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ORIGINAL PAPER

A conflict resolution method for waste load reallocation in river systems

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Abstract

Various urban, industrial, and agricultural pollutions discharge more than river self-purification potential damages river ecosystem and increases water treatment costs. As different decision-makers and stakeholders are involved in the water quality management in river systems, a new bankruptcy form of the game theory is used to resolve the existing conflict of interests related to waste load allocation in downstream river. The river restoration potential can allocate to the conflicting parties with respect to their claims, by using bankruptcy solution methods. In this research, dischargeable pollution loads to Karun River are determined by pollution sources in various scenarios using bankruptcy methods for conflict resolution. For this purpose, the QUAL2 K river water quality simulation model is integrated with particle swarm optimization model, while various pollution loadings discharge policies have been determined based on bankruptcy method. This method was employed in one of the most pollutant rivers of southern Iran. As the salinity is one of the most important problems in the Karun River, the electrical conductivity is considered as water quality index. The results show that the proposed model for waste load allocation can reduce the salinity of the allocated water demands as well as the salinity discharged into the river. It should be noted that the suggested method does not necessarily minimize the total cost of wastewater treatment in the basin and might result in suboptimal allocations from an economic optimization method. But it should be the emphasis that this method can be used to develop practical solutions when utility information is not available or reliable, side payments are not feasible, and parties are not highly cooperative.

Keywords Bankruptcy method · Pollution load · QUAL2 k · River water quality management

Introduction

Resolving conflicts over quality and quantity of water is the most important issues in water resources management. Increasing consumption or reducing the accessible water resources increases the probability of conflicts among various beneficiaries. In common models of river water quality management, the permitted wastewater discharge rate for each of pollutant resources is determined based on minimization of treatment costs by considering downstream water quality limitation as to the constraint or minimizing the water quality violation from the standard by considering treatment budget limitation as to the constraint. In recent years, with the development of game theory application in water resource management, use of conflict resolution approaches has been taken into consideration in addition to economic and environmental issues by environmental planners in order to specify the pollution share level.

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In Kerachian and Karamouz (2007) research, optimum utilization rules to manage water quality in river system developed using a conflict resolution method combined with a water quality simulation model and genetic algorithm-based stochastic optimization model. In this study, a new form of Nash bargaining theory was used for conflict resolution to supply water for various demands, allocated water quality, and pollution load allocation in the river downstream. The obtained results from the suggested method on Qomrud river system in the center of Iran showed that the suggested model to utilize water and pollution load allocation can reduce the allocated salinity to various demands and also river water salinity.

In Mahjouri and Bizhani-manzar (2013), river water quality policies, optimization models, and conflict resolutions were formulated. Comparison of two approaches results shows the importance of cooperative performance to obtain maximum income in using superficial water sources in studying river water quality and quantity. Final results showed that the cooperative participation of water consumers in the game results in final net income.

Also, a fuzzy bargaining model based on Rubinstein's theory for various conflict resolutions among water consumers in the urban district of Tehran, Iran, was offered by Kerachian et al. (2010). A new method was used by Nikoo et al. (2013) to optimize Karun River pollution load by considering uncertainties about river discharge, wastewater pollution load, and water demand. In this research, an uncertain dynamic model was used by considering input uncertainties.

An environmental penalty function to manage rivers quality was developed by Abed-Elmdoust and Kerachian (2012) using the n-person evolutionary game. A certain two-objective model was developed by Liu et al. (2014) in China for simultaneous pollution load and water allocation as a model. In this regard, a hydrodynamic model was used to model river water rate changes and NSGA-II model was used to solve pollution load and water allocation optimization.

An optimization-simulation model was suggested by Tavakoli et al. (2015) to allocate pollution load discharged to the rivers from agricultural lands considering uncertainties. They used SWAT (Soil and Water Assessment Tool) simulation model to estimate quality and quantity of agricultural flows and used the QUAL2 Kw model to simulate river water quality.

A method was introduced by Dehghan Manshadi et al. (2015) based on cooperative games and the concept of virtual water to evaluate the impact of water transfer projects on water quantity and quality. In this suggested model, first, an optimization model with economic objective function based on virtual water concept was developed that maximized net benefit of trans-boundary water transfer. Then, efficient flow reduction effect was estimated using virtual water concept and Nash equilibrium to supply water quality necessities. Finally, cooperative game theory approaches were used for reallocation of net benefit to obtain justice and recover enough motivations for water consumers. Results showed that the suggested method can be an effective tool to obtain sustainable development in trans-boundaries water allocation.

