

Original paper

Developing a semi-distributed decision support system for great Karun water resources system

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ABSTRACT

In this study, water resources system of Great Karun watershed is modelled as a semi-distributed system considering the diversity of demand sites downstream of Olya Gotvand and Dez reservoirs in southwest of Iran. The main aim of the present study is to develop a basin's decision-support system to assist decision-makers in examining the impacts of different operating policies prior to their implementation. According to the basic characteristics of the system, a decision-support system is developed applying water evaluation and planning system (WEAP) model. Calibration of the developed model is important based on the Demand sites diversity and the spatial scale of the modelled basin. To calibrate the simulation model, a Harmony Search (HS) Optimization Algorithm is applied in an innovative framework. The comparison of the achieved results with the observed data indicates the accuracy of the calibrated model. It is also clear that, regardless of the quality parameters of the flow, all urban, industrial, agricultural and aquaculture demands at the basin level have been satisfactorily fulfilled in the study period. Of course, it should be noted that by taking into account the qualitative criteria, the obtained results will obviously change.

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1. Introduction

The use of decision-support models is essential for proper and efficient management of complicated multi-reservoirs systems. Recently, it has been proven that one of the key points of integrated management of water resource systems is adopting software packages that model whole of the system continuously and using the novel technologies and connecting to climate, meteorological and hydrologic forecasting models to help system managers.

Unfortunately, in Iran, operation of such systems is not commonplace even for the most important and challenging basins, such as the Great Karun river basin, and even it can be seen that the operational policy of reserves is often extracted in a localized and cross-sectional manner without regard to the interactions of other components. This causes a lot of clear and latent costs for the management of the basin. Despite of the many hydrological and hydraulic models that have been provided for different basins in Iran (Moazami et al. 2016), water resources systems suffer from the lack of proper vision of implementation consequence of different management strategies. In the presence of a coherent and intelligent (or semi-intelligent) computer system that can perform scientific and technical modeling by using various data related to the whole system and by combining it with efficient management models show the implementation results of several different policies of exploitation can eliminate many of the damages or reduce their severity before they are applied to the system.

The Great Karun river basin is the biggest watershed in Iran, which not only plays a very important role in the development of beneficiary provinces, but also has been transformed into national capital with water transmission plans, such as Dez-Qomroud and its place in providing national energy network. While the numerous stakeholders are waiting to benefit from the system's resources, being multi-reservoirs and multi-purposes, makes the management of the system more complex (Labadie. 2004). The main objective of this

research is developing an appropriate decision-support system to facilitate the identification of all components of the water resources system of Great Karun river basin and their interactions. Due to the lack of previous applied studies on the development of dedicated decision-support systems for the Great Karun, this plan can be considered as a prelude to this context, which can be used in future development plans. Since, contrary to other previous developed models, the main focus of the model development in this research is on the accuracy of the modeling of distributed demands through the basin. This model provides sufficient insight on consequences of different operational policies or any changes in the system configuration for decision-makers and can be considered as the basis for developing wider and more efficient models for better management of the water resources management. Using such a decision support system, we can estimate the severity of deficits more precisely for different demands and evaluate the impact of shortages in different demand categories. Another advantage of using such a system is that by implementing quality models within the provided DSS, system failures can be identified due to low flow quality. In recent years, despite of availability of sufficient water resources, satisfying municipal and agricultural demands downstream of the basin have been impossible due to low water quality.

To consider the literature of related works in Iran, the following categories can be presented. Most of the water resources models applied in Iran have been developed based on the integrated demand sites and regardless of the diversity of the demand sites throughout basins (Afzali et al. 2008; Abadi et al. 2015; Abrishamchi and Tajrishi 2005; Ahmadi Najl et al. 2016; Kim and Heo. 2006) while to determine the exact consequences of the adoption of management policies, the distribution of demand sites at the basin level must be sufficiently considered (Ashrafi and Dariane. 2017). Many studies on Karun's basin have been conducted focusing on qualitative issues (Emamgholizadeh et al. 2014; Semiromi 2011; Keshavarzi et al. 2015). The operation of the system was not as the main aim of these

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studies, where the modeling was usually carried out based on the hydraulic and qualitative simulations (Afkhami et al. 2007 b; Hosseini-Zare et al. 2014). These studies are conducted either regardless of how the demands were distributed through the basin or with regard of demand sites distribution, but the operating policy of the system was not a component of the study objectives (Nahvi et al. 2018; Afkhami et al. 2007a). Many studies have been carried out in Iran's basin to investigate the impacts of climate change on water resources and to estimate their results (Moazami et al. 2016; adib et al. 2018; Dehghani et al. 2014). In these studies, the optimal policy of water resources operation is not considered and accurate calculations with acceptable details are not carried out in this regard. Some other studies have been conducted using hydrological and hydraulic models (Afzali et al. 2008; Nikouei et al. 2012; Afkhami et al. 2007a; Hosseini-Zare et al. 2014; Assani et al. 2011). In such studies, water resources system management and impact of different strategies on system performance is not discussed. In most of these studies, details of water resources systems and demand distribution within the basin are either not considered or modeled briefly with very few assumptions. Also, to solve existing disputes over inter-basin water transfer, several studies have been carried out using simulation and optimization models of water resources systems (Toosi and Samani. 2014; Safavi et al. 2015; Abed-Elmdoust and Kerachian. 2014). In most of these studies, the main goal is to divide the water between adjacent basins based on the overall benefit of each basin or criteria for the lumped demands of the basin. Therefore, details of flow distribution at each basin level and dispersion of consumption sited in each region were not considered.

