one of the greatest challenges faced across the globe in the 21st century, especially developing countries (including India). In India, studies on conjunctive use of surface water and groundwater resources are very limited. The Damodar Canal Command is one of the most important agricultural regions in West Bengal, Eastern India and it experiences acute water scarcity during dry seasons for both domestic and agricultural purposes. In this study, the Damodar Canal Command (7470 km^2) was selected as study area with an overall goal of developing a conjunctive use plan for the sustainable management of irrigation water and land resources. To date, no scientific studies on conjunctive use of surface water and groundwater has been carried out in the study area. To achieve the goal, statistical analyses (including trend analysis) of pertinent hydro-meteorological data of 35 years (1979-1013) for 14 weather stations were carried out. Spatio-temporal analysis of water demand and supply under different climatic conditions was investigated at a block level using 2004-2013 data. Further, the assessment of groundwater potential was carried out following an integrated geospatial and Multi-Criteria Decision Analysis (MCDA) approach. Using selected thematic layers and GIS-based MCDA techniques (Analytic Hierarchy Process and Catastrophe theory), groundwater potential zones in the study area were delineated, and the results were validated using a novel approach. A scientifically sound methodology to assess rainwater harvesting potential as well as to identify suitable sites for rainwater harvesting and recharge structures using AHP (Analytic Hierarchy Process) and MCDA techniques is also presented in this study. Finally, conjunctive use plans were developed taking into account spatial variability of irrigation water supply for two scenarios (‘normal’ and ‘dry’ climatic conditions) using optimization modeling. A linear programming (LP) model with an objective function of maximizing net benefits and suitable constraints was developed. The developed LP model was solved using Lingo optimization software for the optimal allocation of land and water resources under varying climatic conditions.

The analysis of three trend detection tests indicated that the annual rainfall time series of Burdwan-I and Mejhia stations have a significant increasing trend at the rate of 18.98 and 20.61 mm $year^{-1}$, respectively. Significant decreasing trends (-0.022 to -0.064 °C $year^{-1}$) were found in the T_{max} time series for the months of July (13 stations), September (13 stations), October (11 stations) and November (5 stations), whereas significant increasing trends (0.023 to 0.03 °C $year^{-1}$), were found in the T_{min} series for the month of May at most of the weather stations. Based on the variability of mean annual water supply, the study area was categorized as (a) 'very low' (covering 14% of the study area), (b) 'low' (18%), (c) 'moderate' (23%), (d) 'high' (20%), and (e) 'very high' (25%). On the other hand, based on the variability of mean crop irrigation requirement, the area was categorized as (a) 'very low' (3% of the study area), (b) 'low' (10%), (c) 'medium' (17%), (d) 'high' (7%), and (e) 'very high' (63%). The Dynamic Groundwater Reserve in the study area during 2004-2013 varies from 4117 MCM in 2006 to 6469 MCM in 2013, with a coefficient of variation of 15%.

The performance of the AHP technique for assessing groundwater prospect was found superior (prediction accuracy = 82%) to the Catastrophe technique. Considering the groundwater potential yielded by the AHP technique, the study area can be divided into four zones: (a) 'very good' (covering 19% of the study area), (b) 'good' (49%), (c) 'moderate' (28%), and (d) 'poor' (4%). Moreover, the study area can be categorized into four classes/zones of rainwater harvesting (RWH) potential. 'High' rainwater harvesting potential zone covers the maximum area (47% of the total area). The zones of 'moderate', and 'very high' RWH potential cover 38 and 8% respectively, while the 'poor' RWH potential zone covers 7% of the study area. The zones suitable for the construction of farm ponds encompass an area of 2314 km^2, whereas about 42 km^2 area is suitable for the construction of percolation tanks on the ground. In addition, 69 percolation tanks and 33 check dams along the streams are identified for artificial recharge of groundwater. The results of optimization modeling indicated that it is possible to obtain the net benefit of Rs. 24818.00 million during 'normal' years and Rs. 14679.00 million during 'dry' years due to the efficient allocation of land and available irrigation water resources to the existing cropping pattern. If the available Dynamic Groundwater Reserve is fully utilized for irrigation, these net benefits can be increased by 197% in 'normal' years and 267% in 'dry' years. Based on the results of this study, efficient management strategies could be formulated by the concerned planners/decision makers and practicing engineers to ensure sustainable management of land and irrigation water resources in the canal command, which in turn can ensure sustainable agricultural production and water security.

Keywords: *Hydro-meteorological variability; Irrigation water supply; Crop water demand; Water deficit; Dynamic groundwater reserve; Geospatial techniques; Multi-criteria decision analysis; Analytic Hierarchy Process; Catastrophe theory; Groundwater potential mapping; Rainwater harvesting; Artificial recharge; Conjunctive use planning; Optimization modeling; Canal command.*