Bankruptcy solving methods have been attracted by researchers and expertise of water sources management in recent years. A bankruptcy problem is a distribution problem in which a specific value allocation is mentioned by sources or good to a group of beneficiaries, while sources or good amount are not sufficient to fulfill all demands (Herrero and Villar 2001). Bankruptcy methods have been used in water resources studies because some important and high applied problems in water sources management such as limited water resources allocation to users can be defined and examined as a bankruptcy problem.

Application of bankruptcy in water resources allocation was offered by Kampas and White (2003). Thus, bankruptcy problem resolutions were used in the southwest of Britain to establish allocation permission for a small catchment area. The obtained results showed that allocations depend on bargaining potential of each beneficiary. On the other hand, it was shown that the various rules of allocations have a different scenario to divide the obtained benefit among beneficiaries. One benefit of this analysis is the quantification of justice issue for allocation permission, and not only it makes an adaptive resolution by bargaining if there are social challenges, but also it provides relative justice to evaluate various policies selection. In another study by Sheikhmohammady and Madani (2008), results of using three main rules of bankruptcy problems were examined for conflict resolutions of five countries around the Caspian Sea in using the present gas and oil sources in this sea. Results of this study showed that constrained equal award (CEA) rule is the better social optimized choice according to social selection rule than two other rules of bankruptcy problems including proportional bankruptcy rule (PRO) and moderated PRO.

The application of game theory in water resources management and conflict resolutions chronically was studied in a research by Madani (2010) using a series of noncooperative games. The noncooperative game theory capabilities were described in the identification of nature and the real conflicts resolutions of water sources. In addition, the dynamic structure of water sources and the importance of considering game evolutionary path were studied along with studying such issues.

The bankruptcy problem was studied by Ansink and Weikard (2012) based on its rules and changing river water allocation to the bankruptcy problem. Four rules including proportional bankruptcy (PRO) rule, constrained equal award (CEA) rule, constrained equal loss (CEL) rule, and Talmud rule were applied, and their performances were evaluated effectively to solve river water allocation problem.

Using various rules of bankruptcy problem including the PRO, moderated PRO, CEA, CEL, Talmud rule, and Pineal's rule were examined in water sources conflicts by Madani and Zarezadeh (2012). The rules for an assumed conflict about the underground water source were executed in this research, and the obtained results about their application were examined and discussed.

In another study by Madani et al. (2014), four rules of PRO, CEA, CEL, and Talmud were studied for conflict resolution among eight riparian provinces around Qizil Üzan–Sefīd-Rūd catchment. The obtained results showed that CEL-based structure provides the most acceptable allocation under the various studied scenarios based on the principle of plurality.

In addition, a new bankruptcy problem resolution approach was suggested by Madani et al. (2014) to solve the trans-boundaries conflicts (trans-province) in which the total riparian partners' demands were more than the existed water amount that time and place changes were considered in it. In this model, four bankruptcy problems were developed based on four rules of bankruptcy problem resolution including PRO, moderated PRO, CEA, and CEL. Moreover, a criterion of acceptability was introduced based on claims and dissatisfactions allocation among beneficiaries in the mentioned research.

A new method to solve bankruptcy for conflict resolutions about water sources was offered by Mianabadi et al. (2014) that considered brokers' participation in total sources besides their claims. They executed their suggested method on Euphrates River and compared the obtained results to the results of four rules that apply to solve bankruptcy problems including PRO, CEA, CEL, and proportionality sequential sharing. They showed that the suggested method for the related conflict resolution to river allocation problems is prior to the performance of other methods.

A method for water sources allocation was provided by Sechi and Zucca (2015) in a sophisticated system under water shortage conditions using bankruptcy game rule. In the provided method by them, users' priority is considered which is determined by their intentions to pay costs for water. They executed this method with five various rules of bankruptcy method including PRO, moderated PRO, CEA, CEL, and Talmud rule first on a simple aqueous system and then on a sophisticated and multi-objective aqueous system in Italy. They showed that the moderated PRO and Talmud rule provided better results based on the balancing of the existed sources.

A method based on beneficiaries participation was developed by Arjoon et al. (2016) to allocate welfare by maximizing the obtained economic benefits from water consumption and then the allocation of these benefits by a fair method in Nile trans-boundaries catchment. Total benefits based on some famous features of bankruptcy problem were allocated among water consumption brokers. In this study, a new method was also provided to consider water participation of riparian countries in the formation of a big cooperative association.

