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Discharge permit market and farm management nexus: an approach for eutrophication control in small basins with low-income farmers

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Abstract The economic concerns of low-income farmers are barriers to nutrient abatement policies for eutrophication control in surface waters. This study brings up a perspective that focuses on integrating multiple-pollutant discharge permit markets with farm management practices. This aims to identify a more economically motivated waste load allocation (WLA) for non-point sources (NPS). For this purpose, we chose the small basin of Zrebar Lake in western Iran and used the soil and water assessment tool (SWAT) for modeling. The export coefficients (ECs), effectiveness of best management practices (BMPs), and crop yields were calculated by using this software. These variables show that low-income farmers can hardly afford to invest in BMPs in a typical WLA. Conversely, a discharge permit market presents a more cost-effective solution. This method saves 64% in total abatement costs and motivates farmers by offering economic benefits. A market analysis revealed that nitrogen permits mostly cover the trades with the optimal price ranging from \$6 to \$30 per kilogram. However, phosphorous permits are limited for trading, and their price exceeds \$60 per kilogram. This approach also emphasizes the establishment of a regional institution for market monitoring, dynamic pricing, fair fund reallocation, giving information to participants, and ensuring their income. By these sets of strategies, a WLA on the brink of failure can turn into a cost-effective and sustainable policy for eutrophication control in small basins.

Keywords Best management practices (BMPs) · Discharge permit market · Eutrophication · Low-income farmer · Non-point sources (NPS) · Soil and water assessment tool (SWAT) · Water quality trading (WQT) · Zrebar Lake

Introduction

Eutrophication is a widespread challenge for lakes and aquatic life. Nutrients discharged by non-point sources (NPS), mainly farmlands, are responsible for this phenomenon (Perera et al. 2015). A gamut of strategies, termed as best management practices (BMPs), are applied to reduce the nutrient loads discharged by farmers. Using modifications for tillage, land uses (LUs), or fertilizer applications are typical examples of BMPs (Liu and Lu 2015) even though their effectiveness depends on case-specific factors (Yang et al. 2012). For example, Ghebremichael et al. (2010) showed that the

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same LUs have significantly different pollution transport depending on their soil properties and land slopes. This emphasizes the necessity of a profound analysis through integrated farm and basin modeling that identifies critical source areas (CSAs) (Comin et al. 2014), and predicts the degree of pollution abated by BMPs (Ouyang et al. 2008). To this end, a myriad of simulation methods have been developed out of which the soil and water assessment tool (SWAT) (Arnold et al. 1998) is the most popular.

SWAT is an eco-hydrological program for watershed-scale modeling. Recent literature has pointed to its applicability and advantages in modeling NPS pollutions (Zhang et al. 2012), CSA identification in nutrient transport (Niraula et al. 2013), estimation of nutrient export coefficients (ECs) (Liu and Lu 2013), and tracking the effects of changing LUs (Wilson 2015). In addition, Liu et al. (2014) used SWAT to assess the efficiency of the BMPs of spatial differentiations of crop productions in small farms. They concluded that crops grown in the vicinity of surface waters are more responsible for their pollution than those planted in the highlands. Santhi et al. (2013) assessed the consequences of using BMPs on surface waters and croplands by SWAT. It was discovered that reducing 20 to 60% of nitrogen (N) loads discharged by emission sources could decrease N content by up to 20% in the estuary of the Gulf of Mexico. Lam et al. (2011) declared that SWAT is a promising model for estimating the effectiveness of BMPs. In their analysis, the viable abatement values of N, phosphorus (P), and sediments were estimated to be 20, 5, and 5%, respectively, and that the combination of different BMPs demonstrated up to 50% higher N removal with annual cost equaling €93,000. Despite these approaches, it is uncertain whether these BMPs are sustainable in areas with low-income farmers. Chen et al. (2014) argues that decision-makers should pay more attention to the cost effectiveness of BMPs than their abatement potential. Otherwise, any waste load allocation (WLA) policy for NPS, i.e., total maximum daily loads (TMDLs), may not last long. In such a case, water quality trading (WQT) is likely to have a better chance to put more efficient strategies forward.

WQT is a market-based framework in which emission sources can find economic incentives within environmental WLA strategies (USEPA 2004). It has been brought up that point sources (PS) and NPS can come to an agreement on trading discharge permits (TDP) for nutrient control (Ribaudo and Gottlieb 2011; Corrales et al. 2014). It is mostly for this reason that, in WQT, emission sources with higher incremental abatement cost (PS) can use the others' potential (NPS) for nutrient removal with lower cost. Eventually, the former repays the services of the latter in the form of trading permits. On the whole, this reduces total abatement costs and increases economic benefits. However, this strategy is more challenging in markets with multiple pollutants (Jamshidi and Niksokhan 2016) or among the farmers only (Ribaudo et al. 2014a). Still, there is a lack of knowledge of how and under what conditions low-income farmers find cost-effective solutions to willingly participate in a multiple-pollutant discharge permit market. It is noteworthy that the success of the market is reliant on the location of emission sources (Zhang et al. 2013), the preceding TMDL policy (Jamshidi et al. 2014), well-matched trading partners (Wittmann 2014), the scale of the market (Doyle et al. 2014), seasonal variations (Horan and Shortle 2011), and transaction costs (Ribaudo and Nickerson 2009). These may limit the potentials of effluent trading and lead the market into failure (Zhang et al. 2014; Borghesi 2014). In order to cover the limitations and increase the motivations and flexibility of TDP, several supportive strategies have been brought up. For instance, Jamshidi et al. (2016) emphasized market pricing and integrating reclaimed water as well as raising the flexibility of discharge permit market in times of seasonal variations. Ribaudo et al. (2014b) focused on choosing an eligible baseline in trading so that subsidies allocated to the farmers increase their incentives. Feizi Ashtiani et al. (2015) set up a fund reallocation policy to enhance the equity of WLA among PS trading partners. Yet, further studies are required to evaluate the strategies and conditions of a multiple-pollutant discharge permit market in small basins with limited income.

