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Value Index, a Novel Decision Making Approach for Waste Load Allocation

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***Abstract*—**Waste load allocation (WLA) policies may use multi-objective optimization methods to find the most appropriate and sustainable solutions. These usually intend to simultaneously minimize two criteria, total abatement costs (TC) and environmental violations (EV). If other criteria, such as inequity, need for minimization as well, it requires introducing more binary optimizations through different scenarios. In order to reduce the calculation steps, this study presents value index as an innovative decision making approach. Since the value index contains both the environmental violation and treatment costs, it can be maximized simultaneously with the equity index. It implies that the definition of different scenarios for environmental violations is no longer required. Furthermore, the solution is not necessarily the point with minimized total costs or environmental violations. This idea is testified for Haraz River, in north of Iran. Here, the dissolved oxygen (DO) level of river is simulated by Streeter-Phelps equation in MATLAB software. The WLA is determined for fish farms using multi-objective particle swarm optimization (MOPSO) in two scenarios. At first, the trade-off curves of TC-EV and TC-Inequity are plotted separately as the conventional approach. In the second, the Value-Equity curve is derived. The comparative results show that the solutions are in a similar range of inequity with lower total costs. This is due to the freedom of environmental violation attained in value index. As a result, the conventional approach can well be replaced by the value index particularly for problems optimizing these objectives. This reduces the process to achieve the best solutions and may find better classification for scenario definition. It is also concluded that decision makers are better to focus on value index and weighting its contents to find the most sustainable alternatives based on their requirements.

***Keywords*—**Waste load allocation (WLA), Value index, Multi objective particle swarm optimization (MOPSO), Haraz River, Equity.

I. Introduction

BASED on recent developments for environmental engineering and particularly, integrated water resource management, the accurate and rapid planning and decision making approaches are turned into a prerequisite for water quality management. There, rivers as typical water resources should be pointed out as primary targets to find an optimized solution for waste load discharges. In general, the main problem of surface water quality is related to the development plans in the basins so that emission sources discharge wastewater without proper treatment. For better surface water quality management and more sustainable decision making, one should determine the treatment levels regarding the environment, economic and social aspects under waste load allocation (WLA) policy [1].

WLA determines pollutant removals (or treatment levels) at different point sources to ensure that water quality standards do not exceed throughout the receiving water body. The optimal WLA points out that the treatment vector selected not only maintains the water quality standards, but also results into the best value of objective function defined for the management problem [2]. It means that WLA can satisfy quality standards and simultaneously minimize the costs imposed to the treatment facilities [3]. Since these contradictory objectives are required in the decision-making, the multi objective optimization models are used to find the best solutions. For example, for water allocation [4], surface water quality management [5], water distribution network [6], reservoir operation [7], [19] and waste load allocation [8], [9], these models are used. However, the utilization of integrated simulation-optimization techniques may provide more efficient policies with the expanded capabilities. Saadatpour and Afshar (2007) have addressed the waste load allocation in uncertain conditions. In their research, the cost function and the quality standards for water were considered as fuzzy values [10]. Yandamuri et al. (2006) solved the WLA problem in the form of two multi-objective models using genetic algorithm. In the first model (cost-performance), only the minimization of violations of quality standard was considered but in the second model (cost-equity-performance), the equity index was also included [5]. Also, Mostafavi and Afshar (2011) have optimized the cost-performance model by including several different wastes [3].

In some cases, in addition to the environmental and economic factors, various decisive parameters such as inequity index and social welfare are effective for WLA [1]. This may increase the calculations in binary optimization methods and motivate researchers to use mathematical approaches in accordance to the multi criteria decision making (MCDM) methods [11]-[13]. However, it is verified that these methods are capable to provide a framework for optimal WLA for integrated water resource management; it is rather complicated to solve MCDM problems with naturally contradictory objective functions [12]. For this purpose, different scenarios

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are defined to use conditions instead of an objective function. It may also increase the calculations, or even reduce the accuracy of solutions [15]. Another approach is that a multi criteria functional index, as a replacement to different objectives, is defined to shorten the mathematical calculations using single-objective optimization methods [15]. For instance, Axelrad and Feinerman, (2009) have previously used total social welfare as a comprehensive index for decision making [16]. Likewise, water quality index (WQI) can be used for comprehensive analysis of the quality of surface waters. Since pollution removal efficiency, total abatement costs, and environmental risks of violations are primary parameters in monitoring and performance assessment for WLA, it is recommended that a value index should be defined instead to replace the complicated mathematical computations that involves all above.