Based on the efficiency of bankruptcy method in water management issues and related conflicts resolutions to water resources, application of these methods to solve the water quality conflicts of rivers was examined in this research. The performance of the mentioned methods by execution of them is evaluated on Karun River as the most water-rich river of Iran. In addition, the QUAL2 K model was used in this model to simulate Karun River water quality and particle swarm optimization (PSO) algorithm was used to find the optimum value of the objective function based on bankruptcy rules. Finally, the general performance of the suggested method and also each of its subsets is evaluated among various beneficiaries in the determination of pollution load discharge policies. So, application of bankruptcy rules in the context of water quality management and the array of technical tools (e.g., water quality simulation, PSO) employed is the contribution of this work.

Materials and methods

The objective of this research is providing a solution based on bankruptcy problem to manage Karun River water quality management in the southwest of Iran and conflict resolutions about pollution load discharged to this river. The QUAL2 k model has been used in order to simulate river water quality changes in Karun River from Gotvand dam to Ahvaz City. As the salinity is the most important problem in Karun River, the electrical conductivity (EC) was considered as water quality index and simulated along the river. Then, objective function was optimized based on bankruptcy problem resolution rules using particle swarm optimization (PSO) algorithm. Various stages of research operation were presented based on a flowchart in Fig. 1.

QUAL2 K river water quality simulation model

In this study, the QUAL2 K model (Chapra et al. 2008) is used to simulate river water quality variations. The dominant equations in this model are advection–diffusion equations. Diffusion is solved by the assumption of steady non-uniform flow. Dominant equations for time are solved implicitly and if possible as the backward difference. Both methods of diffusion and horizontal movement in mass equilibrium are stated as follows:

$$V\frac{\partial c}{\partial t} = \frac{\partial\left(Ac \cdot E \cdot \frac{\partial c}{\partial x}\right)}{\partial x}\mathrm{d}x - \frac{\partial(Ac \cdot U)}{\partial x}\mathrm{d}x + V\frac{\mathrm{d}c}{\mathrm{d}t} + S \quad (1)$$

where V is the volume, C is the concentration of materials, Ac is the cross-sectional area, E is the longitudinal propagation coefficient, x is the distance (in the direction of flow from the loading point), U is the average speed, S is the external (positive) source or sink (negative) of the constituent elements, and $V\frac{\partial c}{\partial t}$ is the concentration/time change rate.