This study puts forward a new perspective based on a discharge permit market and farm management nexus for more sustainable nutrient reduction in lake basins. Its aim was to find economically motivating WLA strategies in small basins with low-income farmers. For this purpose, two actions were the main contributions of this research. First, integrated watershed modeling by SWAT presents a comprehensive conclusion on CSAs and the efficacy of BMPs. This identifies cost-effective WLA

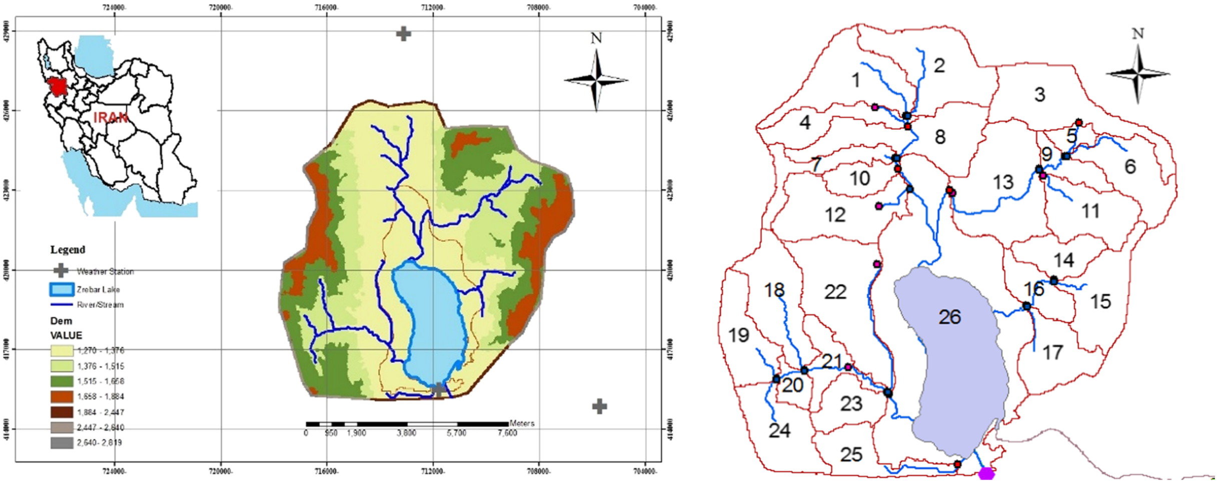

Fig. 1 Digital Elevation Model of Zrebar Lake (*left*) and its 26 sub-basins in SWAT (*right*)

(as TMDLs) for different croplands and LUs with respect to their net income and total abatement costs. Second, the WLA is promoted by a multiple-pollutant discharge permit market with supportive strategies to increase the willingness of farmers to adhere to this environmental conservation policy. The analysis of trading N and P permits, their pricing, and the effects of supportive strategies are carried out in this action. We reached these conclusions using the small basin of Zrebar Lake in Iran that currently has a eutrophication problem.

Materials and methods

Study area

Zrebar Lake is a touristic site with an area of 89 km^2 and an average precipitation of 650 mm/year located in the west of Iran in Marivan, Kurdestan (Fig. 1). Its LUs are mainly irrigated farms (30%), rain-fed (RF) croplands (30%), oakwood (22%), and grasslands (17%). The total volume of the lake annually ranges from 23 to 48 mm^3. This is set by an embankment dam built in 1995 to allocate water for farm irrigation downstream. An artificial canal also diverts 10 mm^3/year of the Ghezelchesoo River (GZC) to the lake and transports sediments and pollutants discharged upstream (Imani et al. 2016). In this research, the study area was divided into 26 sub-watersheds (Fig. 1) whose components were broken into smaller fractions termed hydrologic response units.

SWAT model

The SWAT is a semi-distributed model that uses topography data, soil properties, land use/cover (LULC) type, and climate data to simulate the watershed and predict the impacts of different BMPs. SWAT uses, respectively, five and six pools for modeling N and P cycles. The losses of organic N and P depend on their concentrations in the top layer of soil, sediment yield, and enrichment ratios. Nitrate leaching depends on total runoff, lateral flow, and percolation volume. Soluble P also depends on the soil partitioning coefficient and runoff volume. More details can be found in Neitsch et al. (2005). The background dataset required for watershed modeling is shown in Table 1. The SWAT internal weather generator (Schuol and Abbaspour 2007) was used to compute any missing climatic data in the period of 2000 to 2014. The monthly data of flow rates and water quality samplings were used for model calibration and validation.