Recently, value index is introduced as an innovative approach for unit process selection and wastewater treatment optimization [14]. It uses scores to determine the values of environmental risks, removal efficiency and total abatement costs. Therefore, the definition of value index that includes all these parameters may help to reduce the calculations of problems that intend to optimize solutions with more than 2 parameters. This paper focuses on finding the possibility and outcomes of WLA optimization by value and inequity indices simultaneously as an innovative approach instead of conventional two-steps optimization method. For this purpose, Haraz River area is studied.

II. Materials and Methods

A. Study area

Haraz River is located in the North of Iran, with total length of 185 km and maximum flow rate of 94 MCM/yr. It originates in Alborz Mountains and ends up to the Caspian Sea [17]. For around 40 km in upstream, it is the main receiving water body of several fish farming discharges. These can build up eight colonies that here are termed as point source polluters (Fig. 1). It is noteworthy that the effluents are currently monitored by command and control (C&C) policy in regard to the concentrations of biochemical oxidation demand (BOD) at discharge points. This is required to be removed at least about 90%. However, monitoring dissolved oxygen (DO) may be more efficient in the whole receiving water body instead. Therefore, this study uses simulation methods at first step to find appropriate and economical TMDLs based on DO concentrations.

B. Methodology

In the first step, river was simulated by Streeter - Phelps equation in MATLAB software to achieve DO profiles. It was then optimized twice by MOPSO. It should be mentioned that the efficiency and practice of MOPSO as a meta- heuristic explanatory algorithm has been previously approved by different studies. Baltar and Fontane (2008) used MOPSO to solve a multipurpose reservoir operation problem with four objective functions. [18] Azadnia and Zahraie (2010) used the MOPSO for the operation of Sefidrud reservoir to simultaneously supply the downstream demands and sediment discharge [19]. They also discussed about the potential of MOPSO algorithm on finding non-inferior solutions with high diversity. Rahimi et al. (2013) compared the performance of the MOPSO and the NSGA-II algorithms in the reservoir operation of Doroudzan Dam. The comparative results verified the efficiency of the former for optimum solutions achievement for reservoir operation [20].

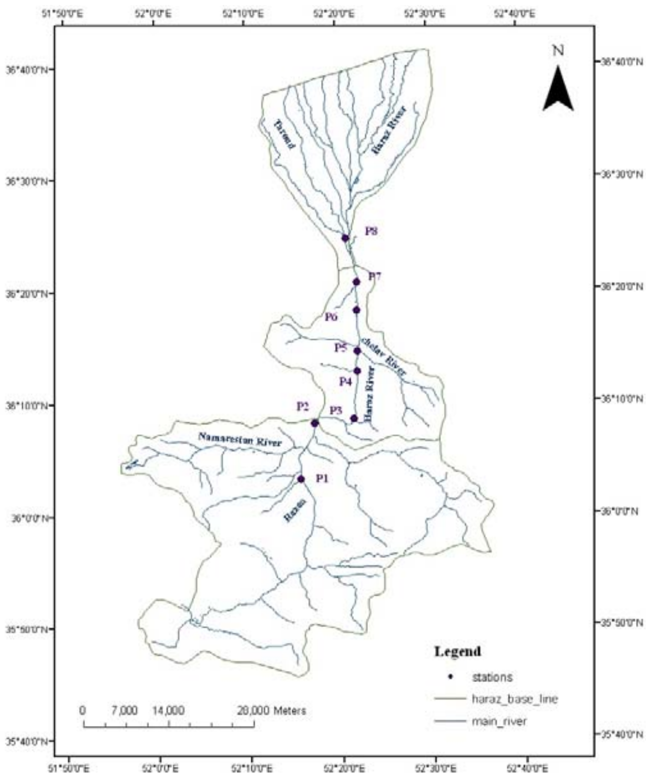

Fig. 1 Study area and location of emission sources

Here, MOPSO is used to find two sets of non-dominated solutions. The first shows the Pareto solutions of minimum total treatment costs (TC) versus minimum total environmental violations (EV) while the second points out to the minimum TC versus minimum total inequity index (TI). These functions are defined here as Z_1, Z_2 and Z_3 respectively by (1), (3) and (4) as [1], [21].

$$Z_1 = Min \sum_{i=1}^{n} C_i(x_i) \tag{1}$$

Z1 is TC objective function, n is the number of point sources here equals 8, Ci is the annual capital and operating cost of wastewater treatment plants per volume ($/m3) determined by (2), xi is the biochemical oxidation demand (BOD) removal determined by the optimization model, and Qi is the annual average flow rate of discharger i (m3).

