Surface water quality management using an integrated discharge permit and the reclaimed water market

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ABSTRACT

Water quality trading is a sustainable framework for surface water quality management. It uses discharge permits to reduce the total treatment costs. For example, the case of Gharesoo River in Iran shows that the nitrogen permit market between point and non-point sources is 37% more economical than the command and control framework. Nevertheless, the cost saving may be reduced to 6% by the end of the study period (2050). This depression may be due to the limited technical support for wastewater treatment plants. Therefore, an integrated market is recommended in which the discharge permits and the reclaimed water are traded simultaneously. In this framework, the allocation of secondary treated domestic wastewater for irrigation can provide capacity for other pollutants to discharge into the surface water. This innovative approach may decrease the total treatment costs by 63% at present, while 65%, may be achieved by the end of the study period. Furthermore, this market is able to determine the environmental penalty, trading permits, and reuse prices. For example, the maximum ratio of the average reuse price to the penalty cost is determined as 1 to 10. It is introduced as an incentive indicator for stakeholders to consider the integrated market. Consequently, the applicability and the efficiency of using this approach are verified long term.

Key words | Gharesoo River, Iran, nitrogen market, total abatement cost, trading discharge permits (TDP), wastewater reuse

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INTRODUCTION

Water quality trading (WQT) is a promising policy for meeting water quality standards, in which the ambient discharge framework determines the total maximum daily load (TMDL). This framework considers environmental remediation capacities and a site is specified for monitoring the downstream of all discharges. If the pollution exceeds the standard limits at checkpoint, the environmental penalty would be charged. Accordingly, stakeholders are interested in cooperating for a more economical waste load allocation.

The policy of trading discharge permits (TDP) first focuses on stakeholders that can take advantage of efficient and cost-effective wastewater treatment plants as permit sellers. Because of low marginal treatment costs, and probable high impact on river quality, they are required to reduce organic loads beneath TMDL values. The surplus reduction is sold as permits to other polluters who have not been able address standard limitations economically. Consequently, it can induce both emission sources and monitoring organizations to cooperate in order to control the whole watershed quality (Eheart *et al.* 2004).

During the last decade, the feasibility and efficiency of WQT have been investigated in the literature. Previous studies have emphasized finding the potential market for discharge permits among different stakeholders, including point and non-point sources (Collentine 2005; Ranga Prabodanie *et al.* 2010; Ribaudo & Gottlieb 2011). Based on an analytical decision making framework outlined by USEPA (2004a), the TDP market can determine the interactions of emission sources. This is defined by estimating the projected loads, TMDL limitations, the potential reduction of loads, the incremental and total treatment costs, and the impacts of pollutants on surface water quality. This may lead to a promising technical, environmental, and economical policy in both the short- and long-term. However, at a larger scale, the results may not accurate enough to forecast exact outcome (Boyd & Greenwood 2005). Therefore, in order to find a supportive rational decision-making

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approach with the lowest uncertainty, the interactions of market stakeholders and their risks have been simulated through decision-making support systems and modelled with fuzzy logic (Niksokhan *et al.* 2009a, 2009b; Nikoo *et al.* 2011; Nguyen *et al.* 2013). In addition, in order to control eutrophication and manage surface water quality, parameters such as phosphorus and nitrogen have been considered in the TDP market (Ribaudo *et al.* 2005; Kardos & Obropta 2011). Moreover, Ghosh *et al.* (2011) and O'Grady (2011) have previously reviewed the economical and socio-political aspects and barriers of this framework in different conditions. In spite of the advantages of TDP, market interactions are rely on surface water characteristics, uncertainties, types of pollutant, and mostly technical limitations on wastewater treatment.

This study aimed to find an economical market for nitrogen discharge permits for Gharesoo River in the west of Iran. In order to have a more comprehensive assessment of market-based interactions, domestic wastewater reclamation and reuse has been considered within the program. This innovative integrated water and wastewater management approach is intended to overcome technical limitations for surplus load reduction and to increase the outcomes of the market.