Model modification

We represented the lake in modeling by adding a reservoir in SWAT. Its surface area changes in accordance with the inflow volume as Eq. 1.

$$\mathrm{SA} = \beta_{\mathrm{sa}} \times V^{\mathrm{expsa}} \tag{1}$$

where SA is the surface area of the water body (ha), V is the volume of water in the reservoir (m^3), β_{sa} is a coefficient, and expsa is an exponent. The coefficient and the exponent were calculated by solving Eq. 1 using two initial

Table 1 Required datasets and their sources

Theme	Data basis	Source and scale
Topography	Digital Elevation Model (DEM)	National Aeronautics and Space Administration database of the USA, 30-m resolution grid
Land use data	Land use maps	Iranian Forests and Farms Organization (2006); 1000-m resolution grid
Soil data	Soil properties, soil layers	Global soil map, Food and Agriculture Organization (FAO 1995); 1:500,000
Climatic data	Minimum and maximum daily temperature, mean monthly and daily precipitation, relative humidity, wind velocity	Iran Meteorological Organization (IRIMO); (2000–2014)
Hydrological data	Monthly flow rates, Zrebar Lake water level, dam operation, and discharge rate of GZC	Kurdistan regional Water Authority, Ministry of Energy (2005–2013)
Water quality	Nitrogen and phosphor concentrations of Zrebar Lake, pollution discharge loads	Department of Environment—Kurdistan province (2005–2006 and 2009–2013); export coefficients (Chapra 1997)
Management practices	Planting types, tillage, harvesting, grazing, fertilizers application and their types, irrigation	Ministry of Agriculture—Kurdistan province (2000–2014)
Crop yields	Typical yields and evapotranspiration data	Ministry of Agriculture—Kurdistan province (2014)

conditions. These were derived from the operation of primary and emergency spillways of the embankment dam (Imani et al. 2016). In order to gain a more precise calibration of the nitrate and phosphate concentrations in the lake, an area-volume curve was developed using the experimental data as Eq. 2, and the SWAT code was modified in order to simulate the reservoir surface area in previous studies (Tegegne et al. 2013).

$$\mathrm{SA} = 146 + 0.0068 \times V - 0.0005 \times V^2 \qquad (2)$$

The model was calibrated by the SWAT calibration and uncertainty procedures (SWAT-CUP) (Abbaspour et al. 2007) using monthly observed data of inflow (2005 to 2013) and the concentrations of N and P in the lake in the periods of 2005 to 2006 and 2009 to 2013. Two indicators, the regression coefficient (R^2) and the mean square error (RMSE), were used to validate the calibration. The simulation was carried out for 9 years from 2005 to 2013. The validation was implemented by the observed data of 2013 for nutrient concentrations and lake volume. In order to decrease the time for SWAT modifications, sensitivity analysis was carried out by SWAT-CUP (Abbaspour et al. 2007). This highlighted 29 parameters that had relatively high t stats and low p values. The higher number of absolute t stats and nearly zero p values expressed higher sensitivity. The parameters with the highest sensitivity were the curve number (CN2), fraction of algal biomass as phosphorus (AI2), and phosphorus percolation coefficient (PPERCO).

Crop yield analysis

The main crops of the study area were wheat, barley, onion, tomato, tobacco, alfalfa, and pea crops in addition to grapes and apple gardens. Their specifications were introduced to SWAT and calibrated via their typical yields and evapotranspiration data in the same manner as previous studies (Ashraf Vaghefi et al. 2014, 2015; Faramarzi et al. 2010). After some iterations, the optimal parameters of plants in the SWAT for crop yield analysis were determined as shown in Table 2.

Management strategies

The management practices used for NPS pollution abatement include irrigation and fertilizer reduction to 25% (C1), 50% (C2), and 75% (C3). Since reducing water or fertilizers both have analogous impacts on cutting crop production, we analyzed their overlapping effects and total costs. Using slim (F1) or wide (F2) filter strips with 10- and 25-m width,

Table 2 Optimal values of effective parameters for crop yield analysis

Parameter	Grape	Apple	Tobacco	Onion	Tomato	Alfalfa	Pea	RF barley	RF wheat	Barley	Wheat
BLAI	7.5	5.9	4.5	3	6	5.5	3	3.5	4	4.5	5
HVSTI	1.5	0.9	0.45	1.25	1.8	0.9	0.3	0.4	0.4	0.45	0.15
DLAI	0.99	0.99	0.7	0.6	0.95	0.99	0.75	0.6	0.5	0.6	0.5
FRGRW1 (%)	0.1	0.1	0.15	0.15	0.15	0.02	0.15	0.15	0.05	0.15	0.05
LAIMX1 (%)	0.15	0.4	0.05	0.1	0.05	0.01	0.01	0.01	0.05	0.01	0.05
FRGRW2 (%)	0.5	0.5	0.5	0.5	0.35	0.15	0.5	0.45	0.45	0.45	0.45
LAIMX2 (%)	0.75	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
T_{base} (°C)	18	18	0	7	18	20	0	0	0	3	10
T_{opt} (°C)	30	28	20	20	30	30	14	25	20	28	25
EXT_COEF	0.65	0.65	0.65	0.65	1	0.57	0.65	0.65	0.65	0.65	0.65
BIO_E (kg.ha^{-1})/(Mj.m^{-2})	90	60	39	35	90	90	25	50	35	40	33

respectively, are two other options that were analyzed. Additional techniques that were analyzed included the use of slim buffer filter strip (G1) or hydroponic floated plants (G2), which are two alternatives for pollution control discharged by GZC. Other strategies like paying for environmental penalties (P1), and trading credits (T1 and T2) were also considered in this framework. The BMPs and their effectiveness on the quality of Zrebar Lake, modeled by SWAT, are summarized in Table 3, and will be further discussed in this research.

