Scenarios Evaluation in Water Resources Management in the Standpoint of System Sustainability and Conflict Resolution Theory

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Abstract: scenarios evaluation in water resources planning and management has done by the objective of increasing efficiency and systems sustainability and decreasing probable conflicts. Development and Simulating of the scenarios based on the results of the optimization model that optimize the reservoir rule carve by Genetic Algorithm. Sustainability indicators and conflict resolution theory, implemented the evaluation of them. Results show that the water resources planning and managing scenarios evaluation by this method lead the water resource systems to sustainability.
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1. Introduction

Operating policy for reservoir management has significant importance, since a reservoir can be used for various purposes including meeting the human demands, energy production and flood control. Some of these purposes are at odds with each other, for example, meeting the human demands and energy production usually go together, however, these may be in conflict with the flood control purpose. Therefore, design of an appropriate pattern for an optimal operation of reservoirs is important. Many researchers have emphasized on the development of an optimal reservoir operating policy. Therefore, Simulation-Optimization models have been generally used for this purpose. Tung et al. (2003) presented a specific kind of rule curve including optimal operational areas from a reservoir. They took the height of the point where the rule curve is broken as the decision variables of the problem. Using that, they submitted their rule curve which included optimal operational areas from a reservoir. Cai et al. (2004) developed a decision support system for water resources planning and evaluation by combining multi objectives analysis and multi decision making criteria. The results of model implementation in north china show the efficiency of that DSS in conflict resolution and water systems sustainability.

In this paper, to apply different approaches of operation of Karkheh reservoir system, two scenarios are extended. Scenario evaluation is one of the valid methods of analysis methods in planning and water resource management. Thus, in this study, this purpose is done by evaluation of system sustainability by sustainability indicators of water resource systems and system analysis by conflict resolution theory. Scenarios are analyzed and compared in two scales of seasonal and annual and the best scenario is selected. Development of scenarios is done based on two different approaches in integrated operation of reservoir that is elaborated as:

VD scenario: in this scenario, the operator by considering climate prediction at the beginning of water year manages the probable tension to water resource system of the watershed by applying logical change (reduction or increase) of downstream agriculture demands. In this scenario, the operator accepts the operation risk of the reservoir and social, economical tensions at the beginning of the water year and tolerates demand management costs.

CD scenario: In this scenario the operator by the rule curve extracted from reservoir operation historical period and by assuming not applying tension to beneficiaries or development of downstream consumptions during water year by applying resource-based policies, supply management is done. In this scenario, bargaining and social tensions are less in short term.

The aim of developing these two scenarios is the comparison of common approaches of water resource management and long-term evaluation of operation policies of water resource systems that is not possible without using historical data and optimization-simulation models. Integrated Water Resources Management is the map of a way for sustainable development that planning and operation management tools of water resources systems are defined and its process is determined. Localization of these processes is possible by development of local scenarios and their integrated evaluations.

2 Problem Formulation

The efficiency of the systems is evaluated in the form of three definite concepts that is correct in water resources systems:

1) How often the system is failed in a definite time interval?(Reliability)
2) What is the probability of system returning to a good state after a failure? (Resiliency and Fixing)
3) How sever are the observed failures (Vulnerability)

2.1 Reliability

According to the definition of Hashimoto et al (1982), reliability means that no failure is occurred in operation of the system in a definite period:

$$\alpha = Prob\left[X_t \in S\right] \quad (1)$$

This indicator indicates the amount of fulfilment of the purposes of the system and one of the most important indicators to investigate the efficiency of operation policies of water resources systems at normal conditions. To calculate the qualitative or quantitative reliability, quality and quantity time series of water quality of each section is plotted and the demand of that section is considered as the water quantity threshold of that section. If the attributed time series is higher than the demand value, failure is not occurred in the system and $X_t \in S$

In long-term, water resources systems are faced with the risk of intrinsic and uncertain change and the lack of information and knowledge. Risk is regarded as one of the important components of water resources management. From a comprehensive view, reliability shows the success of the system and risk indicates the frequency of system failure. Reliability definitions in water resources management are including as follows:

- Reliability of event that indicates the ratio of the number of success periods of the system to operation periods.
- Time reliability that is calculated as time ratio in which the system is in success condition to total operation (function).
- Volume reliability that is calculated sometimes as the ratio of the supplied volume to the total required volume.