It should be noted that the development of semi-distributed models for the simulation of water resource systems in other countries has been carried out for various purposes (Ashrafi et al. 2017; Sulis. 2009; Bastiaanssen. 2005; Mysiak et al. 2005; Giupponi. 2007; Parkinson et al. 2018). Unfortunately, in Iran, such a model has not been developed even for very important water resources systems in the country (e.g. Great Karun river basin).

2. Semi-distributed water resources system

Fig. 1 is presented to describe the proposed approach in developing a semi-distributed water resources system for great Karun river basin. In this Fig., different parts of the research are illustrated as a flowchart/diagram to declare the structure of the applied methodology.

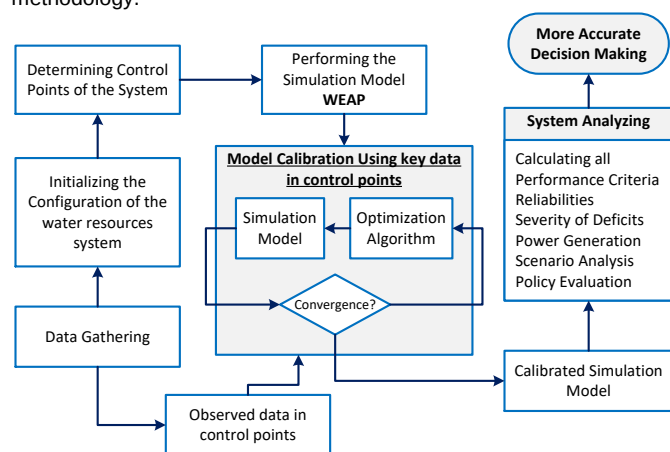


Fig. 1. The flowchart of the proposed approach.

In this section, the configuration used to develop the simulation model is described briefly. In configuring general schematic of the water resources system, the control points including: basin and sub-basin inflows, withdrawal nodes, and hydrometric nodes are very important to control the model accuracy. Moreover, the location and rates of modeled return flows of some consumption elements, such as agricultural networks are effective in forming an accurate behavior of the system. Different withdrawal nodes are embedded within the simulation model for various consumption elements, such as agricultural networks, municipal demands, aquaculture farms, industrial demands and water transmission canals. The various types

of elements considered in the simulation model are described in Table 1. As shown in Table 1, the studied system is a complex and large-scale water resources system while, various challenges should be tackled to simulate and optimize the system. Fig. 2 shows the schematic representation of a modeled water resources system along with the location of Great Karun basin. In water resources management, supply of drinking water has priority over the agricultural demands. The position of the hydrometric stations used to monitor and control the modeling results is presented in Fig. 2. The control points available on the route of Karun and Dez rivers include the entry points of water to the river and the output points from the river, which these points are often considered as storage reservoirs, regulating dams, diversion dams, drains and water transmission canals. In this study, both Olya Gotvand reservoir on Karun River, and Dez reservoir on Dez River are the beginning control points at the basin. Hydrometric stations are other control points that can provide useful data during the calibration process. The calibration is carried out to determine the correctness of the location and values of different modeled demand sites, suitable values of parameters and accurate operating policy of the system elements. Table 2, represents the characteristics of the storage reservoirs and hydropower plants of the system. Moreover, there are two regulatory reservoirs, downstream Dez and Olya Gotvand reservoirs to regulate the power plant outflows over daily time steps.

Table 1. List of the considered system elements.

Element type	Element	Number of elements in the modeled configuration of the system
Regulator	Storage reservoir	2
Regulator	Regulatory reservoir	2
Regulator	Hydropower plant	2
Regulator	Diversion canal	3
Regulator	pump station	1
Resources	Head flow and sub-basin flow	15
Resources	Ground water node	6
demand site	Municipal distribution network	9
Demand site	Irrigation network	17
Demand site	Fish hatchery demand	11
Demand site	Local irrigation water right	11
Demand site	Industrial demand	8
Demand site	Mixed industrial and municipal demand	1
Check point	Hydrometer station	10
Auxiliary node	Withdrawal node	58
Auxiliary node	Return flow	22

In order to prevent the salinity expansion in downstream of Karun river, the Mared canal is supposed to transfer 48 cubic meters per second. Also, Karkheh Spill Canal is designed to transfer up to 500 mcm per year from Dez river basin to Karkheh river basin. This Canal can be active only in wet seasons, while the basin inflows exceed the normal trend.

2.1. Development of the simulation model

Based on the configuration presented in the previous section and available data, the system simulation model was developed in WEAP environment and calibrated using validation algorithms. In the provided model, different kinds of demands such as municipal, agricultural, aquaculture, industrial demands, and inter-basin transmissions, are supplied considering different priorities. Also, basin head flows, sub-basin inflows, demand return flows and flow losses in different intervals are considered as the key variables of the simulation model. For the great Karun river basin this is the first model that has been extended to this level of details.

Calibration can be assumed as determining and correcting the values of coefficients and parameters of a model according to the available

data of the system. The calibration is based on search algorithms that determine the values of the model parameters (θ) in such a way that the model results have the highest compliance and consistency with observations. The important point is that water resources models cannot be expected to accurately and fully comply with the past behavior of the system. It is because of that the system's historical management is not necessarily based on the principles of management assumed within modeling and many basic assumptions

about model development can be violated in real-world. Therefore, in model calibration of water resources, getting a percentage of accuracy that indicates the correct implementation of the basin schematic and determines the approximate values of the model parameters is sufficient. Therefore, the observational discharges at the control points can be compared to the calculated ones in order to calibrate the model.

