Pertanika J. Sci. & Technol. 27 (4): 1881 - 1900 (2019)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Water Quality Effects on the Optimal Water Resources Operation in Great Karun River Basin

Iman Ebrahim Bakhsipoor, Seyed Mohammad Ashrafi* and Arash Adib

Department of Civil Engineering, Faculty of Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran

ABSTRACT

The recent drastic decrease in the surface water resources quality has limited water resources managers in Great Karun river basin, southwest of Iran. In this research, the effects of water quality on the satisfaction of different demand sits in Great Karun river basin is modeled and studied by dint of systemic analysis principles based on the actual conditions in the river basin. In addition, different scenarios of water resources quality management are defined and the effect of implementing these scenarios on the demand satisfaction criteria is considered. The achieved results indicate the interactive relationship between quality conditions and performance of the system in demand satisfaction. It means that, the applied operating strategies can improve the demand coverage and reliability of the system only if the quality improvement is considered in extracting those strategies. The considered scenarios are able to improve average monthly demand coverage between 0% and 700% for Abadan city as a critical point within the system. Comparison of different quality management scenarios declares that decreasing the amount of agricultural demands has the most impact on reducing the flow contamination and improving the demand satisfaction throughout the basin, especially in downstream areas like Abadan City. This is due to the wide area of agricultural demands within the basin. Reduction of the agricultural demands causes least contaminated return flows on the one hand, and on the other hand it increases the amount of fresh water of river flows.

Keywords: Great Karun, model calibration, optimum water allocation, water quality modelling, water resources management

ARTICLE INFO

Article history:
Received: 11 January 2019
Accepted: 13 May 2019
Published: 21 October 2019

E-mail addresses:
iman.e.bakhshipoor@gmail.com (Iman Ebrahim Bakhsipoor)
ashrafi@scu.ac.ir; semo.ashrafi@gmail.com (Seyed Mohammad Ashrafi)
arashadib@scu.ac.ir (Arash Adib)
* Corresponding author

INTRODUCTION

As the rate of pollution in human societies increases due to industrialization and population growth, the violation of the flow

ISSN: 0128-7680
e-ISSN: 2231-8526

quality thresholds becomes a more important challenge to the water resource managers. As a result, the contamination/salinity level is the main limitation on water resources planning in many regions (Ashrafi & Mahmoudi, 2019; Karamouz et al., 2004; Mahmoud et al., 2011). In such conditions, it is not possible to manage a real-world water resources system through the water allocation modeling. Rather, the water quality issues must also be taken into account in the operating models. Therefore, the effect analysis of water quality on the allocation strategies of water resources based on the technical complexities of multi-reservoir problems (Ashrafi & Dariane, 2017) creates a fully complicated modeling problem, which calls for the involvement of special computational methods and powerful algorithms (Ghassemi et al., 1995).

In Iran, Great Karun River has the most discharge volume of water and is the longest river that flows into the Persian Gulf. The most important factors and challenges influencing the water resources quality of Karun River are the naturally saline branches and streams (Emamgholizadeh et al., 2014). In the Great Karun basin, the increased salinity of surface water has become an extremely big challenge for the water resources managers in this province since the construction of Gotvand Olya Dam and operation of inter-basin water transfer of Karun and Dez branches. Moreover, given the importance of the Great Karun River, numerous studies have been carried out on it, which have indicated the reduction of the quality criteria such as salinity and electrical conductivity indices in this river (Ehteshami et al., 2014; Hosseini-Zare et al., 2014; Jafarzadeh et al., 2004). The increased water demand in different sectors for purposes such as the expansion of agricultural activities, aquaculture farms, and urban development and industries can greatly influence the quality of water resources in Great Karun basin and the farming soil resources in the future. Due to the fertile soil and clement weather of this area, farming and industrial complexes have been created on the banks of Great Karun basin in addition to the traditional farms, which have a very long history in this region. Given the wide range of the agricultural, industrial, aquaculture, and urban development activities, the degree of contamination of the agricultural water resources and soil resources under study is increasing (Heydari et al., 2013). With a capacity of 4.5 billion cubic meters, Gotvand Olya is the second water reservoir in Iran by volume after Karkheh reservoir, and it is the biggest reservoir constructed over Karun River. As regards its position, this dam is located 10 km northeast of Gotvand City in Khuzestan Province and it is the most downstream reservoir dam over Karun River. The reservoir of this dam has been threatened with salinity since the beginning of its operation due to the placement of this dam in a salt formation (Radmanesh et al., 2013). In recent years (since 2 or 3 years after foundation of Gotvand Olya Dam), although the amount of water was adequate, the EC factor of river flows increased dramatically, several times. This has caused many expensive costs for users and stockholders of agriculture, aquaculture and municipal demands. Therefore, due to the special conditions of Khuzestan Province and the shortage of water resources in recent droughts, we need a management strategy to manage the associated basin, secure the highest level of allocation, and meet various demands with the minimum allowable quality. On the other hand, there is no an official Water Resources DSS for estimating the quality and quantity of available resources within the basin under different probable operating strategies.

Numerous studies have been carried out on the quality modeling and management of water resource systems (Gitau et al., 2016; Nikoo et al., 2013; Carmona et al., 2010; Estalaki et al., 2015; Kerachian & Karamouz, 2007). The main goal of most of these studies is achieving the best allocation strategy for quality thresholds satisfaction. In other words, water allocation must be determined such that it results in the highest level of quality defined in the system. Therefore, due to the special conditions of Khuzestan Province and the shortage of water resources in recent droughts, we need a management strategy to manage the associated basin, secure the highest level of allocation, and meet various demands with the minimum allowable quality (Moazami et al., 2016). Accordingly, in this research the demand satisfaction indices in Great Karun basin in Khuzestan Province is modeled considering the salinity of Karun and Dez rivers under different scenarios. This analysis was carried out by simulating the quality indices and quantity criteria in WEAP model to study the possibility of the maximum demand satisfaction in the presence of the maximum allowable salinity. Next, various scenarios were used to reduce salinity in different periods in Karun and Dez rivers within a 10-year period, and the effect of each scenario on the satisfaction of different demands in this basin was recorded.

STUDY AREA

The study area, with an area of 66930 km^2, included the Great Karun river basin (from the inlet to Khuzestan Plain (Gotvand City) to Abadan and Khorramshahr regions) as well as the Dez River from the inlet to Khuzestan Plain (Dez dam) to Band-e-Ghir (where it reaches the Great Karun River).