Total maximum daily load

In the first scenario, the simulation results were used to assign typical total maximum daily loads (TMDLs). This policy aims to reduce 50% of N and 40% of P content of the lake to restore the water quality back to what is was in

Table 3 BMPs and their overall effectiveness on the concentration of nutrients in lake

Alternatives	Title	N reduction (%)	P reduction (%)	Abatement Cost ($/month)
C1	Using less water and fertilizer (25%)	15	20	See note A.
C2	Using less water and fertilizer (50%)	20	20	See note A.
C3	Using less water and fertilizer (75%)	25	20	See note A.
F1	Using slim filter strips (10 m width)	60	50	See Note B.
F2	Using wide filter strips (25 m width)	85	60	See Note B.
G1	Using slim filter strips at upstream to reduce GZC pollution	50	50	5000
G2	Using slim filter strips at upstream and floated plants to reduce GZC pollution	55	60	6500 (See Note C)
W1	Constructing WWTP for rural areas	75	60	8500 (See Note D)
P1	Paying environmental penalties	–	–	–
T1	Selling discharge permits	–	–	–
T2	Buying discharge permits	–	–	–

Note A.The abatement cost is calculated in Table 5 regarding the crop yield analysis

Note B.Total capital cost of planting buffer filter strip around the lake is calculated about $1250/month per 1-m width. If a cropland ultimately covers 30% of LUs and uses F1, it costs $3750/month

Note C.The differences between G1 and G2 about $1500/month is due to the floated plants as previously calculated by Jamshidi et al. (2015).

Note D.Total capital and operating cost of wastewater treatment facility is calculated by the cost function proposed by Jamshidi and Niksokhan (2016) for 60% nutrients removal for 7000 inhabitants

2005. It should be noted that farming activities and NPS discharges are dependent on seasonal variations. The eligible baseline was determined on a monthly scale when all farmlands are under cultivation.

Water quality trading

In the second WLA scenario, WQT seeks the least-cost WLA that simultaneously minimizes the nutrient loads discharged by farmers. An Excel-based optimization model was developed based off of previous studies to determine the incremental abatement costs of potential permit sellers and customers (Jamshidi et al. 2015). Here, the environmental conditions demand that the total number of reduced surplus loads must be greater than required credits. Finally, the economic motivations of the proposed market were evaluated in which the optimal pricing for permits and penalties were determined.

$$\mathrm{TC} = \sum_{\mathrm{i}=1}^{m} \mathrm{C_i} + \sum\sum\left(P_\mathrm{n} \times L_\mathrm{n} \pm P_\mathrm{r} \times L_\mathrm{t}\right)_{i,j} \tag{3}$$

where TC is the total cost of the whole polluters (m), C is the abatement cost, and P_n and P_r are the primary penalty and permit prices, respectively. L_t refers to the number of permits traded by each LULC, while L_n is the abatement load where management practices are not properly used and a penalty is likely to be charged. The N and P market are represented by the counters i and j, respectively. The schematic diagram of methodology is illustrated in Fig. 2.

Market conditions

This study put forth five conditions that are of vital importance for having a robust market among low-income farmers. To start with, the overall abatement and trading costs of each emission source in WQT should be less than its typical TMDL policy without WQT. This ensures that dischargers may not leave the market to gain more benefits through a conventional strategy. Second, the TC of each cropland should be less than its net income. It is not fair or sensible that farmers pay for the environment more than their income. Third, P_n must be greater than P_r. This enforces emission sources to cooperatively participate in the market. Fourth, it is not preferred that farmers gain extra benefits and increase their income in comparison with the scenario in which there is no environmental conservation strategy. This may provoke other farmers to change their LUs for raising specific crops in an attempt to gain higher benefits. This causes adverse effects on the environment and market interactions sooner or later. Fifth, it is also recommended that no farming should be abandoned only because of its pollution. Therefore, market managers must financially support the owners of croplands that are likely to be harmed by TDP. Apart from these conditions, authenticating the market with high transaction costs or externalities will require further studies.

Results and discussion

SWAT modeling outputs

Both Fig. 3 and Table 4 show that the SWAT model was successfully calibrated with respect to the flow rate and nutrient concentrations in the lake. Here, the modifications applied to the reservoir volume and the sensitivity analysis enabled the development of a proper model. Figure 3 also implies that Zrebar Lake has a hypertrophic condition. The phosphate concentration exceeds 0.15 mg/L. This has been introduced as a near threshold for hypertrophic conditions in lakes by Cao et al. (2016) and Horppila et al. (2017).