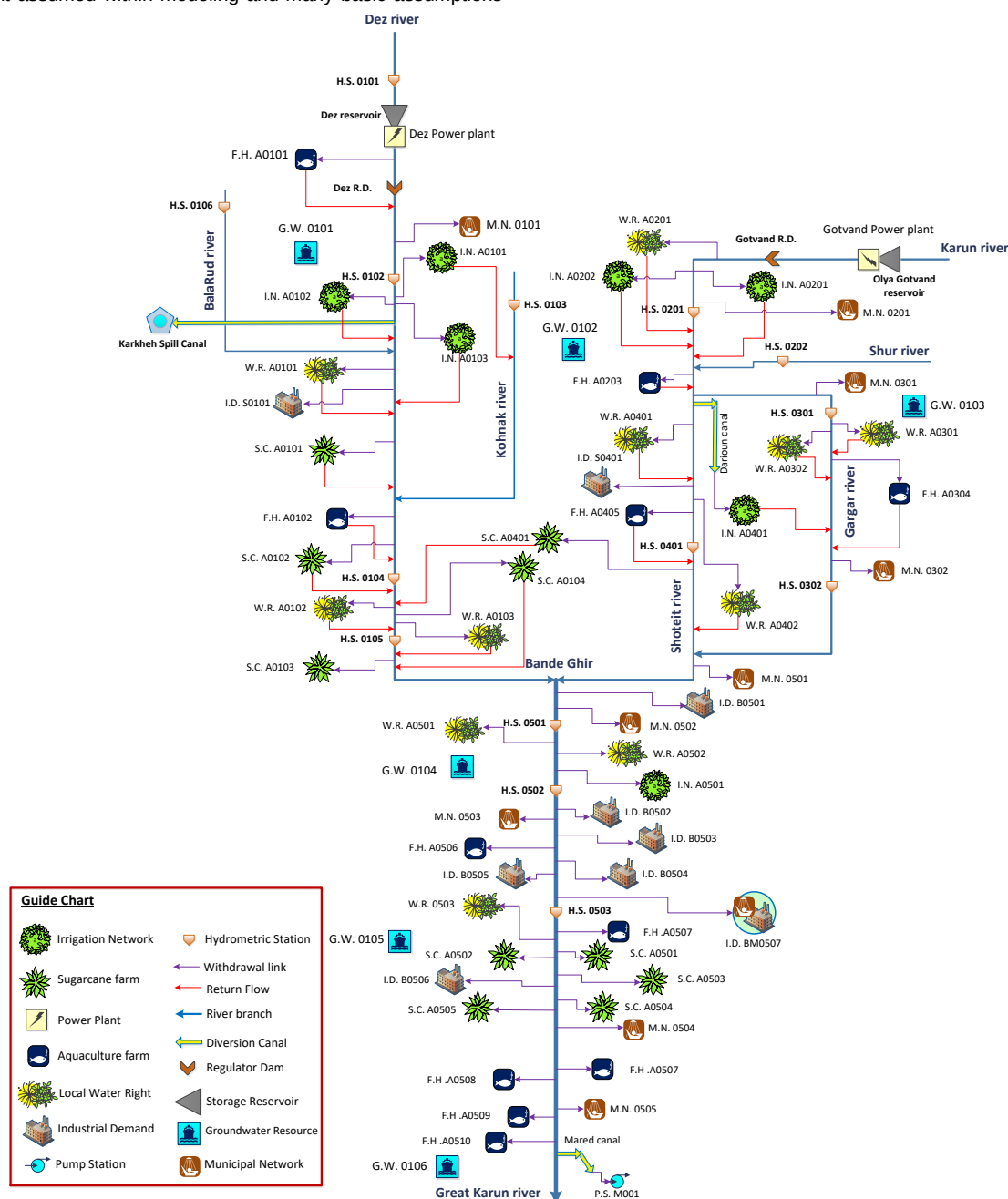


Fig. 2. The schematic of great Karun water resources system.

Table 2. Characteristic of system reservoirs and power plants.

	Dez reservoir	Olya gotvand reservoir
Area of upstream basin (Km ²)	17430	32425
Mean annual inflow (cms)	257	466
Normal water level (masl)	352	230
Minimum operation level (masl)	310	185
Dead storage (mcm)	117	1126
Active storage (mcm)	3050	2048
Plant capacity (MWH)	1500	520
Power plant efficiency (%)	93	89

Fig. 3 illustrates the monthly average inflows of the system recorded throughout the studied horizon. As shown, the main basin inflows belong to Dez and Karun rivers. Although, sub-basin inflows are ignorable, in this research all resources are simulated within the proposed model.

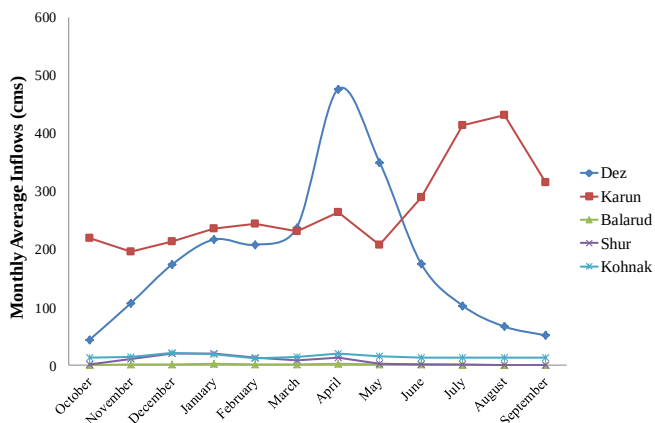


Fig. 3. The monthly average inflows of the system.