MATERIALS AND METHODS

Case study

This research has been carried out on an analytical case study of Gharesoo River, in the west of Iran. In accordance with previous studies, the main pollutants were identified as domestic, agricultural and industrial sources (Jamshidi *et al.* 2013). The effluent flow rate and the total nitrogen (TN) load discharged to the surface water were estimated using export coefficients and statistical reports (Table 1). Qual2kw software was used for river simulation as recommended in previous studies (Pelletier *et al.* 2006; Kannel *et al.* 2007). Accordingly, through sensitivity analysis, the impacts of pollutant reduction incurred on the quality of the terminus point are calculated and normalized by Equation (1) (Jamshidi *et al.* 2013).

$$IF_i = \frac{\mathrm{d}TN_i}{\sum_{i=1}^{m} \mathrm{d}TN_i} \tag{1}$$

In which IF_i is a dimensionless impact factor, $\mathrm{d}TN_i$ is the value of nitrogen concentration (mg/L) reduced in terminus point as a matter of one unit reduction (ton/year) of the projected loads, i is the emission source, and m is the total number of emission sources. The IF expresses the proportionate impacts of load reductions achieved by each of the emission sources and can assist decision makers to calculate the prices of trading permits. The calculated impact factors are shown in Table 1.

Methodology

WQT aims to find a least cost waste load allocation policy. Therefore, economical factors play a key role in decision making. Accordingly, the total cost (TC) is calculated as Equation (2) (Niksokhan *et al.* 2009a).

$$TC = \sum_{i=1}^{m} (C \times Q + P_n \times L_{\mathrm{d}} \pm P_{\mathrm{r}} \times L_{\mathrm{t}} \pm R \times L_{\mathrm{r}})_i \tag{2}$$

where TC is the annual total costs ($), C is the annual capital and operating cost of wastewater treatment plants per volume ($/m^3), Q is the average design flow rate of wastewater treatment plants (m^3/yr), P_n is the average cost assumed as environmental penalty ($/Kg), L_{d} is the annual not authorized loads discharged (Kg/yr), P_{r} is the incremental cost of permits calculated by Equation (3) ($/Kg), L_{t} is the annual loads traded (Kg/yr), R is the assumed average market price of treated wastewater reuse ($/Kg), and L_{r} is the annual nitrogen loads reused (Kg/yr). In addition, m is the number of emission sources included in the program.

To calculate C, the average annual capital costs per volume are estimated by the TCs of 50 domestic and

Table 1 | The effluent characteristics of the main pollutant sources of Gharesoo River

Application	Source type	Estimated effluent volume discharged (MCM/year)	Estimated TN load discharged (Ton/year)	Average concentration of TN (mg/L)	Impact factor (%)
Domestic	Point	4.9	300	61.5	32.5
Agricultural	Non-point	21.1	420	20	36
Industrial	Point	1.8	91	50	31.5

industrial wastewater treatment plants constructed in Iran from 2010 to 2013 (Jamshidi *et al.* 2013). Furthermore, the annual operating and maintenance costs are estimated to be about 7 to 12% of the capital costs (USEPA 2007). L_d and L_t are calculated based on formulae outlined in similar studies (Boyd & Greenwood 2005; USEPA 2004a, 2009).

Typically, two methods are used for market pricing. First, the government imposes the basic price of goods while the second is derived through the market's dynamic interactions. For example, the penalty price is usually determined by the government. However, in this approach, the maximum reuse price and the minimum penalty price are proposed to the government through the market outcomes. Moreover, the permit price is determined by the seller as shown below.

$$P_r = \frac{IF_B}{IF_S} \times IC_s \times d \qquad (3)$$

In which IF_B and IF_S are the impact factors of the buyer and seller pollutants, respectively. IC_s is the incremental cost of pollution reduction assigned to the emission source selling permits ($/Kg), and d is the coefficient resembling discount or benefit percentage. This equation is intended to compute the permit price that will be paid by the buyer. It can convert the incremental treatment costs of permit sellers (IC_s) by the ratio of impact factors. It is recommended that the seller uses a discount or benefit factor to make this market profitable for all stakeholders. This may persuade them to consider the trading market. It should be noted that using a discount would not necessarily impose excess treatment costs for the seller. However, in some cases, it may lead to more economically efficient trading for permit buyers. This coefficient is assumed as 1 for all scenarios in this study.

In this study the following is assumed.

