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Research Article

Optimal-Fair Waste Load Allocation of River System Based on Rawls Theory

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Abstract
Waste load allocation (WLA) is a policy-making framework that can simultaneously consider multiple objectives, such as equity, environmental violations, and economic efficiency. This study developed a WLA framework focusing on equitable perspective from Rawls' theory of justice. For this purpose, the optimal scenarios were generated by calling the Streeter-Phelps equations for river simulation with the NSGA-II optimization algorithm. In addition, equity indicators were used to improve the optimization problem based on three objective functions simultaneously: minimizing treatment costs, environmental violation, and inequity. COPRAS method was also used to select the optimized WLA scenarios. Results showed that the optimal WLA scenario based on equity can improve the practicability of WLA in river system by deriving reasonably cost-effective and environmental friendly solutions with about 70% BOD removal for polluters in Haraz basin, northern Iran. Therefore, based on three dimensional multi-objectives WLA, equity could show its potential on highlighting optimal alternatives without extreme total cost or environmental violations.
Keywords: Justice, multi-objective optimization, river, wastewater treatment, water quality management.

Introduction

Global attention has been drawn to the overall deterioration of water quality due to fast industrialization, population growth, and a steady decline in the amount of safe water supplies accessible. In this context, accurate and timely planning and monitoring on surface waters are inevitable. Since, rivers are critical water resources in most developing countries, optimal strategies are required for the management of water pollution loads. It is essential due to the challenges of pollution control, like treatment costs, and increased competition for limited pollution rights, resulting in conflicts among emission sources (Xu et al., 2015; Xu et al., 2017; Weng 2007). In general, surface water quality issues are related to the development plans in the basins so that stakeholders' may discharge to the rivers without fitting treatment. For improving water quality and more sustainable decision making, one should determine the required wastewater treatment levels, known as waste load allocation, with respect to the environmental and socio-economic conditions of river basin.

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Waste load allocation (WLA) has been widely used for limiting the pollution discharged into the water bodies and considers the determination of the allowable waste load discharged from different emission sources (Loucks et al., 1985; Mahjouri and Bizhani-Manzar, 2013). WLA generally incorporates water quality simulation in order to describe the relationships between river quality levels and wastewater treatment plans (WWTPs). Timing, spacing, and the mass of pollutant discharged to the rivers could be managed by optimizing and defining a WLA problem by considering a number of emission sources. Moreover, in an optimal strategy, the pollution removal efficiency is determined for obtaining acceptable water quality according to the economic and equity conditions of river management (Burn and Yulianti 2001; Yandamuri et al. 2006). In addition, these problems can be defined by minimizing treatment costs specifying a minimum allowable water quality or different fairness indices in the receiving water body. For this purpose, simulation-optimization tools can be used to provide more efficient strategies with high capability and potential (Burn and Yulianti, 2001; Rani and Moreira, 2010).

Traditional WLA models seek to maximize economic-cost efficiency for single objective considering water basin dischargers/agents characteristics (Burn and Lence 1992; Murty et al., 2006; Tung 1992), whereas WLA is inherently defined as a multi-objective problem in real-world and it can incorporate other aspects of water quality management. Recently, different studies have focused on WLA problem on water bodies. For instance, Qin et al. (2009) developed Interval Quadratic Waste Load Allocation (IQWLA) model for quality management of Xiangjiang River in China using vectors and metrics to configure constraints of water quality model. They also analyzed uncertainty associated with quality parameters of river, costs and environmental guidelines.

Dischargers and stakeholders involved in the quality management of a river have responsibility for the pollution control. In this regard, decision-makers need to configure a pollutant load allocation rule to achieve the desired objectives through employing strategies and regulations. Also, different multi-objective optimization algorithms such as NSGA-II (Rathnayake and Tanyimboh, 2015), Non-dominated Archiving Multi Colony Ant Algorithm (Mostafavi and Afshar, 2011), Weighted Multi-Objective Simulated Annealing (MOSA) (De Andrade et al., 2013), and MOPSO (Feizi Ashtiani et al., 2015) have been developed for WLA problems.

Equity is decorated by the benefits or costs of allocating waste according to treatment costs, the distribution of absolute or relative equal waste loads between pollutant discharges, and the distribution of the waste load is proportional to the rate at which the waste load is removed (Park 2010). Various studies have been analyzed the concept of justice in WLA problems. For example, Yandamuri et al. (2006) used genetic algorithm to solve the WLA problem in the form of two multi-objective models.