The Great Karun river basin includes the largest rivers by discharge volume of water (Karun, and Dez rivers) in Iran. This basin has important role in hydropower energy production and supplying drinking, industrial and agricultural demands in the provinces of Khuzestan, Chahar Mahal and Bakhtiari, Kohkiluyeh Boyerahmad and Lorestan. As regards the geographical coordinates of this basin, it is located at longitude 48^o 15’to 52^o 30’ E and latitudes 30^o 17’ to 33^o 49’N. Figure 1 represents the location of Great Karun river basin in Iran. Karun River originates from the Zagros Mountains 75 km south of Isfahan, and running to the north of Shushtar City, where it is divided into the Gargar and Shoteit branches. These two branches are merged in a region called “Band-e-Ghir” to form the Great Karun River along with Dez River. Smaller branches such as the Shur Dashte Bozorg, Balaroud, and Kohang branches also join these rivers, but they do not significantly change the trend of seasonal changes in the Great Karun River due to their annual input volumes. In addition, some of the pollutants flowing into Karun and Dez rivers include the agricultural effluent (from the irrigation networks, Sugar Cane development projects, and farming water rights), industrial sewage, and industrial effluents (Ashrafi & Mahmoudi, 2019).

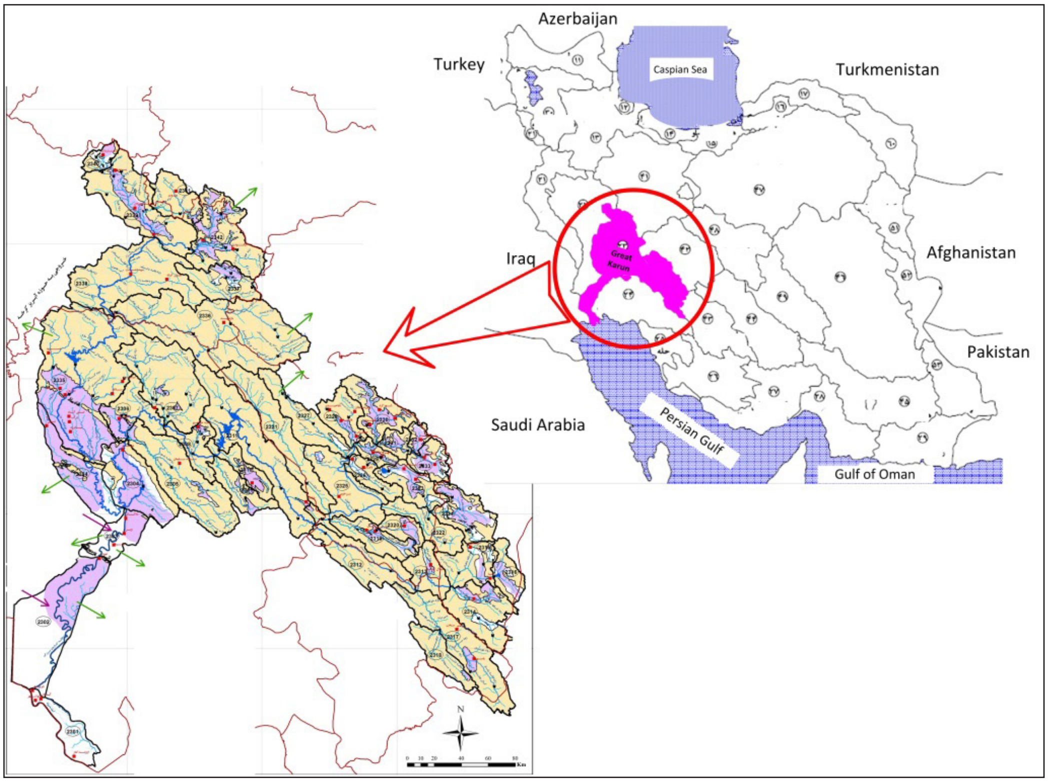

Figure 1. The location of Great Karun river basin in Iran

Based on the last study it should be noted that, the total water demands throughout the basin is growing up from 16700 *mcm/year* at near future, to 19000 *mcm/year* at long future. That indicates 14% growing rate for total demand (Dezab, 2011). About 74.6% of the basin consists of mountainous and highlands, while plains and low elevation areas cover about 25.4% of the basin. It is bounded by the Karkheh basin on the west, the Salt Lake, Gavkhouni and Bakhtegan-Maharlou on the north and east, the Zohreh-Jarahi Basin on the south and east. The basin joins the Arvand River and then the Persian Gulf at the outlet.

Seasonal and spatial variation of meteorological conditions in Great Karun river basin is significant. In flat areas, the summers are hot and humid, and the winters are moderate and slightly moist. At higher elevations, the winters are cold and dry and the summers are mild. Mean annual precipitation throughout the basin varies widely, ranging from 102 *mm* in South Ahvaz sub-basin to 1165 *mm* in Bazoft sub-basin. Generally, in mountain areas mean annual precipitation is slightly less than 715 *mm* which often occurs as snowfall during the mountain months. In flat Areas the precipitation occurs as rainfall. The actual evapotranspiration in mountain areas of the basin is around 12730 million cubic meters annually, which is almost equal to %35 of mountainous annual precipitation. In flat areas like South Ahvaz sub-basin, the annual evapotranspiration is up to %86 of annual precipitation.

MODEL DEVELOPMENT

In order to evaluate the effects of quality management strategies on the water allocation properties, the water resources simulation model is executed in different conditions. As presented in Figure 2, the configuration of Great Karun water resources system should be determined at the first step of the research. The system detail implemented within the configuration is really important, while simulation models are founded based on the system configuration.

The simulation models should be calibrated to evaluate the performance of the system accurately. The water resources management model is developed with monthly time step based on available data of the system. In this study, a simulation optimization approach is proposed to calibrate the simulation models. Water Evaluation and Planning (WAEP) model is applied for developing water resources simulation model while the Self-adaptive Melody Search (SaMeS) optimization algorithm is implemented as an optimization scheme.

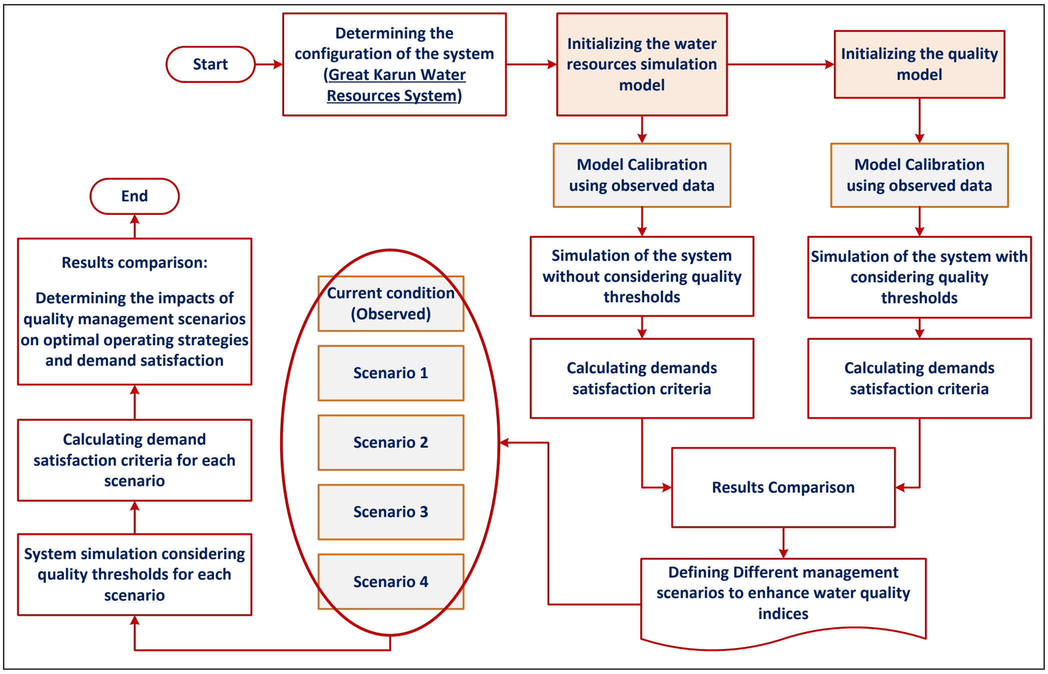

Figure 2. Flowchart of the presented research methodology

Results comparison of current condition evaluation can be really helpful while the effect of water quality on the system reliability is considerable. It is so important when the results of quality models usually are not considered by decision makers.

