Optimal water utilization policy with sustainable aquifer approach with simulation and decentralized optimization

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Abstract

Nowadays, providing optimum solutions to water resources exploitation problems has become one of the major concerns of decision makers. In this study, a multi-objective model was developed for coupled surface and groundwater resources allocation considering different interactive scenarios between stakeholders and ecosystem. The general algorithm for water resources allocation was based on an optimization model coupled with environmental-agricultural model. The optimization approach reduced the irrigation water allocation to 78%. While the 7% reduction was allocated to meet the aquifer and agricultural demands of the study area, the cultivation cost was raised by only ~1.3%.

Keywords: groundwater, stakeholders, ecosystem, optimization.

1- Introduction

Nowadays, due to severe environmental consequences of water demands, optimum approaches incorporating coupled quantitative and qualitative aspects of water resources must be adopted. (Chandio et al. 2012). Conjunctive surface and groundwater models for proper allocation of water resources are becoming popular. Previous studies on water resource exploitation generally fall into nine categories: optimization for conjunctive exploitation planning, groundwater management, seawater penetration management, irrigation management, optimal cropping pattern, reservoir operation, resource management in arid and semiarid regions, solid waste management and other uses such as hydropower generation and sugar industry (Singh, 2014). Therefore, there is lack of large-scale conjunctive-use optimization models contemplating economic details and parameters. Furthermore, there are a limited number of studies on groundwater resource exploitation in aquifers with severe negative water balance. Chen et al. (2016) studied groundwater in Yinchuan Plain, China, where groundwater is a vital resource for agriculture, industry, economic, and social development.

Marques et al. (2018) developed a four-objective optimization model to design flexible water distribution networks. Economic studies are often carried out in parallel with those of hydrological studies while socio-economic aspects have not been taken into account in an integrated way (Grémont et al. 2015). Cooperative research between economists and hydrologists to improve the economic value of

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water, while maintaining social values, contributes to establishing a sustainable environmental system (Ossa-Moreno et al. 2018).

In this study an optimization approach was adopted to determine the optimal policy associated with the existing water exploitation scenario while ensuring future sustainability of the aquifer (environmental objective), supplying drinking and industrial water demands (social objective) and maximizing agricultural benefits (economic objective). The case study region is a part of Tehran-Karaj aquifer located in central Iran. Numerous studies have been conducted on groundwater allocation modeling and optimization. However, there has not been sufficient attention paid to economic and environmental allocation aspects.

2- Methodology

In this study, three objective functions were contemplated involving supply of drinking and industrial water, improving agricultural economy and aquifer status. The first objective function (Z1) was to minimize the difference between the demand and the allocation of drinking and industrial water. The second objective function (Z2) was developed to improve the agricultural economy for the stakeholders. The third objective function (Z3) maintained aquifer status in such a way that it may be exploited in long term by all stakeholdersFurthermore, the return flow from drinking, industrial and agricultural uses was incorporated in this objective function. The objective functions are as follows:

$$Z_1 = min(\sum_{i=1}^{n}(Et_i * A_i) - Xs_{u.d}) \quad (1)$$

$$Z_2 = max(A * \sum_{i=1}^{n} a_i \times y_i \times B_i) \quad (2)$$

$$Z_3 = min(V_{g85} - 0.8\sum_{i=1}^{n}(b_i \times ET_i \times S_y \times A_i) - 0.2Xs_{u,d}) \quad (3)$$

In the second function, the performance is calculated according to the water distribution efficiency in the field while crop sensitivity coefficient (K_i) is determined as follows (Ayers and Westcot, 1985):

$$y_i = y_{imax} * (1 - \sum_{i=1}^{n} k_i \times (1 - \frac{W_i}{ET_i}) \quad (4)$$

In this study, water allocation priority from higher to lower was assigned to, drinking, industrial and agricultural, respectively.

3- Results and discussion

Given the results, the conjunctive exploitation policies and guidelines for each sector may be developed. Finally, after comparative evaluation and determining the minimum distance between the function values, the first scenario was selected as the best scenario. In this scenario, 99.69% of drinking water was met while at the same time, by changing the cropping pattern, about 3.03 MCM per year could be allocated to the aquifer. In other words, not only did this scenario reduce water withdrawal from the aquifer, but also it could almost entirely satisfy the drinking and industrial water demands.

As previously stated, the selected scenario resulted in water saving of 8% of the total water demand in the study area and added this volume to the groundwater resources. Since water supply in the study area is mainly dependent on groundwater, this long-term saving can gradually bring about stability in the aquifer. Moreover, while 85% of the water is currently allocated to agricultural demand, optimization model reduced this value to 79% and allocated the remaining 6% to the aquifer for restoration purposes. The results of the optimization model based on the weights of objective functions determined different sets of water allocation to the stakeholders. Using these results, stakeholders would understand the advantages/disadvantages associated with different objective function weights and hence effectively negotiate with other stakeholders.

4- Conclusion

In this study, a multi-purpose water allocation model was proposed using three objective functions. The results demonstrated that stakeholders may be divided into two categories with respect to the weights: sensitive and non-sensitive stakeholders. Agricultural and horticultural users are not significantly dependent on the weights of objective functions, while drinking water and the aquifer are considerably sensitive to the weights. Thus, decision makers do not necessarily require the weights of objective functions to make decisions on non-sensitive stakeholders. A set of objective function weights was selected by comparing water allocation values. As such, the average allocated water to stakeholders were determined as 15, 79, and 7%, respectively, for drinking, agricultural and aquifer demands. However, the current values in the region are equal to 15, 85 and zero percent, respectively. Similar water resource allocation exists in many parts of the world so that the developed methodology may be adopted as an effective tool to determine optimum solution to allocate water to aquifer reclamation while meeting the other demands.

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