The first model (cost performance) only considered minimizing quality criterion violations, while the second model (cost-equity performance) also included justice indices. Also, Xu et al. (2017) developed a bi-level WLA programming (BWLAP) model based on water function zones in the Tuojiang River, China. Their model is then utilized for determining the optimal WLA scheme, and allocation based on equity for the river administrator as well as discovering water quality changes in the river. In the context of justice from a theoretical point of view, Rawls (1997) discussed about for freedom of opportunity to exist there must be an opportunity for everyone in every institution. Rawls' criterion is based on the hypothesis that for justice to occur, there must be "fairness" in the sense that individual self-interests do not affect the initial allocation of resources (e.g., runoff). To achieve this, Rawls suggested the concept of a leading position. In this concept, representative stakeholders enter into social contracts for the distribution of resources under a veil of ignorance of their ultimate position in society. Therefore, for water resources management to meet the Rawlsian definition of social justice, the distribution of rights to water resources should be similar to what happens when representatives of society allocated rights without knowing their own ultimate rights (Tisdell, 2007).

To solve complex water resources problems, Multi Criteria Decision Making (MCDM) has proven to be one of the leading tools for efficient planning (Roozbahani et al., 2020). Complex Proportional Assessment (COPRAS) method is one of the latest MCDM methods. The COPRAS method has different potentials such as computational simplicity, reducing computational time, ranking across scenarios, simultaneous use of quantitative and qualitative criteria, and the capability to calculate positive and negative criteria individually in the analysis process and in adjustment to local and empirical conditions. Application of CORAS has been applied in different studies. For instance, Roozbahani et al. (2020) used COPRAS method in an inter-basin water transfer planning. Also, Golfam and Ashofte (2019) used COPRAS method to select the most capable scenario for adapting the system to climate change impacts on agricultural water supplies in the Kalank River Basin, East Azerbaijan Province, Iran.

This study provides an integrated framework for WLA by including equity viewpoint. First, by calling Streeter-Phelps (S-P) equation for river simulation in NSGA-II, optimal scenarios for WLA are generated. In addition, by employing equity indices of Rawls' justice theory, the optimization was carried out based on three objective functions: minimizing the treatment cost, environmental violation from the standard limit, and inequity. Later, by the application of COPRAS method, the most optimal WLA scenarios are selected and compared for a case study in Haraz Basin, northern Iran.

Material and methods

In this research, a framework is proposed by incorporating NSGA-II optimization algorithm and COPRAS method for fair WLA in the rivers. The detailed steps of this framework are presented in Fig. 1.