2.2 Resiliency (Reversibility)

Resiliency indicates the probability of the system returns to optimal state after a failure. Resiliency of a system in a planning horizon is defined as follows:

This index is of great importance in drought and flood periods because the damage of floods and droughts is consistent with the bad performance of time period of the system.

To calculate the qualitative or quantitative resiliency qualitative and quantitative time series of water attributed to each section is plotted and the demand of that section is considered as water quantity threshold to each section. According to the definition of Cai (2004), quantity resiliency is the time period that the system requires to return to the normal state that is achieve by division of the maximum consecutive periods of failure by total period.

2.3 Vulnerability

Vulnerability shows the magnitude of the system failures. To measure the system vulnerability, the damage severity index is defined. Hashimoto et al (1982) defined system vulnerability as follows:

$$\nu = \sum_{j \in F} s_j e_j \quad (3)$$

Let e_j be the probability that X_j, corresponding to S_j, is the most unsatisfactory and sever outcome in F set. In some references, (the value of severity is defined as average exceeding of threshold value as follows (Loucks, 2006) :

$$\nu = \frac{sum of\ possitive value of \left(X_t - \hat{X}\right)}{number of\ times an unsatisfactory value occurred} \quad (4)$$

Where X_t is the attributed water or water quality; $\hat{X}$ is the qualitative and quantitative threshold of the system.

According to the definition of Cai, the minimum demand supply is raised as the magnitude of failure. It can be said that in addition to the 3 mentioned indicators, there is another parameter in the evaluation of sustainability of water resources systems including healthy environment, fair attribution and social-economical acceptance.

3. Problem Solution

The extended scenarios are compared by the evaluation of system sustainability indicators of the system as reliability, resiliency and vulnerability are calculated for parameters of downstream demand supply, the lack of excess discharge and the losses of dam reservoir spill. Evaluation scale is defined in two seasonal and annual states to analyze the management approaches of two defined scenarios from the aspect of short-term and long-term sustainability.

3.1 Evaluation in seasonal scale

In this section, the results of performing the model in seasonal scale is investigated by sustainability of resources-consumption system of Karkheh and planning period is including 164 steps equals the number of 41 seasons of simulation period.

3.2 Demand supply

By assuming the deficit or the lack of total demand supply as failure, three sustainability indicators of the system are calculated for two scenarios and the result is as follows:

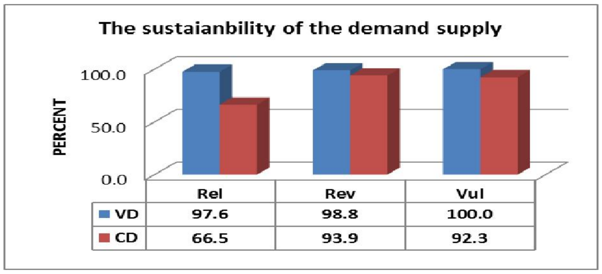

Fig.1 The sustainability of demand supply for different scenarios in seasonal scale

As it is shown in fig. 1, in planning and seasonal analysis of the operation policies of the reservoir, the system reliability of demands supply is significantly better in VD scenario and the system in this scenario immediately returns from failure state to natural sate of demand supply. It can be said that failure severity or in other words, the minimum demand supply is occurred in this scenario and when downstream consumptions are drinking, industry and environmental demands, the prediction of providing the alternative resource is essential.

3.3 The lack of excess discharge

By assuming the discharge of reservoir more than the demand of a definite season as failure, three sustainability indicators of the system are calculated for two scenarios and the results are presented in Fig. 2.