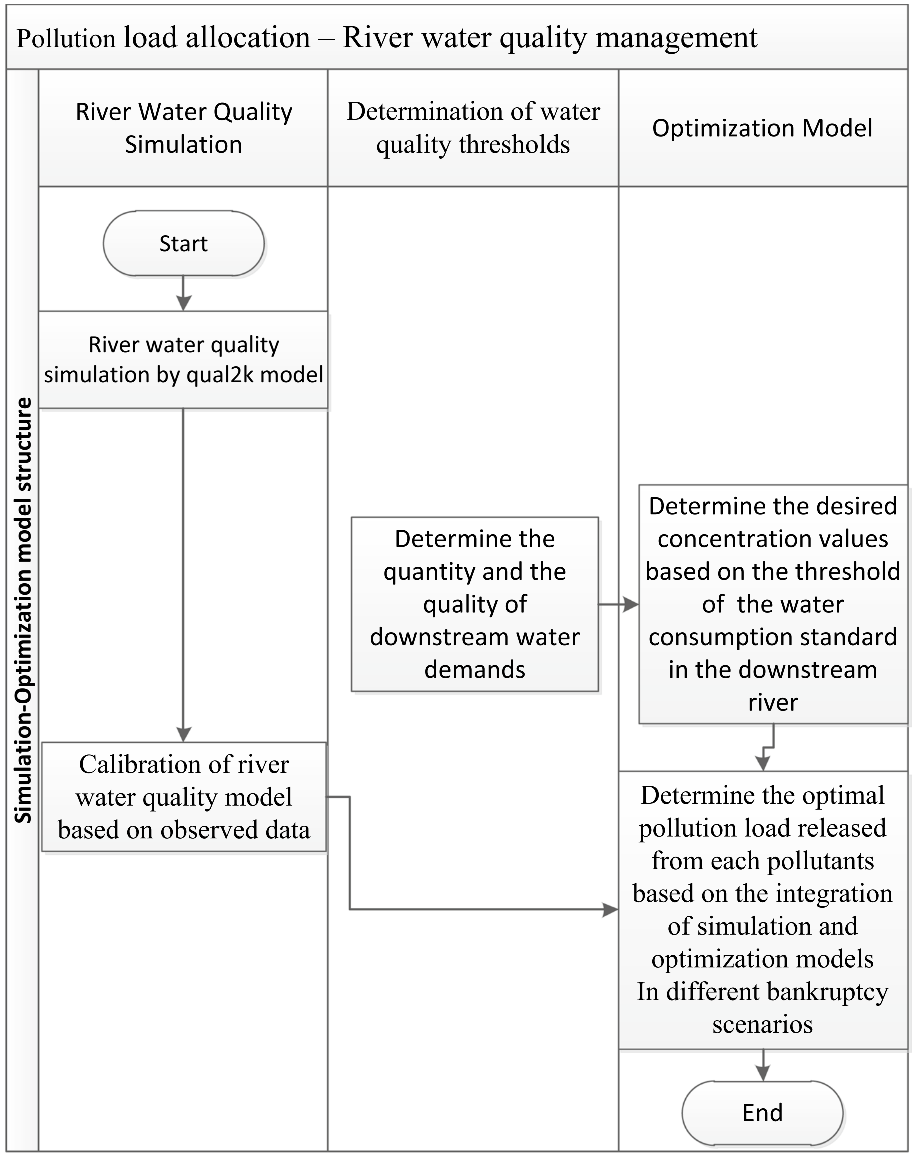

Fig. 1 Various stages of research operation

This model has an automatic calibration system using a genetic algorithm from $f(x)$ function to maximum fitting goodness as follows:

$$f(x) = \left(\sum w_i\right) * \left\{ \sum \frac{1}{w_i * \frac{\left(\sum o_{ij}/m\right)}{\left(\sum \left(p_{ij} - o_{ij}\right)^2 / m\right)^{0.5}}} \right\} \quad (2)$$

where o_{ij} is the observed values, p_{ij} is the predicted values, m is the number of the observed and predicted value pairs, w_i is weight coefficient, and n is the number of various state variables in bilateral weight normal RMSE (root-mean-square error).

Pollution load allocation using a bankruptcy approach

Theory of bankruptcy is regarded as one of the analytic methods which could be used to allocate remain resources among the members during system bankruptcy. The aim of this method is to distribute an asset to a group of creditors when this amount is not adequate to meet their credit's claim. In recent years, several bankruptcy rules have been developed. Some of these rules are based on cooperative bankruptcy game. Among the most frequently used bankruptcy rules, we can refer to consistency, constrained equal loss (CEL), and constrained equal award (CEA) rules, which are in the equal proportion of claims, losses, and awards (Herrero and Villar 2001).

Later, bankruptcy rules and relationships are explained. The mentioned methods can provide acceptable results although they have simplicity in calculations. The differences of these methods are obtained from different definitions in source allocation among players. The common bankruptcy methods in the determination of treatment level and pollution loads permitted to discharge to the river included the following cases:

Proportional rule (PR)

Pollution load of each pollution sources is reduced by equal percentage as follows:

$$EC_i^{\mathrm{New}} = x_i * EC_i^{\mathrm{Old}} \tag{3}$$

where EC_i^{Old} is the concentration of pollutant waste i and EC_i^{New} is the concentration of pollutant waste i after x_i % treatment.

Constrained equal award rule (CEA rule)

In this state, dischargeable concentration amounts by pollutant units in system bankruptcy resolution chronically increase from 0 equally to the maximum concentration until dissolved oxygen concentration exceeds standard level. The objective function in this part is dischargeable concentration maximization by any of pollutant sources.

$$\max EC_{\text{equal release}} \tag{4}$$

$$EC_i^{\mathrm{new}} = \min\left(EC_{\text{equal release}}, EC_i^{\mathrm{old}}\right) \tag{5}$$

Equation (5) shows dischargeable concentration that equals to the minimum dischargeable concentration amount and pollutant amounts before treatment, and electrical conductivity amount in control point is obtained by simulation of discharged pollution with QUAL2 K model. This state of bankruptcy model is suitable for the pollutant sources with low pollution load.

Constrained equal loss rule (CEL rule)

In this state, the system reduces an equal amount of pollutants concentration from each source to reduce the EC amount of river water at control point to the standard level. The objective function in this part is minimization of pollutant concentration reduction by each source.

$$\min EC_{\text{equal treatment}} \tag{6}$$

$$EC_i^{\mathrm{new}} = \max\left(EC_i^{\mathrm{old}} - EC_{\text{equal treatment}}, 0\right) \tag{7}$$

Equation (7) shows the dischargeable concentration that equals pollutant concentration before treatment minus concentration reduction for each pollutant sources. The electrical conductivity amount in control point is obtained by using QUAL2 K model.

Talmud rule (Tal rule)

This method is a combination of two CEL and CEA rules. For execution, at first, the EC amount at control point is obtained by considering $0.5 * EC_i^{\mathrm{old}}$ for pollution discharge of each pollutant. The QUAL2 K model is used to calculate EC at the control point (EC_{model}). If EC_{model} amount is bigger than permitted and standard level (EC_{standard}), the CEA method is used for determination of pollution permission. In contrary, if (EC_{model}) is smaller than the standard or the permitted level (EC_{standard}), the CEL method is used for determination of pollution permission. Finally, acceptance of each bankruptcy methods is not possible for all beneficiaries and may obtain the maximum allocation amounts using various methods which results in different prior methods based on beneficiaries view. There are various solutions to evaluate sustainability and acceptance of a method in a game.