(1) During a period of 30 to 35 years, domestic, agricultural and industrial pollutants may grow annually about by 3%, 0.8% and 1%, respectively, which leads to an enhancement in the projected loads (USEPA 2004a). As the efficiency of wastewater treatment processes rely on hydraulic retention time, it is assumed that each unit is able to work efficiently only to 1.5 times of their designed value. Otherwise, the second module is required to treat the excess influent (Tchobanoglous *et al.* 2003).

(2) The TMDLs are assumed based on national standard limits. They are 400, 1,000 and 150 Kg/day for domestic, agricultural and industrial pollutants, respectively.

(3) The treatment processes are classified into four groups with respect to their efficiency and TCs (USEPA 2007; Jamshidi *et al.* 2014):

- Process A includes typical secondary wastewater treatment units such as conventional activated sludge and extended aeration with an average of 15% in TN removal.
- Process B incorporates typical tertiary wastewater treatment units with 75% TN removal efficiency such as trickling filters, sequencing batch reactors and a modified Ludzack–Ettinger process.
- Process C is classified as high technology based processes able to remove more than 90% TN, such as the Bardenpho process (IV or V stages), membrane bioreactors, integrated fixed film activated sludge, and moving bed biofilm reactor.
- Process D includes natural and low-operating requirement units, such as constructed wetlands or lagoons. It is assumed that they are only used for non-point pollutant sources such as rural and agricultural wastewaters because of their odor emission and land requirements (Heberling *et al.* 2010). The annual average efficiency is assumed to be about 30% for a 24-hour detention time.

(4) Domestic and industrial pollutants typically have a significant amount of biochemical oxidation demand. Therefore, it is assumed that these emission sources are not allowed to discharge without constructing any treatment units. At the very least, they have to use Process A for pollution control.

(5) Regarding the high quality variations of industrial wastewaters and the existence of exotic compounds in industrial and agricultural wastes, it is assumed that only treated domestic wastewater can be used as reclaimed water for irrigation (USEPA 2004b).

RESULTS AND DISCUSSION

For a better conclusion, the results are discussed in two scenarios. First, the efficiency of the TDP market is compared to the conventional command and control approach. Second, the results of using reclaimed water in TDP are evaluated in comparison with the outcomes of the first scenario. Both are considered in terms of the present time (2014) and the end of the study period (2050).

Scenario 1 – TDP market

At present, all polluters have to construct and operate processes B, D, and B, respectively to meet the standard limits in the conventional system. This will cost approximately 3.22 M$/yr (Table 2). If the TDP is used, the total abatement cost would be decreased to 2.02 M$/yr. This equals 37% cost savings (Table 3, Part A) in which the emission sources (domestic and industrial) with lower incremental costs are permit sellers while the sources with higher costs (agricultural) are buyers. It points out that a discharge market between point and non-point sources may lead into a more efficient and applicable framework as expected (Collentine 2005; Ranga Prabodanie *et al.* 2010; Ribaudo & Gottlieb 2011). In this case, the values of permits traded amounts to about 0.67 M$/yr (Equation (3)) and the minimum annual penalty of excess discharge is considered to be 5,000 $/Kg (equals about 13.7 $/Kg daily). This can force stakeholders to consider the market and preserve the environment. For this purpose, the penalty price is determined in such a way that the application of advanced technologies (for example process B or C) for point sources is economically more favorable than environmental penalty charges. For example, if 420 Kg/d of domestic nitrogen loads are not legally discharged to the surface water, the total penalty would cost about 2.1 M$/yr. This is calculated by multiplying the load by the basic annual penalty price (5,000 $/Kg). Therefore, Process C may be an even more economical alternative (2 M$/yr).

It should be explained that at present (Table 3), the agricultural industry is interested in buying permits for 150 Kg/d surplus loads instead of paying for penalties or constructing Process D. Furthermore, it prefers to buy permits from a seller with a lower market price. Therefore, it may only deal with the domestic market (with 9.4 $/Kg) rather than with industry (with 19.1 $/Kg). As a consequence, 0.51 M$/yr would be traded, while industry could not gain any benefits from the market, unless it uses a discount factor (d) of 0.5 or less to decrease its own permit price from 19.1 $/Kg to less than 9.5 $/Kg to gain profits in a competitive market.

