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Quantitative Model of Optimal Conjunctive use of Mahabad Plain's Surface and Underground Water Resources

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ABSTRACT: According to available information and the population growth as well as the ever-increasing development of agriculture, there is an upward trend in withdrawals from surface water and groundwater resources in different regions of the country such as Mahabad to provide water demand for the region. The optimal conjunctive use of surface and groundwater resources is one way to providing the water demands in crisis and drought situations. In this study, a management model based on effective techniques of optimization and simulation has been developed to solve the optimization problem. Variation of groundwater table level in Mahabad plain was simulated using GMS software initially. Then based on the results of this simulation, artificial neural network was trained to use in simulate-optimization system. Genetic algorithm was used to solve the optimization problem. The results indicate that this model is powerful and effective for solving large-scale problems and optimal conjunctive use of surface water and groundwater resources of Mahabad. Based on the results of the research and running of the model, the approximate share of water supply of water resources, is respectively 13.5 and 86.5 percent of surface water and groundwater resources.

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1- Introduction

Today, water resources management, with emphasis on joint operation of surface and groundwater resources, is on the agenda of all utilities organizations. In conjunctive use, water needs are provided by surface and underground resources [1]. Separate use of resources can lead to many problems such as water deficit in drought situations, unsustainable production of crops, falling of groundwater level and increasing of pumping costs. While the integrated use of surface and underground resources can increase the reserve of water resources, minimizing the negative effects of separate use of resources and efficient and optimal water management.
In 2009, Yang used the combination of genetic algorithm, dynamic programming and ISOGUAD groundwater simulator to solve a multi-objective integrated water resource management problem [2]. Many studies also have been carried out in Iran. Karamuoz et al. (2004) demonstrated the application of genetic algorithm and artificial neural network in the conjunctive use of surface waters and underground waters in south of Tehran [3].

2- Materials and methods

2- 1- Case study and quantitative model of optimal conjunctive use

The ultimate goal of this study is to determine water withdrawal from surface water and groundwater resources in Mahabad Plain (with area of 249 km^2, located in south of Urmia Lake and has water crisis that surface flow into the plain from Mahabad river has been shown in Table 1. [5]) in a one-month periods so that, while estimating all existing constraints, the difference between supply and demand of water rates and groundwater levels can be minimized. To solve this problem, firstly, the model of the groundwater simulator should be calibrated and verified using the GMS software (which uses the MODFLOW mathematical model). The results of the implementation of the groundwater simulator model will be used to train artificial neural networks. Then, the results of the trained artificial neural network will be used in the optimization model of genetic algorithm to obtain an optimal combination policy for surface and underground water resources. In this research, GMS model was used to simulate groundwater flow.

2- 1- 1- Optimization model structure

The problem in this research is a multi-objective optimization problem, and the structure of the proposed objective function and its constraints that is shown below, is similar to that used by Karamuoz et all [4]:

*Objective function:

$$\min w_1 Z_1 + w_2 Z_2 \qquad w_1 + w_2 = 1 \tag{1}$$

*Constraints:

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$$Z_1 = \begin{cases} 0 & \text{if } D_{ym} \le R_{ym} + G_{ym} \\ \sum_{y=1}^{Y}\sum_{m=1}^{12}\left[\left(D_{ym} - Q_{ym} - G_{ym}\right)/D_{ym}\right]/\left(12\times Y\right) & \text{if } D_{ym} \ge R_{ym} + G_{ym} \end{cases}$$

$$Z_2 = \sum_{y=1}^{Y}\sum_{m=1}^{12}[\left(\Delta L_{ym}/\Delta L_{\max}\right)]/(12\times Y) \quad (2)$$

$$\Delta L_{ym} = f\left(G_{ym}\right) \quad (3)$$

$$Q_{ym} \le R_{ym} \quad (4)$$

The first objective (Z_1) is minimize the difference between supply and demand of water and the second objective (Z_2) is minimize the fall in groundwater level. In the above functions, D_{ym}, Q_{ym}, G_{ym}, R_{ym}, and Δl_{ym}, are respectively the amount of water required, the amount of water taken from the surface water resources, water withdrawal from groundwater resources, the amount of water in the surface waters and the amount of fall of groundwater level in the m_{th} month of y_{th} year.