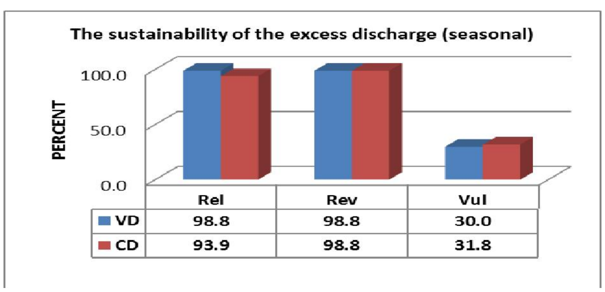

Fig. 2 The sustainability of supplying demand for different scenarios in seasonal scale

The comparison of the system behaviour indicates that in both system management approaches, the system had good vulnerability and resilience. The Reliability of VD scenario is a little higher than CD scenario. Considering the extraction of rule curve based on long-term historical statistic, in the selection of the best scenario, the parameter can't have important role in seasonal evaluation.

3.4 The lack of spill of reservoir

By assuming the spilled volume of water as losses and failure, three indicators of system sustainability are calculated for two scenarios. Fig. 3 shows the results of this calculation. It can be said that in water resources system of this watershed, there is no adverse effects and the production of hydro energy is planned, if necessary. This parameter is investigated for comparison.

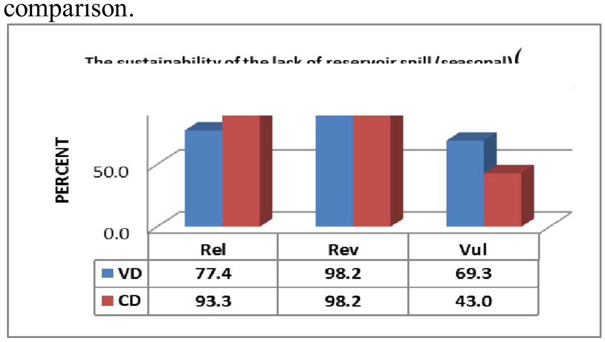

Fig. 3 Seasonal sustainability of the lack of reservoir spill in seasonal scale

As it is shown, CD scenario has better performance regarding the assurance of the lack of reservoir spill and the severity of the spills and the damage to the downstream installations and ecosystem. As the effects of this parameter are important in short-term scales, the comparison of the seasonal indicators can be helpful in decision making.

3.5 Evaluation at annual scale

In this section, the results of performing the models in the annual scale are investigated by the system sustainability of resources-consumptions system of Karkheh and planning period is including 41 steps that equal the number of years of optimization-simulation model.

3.6 Demand supply

By considering the deficit or the lack of supplying the total demand, as failure, three indicators of sustainability of the system are calculated for two scenarios and are presented in Fig.. 4.

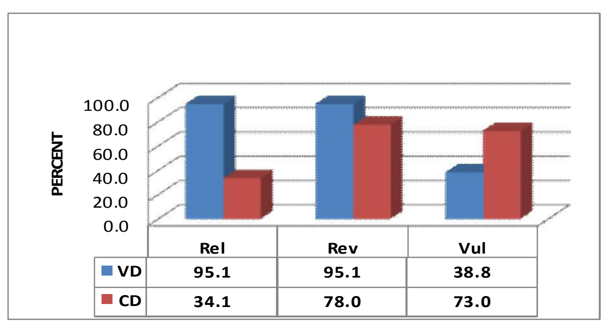

Fig. 4 The sustainability of supplying demand at annual scale

As it is shown in the results, VD scenario by being the best in three indicators (high reliability and resiliency and low vulnerability) compared to CD scenario, confirms long-term planning approach in meeting the demands. The values indicated that in this scenario by following the extracted rule curve in 95% of the planning years, supplying the demand is done without any problem or challenge.

3.7 The lack of excess discharge

By assuming the discharge from the reservoir more than the demand of a definite year as failure, three indicators of system sustainability are compared for two scenarios and the results are as Fig. 5.

