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Optimal operation of reservoirs with increasing water use efficiency: Climate change adaptation approach (case study: Jareh Dam)

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ABSTRACT: Impacts of climate change on water resources will force decision-makers to adopt climate change adaptation policies in order to reduce social-economic problems and difficulties resulting from it and water resource sustainable development. One of the adaptation methods is to increase water use efficiency in agriculture that will adjust climate change impacts include decreasing runoff and increasing water demands. In this study, the impact of water use efficiency as a climate change adaptation approach is assessed in the optimal operation of JAREH dam. Fifteen climate change scenarios were generated by using downscaling technique on CMIP5 data for the near (2020-2044) and far (2070-2094) future. Based on these scenarios, time series of reservoir inflow and downstream water demand were projected for both future periods. An optimization model is developed considering the water efficiency coefficient parameter in order to define four water use efficiency scenarios (0-S1, 0.1-S2, 0.3-S3, 0.5-S4). Results show that reservoir inflow decreases up to 18.8% and water agriculture demand increases up to 29%. The amount of water allocation would increase up to 18.7% in the future periods than in the baseline period under S1 scenario to supply the increased water demand, which may decrease reliability of reservoir system for water allocation. Increasing water use efficiency coefficient up to 0.5 in the future periods would increase system reliability up to 20% that will reduce social-economic problems caused by climate change impact in this study area.

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1. INTRODUCTION

Lack of precipitation, limited freshwater resources and low water use efficiency have made the great challenge of food and water security. On the other hand, the increase in greenhouse gases emission in recent decades has led to changes in hydrological cycle. According of the fifth report of the Intergovernmental Panel on Climate Change (IPCC) [1], global air temperature on the land surface will rise further than the oceans, which lead to exacerbation of extreme phenomena such as floods and droughts. This will affect the optimal operation of the reservoirs in the future more than ever. But what is worth pondering is identifying appropriate adaptation measures to enable this sector to effectively deal with these changes. One of the ways to adapt to climate change in reservoir operation is to increase water use efficiency in the reservoir downstream zone, which can lead to the adoption of macro-policies for environmental sustainability under future climate change.

The operational policies compatible with future climate change impacts are formulated using four sub-models including: climate scenarios projection under different emission scenarios, reservoir inflow simulation based on future climate scenarios, estimate future demand in the reservoir downstream zone, and optimization model. In this study, the effect of increasing water use efficiency on the operation of the Jareh dam reservoir located in southwestern Iran was investigated for adaptation to future climate change. To this end, climate change scenarios were generated based on the outputs of five CMIP5 under three emission scenarios RCP2.6, RCP4.5, and RCP8.5 for the two future periods (2020-2044 and 2070-2094), which were downscaled using Artificial Neural Network (ANN) model [2]. A rainfall-runoff simulation model based on perceptron multilayer neural network [3,4 and 5] was made using monthly precipitation data at 9 rain gauges and monthly runoff data for the baseline (1990-2014), and it was then applied to simulate the monthly reservoir inflow under future climate change scenarios. Downstream demand was also obtained using the regional cropping pattern and FAO-56 method [6, 7, and 8] for each future climate change scenario assuming no change in crop pattern. Finally, an optimization model [9, 10 and 11] was developed to investigate the effect of water use efficiency; and Genetic Algorithm (GA) was used to solve it.

2. MATERIAL AND METHOD

2.1. Case study

The Jareh dam is located downstream of the Yellow river basin with a storage capacity of 225.56 MCM (in normal level), 35 kilometers northeast of Ramhormoz city in

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Khuzestan province, with the aim of irrigating 22000 hectares of agricultural land. The average annual precipitation is 584 mm, the average annual temperature is about 21.6 C, and the average annual inflow to the reservoir is 246 MCM. The annual downstream demand for irrigation is about 294.15 MCM, and for environmental flow requirements is about 43.95 MCM.