The adjustable parameters in calibration process are: demand allocation priorities, the percentage of flow consumption and return flows and the percentage of diverted flow at the division node of Gargar from Karun. The applied hydrometric stations within the calibration process can be listed as follows; Dezful, Harmaleh, and Bamdejh stations at Dez river, Gotvand, Shushtar, Arab Hassan, and Vali Abad stations at Karun river, and Molasani, Ahvaz and Farsiya stations at Great Karun river.

2.2. WEAP model as a generic computational tool

Water evaluation and planning system (WEAP) is a scenario based simulation tool for integrated simulation and analyzing water resources systems which was developed by the Stockholm Environment Institute (SEI). As a simulation tool, WEAP incorporates supply and water demand management, water quality, and ecosystem preservation and protection values into a water resources planning and policy analysis tool (Kaddoura, and El Khatib, 2017). WEAP is an object oriented, programmable software that provides integrated water management modeling and can be used in urban and agricultural systems in a catchment area or in complex multi-reservoir systems consists of several river basins. The ability of performing integrated modeling can be accounted as the main advantage of WEAP where, the developed model is a suitable laboratory for testing various development and management strategies. As a policy analysis tool, WEAP evaluates the full range of water development and management alternatives, and includes multiple and competing uses of water systems in computing. WEAP uses a standard linear programming model in two sub-steps for solving water allocation problems at any time step (Stockholm Environment Institute, 2015a). The objective function is maximizing of the supply percentage of requirements of demand sites in accordance with the predefined priorities, mass balance, and other constraints. All constraints are considered consequently in each time step and according to the priorities of different resources and demand sites.

The applied approach for water resources modeling in WEAP consists of the following steps (Sieber and Purkey, 2015): System set up: definition of the time and spatial boundaries, components, and configuration of the system. WEAP is able to perform in a wide range of time steps (from one day to one year is acceptable). Current accounts set up: current amount of demands, available resources, and supply should be presented in a static form. It is necessary to define and start different scenarios. Scenario analysis: different probable alternatives of management policies, costs, and climate change and their future impacts can be considered in the form of scenarios. Evaluation: regarding sustainable water consumption, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables, different scenarios are evaluated (Kaddoura and El Khatib, 2017).

Recently, based on WEAP capabilities, its application has been raised in the field of energy and water resources planning and analyzing operation strategies (Sun et al. 2018; Hund et al. 2018; Kaddoura and El Khatib, 2017; Dodder 2014). The most important advantage of WEAP is that, the user can control the level of detail of the data structure to make an up to dated model based on the available information. Also, users are allowed to provide WEAP models based on the user defined variable sets and equations for modeling unique local conditions which are not common. Moreover, the full version of WEAP is free to use for non-profit, governmental, or academic institutions based in a developing country (Stockholm Environment Institute, 2015b).

2.3. Proposed calibration approach

Due to the high dimensions of the studied problem, the proposed algorithm for adjusting the model parameters faces serious challenges. Hence, a specific dimension reduction strategy is applied in this study to reduce the complexity of the optimization problem. In such problems, more efficient search methods can achieve more accurate calibrated models (Ashrafi and Kourabbaslou, 2015). Fig. 4 schematically shows the proposed approach.

The calibration model can be defined in the form of an optimization problem as follows:

$$\theta = \underset{\theta}{\arg \min} \|u_D(x, P, \theta) - u_D^{obs}\|, \quad \theta \in P_{ad} \quad (1)$$

where, θ is the adjustable parameters, u_D^{obs} indicates the observed data, $u_D(x, P, \theta)$ is the model output where x, P , and θ are the vectors of model input variables, fixed parameters of the model and adjustable parameters, respectively. As shown in Fig. 4, the model parameters are divided into three independent categories. To initialize the simulation model, all model parameters are determined by those logical values (more probable value of each parameter). Each category of parameters is calibrated at a separate calculation phase.

Calibrated parameters of each phase are entered into the next stages as fixed values of model parameters and are used to optimize the parameters of the next phases. The obtained values of the three calibration phases are not certainly optimal, since the obtained values for each category of parameters are based on the specified fixed values of others. These values are considered as an appropriate initial solution for the original calibration problem. The set of obtained values of parameters are entered into an overall simulation-optimization model in which all the parameters are adjusted simultaneously to find the coordinated values. This model converges rapidly and finds optimal values of parameters. Accordingly, the equation 1 can be transformed into equation 2.

$$\theta_k = \underset{\theta}{\arg \min} \|u_D(x, p_k, \theta_k) - u_D^{obs}\|, \quad \theta_k \in P_{ad}, \quad k=1, 2, 3 \quad (2)$$

$P = \{\text{Known parameters, unknown parameters}\}$
 $p_k = P - \{\theta_k\}$

In each calibration phase, the adjustable parameters of the model (θ_k) are considered as the decision variables of optimization model. Other parameters of the model (p_k) are fixed value parameters while those have been optimized in previous phases or assumed equal to the initial values. The objective function of the optimization model can be accounted in hydrometric stations of the system based on the calculated and observed flow rates. Therefore, equation 1 is implemented as follows:

$$\min (\text{Max RMSE}_j), \quad j=1, \dots, m$$

Subject to:

$$\begin{cases} \text{All constraints adopted within the simulation model} \\ \text{All constraints imposed by the operating strategy} \end{cases} \quad (3)$$