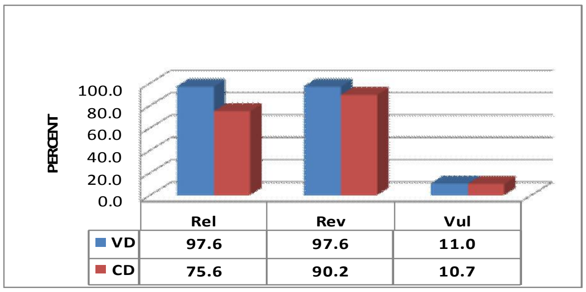

Fig. 5 The annual sustainability of the lack of excess discharge at annual scale

The superiority of VD scenario in this parameter is obvious and vulnerability index shows that in both scenarios, the excess discharge of the reservoir is reduced that controls the vulnerability of the downstream system. This issue in seasonal comparison of this parameter supports this reasoning. Indeed, the formulation of the strategy and operation curve is considerable by the logic of distributing the adverse effects during the period and reduction of extreme in the results.

3.8 The lack of spill of the reservoir

By considering the spilled water volume as losses and failure, three indicators of sustainability of the system are calculated for two scenarios and the result is presented in Fig. 6. With reference to the explanations of seasonal evaluation of this parameter, this comparison is not analyzed in annual form.

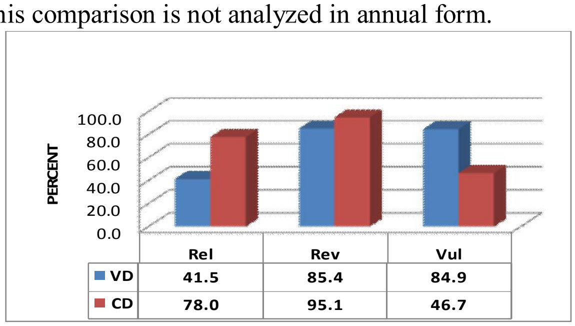

Fig. 6 The sustainability of the lack of reservoir spill at annual scale

3.9 Conflict resolution in water resources management

In a decision making process, if the number of decision makers is over one person then decision making will face to some problems, because different persons have different goals, view points and priorities and the final solution must be compatible to all different ideas. There are many ways to solve these problems which named Conflict resolution models. Priority in allocation rates to different consumptions is one of the most important decisions and must involve the stakeholders' utilities and conflict resolution among them.

In 1954, John Nash claims a solution for the negotiation problem which involves all the conditions for a legal solution in a negotiation problem. Two models were developed by Nash which involved symmetrical and unsymmetrical solutions. Symmetrical solution is as if the opponents of a symmetrical negotiation Problem, in disagreement, have equal proportion, this solution also allocate equal proportion too each of them finally. If the participants are over two in a negotiation problem the g function will be defined as equation (5)

$$g(u_1, u_2, \ldots, u_n) = (u_1 - d_1)(u_2 - d_2)\ldots(u_n - d_n) = \prod_{i=1}^{n}(u_i - d_i) \quad (5)$$

Which u is utility function and d is disagreement point component for each participant and n is a number of participants. As previously defined, the solution of a negotiation problem by Nash model is found by following optimization problem:

$$\begin{aligned} &\text{Maximize } g = \prod_{i=1}^{n}(u_i - d_i) \\ &\text{Subject to : } u_i \geq d_i \quad i = 1,\ldots,n \\ &u = (u_1,\ldots,u_n) \in U \end{aligned} \quad (6)$$

The modified Nash model developed after some problems such as inefficiency of symmetric model in cases of un symmetric and not make any attention to participant's importance and relative strength of them in problem. In this case the g function will be defined as equation (7).

$$g(u_1, u_2, \ldots, u_n) = (u_1 - d_1)^{w1} (u_2 - d_2)^{w2} \ldots (u_n - d_n)^{wn} \quad (7)$$

Which u is utility function of participant I and $(d_1, d_2, \ldots, d_n)$ is the disagreement of participant's vector. W_i is the relative strength of problem opponent. With due attention to relative weight, equation (8) must be true.

$$\sum_{i=1}^{n} w_i = 1 \qquad (8)$$

n is the number of participants (decision makers).

By rewriting equation (6), optimizing problem can be solved by equation (9)

$$\begin{aligned} &Maximize\ \ g = \prod_{i=1}^{n} (u_i - d_i)^{wi} \\ &Subject\ to: u_i \geq d_i \quad i = 1,\ldots,n \\ &u = (u_1,\ldots,u_n) \in U \end{aligned} \qquad (9)$$

In this research the multiplier symmetric Nash equation has been used as criteria for assessment of conflicting rate because of its abilities.