Particle swarm optimization (PSO) algorithm

PSO algorithm is a global minimization method for problems with one point or surface solution in an n-dimensional space. In such space, some assumptions are proposed; elementary speed is allocated to them, and collection of communication channels is considered among particles. Then, these particles move in solution space and the obtained results are calculated based on a "competency criterion" after each time interval. Chronically, particles accelerate toward particles with higher competency criterion and are placed in a similar communicative group. Although both methods act well in a range of problems, this method has shown a great success in consistent optimization problems.

The main form of PSO algorithm acts having a population called "set" and candidate solutions called "particle." These particles move in searching space based on several simple formulas. Movements of these particles are guided by the best-found position in searching space by themselves and also the best-found positions by total set, and they guide set movement to find better positions. This process repeats and it is hoped by its doing, but it is not guaranteed to discover a proper solution eventually. Another intention in research is an attempt to stay far from premature convergence (optimization stationary). For example, some methods can be obtained to prevent premature convergence by reversing or making turbulence in PSO particles movement (multi-set optimization). Multi-set optimization can be also used to implement multi-objective optimization and eventually advances in optimization by PSO behavioral parameters.

Pollution load allocation

Different pollution reduction scenarios will be proposed by the bankruptcy optimization models based on various notions of fairness. There is always at least one point pollution source who finds one of the given alternatives unfair, because they can gain more under another rule. So, acceptability of different solutions is always questionable. The plurality index can be considered as an indicator of willingness to a decision rule in multi-participant decision-making problems as one of the most commonly used social choice (voting) methods. So, the number of stakeholders who prefer one method to the others is simply an indicator of the degree of acceptance of that method (Madani and Dinar 2013).

There is a need for evaluating the acceptability of different bankruptcy solutions because of the possibility of the rejection of suggested allocations and the difference in the notion of fairness by the pollution source (beneficiaries), who find certain allocation rules of pollution permits unfair. In the case of asymmetric powers, popularity of each solution is a simple indicator of its potential acceptability, but when powerful parties do not support the most popular solution, the majority cannot necessarily determine the feasible solution. Based on the formulation, most of the time Talmud rules are more acceptable.

Case study

Karun River with an annual average discharge of 12,000 MCM is the largest river in Iran which supplies the domestic water demands of several cities and villages and about 9 billion cubic meters of industrial, agro-industrial, and agricultural water demands in the Khuzestan Province.

Water pollution due to urban, rural, and industrial wastewater discharge and also the discharge of agricultural return flows to the river has endangered the aquatic life of the river and has caused deviation from water quality standards. The recent investigations on the river have shown that the concentrations of most of water quality variables such as TDS (or EC), COD, coliform bacteria, and total phosphor are more than water quality standard. Because of lack of information about the quality of return flows, in this study, only EC is considered as water quality variable and simulated along the river.

In this research, an important section of Karun River from Gotvand regulatory dam to Ahvaz city (Fig. 2) is considered as a case study. The river water quality model considering the effects of input and output flows has been executed using QUAL2 K. Then, each permitted EC share of each pollutant sources has been determined using bankruptcy resolution rules for the various amounts of permitted EC values in control point. Table 1 shows EC values of each input flows to Karun River in the studied area.

Results and discussion

The QUAL2 K model is calibrated and verified for Karun River in the studied area. The optimization process was executed using four defined objective functions based on four rules of bankruptcy problem linked with the QUAL2 K model to simulate water quality in the studied area. Optimization process was executed by considering five threshold values of 1000, 100, 1200, 1300, and 1400 *μmhos* for the permitted EC amounts in the control point (EC_{standard}).

The introduced PRO rule in part 2-3-1 in the first step was the basis for determination of the permitted share of each pollutant source for each of five mentioned thresholds. The obtained results in this step are shown in Table 2. The proportional value is also shown in the last arrow of Table 2. As it is observed in Table 2, the calculated proportion for pollutants that reduced value to their initial value based on PRO rule is 0.7003, 0.7703, 0.8403, 0.9103, and 0.9804 for each of five permitted EC values in control point (EC_{standard}) which means 1000, 1100, 1200, 1300, and 1400 *μmho*, respectively. Obviously, permitted EC values of all input flows in using proportional rule reduce in comparison with the initial value.