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

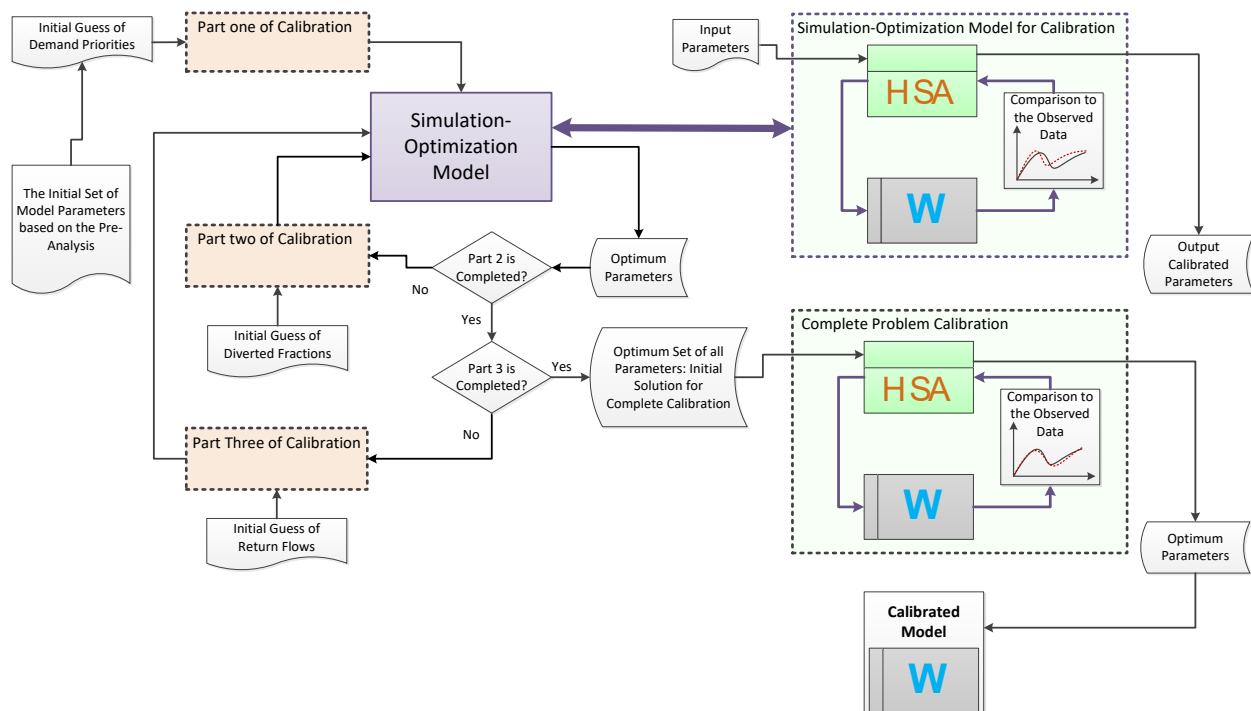


Fig. 4. The flowchart of the proposed calibration approach.

where, N_j is the number of recorded observations in j th station, $(Q_{\text{model}})_i^j$ and $(Q_{\text{obs}})_i^j$ indicate the i th calculated and observed data at the j th hydrometric station, respectively. Harmony Search (HS) algorithm is applied to optimize the problem. The Harmony Search algorithm has been developed as a meta-heuristic search method inspired by the processes of the minds of the musicians when creating a new harmony (Ashrafi and Dariane 2013). To start the search process in HS, an archive named Harmony Memory (HM) with a certain number of harmonies that are generated randomly within the variables possible range is formed. In order to improvise new harmonies (identical to new solution of the optimization problem) some operators are defined for simulating the improvisation processes, which can be described as follows; in Harmony Memory Consideration Operator, for each new variable within a new solution, any of the corresponding variables can be selected randomly from the stored harmonies in the memory. This process is controlled by a parameter (HMCR), which determines the memory consideration rate.

$$x_{\text{new},j} \in \{x_{1,j}, x_{2,j}, \dots, x_{\text{HMS},j}\}, \quad (4)$$

with probability HMCR for $j=1, \dots, D$

where, $x_{\text{new},j}$ is the j th variable of the new improvised solution. In this equation, according to the pitch adjusting operator, the selected notes of the memory can be slightly changed randomly and then be implemented within the new improvised harmony. The rate of modified variables in each new solution is controlled by pitch adjusting rate parameters (PAR).

$$x_{\text{new},j} = x_{\text{new},j} \pm bw, \quad (5)$$

with probability (PAR×HMCR) for $j=1, \dots, D$

where, bw named bandwidth distance and determines the scale of variable adjustment. Through the operator of Randomization, new variables randomly created in their possible ranges as follows;

$$x_{\text{new},j} \in [LB_j, UB_j] \text{ randomly}, \quad (6)$$

with probability $1-\text{HMCR}$ for $j=1, \dots, D$

where, LB_j and UB_j determine the lower bound and upper bound of possible range of the j th variable. More details about HS algorithm can

be found in the main references (Geem and Sim. 2010; Ashrafi and Dariane. 2011; Ashrafi and Kourabbaslou. 2015).