In 2050, the domestic facility would probably have to construct the second module of the treatment plant using process C. However, there is no applicable second module for agricultural waste management. So it has to pay a penalty of about 0.32 M$/yr, which can increase its TCs to 1.52 M$/yr (Table 2, Part B). As a consequence, the overall cost of TN reduction through the conventional system is calculated as 5.54 M$/yr. Here, the alternative for domestic emission sources is B and C, agriculture has to take process D in addition to paying the penalty, and industry chooses process B (Table 2, Part B). However, the TDP can use the potential surplus reductions of other stakeholders to free agriculture from the penalty charges; its revenues would be dramatically lowered. For example, treatment costs for domestic emission sources may be increased considerably, while revenues from selling permits from domestic and industrial sources would only be small amounts of 0.03 M$/yr and 0.18 M$/yr, respectively. Therefore, this market can simply save 6% of TCs in comparison with the conventional system, and can reduce it to 5.22 M$/yr (Table 3, Part B). It can be concluded that after 35 years, the nitrogen market may encounter a 67% depression.

In this scenario, it is implied that however TDP can be introduced as an economically efficient approach, its performance is completely reliant on the capacity of wastewater treatment plants for surplus load reductions. Accordingly, it is essential to find a sustainable and economical solution to prevent nitrogen load from being discharged to the surface waters. Therefore, wastewater reclamation and reuse policy is recommended for consideration within the TDP framework.

Scenario 2 – application of reclaimed water in TDP

The secondary treated domestic wastewater (reclaimed water) typically has a high nitrogen content. It can be introduced both as a water resource and fertilizer for agricultural purposes (USEPA 2004b). Therefore, its application would be warmly endorsed by farmers and treatment plant owners (Agrafioti & Diamadopoulos 2012; Al Khamisi *et al.* 2013; Mizyed 2013). Furthermore, it can be considered as a management approach to prevent discharging untreated nitrogen load directly to surface waters. This often imposes no considerable costs. Conversely, selling reclaimed water is an additional financial resource for operating wastewater treatment plants. It should be noted that farmers buying reclaimed water by farmers may even reduce the cost of supplying fertilizers. Therefore, all stakeholders (agriculture, wastewater treatment plant operators, and surface water managers) would have motivations for wastewater reuse and reclamation (Anderson 2003; Axelrad & Feinerman 2009; Molinos-Senante *et al.* 2011).

In this approach, at present, if it is supposed that process A is used for domestic wastewater treatment, 123 Kg/d of TN load can be removed (Table 2, Part A) while the excess 697 Kg/d (L_r) would be discharged to farmland. This means that domestic loads would not be projected directly to the surface water. Therefore, 420 Kg/d surplus reductions (equal to

Table 2 | Technical and economic characteristics of alternatives to control nitrogen load

Pollutant source (Wastewater)	Process type*	Projected nitrogen load (Kg/d)	Total reduction needed (Kg/d)	Total reduction achieved (Kg/d)	Incremental reduction needed (Kg/d)	Control incremental capital/O&M** incurred (M$/yr)	Incremental control cost ($/Kg)	Average control cost ($/Kg)	Potential surplus reduction (Kg/d)	Total penalty cost (M$/yr)	TC with penalty (M$/yr)
A. Present											
Domestic	A	820	420	123	297	0.77	N/A	17.2	– 297	1.48	2.25
	B			615	0	1.3	8.5	5.8	195	–	1.3
	C			738	0	2	13.0	7.4	318	–	2
Agriculture	D	1,150	150	345	0	1.2	21.9	9.5	195	–	1.2
Industries	A	250	100	38	63	0.42	N/A	30.7	– 63	0.32	0.74
	B			188	0	0.72	19.7	10.5	88	–	0.72
	C			225	0	1.2	32.9	14.6	125	–	1.2
B. End of the study period											
Domestic	(A,A)	2,307	1,907	346	1561	1.54	N/A	12.2	– 1561	7.81	9.35
	(A,B)			1126	781	2.07	N/A	5.0	– 781	3.91	5.98
	(A,C)			1321	586	2.77	N/A	5.7	– 586	2.93	5.7
	(B,B)			1731	177	2.6	N/A	4.1	– 177	0.88	3.48
	(B,C)			1926	0	3.3	4.7	4.7	18	–	3.3
	(C,C)			2077	0	4	5.7	5.3	169	–	4
Agriculture	D	1,520	520	456	64	1.2	N/A	7.2	– 64	0.32	1.52
Industries	A	354	204	53	151	0.42	N/A	21.7	– 151	0.76	1.18
	B			266	0	0.72	9.7	7.4	61	–	0.72
	C			319	0	1.2	16.1	10.3	115	–	1.2