In the second step, permitted share of each pollutant sources for each of five thresholds mentioned values was determined based on the introduced CEA in part 2-3-2. The obtained results of this step are shown in Table 3. As it is observed in Table 3, this method is suitable for a pollutant with low discharge concentration. For example, pollutant numbers 3, 5, 6, and 12 can discharge their wastewater without any treatment. However, all EC amounts of flows with equal or higher EC than CEA must be reduced to reach CEA amount. In this regard, it seems that CEA rule supplies pollutant sources benefits with relatively low EC more than pollutant sources with high EC.

In the third step, the introduced CEL rule in part 3-3-2 was used to determine the permitted EC share of each input flows for each of five mentioned thresholds. The obtained results of this step are shown in Table 4. Based on the reported results in Table 4, all input flows with any EC values reduce their pollutions equally based on EC using CEL rule. Meanwhile, some small pollutants may be obliged to bring their pollution or EC to zero, while big pollutants may not reduce their pollutions so much. Therefore, it seems that CEL rule supplies pollutant source benefits with relatively high EC more than the ones with low EC.

Finally and in the fourth step, Talmud combined rule, introduced in part 2-3-4, was used to determine permitted EC share of each pollutant for each five threshold values. The objective function for each threshold value (EC_{standard}) was defined in this step in a way like three previous steps