2.4. Hydropower generation

In WEAP software, hydropower generation is calculated based on the amount of flow passing through the turbine and the capacity defined for the maximum turbine flow. For river reservoirs, it is assumed that all demand sites are modeled downstream of the reservoir, so the entire flow released from reservoir is considered as a flow passed through the turbine. The flow passed through the turbines is limited by the maximum turbine capacity and the maximum produced energy with respect to the passed flow in a certain time step. If the released water exceeds the maximum turbine capacity, its surplus value is considered as overflow and is not included in the calculations of energy production. Therefore, the flow passed through each time step is calculated as follows (Sieber and Purkey. 2015).

$$\text{Release (Node)} = \text{Down stream outflow (Node)} \quad (7)$$

It should be noted that, if the output flow exceeds the output capacity of the turbine in each time step, it is assumed that the surplus flow is released from the spill and does not generate energy. As a result, the amount of flow passed through the turbine for generating energy is limited to the following quantities.

$$\text{Volume through turbine (Node)} = \text{Min} [\text{release (Node)}, \text{max. turbine flow (Node)}] \quad (8)$$

The mass of flow passed through the turbine in each period (kg) based on the volume of discharge flow from the reservoir (m^3) is calculated as follows:

$$\text{Mass through turbine KG (Node)} = \text{Volume through turbine (node)} \times 1000 \text{ (kg)} \quad (9)$$

Generated energy in the whole time step (e.g. a month) is calculated in GJ from the following equation;

$$\text{Energy full monthgj (Node)} = \text{mass through turbine kg (node)} \times \text{drop elevation (node)} \times \text{plant factor (node)} \times \text{plant efficiency (node)} \times 9.806 / 1,000,000,000 \text{ (gj)} \quad (10)$$

The flow head for reservoir plants is also obtained from following equation.

$$\begin{aligned} \text{Drop elevation (Node)} &= \text{Average elevation (Node)} \\ &- \text{Tail water elevation (Node)} \end{aligned} \quad (11)$$

$$\text{Average elevation (Node)} = 0.5 \times (\text{Begin month storage (Node)} + \text{End month storage (Node)})$$

In the flow plants, the flow head on the plant is a constant value that the user enters it:

$$\text{Drop elevation (Node)} = \text{Fixed head (Node)} \quad (12)$$

The energy loss during water and power transmission system is assumed equal to 3 m and 4.5 m for Dez and Olya Gotvand power plants, respectively.

One of the key parameters required hydropower generation calculation is the plant factor of power plants. Unfortunately, in Iran, hydropower plants do not generate energy based on the scheduled, derived from a predefined water resources management strategy, but their management is based on the demand of a short term energy market schedule. Therefore, varies in different years and seasons. In order to make a simulation close to the reality of the plant's operating schedule, it is possible to calculate the plant factors based on their actual performance. Here, using ability of automating WEAP software, an iterative algorithm is implemented in the VBScript environment based on the API of WEAP.

3. Results and discussion

The results of the calibrated model represent the ability of the proposed algorithm to calibrate the simulation model of the Great Karun river basin. The simulated flow at the boundary hydrometric stations of the system is shown in Fig. 5.

It can be revealed that the obtained results are good and quite satisfactory for calibration of the model and indicate the validity of the basic assumptions of the developed model. Generally, in water resource modelling, the following factors prevent the complete compatibility of the simulated results with the historical perceptions of the system; The water allocation policy and the priorities considered in the model are not exactly implemented in reality. Usually, the water demands are modeled as fixe values with specified within-year variations. So, yearly and seasonally changes, which occur in reality,

are neglected in modelling process due to lack of information. The amount of different water demands is estimated values and the differences with the actual values cannot be accounted from the available data. The system water loss in different periods are not estimated and reported in any previous report, so it cannot be evaluated in the model correctly.

There is no information about the interaction of surface and groundwater resources in different time steps throughout the watershed. Information on short-term operating policies that have been applied at the time of occurrence of extreme events (e.g. flood, severe drought) are not available. Therefore, these events cannot be modeled within a long term water resources simulation model.

A summary of the simulation results of the system in the base period is presented in this section and analyzed. It can be seen that Dez reservoir has been empty 20 % of months and has been full 3 % of total months. Also, Olya Gotvand reservoir has been completely empty in 7 % of the months and has never been filled. The summary of the reservoirs performance criteria is given in Table 3.

The average monthly storage of Dez reservoir only in four months (March, April, May, and June) exceeded the half of reservoir active storage. While, the average monthly storage of Olya Gatvand reservoir has occupied less than half of the active storage of the reservoir in all months. This should be mentioned that the simulated time interval covers the filling period of Olya Gotvand reservoir that can explain such behavior of the reservoir storage.

In this study, drinking and urban demands have been completely met in all months according to their predefined priorities. Hence, the reliability and quantitative reliability indicator for all municipal demands throughout the system was achieved equal to 100 %. All of the industrial demands, except the Dez sugarcane industries (which reliability is equal to 88 %), have been satisfied with the reliability over 90 %. For Dez sugarcane industries the quantitative reliability is calculated equal to 90 %. The water demands for aquaculture during the entire period have been fully met with over 90 % reliability. The least reliability is related to Andimeshk's fish hatchery site, which is 90 %. The quantitative reliability of this requirement is 94.5 % and the reason for its low reliability is the mismatch of the monthly distribution of this requirement with the natural regimes of the river discharge, which in the periods of low water and vacancy of the reservoir leads to a lack of full supply. The highest reliability is related to the Choebdeh shrimp hatchery farm near Abadan, which was supplied with 100 % reliability, since due to the minimum control of the environmental flow required at downstream of the Karun, there has been sufficient water to meet it.

Table 3. Reservoir performance characteristics.