*The processes mentioned in parenthesis (*x*, *y*) are units used in the first (*x*) and second (*y*) modules of wastewater treatment plant, respectively.

**Operation and maintenance.

Table 3 | The recommended trading program between stakeholders at (A) present and (B) end of the study period

Pollutant source (Wastewater)	Capital/O&M cost (M$/yr)	Incremental control cost ($/Kg)	Potential surplus reduction (Kg/d)	Trading role	Total trading price ($/Kg)	Permit trading cost (M$/yr)	TC (M$/yr)	TC saved (%)
A. Present								
Domestic	1.3	8.5	195	Seller	9.4	– 0.51	0.79	40
Agriculture	0	0	– 150	Buyer	–	0.51	0.51	57
Industries	0.72	19.7	88	–	19.1	0.00	0.72	0
Total	2.02		132.5				2.02	37
B. End of the study period								
Domestic	3.3	4.7	18	Seller	5.3	– 0.03	3.27	1
Agriculture	1.2	0	– 64	Buyer		0.22	1.42	7
Industries	0.72	9.7	61	Seller	11.0	– 0.18	0.54	26
Total	5.22		16				5.22	6

Table 4 | The recommended trading program considering reuse between main pollutants at (A) present and (B) end of the study period

Pollutant source (Wastewater)	Capital/O&M cost (M$/yr)	Incremental control cost ($/Kg)	Potential surplus reduction (Kg/d)	Trading role	Total trading price ($/Kg)	Permit trading cost (M$/yr)	Loads available for reuse (Kg/d)	Reuse trading cost (M$/yr)	TC (M$/yr)	TC saved (%)
A. Present										
Domestic	0.77	2.6	420	Seller	–	– 0.21	697	–0.35	0.21	84
Agriculture	0	0	– 150	Buyer	2.8	0.15	–	0.35	0.50	58
Industries	0.42	0	– 63	Buyer	2.5	0.06	–	–	0.48	34
Total	1.19		208						1.19	63
B. End of the study period										
Domestic	1.54	1.8	1907	Seller	–	– 0.48	1961	–0.98	0.08	98
Agriculture	0	0	– 520	Buyer	2	0.38	–	0.98	1.36	10
Industries	0.42	0	– 151	Buyer	1.8	0.1	–	–	0.52	28
Total	1.96		1236						1.96	65

the reduction needed mentioned in Table 2) would be available in the market (Table 4, Part A). This could provide permits for 150 and 63 Kg/d of the excess loads discharged by agriculture and industries, respectively. It is important that this approach is also able to reduce incremental costs for the permit seller (IC_S) from 8.5 $/Kg (Table 3) to 2.6 $/Kg (Table 4). Consequently, the revenues of the integrated market could reduce the total abatement cost to 1.19 M$/yr (Table 4), which is equal to a 63% reduction in overall costs. In this case, 0.21 M$/yr (Table 4) may be traded in the nitrogen market between the permit seller (domestic) and buyers (industry and agriculture).

Similar to the first scenario, the market is also studied in 2050. It is recommended that after about 15 years, the domestic emission source starts operating the second module with the unit process similar to the first one due to its valuable reclaimed water. Consequently, 1,961 Kg/d surplus reduction would be available as permits and the incremental control cost of domestic wastewater treatment plant may be reduced to 1.8 $/Kg (Table 4, Part B). Hence, the TC could be reduced to 1.96 M$/yr, which is equal to 65% in cost savings. The values of the total permits and reuse traded are about 0.48 M$/yr and 0.98 M$/yr, respectively (Table 4, Part B). It is obvious that the TCs of trading permits are increased in the long term, contrary to the first scenario. Furthermore, the comparison of the TCs of the reclaimed water and the permits traded show that the former is more economically attractive for trading.