2.2. Optimization Model

The objective function is developed to minimize the water supply deficiencies considering water use efficiency. For this purpose, a coefficient is considered as water use efficiency coefficient in the objective function, so that the effect of water use efficiency in the reservoir downstream on reservoir performance indices can be measured. This function is defined as follows:

$$\min: Z = \sum_{t}^{T} \left[\frac{R_t - [D_{at} + (1-\alpha) r_t + D_{et}]}{max[D_{at} + (1-\alpha) r_t]} \right]^2 \quad (1)$$

$$r_t = \left(\frac{D_{at}}{e} - D_{at} \right) \quad (2)$$

Where R_t, D_{at}, D_{et}, r_t, α, and e are monthly release, net irrigation water requirement, environmental flow requirement, return water, water use efficiency coefficient, and overall efficiency, respectively. If α=1, it means that the return water amount is zero and the water use efficiency rate will be 100%. By decreasing the value of α, the water use efficiency rate is reduced to zero. This study uses four water use efficiency coefficients of 0, 0.1, 0.3, and 0.5, which are called S1, S2, S3, and S4, respectively. They indicate an increase in irrigation efficiency up to 16.75%. The constraints of the problem also include continuity equation in the reservoir, maximum and minimum capacity of reservoir, spillway flow, and upper bound of release.

3. RESULTS

Fig. 1 shows the percentage change in release volume, downstream demand and reservoir inflow in the future periods compared to the baseline period under S1 scenario. Due to the decrease in the reservoir inflow and the increased demand, the increased release may indicate reduced reliability of the reservoir system. Thus providing an approach to adapt to future climate change will be inevitable.

By increasing the water use efficiency coefficient, the reliability and resiliency of the system will increase by about 20% and 7% in both future periods, respectively (Fig. 2). System vulnerability is reduced by approximately 31% in both future periods. The system's sustainability index is also increased from 30% to 47%. On the other hand, comparing the sustainability index (SI) in the baseline period with the future periods under S1 scenario shows that SI is equal to 30%. Therefore, the adaptation strategy of increasing water use efficiency in addition to mitigating climate change impacts due to reduced runoff has led to increased sustainability.

4. CONCLUSION

To maintain sustainability in water allocation and sustainable development of water resources, the management of irrigation networks must be adapted to future conditions. One of the adaptation methods is the proper water management, the developed model in this research provides the effectiveness of increasing water use efficiency on the water allocation. By increasing irrigation efficiency from 30% to 47% (S1 to S4), the reliability of the reservoir system will increase from 29% to 49% in terms of climate change (reducing runoff and increasing demand). The increase in system reliability will minimize the socio-economic impacts of climate change in this region and prevents water conflicts.

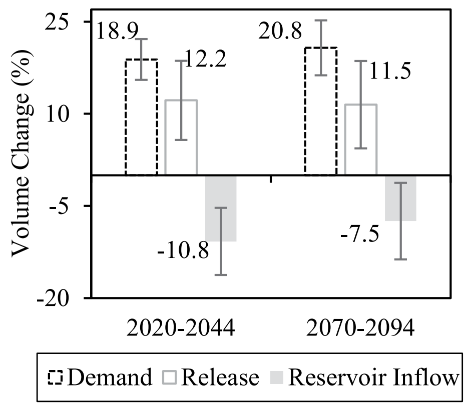

Fig. 1. Volume change for the future periods compared to baseline

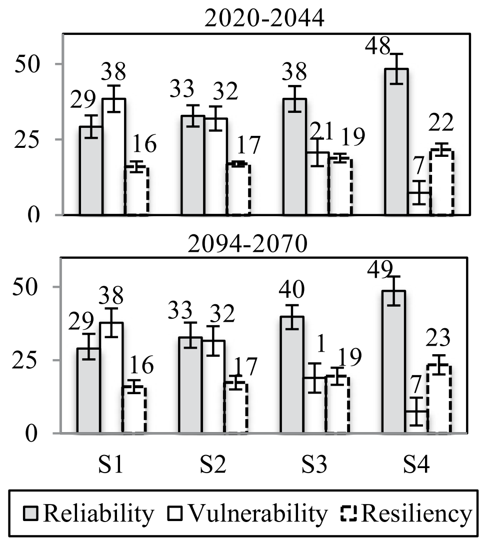

Fig. 2. Reservoir performance indices for different water use efficiency in the future periods

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