Index	Dez Reservoir	Olya gotvand reservoir	Unit
Maximum storage	3174	4671	mcm
Dead storage	1126	1610	mcm
Averaged monthly storage	1778	2885	mcm
Averaged monthly water level	325	207	masl
Averaged annual evaporation	65	111	mcm
Filling percentage	3	0	%
Empty percentage	20	7	%
Maximum monthly storage	3174	4112	mcm
Minimum monthly storage	1126	1610	mcm
Hydropower plant capacity	520	1000	MW
Hydropower plant factor	16	14	%
Hydropower plant efficiency	89	93	%
Averaged annual power generation (Firm)	705	1189	GWH
Averaged annual power generation (Secondary)	1107	1110	GWH
Monthly power generation reliability	97	97	%

As explained above, the water requirements of irrigation networks and sugarcane development and the traditional water rights, have the same preference in terms of the system managing, and based on the location of demands (e.g. being upstream or downstream in the flow direction) their supply priorities have been determined by the optimization model. It can be seen that all these demands have been satisfied with over 90 % reliability. Also, quantitative reliability of all these demands is at an acceptable level and around 95 %. Interestingly, the agricultural demands of Dez river, including

traditional water rights, irrigation networks and sugarcane water demands, have all been met with less reliability (about 90 %) compared to the other areas of the system (i.e. Karun river, and Great Karun river). It is due to the lower natural river flow rate of Dez river compared to Karun river. For the agricultural demands in Dez river sub-area, the quantitative reliability is about 95 %, indicating that little shortages have been happen for these demands during drought periods.

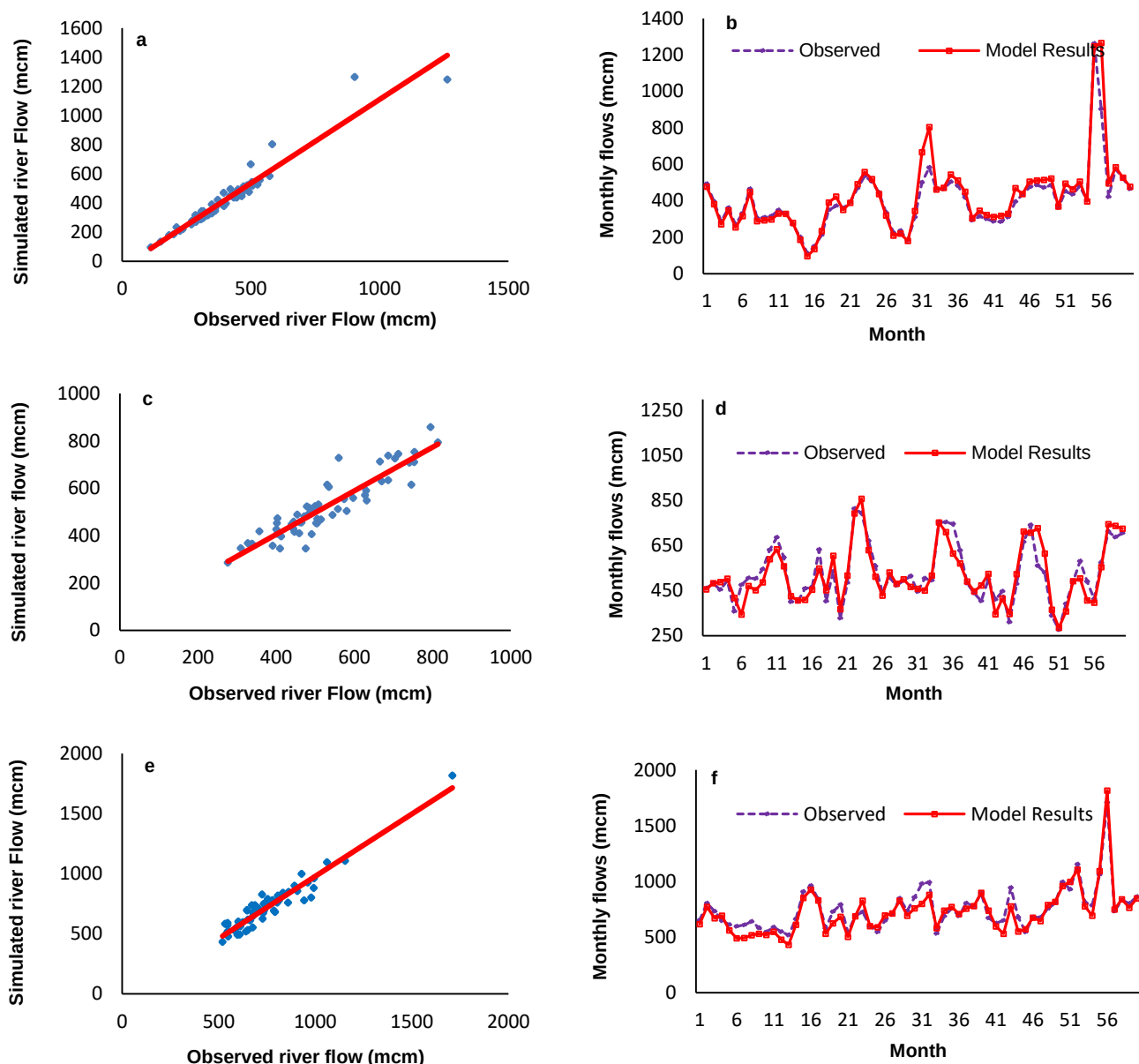


Fig. 5. The result of comparison between simulated and observed data at hydrometric stations. a) Linear regression in Dezful station, b) Streamflow in Dezful station, c) Linear regression in Gotvand station, d) Streamflow in Gotvand station, e) Linear regression in Farsiat station, and f) Streamflow in Farsiat station.