Also, ΔL_{max} is the maximum allowable level of groundwater fall in the plain, Y is the number of years of the planning horizon and w_1 and w_2 are respectively the weights of the first and second target functions. In this research, according to the objective function of the problem. The final requirement is to minimize the two Z_1 and Z_2 functions, which, with a simple weighing and considering the importance (weight) of each of the functions, the whole problem, becomes a single constrained problem, and is solved by techniques of genetic algorithm easily.

Using the experts' opinion, in this research it is assumed that the weight of the first function is 0.3 and the weight of the second function is 0.7, then the objective function is:

$$\min 0.3Z_1 + 0.7Z_2 \quad (5)$$

According to the available data from the library studies and Mahabad Water Resources Administration, the required water (D_{ym}) and available water in the surface water resources (R_{ym}) of the area are presented in Table 2. Also, the maximum drainage level of aquifer (ΔL_{max}) was estimated 4.33 m based on 4 years of observation wells in the area. In this research, a genetic algorithm has been used to solve the optimization problem. Fitness function code of the optimization problem was written in two sections, the artificial neural network and the main function. The purpose of using the artificial neural network in the present optimization model is to find a relation for ΔL_{ym} based on the extracting amount of groundwater (G_{ym}) obtained by MODFLOW.

Table 1. Surface flow into the plain from Mahabad River (MCM) [5]

Water Year			
2010-2011	2011-2012	2012-2013	2013-2014
176.75	189.945	203.04	123.38

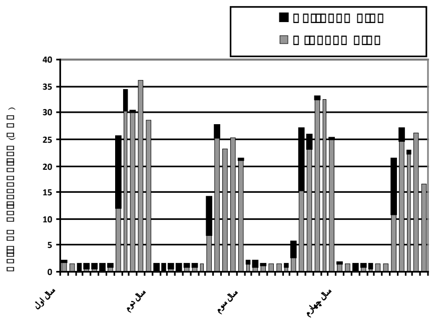

Figure 1. Optimum exploitation of surface and underground water resources of Mahabad plain

3- Results and Discussion

By implementing the genetic algorithm, the model could solve the current optimization problem after 22,000 repetitions. According to this solution, the fitness function

Table 2. Amount of water requirements (D_{ym}) and available water in surface water resources (R_{ym}) of Mahabad Plain (MCM)

Water year	2010-2011		2011-2012		2012-2013		2013-2013	
	D_{ym}	R_{ym}	D_{ym}	R_{ym}	D_{ym}	R_{ym}	D_{ym}	R_{ym}
Oct	2.155	0.47	1.602	4.04	1.965	0.51	1.922	0.28
Nov	1.554	0.46	1.554	3.85	1.978	4.34	1.644	1.59
Dec	1.554	2.94	1.554	12.3	1.606	10.49	1.554	6.47
Jan	1.502	4.72	1.554	9.47	1.502	21.26	1.557	5.85
Feb	1.554	5.94	1.554	25.12	1.554	62.86	1.557	17.65
Mar	1.502	18.48	1.502	20.54	1.554	54.45	1.505	32.28
Apr	1.606	95.61	1.606	39.35	5.861	33.45	1.606	44.62
May	25.481	43.39	14.104	17.17	27.029	11.62	21.626	11.09
Jun	34.198	3.99	27.602	2.49	25.989	3.12	26.995	2.63
Jul	30.296	0.41	23.283	0.1	32.948	0.54	22.981	0.74
Aug	36.212	0.40	25.235	0.17	32.569	0.13	26.097	0.1
Sep	28.471	0.04	21.216	0.04	25.184	0.24	16.671	0.08

value in the last generation equals was obtained -2.98×10-12. Also, optimal values for exploitation of groundwater and surface water resources of Mahabad plain in a four-year horizon are presented in Figure 1. The results of this research are briefly summarized as follows:

1. In Mahabad plain, there are several factors that indicate there will be a shortage of water in the coming years.
2. The results indicate the power and efficiency of the model in solving complex problems and optimal conjunctive use of surface and ground water resources of the Mahabad plain.
3. Optimal conjunctive use of surface and ground water resources of the Mahabad plain minimizes the difference between supply and demand of water to -2.98×10-12 (close to zero) as well as to maintain an approximate level of groundwater level in Code 1281.061 m.
4. Due to the effect of annual and monthly changes in factors such as rainfall in optimal integrated utilization planning, the optimal utilization of surface and underground water resources cannot be determined certainly. Accordingly, the approximate share of water supplied from water resources is 13.5% for surface water and 86.5% for groundwater.
5. Due to the lack of data in this study, the study should be extended by completing data or using techniques to deal with the uncertainty caused by data deficits.

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