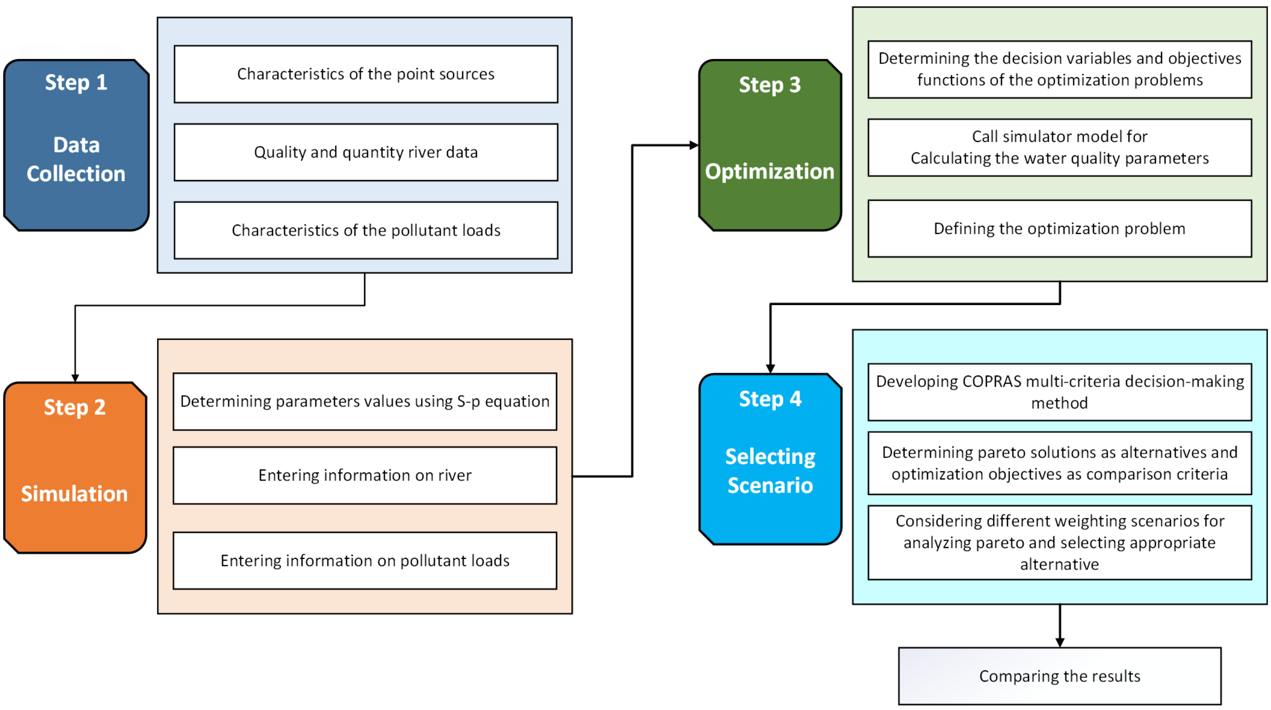

Figure 1. The flowchart of the proposed methodology

Waste load allocation

Different criteria can be used for conflict resolution and WLA among stakeholders. Selecting the most appropriate criteria depends on their efficiency from the decision-makers' point of view (Burn and Yulianti 2001). Therefore, a criterion needs to have different considerations such as pollution removal (%), treatment costs, environmental violations from the standards, fairness index (here known as homogeneous treatment), and capacity in qualitative excess (Niksokhan et al. 2009). The proposed allocation model should consider the costs of pollution removal as well as water quality standard violations. Here, the violations are the problem constraints calculated by the Streeter-Phelps equation. The model relations are stated as follows (Burn and Yulianti 2001):

$$\mathrm{Cost} = \sum_{i=1}^{NS} C_i(x_i) \tag{1}$$

$$V_j = f(x.W.Q.T.K.WQ_{std}) \tag{2}$$

$$\mathrm{Min}\ V = \sum_{j=1}^{NR} V_j(x_j) \quad \text{where } x_i \in (x_1.x_2.\dots.x_{NS}) \tag{3}$$

Where, C_i and x_i denote treatment costs for emission source *i* and its pollution removal efficiency, respectively. In addition, $(x_1.x_2.\dots.x_{NS})$ is a set of selective removal (%), NS is the number of pollution sources. V_j denotes the violation from the standard value which can be defined as the difference between the concentration of qualitative parameter (DO) and the its standard value at the control point *j*. Furthermore, NR is the number of control points; f is the function of hydraulic conditions and loading in the river. X, W, Q, T, K, and WQ_{std} denote the rate of pollution removal, pollution load, stream flow-rate, water temperature, the decay coefficient of the system, and the standard level in the river system, respectively. Eq. 4 determines the violation from the qualitative standard.

$$V_j = \begin{cases} V_j & V_j \geq 0 \\ 0 & V_j \leq 0 \end{cases} \tag{4}$$

Each polluter should bear a specific treatment cost to some extent for pollution removal based on its limitations and considerations. As a result, the total treatment cost for units should be determined using the treatment cost function of each polluter. The construction and operation costs of aerated lagoons in Iran and other counties were referred for estimating the cost function of polluters as bellow (Jamshidi and Niksokhan, 2016):

$$C_i = a_i x^3 + b_i x^2 + c_i x + d_i \tag{5}$$

Where the coefficients of a, b, c, and d are obtained from a research by Feizi Ashtiani et al (2015) for the same case study in Haraz River. Here, x denotes the pollution treatment (%).

Rawls theory of justice

Justice is an abstract concept that its understanding requires reviewing fundamental principles and various types of justice that may help decision-makers to develop and use the theory for fair allocation of benefits and costs in water management issues (Imani et al. 2023).
According to John Rawls theory of justice (Rawls, 1997), social institutions must resolve disputes of two types of economic conflicts and disputes over moral principles in a way that is equitable to all stakeholders. The term of his perspective, "justice as fairness," derives from the principles of justice that specifies how this should be carried out. According to Rawls, a "well-

ordered society" is the one in which certain fundamental justice principles are publicly identified as the foundation for assessing complaints against its basic configuration and demands change, and in which, these primary institutions are in conformity with these principles.

Rawls' theory of justice is thus a distinctively conception, in two general concepts: 1) the fundamentals of justice developed by Rawls are applied directly only to the basic institutions of society, not to the individual's conduct. In addition, fundamentals of justice are not derived from a more general moral theory, including utilitarianism, that also developed into individual conduct. 2) The fundamentals of justice do not exclusively respond an abstract question in political philosophy about which institutions are just. Indeed, Rawls categorized principles of justice into the greatest equal liberty principle, The Difference Principle, and The Equal Opportunity Principle.

According to these explanations, Rawls' theory of justice can be seen as a concept of fairness, which indicates that the privilege of receiving social advantages must provide the possibilities for those who are less fortunate to enhance the quality of their lives. Accordingly, two indices were defined to evaluate how the designed system followed justice from Rawls' point of view. Thus, two comparative indices were conceptualized in which the polluter can be less fortunate to spend more costs and subsequently contribute more to river quality improvement. In this regard, Eq. 6 and 7 are developed as follow:

$$Rawls\ index\ 1\ (RI1) = \frac{(BOD_i)}{(Cost_i)} \tag{6}$$

$$Rawls\ index\ 2\ (RI2) = \frac{BOD_i}{BOD_{max}} - \frac{Cost_i}{Cost_{max}} \tag{7}$$

Where, BOD_i and $Cost_i$ denote the corresponding pollution load and treatment cost of polluter i. In addition, BOD_{max} and $Cost_{max}$ denote to the maximum of BOD and cost of all polluters in a scenario.