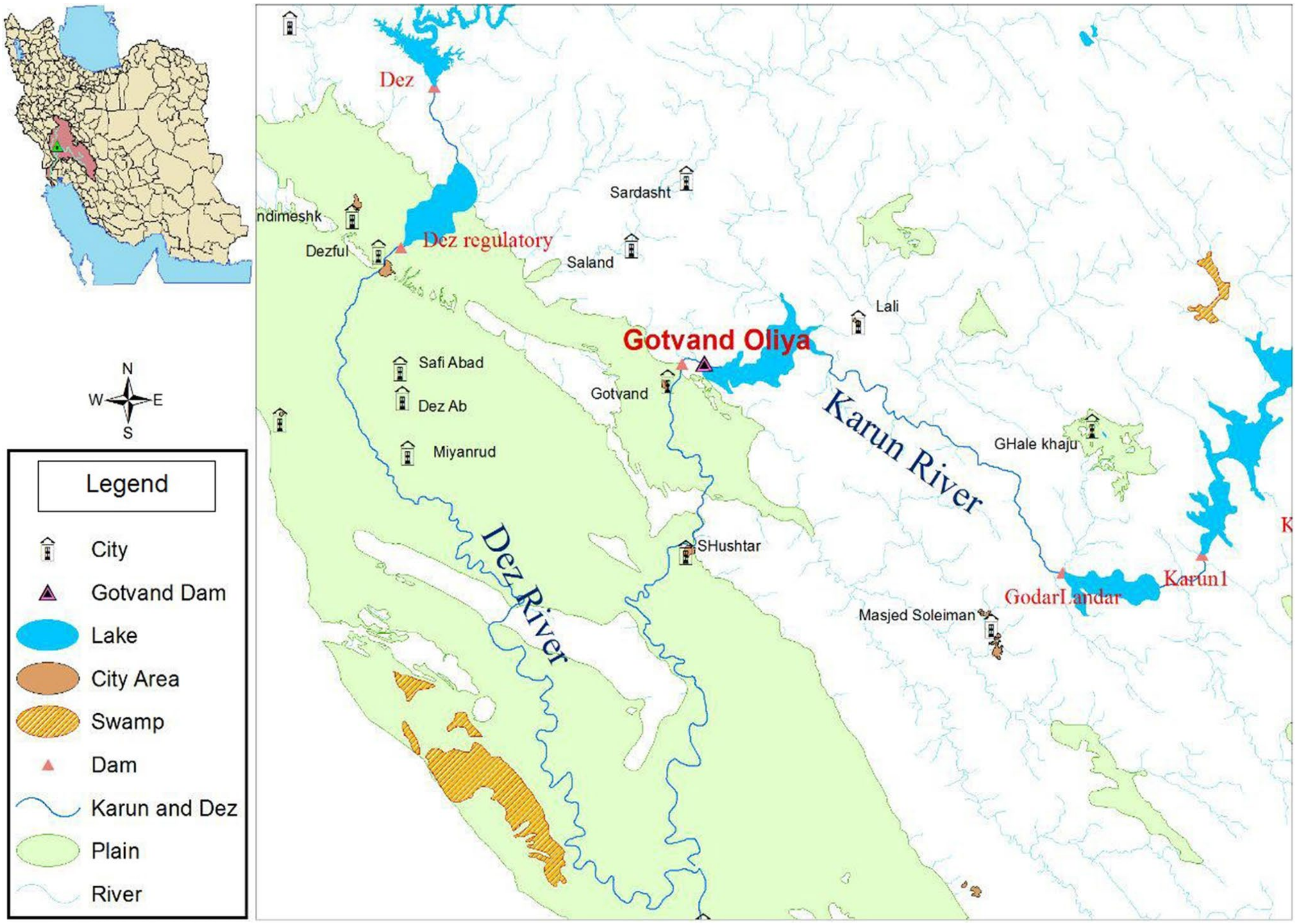

Fig. 2 Study area

Table 1 EC values of the input flows to Karun River in the studied area

Stream	Discharge (m^3/s)	EC (μmhos)
1 (headwater)	194	1200
2	2.73	18,350
3	17	500
4	0.08	6166
5	16	500
6	16	500
7	0.86	1623
8	4	3545
9	16	500
10	2.33	5800
11	61	3010
12	16	500
13	1.1	22,000
14	16	1000
15	9.23	1618
16	3	6475

that the calculated EC deviation by QUAL2 K model was minimized in control point (EC_{model}) from the permitted threshold value. The obtained results of this step are shown in Table 5.

It is to be noticed that the calculated EC value in control point (EC_{model}) to be lower than the permitted threshold value of EC_{standard} control point after halving EC values of each input flow and execution of QUAL2 K model while using Talmud rule. Therefore, one CEA value was added to each halved EC values to determine the new values of EC share for each input flow.

As it is observed in Table 5, using Talmud rule leads to relative benefits supplement of both pollutant sources group with high and low EC. Generally based on the provided results in Tables 2, 3, 4, and 5, the most proper regulations in supplying pollutant sources benefits having low EC include Talmud rule, CEA, PRO, and CEL, respectively. In contrary, CEA and CEL rule in supplying pollutant sources benefits having high EC include CEL, PRO, Talmud rule, and CEA, respectively.

Table 2 Allowable EC share for each input flow in the studied area based on the proportional rule

Threshold Stream	1000 (μmhos) Allowable EC (μmhos)	1100 (μmhos)	1200 (μmhos)	1300 (μmhos)	1400 (μmhos)
1 (headwater)	840	924	1008	1092	1176
2	12,850	14,135	15,419	16,705	17,990
3	350	385	420	455	490
4	4318	4750	5181	5613	6045
5	350	385	420	455	490
6	350	385	420	455	490
7	1137	1250	1364	1477	1591
8	2482	2731	2979	3227	3476
9	350	385	420	455	490
10	4061	4468	4874	5280	5686
11	2108	2319	2529	2740	2951
12	350	385	420	455	490
13	15,406	16,947	18,486	20,027	21,569
14	700	770	840	910	980
15	1133	1246	1360	1473	1586
16	4534	4988	5441	5894	6348
PRO	0.7003	0.7703	0.8403	0.9103	0.9804

Table 3 Allowable EC share of each input flow in the studied area based on CEA

Threshold Stream	1000 (μmhos) Allowable EC (μmhos)	1100 (μmhos)	1200 (μmhos)	1300 (μmhos)	1400 (μmhos)
1 (headwater)	1021.2	1127.4	1200	1200	1200
2	1021.2	1127.4	1454.8	2510.5	6785.7
3	500	500	500	500	500
4	1021.2	1127.4	1454.8	2510.5	6166
5	500	500	500	500	500
6	500	500	500	500	500
7	1021.2	1127.4	1454.8	1623	1623
8	1021.2	1127.4	1454.8	2510.5	3545
9	500	500	500	500	500
10	1021.2	1127.4	1454.8	2510.5	5800
11	1021.2	1127.4	1454.8	2510.5	3010
12	500	500	500	500	500
13	1021.2	1127.4	1454.8	2510.5	6785.7
14	1000	1000	1000	1000	1000
15	1021.2	1127.4	1454.8	1618	1618
16	1021.2	1127.4	1454.8	2510.5	6475
CEA	1021.2	1127.4	1454.8	2510.5	6785.7

Conclusion

Various urban, industrial, and agricultural pollutions discharge more than river self-treatment potential damages river ecosystem and increases water treatment costs. As different decision-makers and stakeholders are involved in the water quality management in river systems, a new bankruptcy form of the game theory is used to resolve the existing conflict of interests related to waste load allocation in downstream river.