After establishing an accurate simulation model different strategies can be planned for enhancing the quality of Great Karun river flow. These strategies are implementable and based on the real condition of the system. The more probable strategies are modeled as four different quality management scenarios in this research. Evaluating the performance of the water resources system under these scenarios determines the effect of the water quality strategies on the allocation and system sustainability. Moreover, the most efficient strategy for reducing the flow contamination can be determined at the end.

Figure 3 presents the schematic of the Great Karun water resources system. Different distributed demands along the system are aggregated within some lumped demand nodes within the modeled basin in this study. Where, the drinking and municipal demands, the agricultural demands, Sugar Cane development sites, traditional farming water rights, aquaculture demands and industrial needs are considered as the main demand components of water resources system. Moreover, return flow of irrigation networks is modeled as a very effective factor in increasing the Electrical Conductivity (EC) indicator of river flows.

In this paper, the Water Evaluation and Planning system (WEAP) model is applied to simulate the water resources system of Great Karun river basin considering water quality and quantity issues under different scenarios. WEAP as a well-known generic tool for integrated simulation and analyzing water resources systems was developed by the Stockholm Environment Institute (SEI). WEAP integrates a spectrum of hydraulic-physical processes with demand management and installed infrastructure into a simple and comprehensive solution. In addition, it can be connected to MODFLOW, for accounting the surface water and groundwater interactions and to QUAL2K for tracing the water quality throughout an integrated system (da Silva & Alves, 2016).

The distributed agricultural and industrial demands are defined as integrated demand sites in three separated sub-areas of the basin, viz. Dez reservoir to Band-e-Ghir, Gotvand Olya reservoir to Band-e-Ghir, and Band-e-Ghir downstream domains (the Great Karun). In each sub-area, the corresponding municipal demands of big cities (e.g. Ahvaz, Abadan Khoramshahr, Dezful, Shushtar, Gotvand) are simulated via separate demand sites. Other drinking and municipal demands of small cities and villages are modeled as aggregated demand nodes in each sub-area. For more details about the developed simulation model refer to Ashrafi and Mahmoudi (2019).

To simulate the EC indicator within the considered system, the WEAP quality model is applied where the decay factor of EC parameter is assumed as zero. According to the National Drinking Water Standard of Iran, the EC values lower than 1650 μmho, values between 1650 and 2500 μmho, and values higher than 2500 μmho represent satisfactory

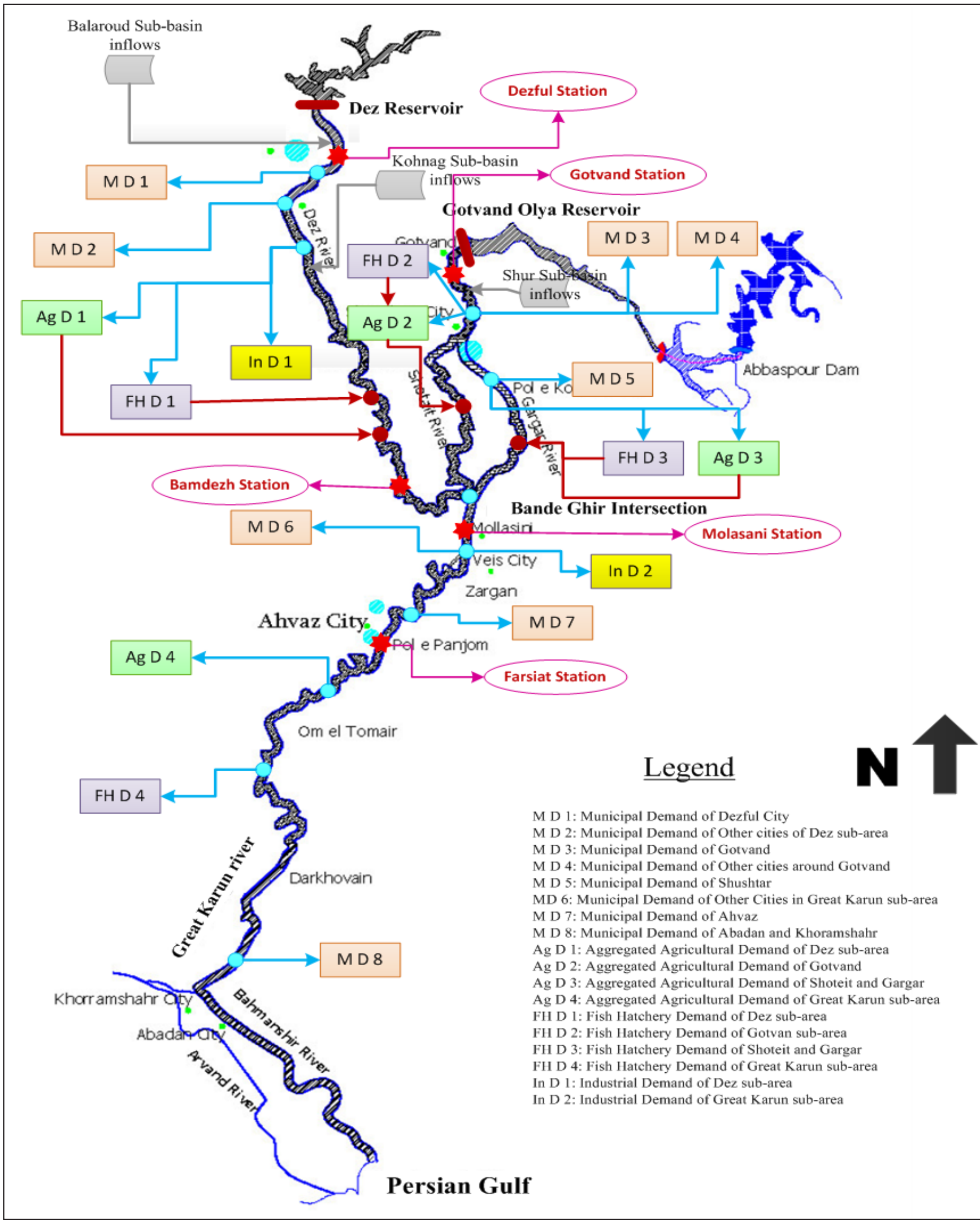

Figure 3. Schematic of the simulated Great Karun river basin

drinking water quality, allowable water quality, and non-allowable water quality, respectively. In this research, the EC of 2500 μmho is used as the minimum allowable water quality for municipal drinking water uses. Besides, the water allocation problem can be formulated through equation (1) considering water quality constraints. In other words, each demand is only met if the value of quality index does not exceed the allowable limit. As a result, it is possible to study the effect of violation of the salinity threshold on the satisfaction of different demand sites throughout the basin.