Optimization model

Optimization algorithms seek to find mathematically optimal solutions for problem solving. Indeed, using optimization problems in water resources intend to optimize variables to obtain the best solutions by considering the maximum or minimum objective functions. For this purpose and through simulation-optimization models, non-dominated solutions are identified and used for further analysis. Different evolutionary algorithms have been used for generating optimal plans in water systems. Based on previous research, multi-objective optimization algorithm by NSGA-II is an efficient tool to solve this issue (Deb et al., 2000 and 2002). NSGA-II is a global search algorithm that mimics the evolutionary process of organisms. The NSGA has an improved mating mechanism dependent upon the crowding distance and performs constraints using an adapted explanation of dominance without the use of penalty functions. At the beginning, a zero level is allocated to all non-dominated individuals. During elimination of the individuals from the population, the lately non-dominated solutions are allocated to level one. This procedure goes on up to the time which all solutions have been allocated a non-domination level. Parents selecting process is carried out using binary tournament selection on the basis of the lesser rank and greater crowding distance. Offspring is generated from the parent population by selection, crossover, and mutation (Foroughi et al., 2019). Finally, the present off-springs and population are sorted another time dependent upon the non-domination and just the best individuals with the number of the population size (Hojjati et al., 2018). The parent and offspring populations are incorporated and compete utilizing an elitist plan to generate the next generation. Another potential of NSGA-II algorithm is to obtain optimal or approximate optimal solutions quickly and accurately. Also, a shared function is used to distribute the solutions for the most cost-effective scenario (Deb et al., 2011). In this regard, the Pareto optimal points are approximated after the entire population is continuously updated using NSGA-II.

In this research, wastewater treatments (%) implemented by polluters are decision variables. Since there are 8 polluters in this problem, the number of decision variables equals 8. Four different optimization problems are defined using 3 objective functions. First, two problems are defined employing three objective function of minimizing violation of the standards value, costs of treatment and equity index of Rawls (Eq. 4) in which the standard values of DO are considered to be 3.5 and 4 mg/L. Second problem is defined utilizing three objective function of minimizing violation of the standards value and costs of treatment as well as equity index of Rawls (Eq.6 and Eq.7) in which standard values of DO are considered to be 3.5 and 4 mg/L. The objectives functions are presented as follow:

$$Z_1 = minimize(f_1.f_3.f_4) \tag{8}$$

$$Z_1 = (f_2.f_3.f_4) \tag{9}$$

Where,

$$f_1 = \sum_{i=1}^{8} \frac{(BOD_i)}{(Cost_i)} \tag{10}$$

$$f_2 = \sum_{i=1}^{8} \frac{BOD_i}{BOD_{max}} - \frac{Cost_i}{Cost_{max}} \tag{11}$$

$$f_3 = \sum_{i=1}^{8} C_i(x_i) \tag{12}$$

$$f_4 = \sum_{i=1}^{8} V_i(x_i) \tag{13}$$

WLA scenarios

In our research COmplex PRoportional ASsessment (COPRAS) method developed by Zavadskas et al. (1994) is employed for selecting scenarios from pareto solutions. COPRAS is one of the multi-criteria decision-making methods and is based on simple concept. In this method, a decision matrix is firstly constructed, the rows of which are design alternatives and the columns of which are comparison criteria. By Eq. 15 the matrix turns as dimensionless.

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nm} \end{bmatrix} \tag{14}$$

$$\bar{X}_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}}; i = \overline{1,2,\dots,n} \; and \; j = \overline{1,2,\dots,m} \tag{15}$$

In this matrix n and m are the number of alternatives and criteria, respectively. Then the matrix is weighted based on the importance of each criterion.

$$\hat{X}_{ij} = \bar{X}_{ij}.W_j \tag{16}$$

COPRAS can classify the criteria into two groups of maximizing and minimizing criteria. maximizing criteria are those that decision-makers prefer to be maximize and minimizing criteria are those that their values are preferred to be at minimum. In the following, using Eq. 17 and 18, the score of each alternative in each group of criteria is calculated.

$$p_{+i} = \sum_{j=1}^{k} \hat{X}_{ij} \; ; i = 1,2, \dots . n \tag{17}$$

$$R_{-i} = \sum_{j=k+1}^{m} \hat{X}_{ij} \; ; i = 1,2, \dots . n \tag{18}$$

Finally, scenarios that get the most score based on Eq. 19 would be chosen for analysis.

$$Q_i = P_i + \frac{R_{min} \sum_{i=0}^{n} R_i}{R_i \sum_{i=0}^{n} \frac{R_{min}}{R_i}} \tag{19}$$

In this research, alternatives are the optimal solutions from the optimization process and optimization objectives are determined as comparison criteria. In order to accurately monitor the optimal solutions, different weighting scenarios were considered. In this regard, in each weighting scenario, one design criteria is given the highest score and the design solution is selected. This approach helps to evaluate the design solutions from one of the criteria each time. Once, all the criteria are given the same weight in order to choose a balanced solution that includes all the criteria in the selection process.