It can also be concluded that BMPs are effective for eutrophication control (Table 3). For instance, 15 to 25% of N and 20% of P concentration in the lake can be reduced by C1–C3. The same results were obtained by Epelde et al. (2015) and Tuppad et al. (2010). However, these strategies reduce the production rates of farmlands. Crop yield analysis by SWAT outlines the effects of BMPs on the net income of farmers (Table 5). It points to the fact that the monetary gain of agricultural activities reaches to \$1.8 million per year in Zrebar Lake. This is equal to \$839/ha, which is not significant. It verifies that farmers need financial support by the government and are hardly willing to pay extra charges relating to environmental penalties or BMPs. In the case that farmers use C1–C3, their total production decreases, which counts toward their total costs. Moreover, Table 3 reveals that using filter strips is the alternative with the highest nutrient reduction (up to 50%) as discussed by Maringanti et al. (2011). Results indicate that wider filter strips

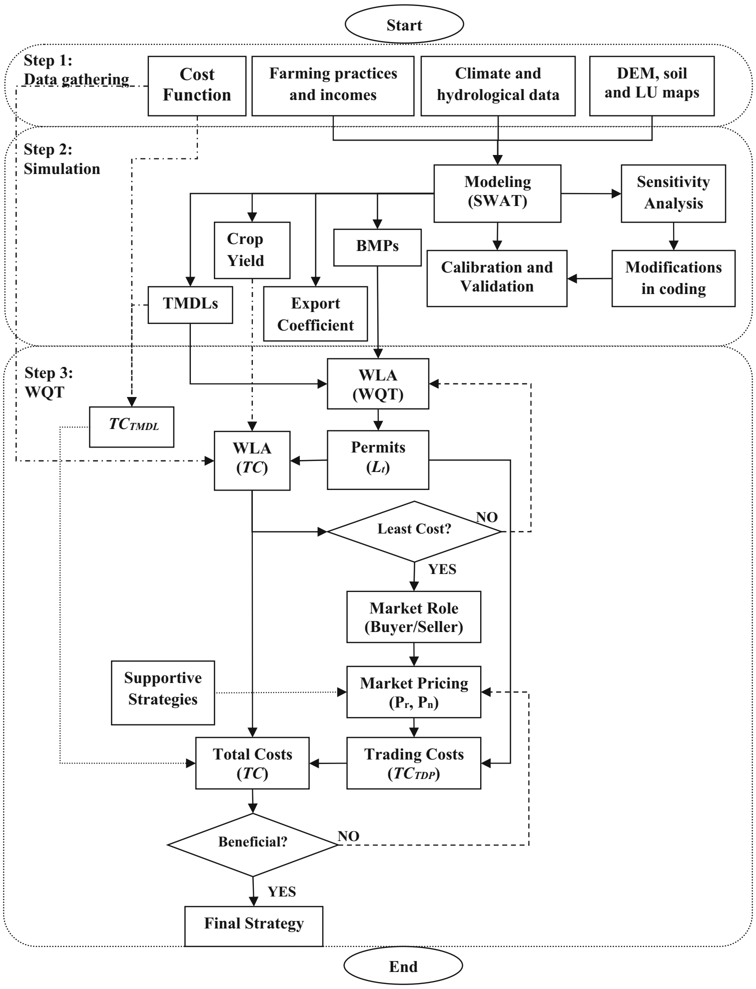

Fig. 2 The flow diagram of methodology

abate higher pollution. However, nutrient abatement would not be necessarily doubled by filters with twice the width.

Nutrient export coefficients (ECs) were also calculated by SWAT for each emission source (Table 6). For example, planting alfalfa annually discharges 68.3 kgN/ha and 1.4 kgP/ha, while RF wheat discharges 3.36 kgN/ha and 0.06 kgP/ha. On average, the agricultural activities annually discharge 21.4 kgN/ha and 0.6 kgP/ha. These coefficients are 1.8 kgN/ha and 0.05 kgP/ha for woods and grasslands. These coefficients highlight the CSAs for lake pollution as fallow lands, apple gardens, and farms growing barley and tomato. Since these values depend on the farming methods, LUs, as well as topographical and hydrological specifications, this study recommends that the same methodology should be followed for other cases to calculate ECs prior to any WLA among NPS.

TMDL

WLA by typical TMDL policy shows that some emission sources have limitations on what strategies they can use due to their total costs or efficiency (Table 7). For example, pollution abatement in rural areas is quite costly. Similarly, this strategy is not able to control the total pollution of grape gardens efficiently as they have to pay environmental penalties (P1). Consequently, the total costs of TMDL policy in Eq. 3 may exceed \$52,000 per month (Table 7). More than \$21,800 per month is required for abatement costs, while \$12,550 per month would be paid as penalties. Since the optimal WLA is a policy that preserves the environment with the least cost, the typical TMDL seems to be not efficient enough in this small-scale watershed. This can be due to the limited capacity of BMPs on pollution abatement

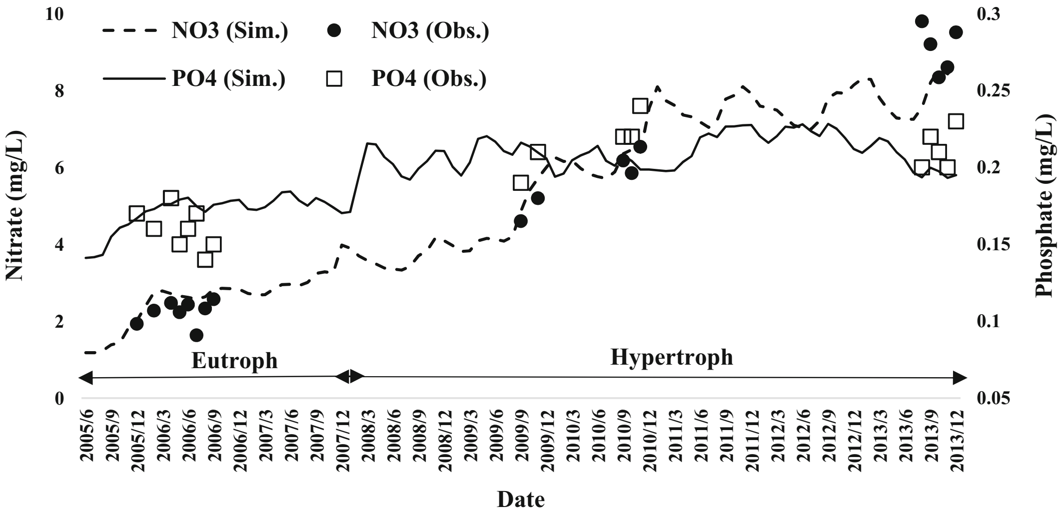

Fig. 3 The simulated and observed concentrations of nitrate and phosphate for calibration

and their nonflexible cost function (Jamshidi et al. 2014). Therefore, the second scenario suggests using WQT for WLA.