$$Max\ (\mathbb{M} = Demand\ Satisfaction\ Rate) \equiv Min\left(\mathbb{Z} = \left\|\overrightarrow{TD} - \vec{R}\right\|\right)$$

$$Subject\ to: \begin{cases} Physical\ and\ Conceptual\ Constraints\ of\ the\ System \\ Mass\ Balances\ for\ different\ Elemnts \\ Quality\ Constraints\ (EC_{sim}(i) \geq\ EC_{Per}(i)) \end{cases} \quad [1]$$

Where, M is a simulated value of objective function that is equal to the absolute differences of Target demands and water releases to supply demands. $\overrightarrow{TD}$ indicates the target demands as an $m \times t$ dimensional matrix, and $\vec{R}$ indicates the water releases which can be determined as a $m \times t$ dimensional matrix. The simulated value of EC parameter in the ith control node is formulated by $EC_{sim}(i)$ and $EC_{Per}(i)$ determines the permissible Electronic Conductivity at the same location. Where m, and t represents the number of demand sites, and the number of simulated time steps, respectively. And the satisfaction rate for i^{th} demand site at n^{th} time step is calculated as follows;

$$DC_{i,t} = \begin{cases} \dfrac{R_{i,t}}{TD_{i,t}}, & if\ R_{i,t} < TD_{i,t} \\ 1, & otherwise \end{cases} \quad [2]$$

Where, $DC_{i,t}$ stands for demand coverage of a certain demand site at a specific time step, which is identical to satisfaction rate.

CALIBRATION OF THE SIMULATION MODEL

Since modeling the flow quality parameters through the river basin is influenced by the distribution of the hydraulic and volumetric parameters of flow, the water resources system simulator must be calibrated before modeling EC distribution. In the water resources simulation models, model calibration refers to the preparation of the model for simulation of the real-world systems. This is carried out through the approximation of some model parameters based on observations and it can be explained as an inverse problem as follows (Sun & Sun, 2015);

$$\theta_{qs} = arg\underbrace{min}_{\theta}\left\|u_D(\theta) - u_D{}^{obs}\right\|, \qquad \theta \in P_{ad} \quad [3]$$

Where, θ_{qs} is a quasi-solution achieved by the optimization process, $u_D(\theta)$ indicates the simulation model output for the certain parameter set, θ, and $u_D{}^{obs}$ represents the observed value correspond to the current model output. It is worth noting that the water resources models cannot be expected to exactly achieve the same values as the observed data. This is why the imposed management strategy of the system is not necessarily based on the operational principles applied in the modeling. Moreover, many of the basic constraints of the real-world system may be neglected or simplified during the expansion of the computational model. A simulation-optimization approach can be implemented to solve equation (3) as an indirect method. Accordingly, Equation (4) states a composite mapping ($\mathcal{DM}$), which summarizes the forward model ($\mathcal{M}$) and the sampling mapping ($\mathcal{D}$) to obtain the system outputs corresponding to the observations using a specified parameter set (θ).

$$\mathcal{DM}(\theta) = u_D(\theta) \qquad [4]$$

Considering the simulation model structure, in this calibration we are searching to obtain proper values of water losses percentages in different sub-areas (δ_{Loss}), the agricultural and industrial return flows (ReF_{Ds}), and the demand supply priorities (Pr_{Ds}) for meeting all simulated demands. Hence, relation (4) can be rewritten as follows;

$$\mathcal{DM}(\theta) = \mathcal{DM}(\delta_{Loss}, ReF_{Ds}, Pr_{Ds}) \xrightarrow[\text{Simulation Model}]{\text{Through the}} u_D(\delta_{Loss}, ReF_{Ds}, Pr_{Ds}) \cong {u_D}^{obs} \, [5]$$

Finally, equation (1) can be regarded as an applied optimization model as follows;

$$Min\ RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[(Q_{model})_i - (Q_{obs})_i]^2}$$

$$Subject\ to: \begin{cases} All\ Contstraints\ adopted\ within\ the\ Simulation\ model \\ All\ Constraints\ imposed\ by\ the\ operating\ Strategy \\ All\ Constraints\ derived\ from\ the\ system\ configuration \\ Q_{model} = u_D(\delta_{Loss}, ReF_{Ds}, Pr_{Ds}) \\ \Rightarrow\ u_D(\delta_{Loss}, ReF_{Ds}, Pr_{Ds}) = Q_{obs} \end{cases} \qquad [6]$$

The advantage of indirect methods in solving such inverse problems is that all of the optimization constraints (derived from the real-world conditions) can be accounted in the simulation model. Figure 4 presents the schematic of the calibration process of the developed water resources simulation model.

The Self-adaptive Melody Search (SaMeS) optimization algorithm was used in this research to find the optimal set of the model parameters. Melody Search algorithm is an algorithm that was introduced for the first time by Ashrafi and Darian (2011). The ability of this algorithm to solve different engineering problems has been proved (Ashrafi &