Case study

Haraz River is located in northern Iran, with total length of 185 km and maximum flow rate of 94 MCM/yr. For about 40 km in upstream (the study area), it is the main receiving water body of several fish farming discharges (Feizi Ashtiani et al., 2015). These can build up eight centralized point sources as located in Fig. 2. It is noteworthy that the effluents are currently monitored by command and control policy with respect to BOD concentrations at discharge points with at least 90% removal. However, monitoring dissolved oxygen (DO) may be more efficient in the whole receiving water body instead.

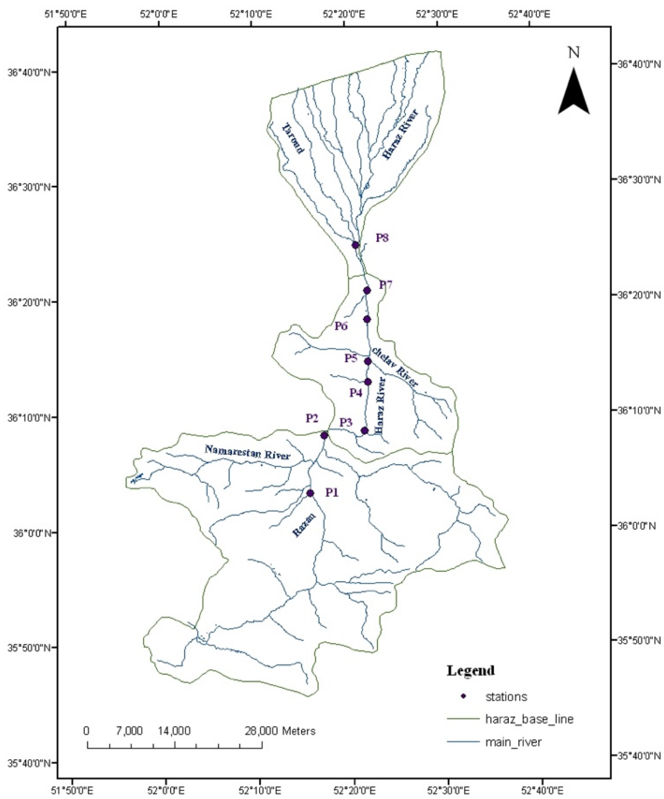

Figure 2. Study area and location of emission sources

Results

Optimization

The first problem minimizes treatment cost, standard violation (in two scenarios), and RI1 simultaneously and, the second problem subsequently replaces RI1 with RI2. Results showed that in both problems, generally with spending more treatment cost, standard violation value would be decreased as shown in Fig.3-Fig.6. What signifies the results from previous studies is that the optimization is a three-dimensional approach. The frequencies show the total solutions from the Pareto front for each objective function.

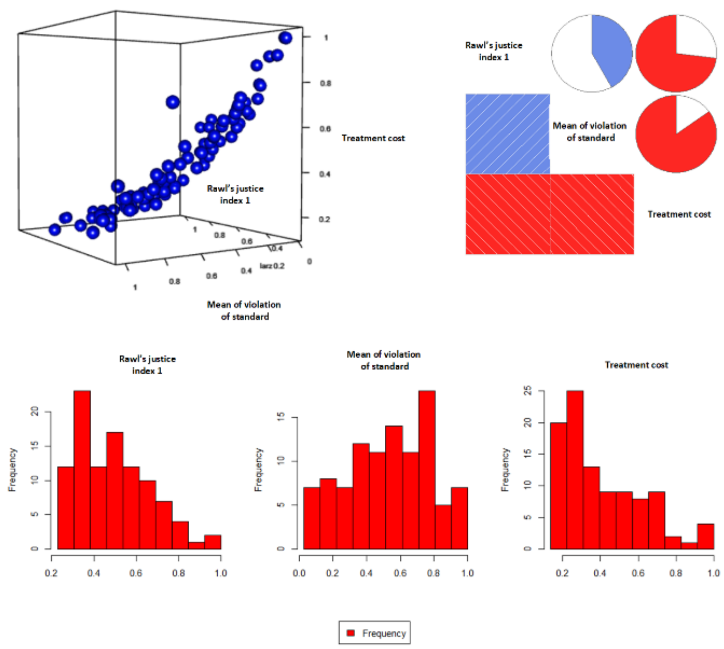

Figure 3. Tradeoff between objective functions with their Pareto front (RI1, DO_{Std}: 4 mg/L)