Fig. 6 shows the average monthly energy production graph. As it is known, the average monthly energy production of the entire system in the spring and summer is more than other times of the year. This is due to the high agricultural, municipal water demands during the aforementioned months, where the system management would prefer to produce energy from released flows. Due to the climate of the Khuzestan region and the tropical nature of the basin, the demand for hydroelectric energy in summer is at its highest level, and therefore more energy production in this period will be considerable.

Another point that is important in managing any water resources system is the annual and monthly output flow of system. In the developed model, the elements of the Karkheh Spill Canal, the Mard Canal and the Haffar river branch are considered as the output points of the Great Karun Basin. As Karkheh Spill is supposed to transfer the surplus flow of Dez basin to the Karkheh basin, it has the last priority in supplying demands. Also, since no specific distribution at the consumption point is specified, the model tries to make this transition uniformly. The demand of the Karkheh Spill was assumed as 500 million cubic meters per year, which is seen to be an average annual transfer of 429 million cubic meters per year. The most monthly transfer values are from December to July. The defined requirement

for Karkheh Spill has been met regularly during the simulation period, except for three time intervals when it has been coincided with the periods of emptying the Dez reservoir.

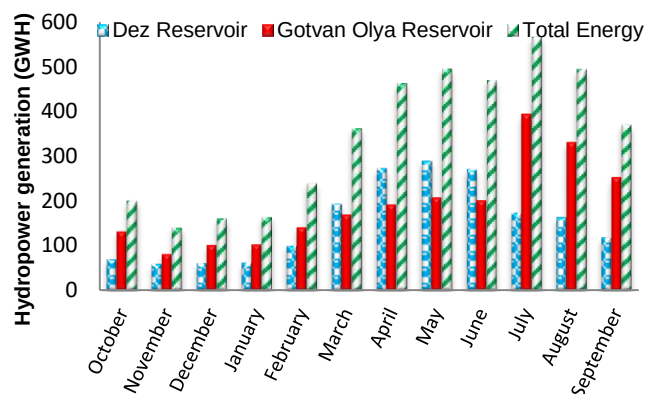


Fig. 6. Average monthly power generation.

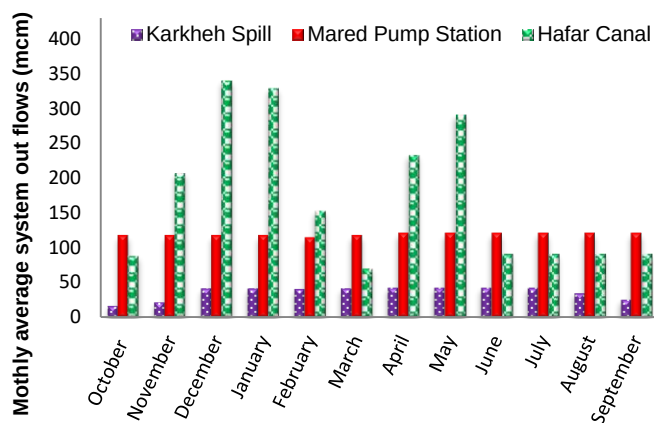


Fig. 7. Average monthly outflows of the Great Karun river basin.

4. Conclusions

In the present study, the water resources system of Great Karun basin, including Dez, Karun and Great Karun river basins was modeled semi-distributed with a smaller special scale than the conventional simulation models. The decision-support system was developed in the WEAP software environment. In this modeling, the diversity of demands throughout the basin is much closer to reality than the past modeling. With realistic consideration of the demand diversity throughout the basin, it is possible to estimate the amount of loss of the resources within the system (due to evaporation, infiltration, etc.), and thus to yield more realistic results. This reduces the amount of decision makers' error in different probable conditions. It should be noted that in such models due to the increase in the number of model parameters, the calibration of model becomes more complicated and more important compared to the models with lumped demands. In this research, an innovative approach is used to calibrate the model with sufficient accuracy. In the proposed approach an optimization-simulation model including Harmony Search Algorithm was applied. The development of such a model for the first time is done for the considered basin and can help decision-makers to make decisions in the most probable circumstances ahead. The results show that in the considered period, all municipal demands of the system have been met with 100 % reliability, agricultural and fish hatchery demands with 90 % reliability, industrial demands with 90 % reliability. In the meantime, the least reliability was related to the sugarcane development industry in Dez river. The least amount of

supply was related to Karkheh Spill Canal, which has not been satisfied for all years and the annual average of supply is 85 %. The amount of Hydropower generation can be estimated in such a system, and the total system output is also calculated. Lastly, it should be noted that these amounts of supply, are regardless of the qualitative conditions of the flow. The advantage of using the developed model is that there is ability to add a qualitative simulator model to it, in which case it is possible to calculate the allocation values by considering the qualitative conditions. Also, this model can be used to extract system reservoir operating rule curves with high precision. These mentioned issues are among the necessary points of the future studies.

Nomenclature

DSS	Decision support system
SEI	Stockholm environment institute
WEAP	Water evaluation and planning system
PPC	Power plant capacity
Pf	Plant factor
E	Power plant efficiency
GJ	Giga joule
GWH	Giga watt hour
MW	Mega watt
Cms	Cubic meters per second
Mcm	Million cubic meters
Masl	Meters above sea level
HS	Harmony search
HM	Harmony memory
HMCr	Harmony memory consideration rate
PAR	Pitch adjusting rate
Bw	Bandwidth distance
LB	Lower bound
UB	Upper bound
Obs	Observed
RMSE	Root mean square error
HP	Hydro power
HMS	Harmony memory size
D	Dimension of optimization problem

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