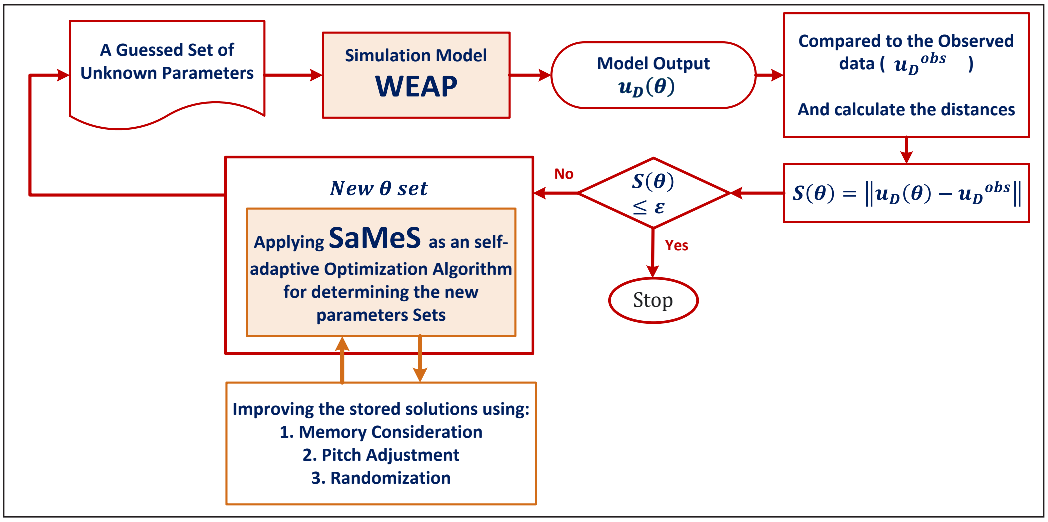

Figure 4. Schematic of the performed calibration process

Dariane, 2013). In addition, this algorithm is developed as a self-adaptive algorithm and it has been used numerously to optimize the water resources management problems as a powerful algorithm (Ashrafi & Kourabbaslou, 2015; Ashrafi et al., 2017; Ashrafi & Dariane, 2017). The three main operators used in this algorithm to find the optimal solution are the Memory Consideration, Pitch Adjusting, and Randomization operators. The modeling of different sub-memories interactions considerably enhances the algorithm performance. See Ashrafi and Kourabbaslou (2015) to find more details about MeS optimization algorithm. The historical observed data of 5 hydrometric stations in the Great Karun river basin are used to carry out the model calibration. These stations are Gotvand, Dezful, Bamdezh, Molasani, and Farsiat hydrometric stations. The locations of these hydrometric stations are shown in Figure 3. The result of calibration process is summarized in Table 1 while the Root Mean Square Error (*RMSE)* and R-Squared (R^2) indicators are presented for estimating the proximity of simulated and observed data. In all hydrometric stations discharge values of different time steps are simulated and compared to the observed ones. As shown in Table 1, the calibrated model can simulate the Great Karun water resources system accurately. Figure 5 shows the results comparison for all considered stations. The general R-Squared indicator is above 0.95 which indicates a good accuracy of the modeling.

Table 1
The results of calibrated model in distributed hydrometric stations

	Gotvand	Dezful	Bamdezh	Molasani	Farsiat
R^2	0.9372	0.9561	0.9178	0.97	0.9316
RMSE (mcm)	52.43	44.052	82.40	35.39	50.26

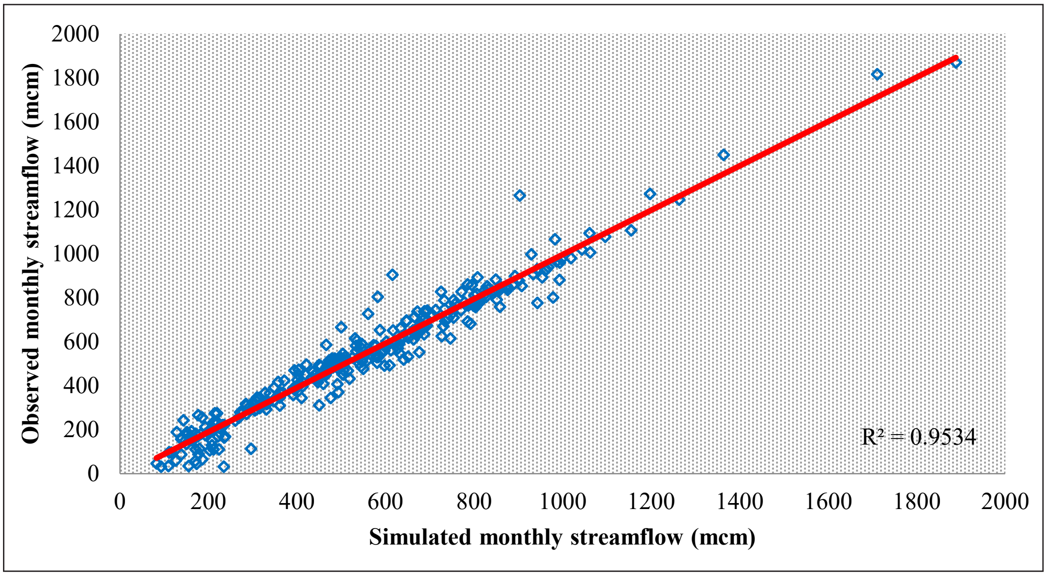

Figure 5. Overall comparison between simulated and observed stream flows in Gotvand, Dezful, Bamdezh, Molasani and Farsiat stations

CONSIDERED SCENARIOS

Water resources system modeling was carried out considering two basic scenarios and four probable scenarios. The basic scenarios are named Scenario 0 and Scenario 00. The probable scenarios were adopted as the proposed solutions to reduce water salinity and enhance the quality of supplied water for critical consumptions. The critical consumptions refer to the water used for drinking purposes in Ahwaz and Abadan Khoramshahr cities that are downstream the intersection of Dez and Karun rivers and are facing the over-salinity problem in some months.

Scenario 0

In this scenario water resources management modeling is carried out regardless the water quality. The results of this scenario form a basic insight about available resources within the system which is helpful to make a fair comparison and understand the effect of water quality on the demand satisfaction process.

Scenario 00

In this scenario the water allocation modeling is performed under water quality constraints for drinking and municipal water demands. The results of this scenario make a good understanding about the real condition of the Great Karun river basin.

Scenario 1

Since the observation data on the study area indicates that the agricultural effluent flowing into Dez and Karun rivers significantly influences the salinity of these rivers, it is possible to improve river water quality by reducing the water consumption in the agriculture sector by new irrigation methods. Hence, assuming a 50% decrease in water consumption using the new irrigation methods, the Dez and Karun sub-basins were modeled in WEAP. Equations 7 and 8 represent the variable changing in scenario 1.

$$WCon(i,t) = 0.5 \times BWCon(i,t) \quad [7]$$

$$ReF(i,t) = \big(1 - WCon(i,t)\big) \times WS(i,t) \quad [8]$$

where, $WCon$ indicates the amount of water consumption, $BWCon$ is the basic consumption rate, *ReF* stands for the amount of return flow, and *WS* is the amount of released water to supply demands. Equation (6) has been formulated for the i^{th} demand site at t^{th} time step. The basic water consumption for different demands is achieved from the observed data or calibration results. Other scenarios executed using the basic consumption values.

Scenario 2

The other solution for reducing the EC factor caused by the agricultural effluent is to treat it before it enters the river. To this end, a scenario was formulated for the construction of treatment plants to treat agricultural effluent in the sub-basins of Karun and Dez rivers and reduce the salinity of the returned flows by 50%.

$$EReF(i,t) = (1 + \alpha) \times EWS(i,t) \quad [9]$$

$$\beta_{S2} = 0.5 \times \alpha \quad [10]$$

$$EReF(i,t) = (1 + \beta_{S2}) \times EWS(i,t) \quad [11]$$

The agricultural impact on the EC factor of river flows is assumed linear (Equations 9 and 11).where, *EReF* is the EC factor of return flows, and *EWS* is the EC factor of released water to supply demands. The α and β_{S2} stand for linear coefficients for modelling the effects of agricultural impacts on EC factor without and with treatment, respectively.