WQT

In WQT, polluters with higher incremental abatement costs or limited alternatives prefer to purchase permits from emission sources that gain benefits by selling credits. Table 8 outlines the least-cost option for WLA based on WQT, which includes five market conditions. The irrigated croplands growing alfalfa, apple, barley, onion, tobacco, tomato, and wheat are introduced as possible candidates for selling credits. This is due to their potential to use filter strips in the vicinity of the lake and their high impacts on water quality. These can employ F1 and F2 coupled with C1 and C2 to provide potential surplus reduction. In addition, GZC should use G2 where it connects to the lake to be a credit seller as well. The others, including RF croplands, rural areas, woods, and grasslands, can purchase credits.

In the proposed WLA, 756 N and 26 P credits would be traded. This reduces TC to $18,700 per month and saves 64% in comparison with the typical TMDL approach. In addition, paying for penalties would no longer be required. These ensure the economic efficiency of WLA as determined by WQT in comparison with the first scenario. Furthermore, the rural areas would no longer be in need of constructing costly tertiary units of wastewater treatment plants; they can purchase credits instead.

Market pricing should be considered with respect to the five conditions. N permits should be at least $6 per kilogram because the tobacco credit sellers may become economically unsatisfied in comparison with the typical TMDL policy (first condition). Moreover, this price cannot exceed $30 per kilogram because the permit buyers, including RF barley and pea, may no longer participate in the market. This draws a stable range of prices. If any transaction costs or externalities toss the trading price out of this equilibrium range, the market would certainly fail.

Woods and grasslands have to purchase permits but cannot afford to do so because they are not in the private sector and do not have any income (second condition). Therefore, the government is responsible for its pollution and should find solutions to protect their land. In this condition, WQT has the potential to provide discounts and allocate subsidies, funds, or credits free of charge for those polluters who cannot afford to buy

Table 4 Performance measures of the SWAT for inflow, nitrate, and phosphate

Parameter	Calibration		Verification	
	R^2	RMSE	R^2	RMSE
Lake inflow (m^3/s)	0.64	0.41	0.76	0.22
Nitrate (ppm)	0.89	1.13	0.70	1.3
Phosphate (ppm)	0.64	0.0064	0.30	0.0064

Table 5 Crop yields, net incomes, and total costs attributed to the planting modifications calculated for each LULC

Land use	Crop yield calculated (ton/ha)	Difference (%) with observed data	Total farming costs (K$/month)	Total farming income (K$/month)	Net income (K$/month)	Net income reduction with planting modification (%)		
						C1	C2	C3
Alfalfa	3.7	52.5	19	20.22	1.22	10.6	17.8	21.3
Apple	11.2	11.8	171.13	176.13	5	17	33.9	52.3
Fallow land	–	–	–	–	–	–	–	–
Barley	2.1	12.5	4.87	4.94	0.07	3.3	26	49
Clover	5	4.2	0.74	2.45	1.71	–	–	–
RF barley	0.9	10	9.4	11.47	2.07	1.5	15.5	42
RF wheat	1.1	8.3	78.2	108.13	29.93	1.9	17.6	42
Grape Gardens	4	16.7	75	112.75	37.75	0.2	2	8
Onion	3.5	12.4	1.55	18.74	17.19	8.3	26.3	46.4
Pea	0.5	0.1	27.75	36.41	8.66	6	6.3	6.9
Tobacco	1.9	17.4	82.41	116.78	34.37	1.2	16.7	40
Tomato	10.1	32.7	4.75	12.31	7.56	71.1	79	89
Wheat	2.8	6.7	28.97	35.19	6.22	2.4	21	56
Agriculture			**503.82**	**655.5**	**151.68**			

Table 6 Export coefficients and total loads discharged calculated by SWAT in each LULC

Land use	Export coefficients (kg/ha)		Area (ha)	Loads discharged (Kg/month)	
	N	P		N	P
Alfalfa	68.3	1.4	87.5	498.4	10.5
Apple	88.1	0	74	543.3	0.0
Fallow land	200.4	18.8	23.2	387.4	36.3
Barley	128	1.3	26.9	286.9	3.0
Clover	58.8	2.93	12.3	60.3	3.0
RF barley	23.6	0.35	145.5	286.1	4.3
RF wheat	3.36	0.06	1000.1	279.8	4.7
Grape Gardens	25.9	0.24	200	431.9	4.0
Onion	39.4	1.7	74	243.0	10.7
Pea	1.2	0.35	290.9	29.2	8.4
Tobacco	40.4	1.4	94.2	316.9	11.2
Tomato	191.3	6	13.5	215.2	6.8
Wheat	26.7	0.3	127.8	284.7	3.3
Agriculture	**21.36**	**0.58**	**2170**	8363	256.1
Woods and grasslands	1.8	0.05	2750	404.3	11.9
Rural area	11.8	0.5	80	78.7	3.5
GZC Canal	–	–	–	4500	150
Total	**10.4**	**0.29**	**5000**	13,346	421.5