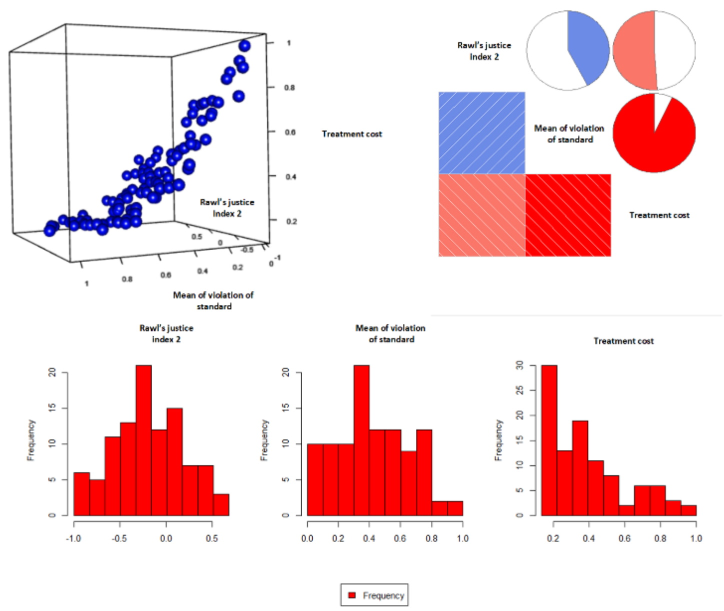

Figure 4. Tradeoff between objective functions with their Pareto front (RI2, DO_{Std}: 4 mg/L)

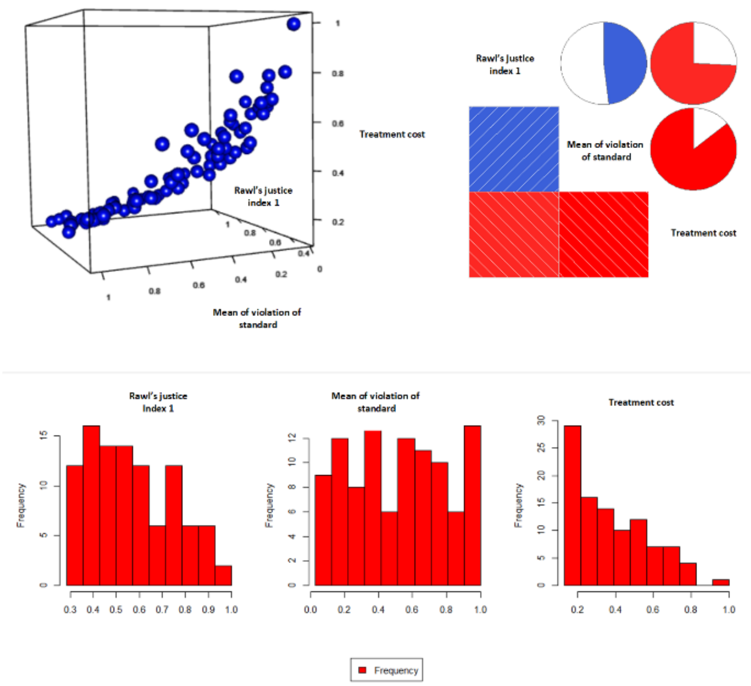

Figure 5. Tradeoff between objective functions with their Pareto front (RI1, DO_{Std}: 3.5 mg/L)

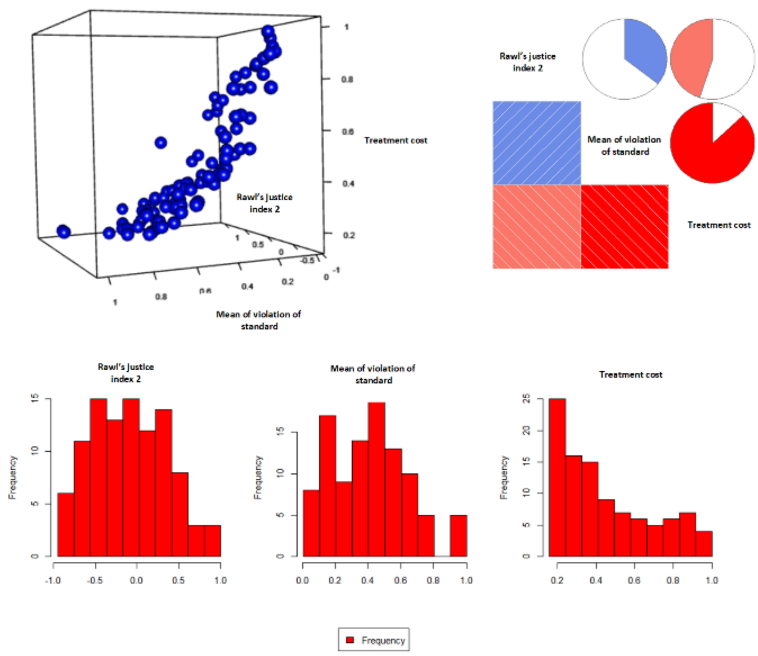

Figure 6. Tradeoff between objective functions with their Pareto front (RI2, DO_{Std}: 3.5 mg/L)