The total treatment costs of emission sources rely on the efficiency of waste load removal and the process in use. Therefore, it is defined as a function of BOD removal. Here, the capital and operating costs are included for 30 years operation and maintenance. It should be noted that the cost function is estimated by a data base of 50 wastewater treatment plants previously practiced in Iran from 2010 to 2013 [22].

$$C_i(x_i) = ax_i^2 + bx_i + c \tag{2}$$

where a, b, and d are given as 13.56, 7.25, and 0.95 respectively through a trendline attained by regression analysis.

$$z_2 = Min\sum_{j=1}^{m} V_j \tag{3}$$

$$V_j = D_{st} - D_{sim.} \tag{4}$$

Z2 refers to the total environmental violations where m is the number of control points, and Vj (mg/L) is the difference between the concentration of the monitoring parameter (and the standard limit at the control point j (4). This is calculated here by Streeter-Phelps equation for dissolved oxygen (DO) [22]. It is noteworthy that Vj relies on the remediation potential of surface waters which is estimated here by the simulation. It means that Vj is dependent on parameters such as, hydraulic conditions, waste loads discharged, the flow rates, and more important the aeration and organic degradation rates.

The TC-EV Pareto solutions determine WLA in a condition that the environmental violation is at its minimum level. Here, for Vj, the minimum DO concentration is set on 3.2 mg/L to surely have a river with more than 3 mg/L DO concentration in optimum WLA. These conditions are also considered in TC-TI trade-off. The latter finds non-inferior solutions in which the inequity index and TC are minimized, simultaneously.

$$Z_3 = Min\sum_{i=1}^{n}\left|\frac{x_i}{x_m} - \frac{W_i}{W_m}\right| \tag{5}$$

Z3 shows the total inequity index in which Wi and Wm are respectively the waste load discharged by polluter i and average of waste loads discharged to the surface water. Other parameters have already been introduced. Minimization of this index means that the dischargers with high waste loads (W) are recommended to remove more organics (x) for WLA rather than polluters having a lesser amount of waste loads. This index may represent the adverse emotional effects of stakeholders that are participated for optimal WLA policy.

C. Value Index

In the second step, the optimization is carried out by calculating the value index. Value index is typically defined by a ratio of total efficiency of the system (E), as a matter of its goals, to the aggregate of total costs and risks. It means that having better organic removal efficiency may increase the value. Conversely, total capital and operating costs (C) in addition to the total environmental and operational risks (R) should be minimized. This is shown in (6) [14]. Here, the environmental violations are included within environmental risk factor.

$$\mathrm{V(x)} = \frac{\mathrm{E(x)}}{\mathrm{R(x)} + \mathrm{NC(x)}} \tag{6}$$

In (6), the value index (V) is a dimensionless number calculated as a function of system efficiency (E), its operational and environmental risks (R) and total capital and operating costs (NC). Here, x is the recommended organic removal efficiency determined by the optimization method. It requires attention that in order to calculate a dimensionless value index, it is necessary to find dimensionless results for all the parameters of E(x), R(x), and NC(x). For example, total treatment costs can not directly add to the risks. Therefore, these results should be normalized in the range of 0 to 1 or used under fuzzy logic method. Here, NC(x) and R(x) are calculated respectively as (7) and (8) for normalization. In addition, E(x) is calculated as the percentage of organic removal.

$$R(x) = \sum \frac{(D_{st} - D_{sim.})}{D_{st}} \tag{7}$$

$$NC(x) = \sum \frac{(C(x) - C_{C\&C})}{C_{C\&C}} \tag{8}$$

where Dst and Dsim are defined earlier and Cc&c refers to the costs attributed to the current command and control policy. NC(x) is the normalized difference between WLA and command and control costs in which it can become negative as well.

III. Results and Discussion

The TC-EV trade-off curve (Fig. 2) shows a set of Pareto solutions in which at the right side, the total environmental violation reaches to its minimum level. Here, the primary objective is met. It determines the most economical WLA in which the standard limits can be preserved.

Fig. 3 demonstrates the TC-TI Pareto solutions. It implies that the WLA defined by TC-EV optimization are almost the most economical solution with the highest inequity index. However, this figure shows that the minimization of inequity index requires more capital costs decreasing the revenues. For example, the solution with the lowest inequity index (2.5) requires 1.64 M$/yr. This is about 64% more than the treatment costs required for the Pareto solution with the highest inequity (4.7) which is about 1 M$/yr. Therefore, the allocation regarding the inequity index seems not economical and may possibly not receive the attentions of stakeholders. In order to find economic, environmental friendly and equal solutions, different scenarios are required to find the optimal solutions in regard [1].

Value trade-off curve has a different point of view in comparison with Fig. 3. The probable accepted solution is a point that has the highest value content in which total costs and inequity are not significant in regard. It should be noted that the environmental risks are considered for value calculations. For example, in the highest value index equals to 2.8 (1/V = 0.36), the inequity and total costs are respectively 2.42 and 2.2. The environmental violation does not exceed 10 mg/L. It points to a solution that its inequity is relatively the same as the best inequity reported by Fig. 3 and its total costs are rather smaller.