Solving the related conflicts to pollution load allocation is mentioned by managers and researchers as an important and principal issue in river water quality management in order to determine the optimum level or management style for each pollutant sources of the river. Various limitations and objectives are usually mentioned such as treatment costs minimization, justice establishment in costs allocation, treatment levels, and reduction in water quality violation severity

Table 4 Allowable EC share of each input flow in the studied area based on CEL

Threshold Stream	1000 (μmhos) Allowable EC (μmhos)	1100 (μmhos)	1200 (μmhos)	1300 (μmhos)	1400 (μmhos)
1 (headwater)	772	872	972	1072	1172
2	17,922	18,022	18,122	18,222	18,322
3	72	172	272	372	472
4	5738	5838	5938	6038	6138
5	72	172	272	372	472
6	72	172	272	372	472
7	1195	1295	1395	1495	1595
8	3117	3217	3317	3417	3517
9	72	172	272	372	472
10	5372	5472	5572	5672	5772
11	2582	2682	2782	2882	2982
12	72	172	272	372	472
13	21,572	21,672	21,772	21,872	21,972
14	572	672	772	872	972
15	1190	1290	1390	1490	1590
16	6047	6147	6247	6347	6447
CEL	428.1271	328.1118	228.0964	128.081	28.0656

Table 5 Allowable EC share of each input flows in the studied area based on Talmud rule

Threshold Stream	1000 (μmhos) Allowable EC (μmhos)	1100 (μmhos)	1200 (μmhos)	1300 (μmhos)	1400 (μmhos)
1 (headwater)	886	986	1086	1186	1286
2	9461	9561	9661	9461	9861
3	536	636	736	836	936
4	3369	3469	3569	3669	3769
5	536	636	736	836	936
6	536	636	736	836	936
7	1098	1198	1298	1398	1498
8	2059	2159	2259	2359	2459
9	536	636	736	836	936
10	3186	3286	3386	1398	3586
11	1791	1891	1991	2359	2191
12	536	636	736	836	936
13	11,286	11,386	11,486	11,586	11,686
14	786	886	986	1086	1186
15	1095	1195	1295	1395	1495
16	3524	3624	3724	3824	3924
TAL (CEA)	286.0132	386.0285	486.0438	586.0592	686.0746

from the existed standards in the suggested models for pollutant sources allocation.

In this study, an approach based on bankruptcy problem resolution rule has been offered for the related conflicts resolutions to the pollutants load allocation to the various existed pollutant sources along a river. This approach was implemented by changing the concepts and considering the river self-purification potential (capacity) as an asset which is to be shared among various beneficiaries. The beneficiaries are the point sources which like to release their wastewater to the river with minimum treatment cost. It should be noted that the suggested method does not necessarily minimize the total cost of wastewater treatment in the basin and might result in suboptimal allocations from an economic optimization method. But it should be the emphasis that this method can be used to develop practical solutions when utility information is not available or reliable, side payments are not feasible, and parties are not highly cooperative.

An interval of Karun River in the downstream area of Gotvand regulatory dam to Ahvaz city was selected as a case study to examine the performance of the suggested method. Four rules of PRO, CEA, CEL, and Talmud rules were used to obtain treatment percentage and the permitted share of each pollutant sources. In all methods, violation of the permitted EC value in control point was considered as an important constraint.

Based on the results of this study, the permitted EC value for all input flows reduces equally than its equal proportion if PRO is used. In addition, each 100 unit in the permitted EC value in control point (EC_{standard}) showed about 7% increase in the calculated proportion.

Moreover, results showed that there is the possibility for flows with pollutions less than the calculated CEA to discharge their wastewater with no treatment. However, flows with EC higher than the ones for CEA, they must reduce the EC of their wastewater to reach CEA value. Consequently, CEA rule supplies pollutant source benefits with low EC more than the ones with high EC.

In addition, EC value of all input flows must reduce with an equal amount by executing CEL rule and sometimes some small pollutants may be obliged to bring their pollutions or EC to zero. In contrary, big pollutions reduce their pollution not so much. Therefore, it seems that CEL rule supplies pollutant sources benefits with high EC more than the ones with low EC.

Furthermore, Talmud rule can be known as the best approach to protect pollutant sources protection with low pollution, based on the obtained results. Using this rule leads to more supplement of pollutant sources with high EC than CEA rule; however, it will be desirable to supply their benefits less than PRO and CEL rules.

Generally, based on the obtained results from this research, Talmud, CEA, PRO, and CEL rules are the most effective ones in supplement of pollutant sources benefit with low EC in the studied area, respectively. On the other hand, CEL, PRO, Talmud, and CEA rules can be known as the most effective ones in supplement of pollutant sources benefits with high EC in the present case study.

As the main source of increasing EC in Karun River is agricultural return flows, evaporation ponds were suggested as a management practice for reducing the amount of EC of each water user discharges into the river. So, in order to execute the results of this study, the optimization of evaporation ponds volume and their locations considered as future studies is recommended.

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