COPRAS analysis

According to the optimized objectives, different solutions are derived from three dimensional multi-objective space. For this purpose, the COPRAS method was used for selecting the optimal solutions. In this regard, in three scenarios, the highest value is given to the goals of equity, standard violation, and treatment cost so that the most compatible solutions are selected. In one scenario, all three objectives are given the same weight so that the solution that considers these indicators is selected.

In Table 1, the results of each polluter treatment (%) in different scenarios is presented. In the solution chosen based on the standard violation, the highest value is related to this goal and as it is known, the polluters have to treat pollution at the highest rate. According to Table 2, this solution with 36.9 billion Rials incurs the highest cost to the system among the selected scenarios. In this scenario, the average amount of standard violation is very low and it can be concluded that the system is in a safe condition.

Table 1. The selected solutions based on COPRAS method (RI1, DO_{Std}: 4 mg/L)

Selected solution by:	Solution number	Pollution removal (%) for each polluter							
		1	2	3	4	5	6	7	8
RI1	37	10.52	10	92.41	78.77	100	100	10	100
Violation	99	53.2	79.4	100	88.04	95.4	79.85	94.78	89
Cost	100	47.32	13.90	18.90	41.25	10	25.04	10	34.75
3 objectives	32	95.05	27.24	84.07	64.81	82.51	76.63	70.93	80.96

Table 2. Objective values in each selected solution (RI1, DO_{Std}: 4 mg/L)

Scenario	Selected solution by:	Objective		
		Equity index	Violation (mg/L)	Cost (Billion Rials)
1	RI1	58.69	0.99	26.9
2	Violation	64.89	0.08	36.9
3	Cost	193.52	2.95	5.1
4	3 objectives	97.81	0.69	20.5

The comparison of the selected solutions based on the standard violation and equity (RI1 and RI2) shows that with 27% less treatment cost, the highest fairness in the WLA system is achievable. In the solution with the highest fairness (Scenario 1), polluters 1, 2, 4, and 7 will face a reduction in total cost, while polluters 5, 6, and 8 will experience cost enhancement and removal efficiency (%). This scenario costs 26.9 billion Rials in overall. Here, the standard violation is about 1 mg/L. In Scenario 3, the solution was selected based on the minimized costs, as the highest standard violation and the least fairness were obtained. In this solution, although the maximum standard violation occurs, DO concentration is still above the standard level and the system remains in safe condition. In Scenario 4, which simultaneously considers the 3 objectives, the total cost is 44.4% less than Scenario 2. Table 3 shows the results of multi-objective optimization based on RI2 with the standard of 4 mg/L (DO_{std}).

Table 3. The selected solutions based on COPRAS method (RI2, $DO_{Std:}$ 4 mg/L)

Selected solution by:	Solution number	Pollution removal (%) for each polluter							
		1	2	3	4	5	6	7	8
RI2	84	74.46	52.91	77.01	73.34	70	80.81	10.61	61.40
Violation	41	100	40.53	100	100	74.79	100	100	43.09
Cost	83	39.29	23.77	26.41	44.65	38.14	56.97	15.69	60.42
3 objectives	84	74.46	52.91	77.01	73.34	70	80.81	10.61	61.40

According to the results, in the selected solution based on standard violation, except for polluters 2, 5, and 8, other emission sources should reach 100% treatment. This solution has a total cost of 40.6 billion Rials, 10% more than the optimization ratio based on RI1 (Table 4). In this solution with 0.002 mg/L violation, the river is quantitatively in a safe condition. By comparing solution 84 (RI2) in WLA with other solutions, we can conclude that a relatively operational WLA (70% BOD removal) can be obtained. On the contrary, other solutions (41 and 83) require extremely high (100%) or low BOD removal (20-40%). Consequently, fairness can imbalance WLA in the river system for more practical wastewater treatment. This solution (84) totally cost 15.2 billion Rials, which is about 62.5% less than the solution with the least standard violation. Here, the average violation is about 1.29mg/L. In the third solution, based on the cost criteria, pollution removal (%) will be significantly reduced in comparison with the least violation solution, whereas the violation exceeds 2.6 mg/L. The latter is not acceptable for a river with minimum allowable DO of 4 mg/L. Here, the highest decrease in pollution removal is attributed to the polluter 7. More interesting is that in the 4th scenario, where all of the criteria are taken into account with equal weights, the optimal solution is identical to RI2 Scenario (solution 84).