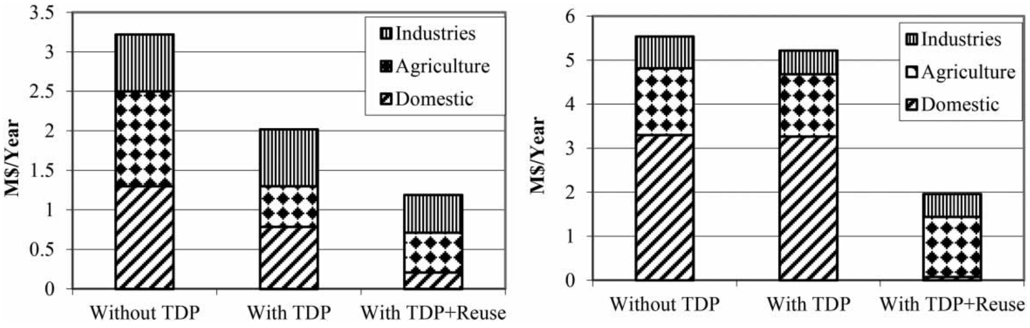

Figure 1 | Total abatement costs in different scenarios at the present (left) and end of the study period (right).

Similar to the penalty cost, the maximum annual reclaimed water price is limited to 500 $/Kg (equals about 1.37 $/Kg daily) to ensure that all stakeholders benefit from the integrated trading market. For this purpose, it is recommended that the reuse trading price should keep all cost savings numerically positive and rational for the stakeholders, of at least 5%. For example, if the annual basic reuse price exceeds 540 $/Kg, the TC savings of agriculture would decline to less than 5% (Table 4, Part B). Therefore, it is implied that the reuse price can balance the internal relations of stakeholders and benefits of trading market similar to the discount factor. This may be influenced by the dynamic demand for treated wastewater reuse and fertilizers, which are recommended for further detailed study.

In the second scenario, it can be concluded that considering reclaimed water within the TDP framework promotes cost savings, and also provides a sustainable solution to resolve the shortcomings of nitrogen permit market in the long term (Figure 1). This is due to the reduction of incremental control costs by using more economical treatment processes, and providing a large number of permit through wastewater reclamation and reuse. Furthermore, it is implied that the reclaimed water price should be determined in regard to the penalty and permit price. For example, the maximum cost of reclaimed water is considered here as about one tenth of the penalty price. This ratio indicates the maximum potential motivation can be provided for stakeholders to participate in the integrated market. The minimum penalty price is used to force emission sources to follow environmental regulations while the maximum trading reclaimed water price is determined to make stakeholders benefit by their attendance in the market. In other words, if this ratio exceeds 1, more incentives would be required. Conversely, for values less than 1, the punishment would have more effect. In addition, it is emphasized that wastewater treatment plants should be designed or operated with respect to integrated water resource management (Adewumi *et al.* 2010). However, due to the dynamic demand for reclaimed water for irrigation, flexible modules are mostly welcomed for wastewater treatment plants. Their optimized configuration needs to be determined based on market demand using decision support systems (Jamshidi *et al.* 2014).

CONCLUSIONS

This study aimed to assess the upgraded nitrogen discharge permits market between point and non-point sources of Gharesoo River in the west of Iran. It can be concluded that TDP is a sustainable and economically efficient approach in surface water quality management. However, its effectiveness is totally reliant on the technical limitations of wastewater treatment plants, particularly in the long term. This can be simply solved by the integration of WQT with the reclaimed water market. The latter brings the flexibility for nutrient-rich effluents to be discharged to farmland instead of to surface waters, without imposing any considerable costs. Consequently, it is verified that either in the short- or long-term, incremental and total abatement costs may be reduced. Moreover, it is implied that the selection of treatment unit process and market pricing should be implemented with consideration of integrated water and wastewater management. Accordingly, it is anticipated that the secondary economic and environmental benefits can be generated by lower fertilizer application, pumping irrigation, and better water resource management. Furthermore, it justifies privatization on operating wastewater treatment plants.

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