Table 7 WLA in TMDL policy and the attributed costs based on management practices

Land use	TMDL (kg/month)		Reduction needed (kg/month)		BMPs in use	Total reduction achieved (kg/month)		Abatement Cost (K$/month)	Penalty (K$/month)	Total Costs (K$/month)
	N	P	N	P		N	P			
Alfalfa	242	6.3	256.4	4.2	F1	299.1	5.2	1.65	–	1.65
Apple	267.3	0.0	276.0	0.0	F1	326.0	0.0	1.65	–	1.65
Fallow land	189.6	21.8	197.7	14.5	F1 + P1	117	9.1	2.85	3.21	6.06
Barley	136.9	1.8	149.9	1.2	F1	172.1	1.5	0.45	–	0.45
Clover	27.7	1.8	32.6	1.2	P1	36.2	1.5	1.23	–	1.23
RF barley	140.5	2.6	145.6	1.7	C2 + P1	85.8	0.9	0.32	2.65	2.97
RF wheat	136.4	2.8	143.4	1.8	C2 + P1	70.0	0.9	5.26	2.63	7.89
Grape	210.3	2.4	221.6	1.6	C2 + P1	129.6	0.8	0.76	3.28	4.04
Onion	116.9	6.4	126.0	4.3	F1	145.8	5.3	0.6	–	0.6
Pea	3.1	5.0	26.1	3.4	C2 + P1	8.8	1.7	0.55	0.78	1.32
Tobacco	151.8	6.7	165.1	4.5	F1	190.1	5.6	1.95	–	1.95
Tomato	100.0	4.1	115.2	2.7	F1	129.1	3.4	0.3	–	0.3
Wheat	134.7	2.0	149.9	1.3	F1	170.8	1.6	2.1	–	2.1
Agriculture	4107.3	138.8	4255.7	117.4		1929.2	39.3	**21.88**	**12.55**	**34.43**
Woods and grasslands	291.3	7.1	113	4.7	P1	–	–	–	4.29	4.29
Rural area	24.4	2	54.3	1.5	W1	59	2	8.5	–	8.5
GZC Canal	2250	75	2250	75	G1	2250	75	5	–	5
Total	6673	222.9	6673	198.6		4238.2	116.3	**35.38**	**16.84**	**52.21**

credits. Fallow lands can also use this approach to reduce their total annual costs. Therefore, farmers would not be economically concerned whenever they leave their lands unfarmed. This would be a kind of supportive or insurance policy for an NPS discharge permit market. Likewise, the GZC management is attributed to the water company and public organizations. These can sell the required N credits to woods and grasslands (113 units) free of charge, including 4.7 units for P permits as well. The GZC can also compensate its surplus abatement cost in comparison with the TMDL scenario by selling the remaining P permits (9.1 units) to the farmers. In this case, the P market price is assumed to be at least $60 per kilogram. This implies that using public properties in association with the private sector can be handled simultaneously by credits and prices. In addition, this policy financially ensures proper agreement and inhibits the framework from any considerable effects on LUs (fifth condition). For example, if we neglect the demands of woods and fallow fields or supportive policies for low-income farmers, they may consider changing their LUs to gain more benefits. However, their current formation is necessary for market success and environmental conservation.

Furthermore, a multiple-pollutant (N and P) discharge permit market points toward a promising policy that increases its flexibility for pricing. The BMPs used in the study area are the same for N and P reduction, but their market prices are different. Consequently, it is implied that N and P credits can be sold at a price that is not necessarily equal. In Zrebar Lake, it was revealed that P permits are the limiting factor of market adjustments. By these prices, a penalty price equal to $35 per kilogram of N and $70 per kilogram of P sounds fair to meet the third condition. This framework identifies the correct boundaries for pricing and leads decision-makers to better economic analysis. However, this framework is recommended to be used dynamically with a coalition of government and farmers (Meckling and Jenner 2016).