Table 4. Objective values in each selected solution (RI2, DO_{Std}: 4 mg/L)

Scenario	Selected solution by:	Objective		
		Equity index	Violation (mg/L)	Cost (Billion Rials)
1	RI2	-2.58	1.29	36.5
2	Violation	-2.23	0.002	40.6
3	Cost	0.37	2.63	5.4
4	3 objectives	-2.58	1.29	15.2

The results of the optimization model based on RI1 with DO limit of 3.5 mg/L is shown in Table 5. According to the results in the selected solution based on the goal of violation of the standard, all dischargers are required to treat with a high percentage, so that by implementing the percentages provided in this solution, the amount of violation of the standard will reach 0.073 mg/L. This solution costs 38.1 billion Rials in total and has the highest cost among the selected solutions. By comparing solutions one and two in Table 6, in order to achieve the highest level of justice, dischargers 1 and 7 are required to increase, and other dischargers are required to decrease the treatment efficiency. The cost of implementing this solution is lower by 15.7 billion Rials compared to scenario 2, whereas it has a much higher violation rate.

Table 5. The selected solutions based on COPRAS method (RI1, DO_{Std}: 3.5 mg/L)

Selected solution by:	Solution number	Pollution removal (%) for each polluter							
		1	2	3	4	5	6	7	8
RI1	92	82.50	10	87.09	10	10	77.93	100	91.64
Violation	45	79.43	84.53	89	89.59	98.13	83.17	72.80	93.20
Cost	12	35.97	33.43	40.64	46.82	12.43	34.13	17.23	50.64
3 objectives	39	65.48	17.80	76.83	59.27	86.80	82.62	77.07	93.16

Table 6. Objective values in each selected solution (RI1, DO_{Std}: 3.5 mg/L)

Scenario	Selected solution by:	Objective		
		Equity index	Violation (mg/L)	Cost (Billion Rials)
1	RI1	69.05	1.41	2.24
2	Violation	74.68	0.073	3.81
3	Cost	223.87	2.46	0.50
4	3 objectives	98.28	0.51	1.87

In solution number 3, according to the choice of the solution based on the cost objective, the pollution removal (%) are very low and the amount of environmental violation is also the highest among the solutions. It is also the most inappropriate solution in terms of equity among other solutions. In solution number 4, which accounts all objectives, the total cost is about 50.9% less compared to solution number 2 and 274% more than the 3rd solution, but with 73% less environmental violation. The results of multi-objective optimization based on RI2 under the standard of 3.5 mg/L are presented in Table 7.

Table 7. The selected solutions based on COPRAS method (RI2, DO_{Std}: 3.5 mg/L)

Selected solution by:	Solution number	Pollution removal (%) for each polluter							
		1	2	3	4	5	6	7	8
RI2	17	100	24.84	82.93	78.42	100	100	10	100
Violation	64	92.10	46.34	100	100	100	71.45	53.91	49.77
Cost	42	22.32	12.82	49.76	23.42	33.81	43.73	39.27	52.92
3 objectives	31	87.73	28.69	73.48	75.62	62.76	80.99	74.45	59.54

According to the results in solution 64, in order to achieve the least environmental violation, polluters 3, 4 and 5 should reach 100% removal. In this solution, with a total cost of 32.4 billion Rials, the average violation of the standard along the river will reach 0.01 mg/L. In solution 17, with the highest equity, the environmental violation only reach 0.5 mg/L and the cost is 8.24% less than solution 64. According to Table 8, in solution 3, despite the fact that it costs a little, the average violation of the standard with a value of 2.41 mg/liter is higher than other solutions. In this solution, the total cost will be significantly reduced by 84.5% compared to solution number 2.

Table. 8. Objective values in each selected solution (RI2, DO_{Std}: 3.5 mg/L)

Scenario	Selected solution by:	Objective		
		Equity index	Violation (mg/L)	Cost (Billion Rials)
1	RI2	-2.51	0.50	2.96
2	Violation	-0.78	0.01	3.24
3	Cost	2.29	2.41	0.52
4	3 objectives	-1.38	0.49	1.74

Conclusion

This study used a simulation-optimization method for multi-objective WLA in river based on Rawls' theory of justice and allowable environmental violations. S-P equations in addition to NSGA-II and COPRAS were used for determining pollution removal efficiency (%) of each emission source. Results showed that using optimal WLA scenarios based on Rawls theory can partially consider fairness perspective in decision-making. More importantly, this study showed that simultaneous three-dimensional optimization with COPRAS works for finding optimal solution based on environmental, economic, and justice objectives. In this condition, equity-driven solutions could point into the most practical options, with reasonably insignificant environmental violation from water quality standards and inexpensive treatment costs. Therefore, we recommend using the equity functions for further WLA instead of conventional two objective economic-environmental optimizations.

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