Scenario 3

Since the EC of the water discharged from Dez reservoir is lower than that of the water released from Gotvand Olya reservoir, it determines the quality of the water provided to the Band-e-Ghir downstream region. However, with the transfer of high-quality water from upper Dez branches to other basins, the shares of Khuzestan and Dez rivers of this quality water have decreased dramatically, resulting in a considerable decrease in the quality of water in Dez and Karun rivers. Hence, in another scenario, the effect of reducing the inter-basin water transfer from Dez river branch is studied. To this end, it is assumed that the amount of transbasin water diversion from Dez branches is decreased to 400 mcm/year. It means that the annual transferred water from Dez River is relatively dropped by half. And hence, the effect of increasing the high quality water of Dez River on the demand satisfaction in downstream areas of the basin is considered.

Scenario 4

In this scenario, the effect of the simultaneous implementation of the three previous scenarios on the water quality improvement is studied.

RESULTS AND DESCUSSION

In the Scenario 0, water allocation was carried out regardless of the quality constraint. This scenario was defined to study the effect of system contamination on the satisfaction of demands. The focus of this research was mainly the degree of satisfaction of the drinking and municipal water demands. Figure 6 shows the average monthly satisfaction of different demands based on the last 10-years statistics.

In the simulation carried out for different municipal, agricultural, and industrial uses in Dez and Karun sub-areas, it was found out that the inputs of Dez and Karun rivers are enough for the quantitative satisfaction of all demands in all months and during most

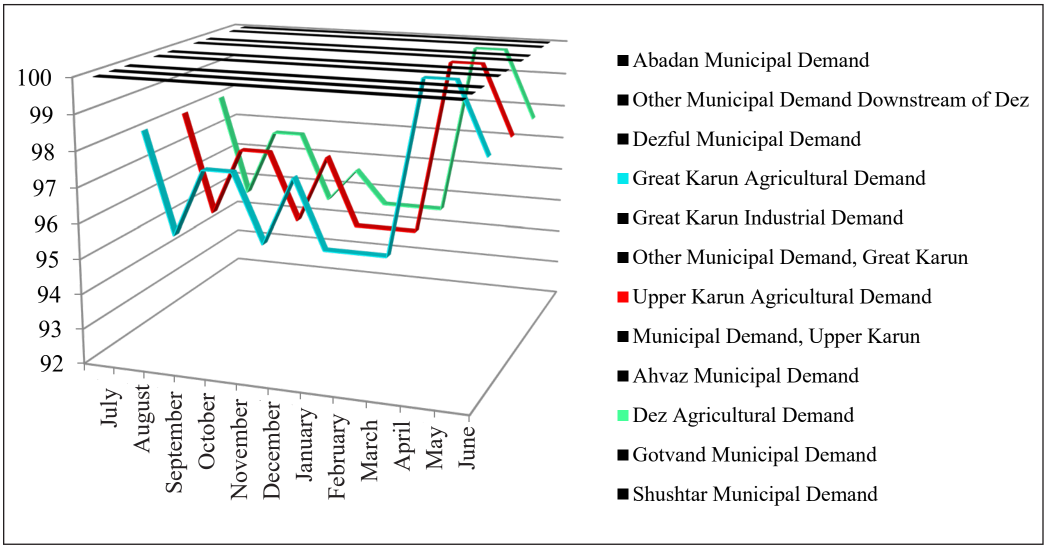

Figure 6. Averaged monthly demand coverage in Scenario 0

simulation years. There were only small shortages in meeting the agricultural demands, which had lower priorities than the municipal needs.

To evaluate the effect of water quality on the demand satisfaction, the simulation was carried out by adding a 2500 μmho quality constraint for the municipal demands. This simulation is named scenario 00. Based on the Iranian water quality standards (Torabian, & Shahavi, 2017) for municipal demands, and in order to maximize the use of available water resources, the water quality threshold is set to 2500 μmho in this study. This threshold is assigned for the quality of river flows with assumption of existing suitable pretreatment before municipal consumptions. The WEAP model does not allocate water to a demand unless the water quality at the point of survey does not violate the minimum limit, which is 2500 μmho. Figure 7 presents the simulation results under this scenario.

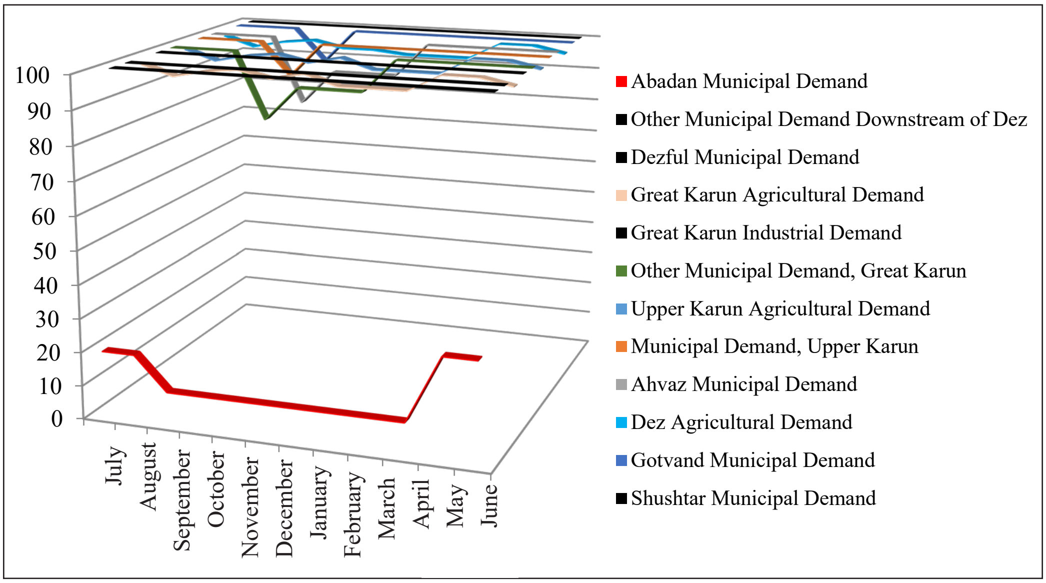

Figure 7. Averaged monthly demand coverage in Scenario 00

By adding adequate quality constraints for different demands, the minimum water quality limit is not met for the municipal water demand of Ahwaz in October, November, December, and January, as well as the municipal water demand of Abadan and Khoramshahr City in all months. Moreover, the municipal water demand of the other cities in the Great Karun sub-basin is not met during October, November, and December due to the high EC values. As seen, the drinking water demands of Gotvand City and other cities downstream Gotvand Olya reservoir, which are placed before the intersection of Karun and Dez rivers, is not met completely during October due to the high EC values of the water discharged from Gotvand Olya in some years of the simulation period.

Under scenario 1, a 50% decrease is observed in the water demands of the agriculture sector and the acceptable quality of the drinking water of Ahwaz City is secured in all months except for October and November. In Abadan, the supply of quality water in most months has increased considerably. Imposing this scenario enhances the monthly average coverage for Abadan municipal demand between 0% and 300% at different months, where the value of EC parameter is decreased between 13% and 29%. Therefore, it seems that reducing the agricultural needs can be a useful solution for improving water quality and providing water quality by reducing the volume of return flow to the river which often is highly unsuitable. However, it does not solve the problem completely.

