ABSTRACT

Fresh groundwater resources in coastal regions are increasingly threatened by heavy pumping and increasing pollution. The contamination of groundwater by seawater intrusion is a well-known concern in most coastal aquifers of the world, which has severe impacts on the coastal people and their economy. Considering sustainable groundwater management in coastal areas, the present study was conceived to carry out comprehensive investigations of coastal aquifers of Purba Medinipur District, West Bengal, and Baleshwar District, Odisha. To date, no scientific studies have been conducted in this study area concerning the management of coastal groundwater resources. In this study, analyses of hydrologic, hydrogeologic, and geochemical data, numerical modeling of groundwater flow and solute transport (seawater intrusion) as well as the optimization of water and land resources were carried out to understand coastal groundwater dynamics and develop an optimal management plan for sustainable utilization of coastal land and water resources in the study area. The rainfall data for 37 years (1983–2019) were analyzed to identify ‘Wet’, ‘Normal’, and ‘Dry’ years. The spatio-temporal variations of monthly and annual rainfalls were analyzed to explore rainfall characteristics in the study area. The spatial and temporal variability of pre-monsoon and post-monsoon groundwater levels and trends in the seasonal groundwater levels were analyzed using the groundwater-level data of 2001–2019. The results of the trend analysis indicated that the groundwater level of Aquifer-1 is decreasing at the rates of 0.18–0.60 m/year in the pre-monsoon season and 0.17–0.60 m/year in the post-monsoon season, while the groundwater level of Aquifer-2 is decreasing at the rates of 0.25–1.07 m/year (pre-monsoon season) and 0.17−0.64 m/year (post-monsoon season). The analysis of stratigraphy revealed that there is a semi-permeable (leaky) confining layer at the top, which consists of ‘clayey sand’ and exists at 20–75 m depth. Thereafter, there exists a Leaky Confined Aquifer (Aquifer-1) at 20–175 m depth which is underlain by a Confined Aquifer (Aquifer-2). The Leaky Confined Aquifer is bounded by a semi-permeable (leaky) confining layer at 20–75 m depth at the top and an impermeable layer at the bottom (50–225 m depth). The second aquifer (Aquifer-2) that exists at 100–300 m depth is sandwiched between two impermeable layers. The results of the geochemical analyses indicated that although greater values (2.81–4.28) of the Seawater Mixing Index were observed in the groundwater of Aquifer-1, both Aquifer-1 (entire study area) and Aquifer-2 (north-eastern part only) are vulnerable to seawater mixing with the groundwater. The Cl^- (Chloride) and TDS (Total Dissolved Solids) concentrations in Aquifer-1, a measure of groundwater salinity, have remarkable spatial and temporal variations during pre-monsoon and post-monsoon seasons.

Moreover, a groundwater flow and solute transport simulation model for the study area was designed and developed using SEAWAT code to analyze seawater intrusion dynamics in the two-layered coastal aquifer system. The designed model was calibrated using groundwater-level and TDS concentration data from 45 observation wells over the study area for the period November 2012 to November 2017 and validated using the data from November 2017 to November 2019. Thereafter, the sensitivity analysis of the developed model was carried out, and the response of the aquifers to salient future scenarios was simulated. The simulated post-monsoon (November 2017) groundwater levels of Aquifer-1 indicated that the groundwater levels are 1 to 2 m lower in the northern part as compared to the central and southern parts of the study area, whereas the TDS concentrations in the north-western and central parts are 700−1000 mg/L and 600 mg/L in the southern part. For Aquifer-2, the simulated post-monsoon (November 2017) groundwater levels revealed that the groundwater levels are 3 to 4 m lower in the northern part of the study area as compared to the southern part, while the TDS concentrations in the north-western and central parts are 750−900 mg/L, and 300 mg/L in the southern part. The long-term simulation results indicated that if the existing hydro-climatic conditions and groundwater abstraction levels continue up to 2029, there will be a significant groundwater decline resulting in an increase in the groundwater salinity of Aquifer-1 and Aquifer-2 in most parts of the study area. The simulation results of the expected sea-level rise in the future revealed that the post-monsoon groundwater level will rise by 0.34−1.24 m (Aquifer-1) and 0.8−9.93 m (Aquifer-2) by November 2045 as compared to November 2019. In addition, by November 2045, the TDS concentration in the groundwater will increase by 23−228 mg/L (Aquifer-1) and 47−1509 mg/L (Aquifer-2) during the post-monsoon season due to the enhanced landward movement of seawater. Finally, an optimization model was developed for the study area to determine optimal cropping patterns, optimal allocation of land and water resources, and the net annual income during 'Normal' and 'Dry' years. The optimization model was solved by using Particle Swarm Optimization (PSO) technique for 'Normal' and 'Dry' years. Based on the optimal cropping patterns and optimal water allocation, the net annual income during the 'Normal' years is estimated at Rs. 557.50 million compared to the current profit of Rs. 461.12 million. On the other hand, the net annual income during the 'Dry' years is estimated at Rs. 597.14 million compared to the current profit of Rs.128.49 million.

The seawater intrusion model developed for the study area can be replicated in other coastal areas in India to combat the obnoxious salinity problem due to seawater intrusion into coastal aquifer systems. The developed seawater intrusion model linked with socio-economic parameters can be helpful in the long-term planning and management of coastal water resources in general and groundwater in particular. Based on the findings of this study, it is recommended that the concerned decision-makers should formulate efficient groundwater management strategies for the study area so as to ensure the long-term sustainability of this vital resource and agricultural production under looming climate change and increasing socio-economic changes.

Keywords: *Coastal groundwater, Hydrogeologic investigation, Trend analysis, Stratigraphy analysis, Geochemical evaluation, Seawater-Mixing Indices (SMI), Leaky Confined Aquifer, Confined Aquifer, Groundwater flow modeling, Seawater intrusion modeling, SEAWAT, Optimization modeling, Particle Swarm Optimization (PSO), Net annual income, Irrigated agriculture, Coastal basin.*