In a basin system the utilities can be defined as type of need securing, quality parameters or economic profit. Negotiation among stakeholders is in this category that it can take the persons who will influence (decision producers) as water responsible or administrator of each need group in the whole basin.

There is a systemic and integrated point of view to allocation problem in this research and the scenarios evaluation will be done by Nash multiplier equation.

Scenarios evaluation with the conflict resolution theory

Scenarios evaluation will be done with the base of the conflict resolution concept and with the use of symmetric multiplier equation in this part, as the disagreement point for each parameter will be derived as below:

$$d = \min(u_1, u_2, u_3) * 0.9 \qquad (10)$$

Tables 1 and 2 show that in the scale of short time management, no variation in consumption values (related to scenario CD) will face the exploitation with lower stress and higher assurance. Whereas in VD scenario annual management with the point of view of conflict resolution will be collect as the best scenario with meaningful difference. If we assess the subject with the governance point of view it can be said that by control of temporary and weak stresses, beneficiary system can manage in long time scale with minimum stress.

Table 1: Seasonal reliability assessment

seasonal scale		REL	seasonal scale		REL
VD	Demand supply	97.6	CD	Demand supply	66.5
	lack of excess discharge	98.8		lack of excess discharge	93.9
	lack of reservoir spill	77.4		lack of reservoir spill	93.3
conflict resolution index		6302	conflict resolution index		7574

Table 2: Annual reliability assessment

annual scale		REL	annual scale		REL
VD	Demand supply	95.1	CD	Demand supply	34.1
	lack of excess discharge	97.6		lack of excess discharge	75.6
	lack of reservoir spill	41.5		lack of reservoir spill	78
conflict resolution index		14440	conflict resolution index		7245

In the point of system reversibility, the management in CD scenario of short or long time scale can be done with lower stress. This condition is meaningful for administrator of dam exploitation and also stakeholders. (Table 3 and 4)

Table 3: Seasonal reversibility assessment

seasonal scale		REV	seasonal scale		REV
VD	Demand supply	98.8	CD	Demand supply	93.9
	lack of excess discharge	98.8		lack of excess discharge	98.8
	lack of reservoir spill	98.2		lack of reservoir spill	98.2
conflict resolution index		1066	conflict resolution index		1837

Table 4: Annual reversibility assessment

annual scale		REV	annual scale		REV
VD	Demand supply	95.1	CD	Demand supply	78
	lack of excess discharge	97.6		lack of excess discharge	90.2
	lack of reservoir spill	85.4		lack of reservoir spill	95.1
conflict resolution index		3231	conflict resolution index		3884

It can be seen the same assessment of reliability in the case of vulnerability in a concept that with agreement of temporary stresses and VD scenario point of view, water resources and demands management will be done with more reliability and less vulnerability in long time (Table 5 and 6).

Table 5: Seasonal vulnerability assessment

seasonal scale		VUL	seasonal scale		VUL
VD	Demand supply	100	CD	Demand supply	92.3
	lack of excess discharge	30		lack of excess discharge	31.8
	lack of reservoir spill	69.3		lack of reservoir spill	43
conflict resolution index		9264	conflict resolution index		2912

Table 6: Annual vulnerability assessment

annual scale		VUL	annual scale		VUL
VD	Demand supply	38.8	CD	Demand supply	73
	lack of excess discharge	11		lack of excess discharge	10.7
	lack of reservoir spill	84.9		lack of reservoir spill	46.7
conflict resolution index		2384	conflict resolution index		2514

4. Conclusion

According to the comparison of two extended scenarios, various technical aspects of VD scenario are selected as the best management approach and the results of performing the mode are analyzed. It can be said that in this study, the development of scenarios was very wide but the aim is the analysis of the approaches and the generalized methodology and results and localization for different conditions consistent with the advantages and limitations. Results show that the water resources planning and managing scenarios evaluation by this method lead the water resource systems to sustainability and indicated the conflict resolution approaches.

5. References

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