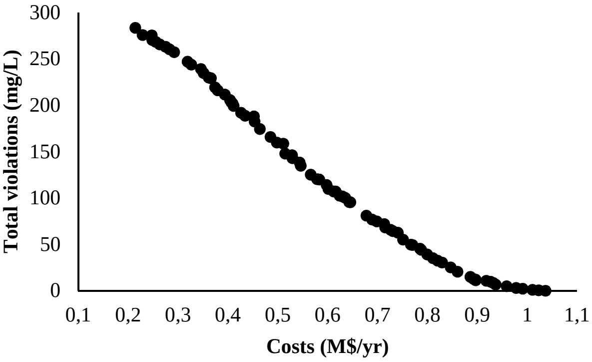

Fig. 2 Total costs - total environmental violations trade-off curve

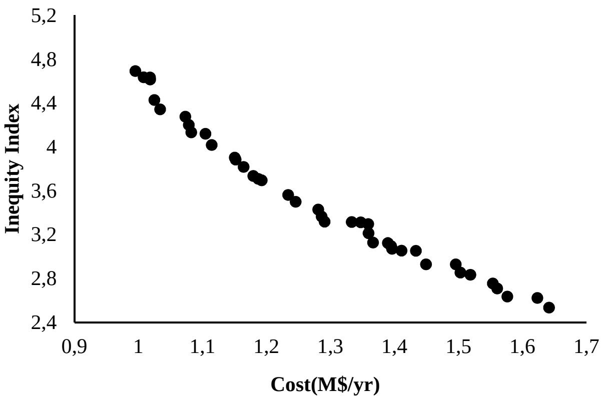

Fig. 3 Total costs - total inequity index trade-off curve

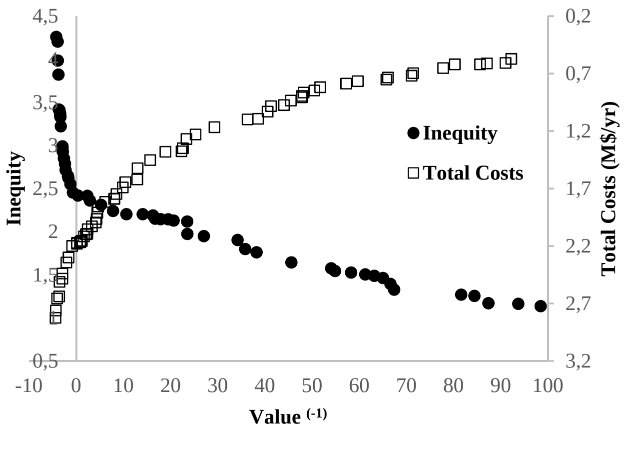

Fig. 4 Value $^{(-1)}$ - total inequity index and total costs trade-off curves

Here, the aggregation of normalized environmental risks and total costs are minimized that made a development for value index. The value index trade-off (Fig. 4) finds solutions in which te inequity is rather the same as Fig. 3 in same total costs. It ranges between 1.1 and 2.5, for abatement costs between 0.7 to 2.2 M$/yr., the best solution with the lowest inequity based on Fig. 3 has 4.7 M$/yr. that here is about 2.2 M$/yr. This is due to the fact that the environmental risks are no longer limited in scenarios and has a freedom of variation in a way that the value index is not reduced significantly. The value may become negative since normalization of total costs or environmental violations are able to become negative and ultimately dominates. Here, it shows WLA that may contain solutions in which the total costs are less that C&C approach (8) or DO is much higher than standard values (7). The results for WLA sound practical. Therefore value index can be maximized for WLA in places that inequity may play great roles such as fish farms. Moreover, Pareto solutions can only find few alternatives that point to the high values. These can find solutions in which the inequity or total costs come to a threshold that hardly changes thereafter.

In spite of the advantages of using value index, it may bring some ambiguity about calculation steps. This index has the potential for upgrading using fuzzy logic systems for scoring risks and costs instead of normalization. In addition, using the weighted factors can satisfy the demands of stakeholders about different strategies. Some may focus on environmental risks while the others may emphasize on total costs. Consequently, strategies may define scenarios that seek for maximum values in regard.

IV. Conclusion

This study presents a novel decision making criteria that contains both environmental violations and total costs within a unified index. Here, the value index is introduced to be optimized simultaneously with the inequity index. Therefore, 3 parameters are optimized in only one step. WLA could verify the feasibility of using this approach to reduce the calculation steps in which the solutions may satisfy the lowest inequity and the highest values simultaneously.

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