Modeling under the scenario 2 secured the allowable quality of the water meeting the municipal water demands of Ahwaz City in all months except for October. However, the problem of meeting the municipal demand of Abadan City has not been solved yet and there is a considerable deficiency in this regard. Under this scenario, no improvement of monthly average demand coverage in Abadan city is observed. However, the average value of EC factor improved around 7%. It means that Scenario 2 is not useful in solving the problem of suppling Abadan municipal demand.

Scenario 3 reveals that reducing the amount of Dez River inter-basin water transfer to 400 *mcm/year* supplies the required quality of municipal demand in Ahwaz City in all months, while the municipal demands of Abadan City remains unmet in whole of the year. Under this scenario the minimum improvement of EC parameter in Abadan station is 11% in August and the maximum value of EC improved is 25%. The reduction of EC value causes the enhancement of monthly average coverage for Abadan municipal demand between 0% and 200% in different months.

In scenario 4, the municipal water demand of Ahwaz City is completely satisfied. It was also found out that the quality of water supplied to Abadan City is improved considerably in this scenario. The minimum and maximum improvement of EC factor is around 29% in November and 38% in January and April, respectively. However, the water demands of this city are not fully met in any month. Figure 8 shows the average percentage of the monthly supply of water to Abadan City under different scenarios. The minimum and maximum demand coverage enhancement in Abadan city under Scenario 4 is 150% and 700%, respectively. The minimum enhancement is achieved in May, and June and the maximum improvement is occurred in April, when the agricultural demands reach their maximum values.

As seen in Figure 8, scenario 4 has the highest impact on the increased supply of drinking water to Abadan City due to the concurrent implementation of the three quality improvement scenarios. As compared to the current situation (scenario 00), the implementation of scenario 2 cannot meet the drinking water quality threshold in Abadan City and fails to improve the satisfaction of its needs despite the increase in the satisfaction

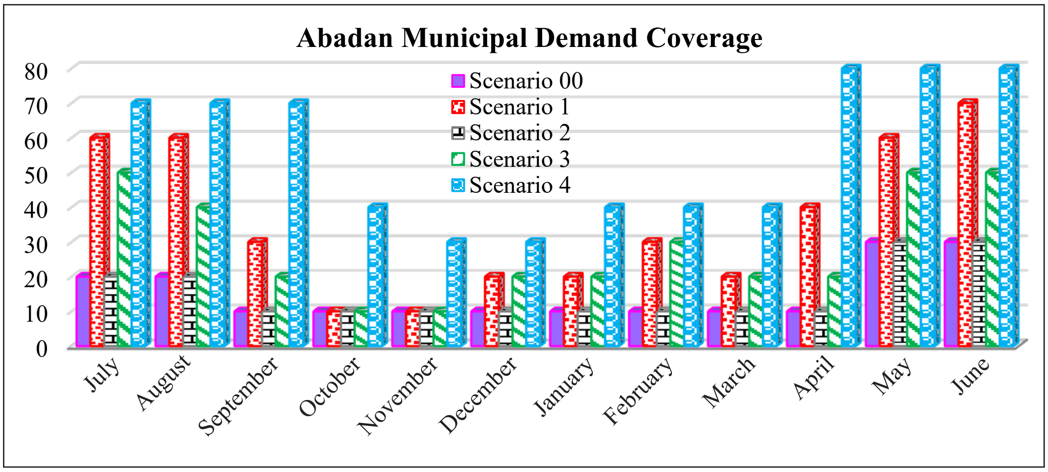

Figure 8. The average monthly demand coverage of Abadan city in different scenarios

of municipal water demands of Ahwaz City and the improvements in water quality in the point of supply in Abadan City. In addition, scenarios 1 and 3 have relatively similar effects on the satisfaction of the drinking water needs of Abadan City in all months of the year except for October, November and February when scenario 1 improved the demand satisfaction rate more. Figure 9 also shows the average monthly EC values of the flow in the simulation period, which confirms the previously mentioned finding.

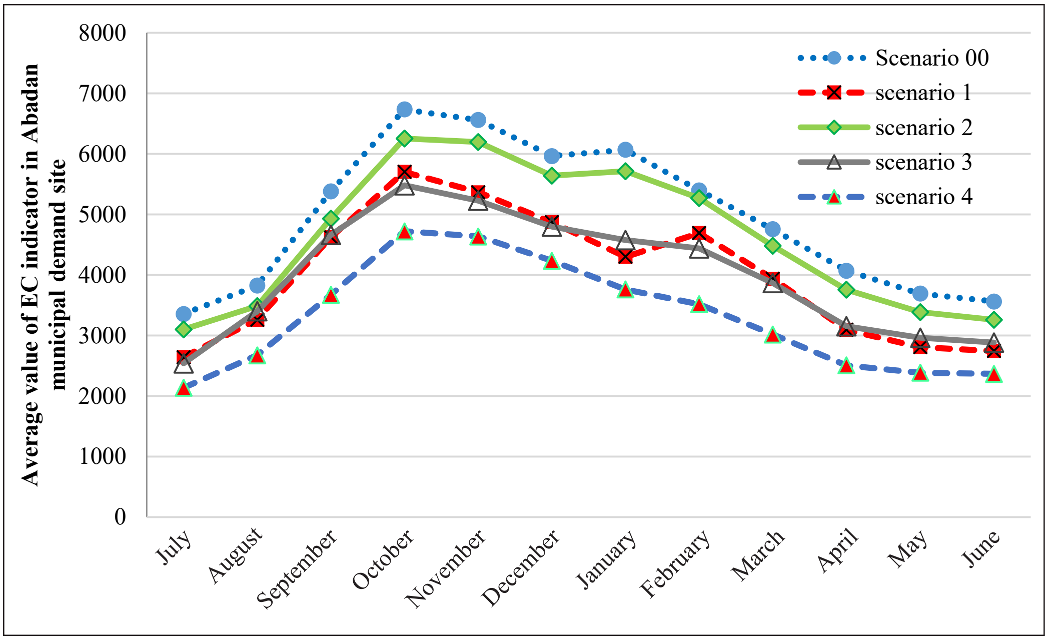

Figure 9. Average monthly value of EC of Great Karun river flow in Abadan municipal demand site

According to the basic concepts of water resources management, enhancing the demand coverage throughout the system results in improving system reliability in a certain time horizon (Hashimoto et al., 1982). It means that, the applied operating strategies which can improve the demand coverage, are able to enhance the reliability of the system.

CONCLUSION

In this research, the water quality of Dez and Karun rivers in Khuzestan was evaluated and the EC index was simulated in WEAP model to evaluate the effect of water quality of these rivers on the satisfaction of the municipal, agricultural, and industrial demands under different scenarios. The results of simulations in different cases indicate that the degree of demand satisfaction in this basin can be changed significantly by the quantitative parameters. In other words, despite the acceptable quantitative flow values the system managers may fail to meet the needs of a region. This has happened several times in recent years in the downstream of Great Karun basin. This is highly important in the disputes over the inter-basin transfer of water. That is to say, the shares of different basins should not be solely determined through quantity flow management as the water quality modeling must also be taken into account. According to the research results, under the existing conditions, it is not possible to fully meet the municipal water demands of the downstream Great Karun basin if the existing hydrologic conditions continue in the future. In this regard, reducing the agricultural water demands in the basin and reducing the withdrawal from Dez branches make the biggest contribution to the satisfaction of the drinking water demands in this basin. Therefore, a 50% decrease in the agricultural water demand, the construction of a treatment plant for treating the agricultural effluent in Dez river sub-area, and the decreased transfer of fresh water from Dez River to other watersheds will significantly improve the current conditions.

ACKNOWLEDGEMENT

The authors gratefully acknowledge all employees of the Environmental Office of the Khuzestan Water and Power Authority (KWPA) who provided insight and expertise that greatly assisted the research although they might not agree with all of the interpretations/ conclusions of this paper. Moreover, the authors are grateful to Dr. H. Hasounizadeh, Mr. E. Mostaghimzadeh, and Mrs. E. Saki for their assistance in gathering the research data.

REFERENCES

Ashrafi, S. M., & Mahmoudi, M. (2019). Developing a semi-distributed decision support system for great karun water resources system. *Journal of Applied Research in Water and Wastewater, 6*(1), 16-24.

Ashrafi, S. M., & Dariane, A. B. (2011, December 5-8). A novel and effective algorithm for numerical optimization: melody search (MS). In *Proceeding of the 11th International Conference on Hybrid Intelligent Systems (HIS).* (pp. 109-114). Melaka, Malaysia.

Ashrafi, S. M., & Dariane, A. B. (2013). Performance evaluation of an improved harmony search algorithm for numerical optimization: Melody Search (MS). *Engineering Applications of Artificial Intelligence, 26*(4), 1301-1321.

Ashrafi, S. M., & Dariane, A. B. (2017). Coupled operating rules for optimal operation of multi-reservoir systems. *Water Resources Management, 31*(14), 4505-4520.

Ashrafi, S. M., & Kourabbaslou, N. E. (2015). An efficient adaptive strategy for melody search algorithm. *International Journal of Applied Metaheuristic Computing*, *6*(3), 1-37.

Ashrafi, S. M., Ashrafi, S. F., & Moazami, S. (2017). Developing self-adaptive melody search algorithm for optimal operation of multi-reservoir systems. *Journal of Hydraulic Structures*, *3*(1), 35-48.

Carmona, G., Molina, J. L., Bromley, J., Varela-Ortega, C., & García-Aróstegui, J. L. (2010). Object-Oriented Bayesian networks for participatory water management: two case studies in Spain. *Journal of Water Resources Planning and Management, 137*(4), 366-376.

da Silva, T. D., & Alves, C. D. M. A. (2016, May 22-26). WEAP and QUAL2K model integration for water quality evaluations as a result of urban expansion scenarios in the federal district of Brazil. In *Proceeding of the World Environmental and Water Resources Congress.* (pp. 330-338). West Palm Beach, Florida.

Dezab, C. E. (2011). *Systemic studies of Dez and Karun watersheds, demands and consumption report*. Ahvaz, Iran: Dezab Company Press.

Ehteshami, M., Biglarijoo, N., & Salari, M. (2014). Assessment and quality classification of water in Karun, Dez and Karkheh Rivers. *Journal of River Engineering, 2*(8), 23-30.

Emamgholizadeh, S., Kashi, H., Marofpoor, I., & Zalaghi, E. (2014). Prediction of water quality parameters of Karoon River (Iran) by artificial intelligence-based models. *International Journal of Environmental Science and Technology, 11*(3), 645-656.

Estalaki, S. M., Abed-Elmdoust, A., & Kerachian, R. (2015). Developing environmental penalty functions for river water quality management: application of evolutionary game theory. *Environmental Earth Sciences, 73*(8), 4201-4213.

Ghassemi, F., Jakeman, A. J., & Nix, H. A. (1995). *Salinisation of land and water resources: human causes, extent, management and case studies*. Wallingford, England: CABI Publishing.

Gitau, M. W., Chen, J., & Ma, Z. (2016). Water quality indices as tools for decision making and management. *Water Resources Management, 30*(8), 2591-2610.

Hashimoto, T., Stedinger, J. R., & Loucks, D. P. (1982). Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water Resources Research*, *18*(1), 14-20.

Heydari, M., Othman, F., & Noori, M. (2013). A review of the environmental impact of large dams in Iran. *International Journal of Advancements Civil Structural and Environmental Engineering, IJACSE, 1*(1), 1-4.

Hosseini-Zare, N., Gholami, A., Panahpour, E., & Jafarnejadi, A. (2014). Pollution load assessment in the soil and water resources: a case study in Karun river drainage basin, southwest of Iran. *European Online Journal of Natural and Social Sciences*, *3*(3), 427-434.

Jafarzadeh, N., Rostami, S., Sepehrfar, K., & Lahijanzadeh, A. (2004). Identification of the water pollutant industries in Khuzestan Province. *Iranian Journal of Environmental Health, Science and Engineering, 1*(2), 36-42.

Karamouz, M., Mahjouri, N., & Kerachian, R. (2004). River water quality zoning: a case study of Karoon and Dez River system. *Iranian Journal of Environmental Health, Science and Engineering, 1*(2), 16-27.

Kerachian, R., & Karamouz, M. (2007). A stochastic conflict resolution model for water quality management in reservoir–river systems. *Advances in Water Resources, 30*(4), 866-882.

Mahmoud, M. I., Gupta, H. V., & Rajagopal, S. (2011). Scenario development for water resources planning and watershed management: Methodology and semi-arid region case study. *Environmental Modelling and Software, 26*(7), 873-885.

Moazami, S., Abdollahipour, A., Niri, M. Z., & Ashrafi, S. M. (2016). Hydrological assessment of daily satellite precipitation products over a basin in Iran. *Journal of Hydraulic Structures, 2*(2), 35-45.

Nikoo, M. R., Karimi, A., Kerachian, R., Poorsepahy-Samian, H., & Daneshmand, F. (2013). Rules for optimal operation of reservoir-river-groundwater systems considering water quality targets: application of M5P model. *Water Resources Management, 27*(8), 2771-2784.

Radmanesh, F., Zarei, H., & Salari, M. (2013). Water quality index and suitability of water of Gotvand Basin at District Khuzestan, Iran. *International Journal of Agronomy and Plant Production, 4*(4), 707-713.

Sun, N. Z., & Sun, A. (2015). *Model calibration and parameter estimation: For environmental and water resource systems*. New York, NY: Springer.

Torabian, A., & Shahavi, S., (2017). Studying Iranian drinking water quality guidelines compared to the authentic world standards. *Journal of Water and Wastewater Science and Engineering, 2*(2), 3-13.