Table 8 WLA in WQT and the attributed costs for each participant

Land use	alternatives in use	Total reduction achieved (kg/month)		Total abatement cost (K$/month)	Permits for sell (kg/month)		Permits for buy (kg/month)		Market role	Trading cost[a] (K$/month)	Total Costs (K$/month)	% cost savings
		N	P		N	P	N	P				
Alfalfa	F1 + C1 + T1	373.8	7.3	1.78	117.4	3.1	–	–	Seller	−1.95	−0.17[b]	>100
Apple	F1 + T1	326	0	1.65	50	0	–	–	Seller	−0.75	0.9	45.5
Fallow land	T2	–	–	–	–	–	197.7	14.5	Buyer	+3.84	3.84	36.7
Barley	F1 + C2 + T1	243.8	2.1	0.47	93.9	0.9	–	–	Seller	−1.46	−1[b]	>100
Clover	T2	–	–	–	–	–	32.6	1.2	Buyer	+0.56	0.56	54.2
RF barley	C2 + T2	71.5	0.9	0.32	–	–	74.1	0.8	Buyer	+1.16	1.47	50.3
RF wheat	C1 + T2	42.0	0.9	0.55	–	–	101.4	0.9	Buyer	+1.58	2.13	73.1
Grape	C1 + T2	64.8	0.8	0.07	–	–	156.9	0.8	Buyer	+2.4	2.47	38.8
Onion	F2 + T1	206.5	6.4	1.5	80.5	2.1	–	–	Seller	−1.33	0.17	72.3
Pea	C1 + T2	4.4	1.7	0.52	–	–	21.7	1.7	Buyer	+0.43	0.95	28.4
Tobacco	F1 + C1 + T1	237.7	7.8	2.36	72.5	3.4	–	–	Seller	−1.29	1.07	45.1
Tomato	F2 + T1	182.9	4.1	0.75	67.7	1.3	–	–	Seller	−1.09	−0.34[b]	>100
Wheat	F1 + C1 + T1	213.5	2.3	2.25	63.6	1	–	–	Seller	−1.01	1.24	41.2
Woods and grass-lands	T2 (free)	–	–	–	–	–	113	4.7	Buyer	+1.98	Free[c]	<0
Rural area	T2	–	–	–	–	–	59	2	Buyer	+1.01	1.01	88.2
GZC canal	G2 + T1	2475	90	6500	225	15	–	–	Seller	−2.09	4.41	11.8
Total		4442	124	**18.71**	**770.6**	**26.8**	**756.4**	**26.6**				

[a] The negative sign refers to the income while positive shows the outcome attained by trading

[b] The negative sign in this column refers to the net income attained by selling permits. This value can be added to the net income in Table 5

[c] Because the total costs exceed the total income of land (fifth condition), the credits are accounted as free for this buyer

In the proposed WLA and market interactions, the irrigated farms with tomato, alfalfa, and barley crops can gain extra benefits by selling permits and increase their annual incomes. This can be both threatening and beneficial for the market. It may threaten the robustness of the market because if other farmers are informed about the benefits of growing these crops, they may change their LUs. Consequently, some crops that play a key role in trading, such as onion or wheat, may be abandoned. In addition, the competition for irrigating tomato, alfalfa, or barley can eventually ruin the market deals, particularly P trading, in the long term as discussed by Frank (2016) in the form of a stadium metaphor. Therefore, the government should control NPS discharge permit markets and enforce a limit on LU changes. This can be tracked by SWAT modeling as recommended by Deng et al. (2015) However, the transaction costs would increase, and in this case, the economical effectiveness of WQT would be jeopardized.

Gaining benefits may also help to turn the market into a more robust policy. In order to satisfy the fourth condition, policy makers can use the fund reallocation strategy developed by Feizi Ashtiani et al. (2015). Here, farmers who grow profitable products may willingly loan some funds to other participants to increase their satisfaction. For example, the owners of tomato, alfalfa, and barley lands who respectively gain surpluses of $343, $168, and $996 per month by WQT, can reallocate this income to financially support other farmers in the seasons when they leave their lands unfarmed. This reduces the total costs of fallow lands to $2328 per month in the environmental conservation policy. This would not be achieved unless a third party, like a financial institution or the government itself, controls the market deals and its interactions. Changing LUs and crops, gaining high profits, and pricing permits should be monitored by this institution. In addition, the institution can offer consultations and insurance to farmers as a consequence of participating in the market. Therefore, the dynamic game for market pricing would become informative. Otherwise, some farmers with alfalfa or barley crops, for instance, would not risk capitalizing filter strips. This is due to the fact that their net incomes are low, at about $1219 per month and $63 per month, respectively. Therefore, WQT would not be cost effective or beneficial enough for the owners of these croplands to willingly participate in the market unless they are informed about the monetary gain to be obtained by selling environmental credits. Here, alfalfa can increase its net income to $1382 per month, while barley will be enhanced to $1056 per month. Otherwise, the total abatement cost may be increased or the market will fail. As recently emphasized by Frank (2016), customers and market dealers should be primarily informed and rational for any success of the market. This also implies that credit allocation and pricing should take into account their total abatement costs, while the overall income of farmers should be considered to be a condition for decision-making. It means that using strategies for water quality management should not be assigned based on the net incomes of stakeholders, particularly farmers.

Finally, in small watersheds or in areas with dominant NPS polluters, it is recommended that decision-makers should focus on policies that consider discharge permit market/farm management nexus for environmental protection. This is because nutrient abatement strategies are limited in practice. However, further conclusions require large-scale watershed modeling as implemented by Abbaspour et al. (2015). More importantly, farmers are economically vulnerable and require supportive strategies to willingly adhere to any environmental policies. Therefore, this methodology could introduce a perspective on the market/farm nexus. It considers flexibility in permit pricing with the possibility of using discount rates (Keller et al. 2014). Here, the income rate and benefits of each farmer are considered within a promising multiple-pollutant discharge permit market between NPS polluters. However, it can be implied that TDP seems more successful in areas with more PS polluters. The PS/NPS market interactions can find more flexibility and agreement possibilities in nutrient allocation to the surface waters. This is due to the fact that wastewater treatment plants have more technological options for nutrient abatement than BMPs. Yet, further studies are required to cover the critical issues in a market/farm management nexus. For example, the influence of taxation, seasonal demands, transaction costs, economic sanctions, drought, climate change, or changes of LUs still need to be discussed.

Conclusions

This paper focuses on finding the optimal WLA for NPS pollution reduction in Zrebar Lake based on a WQT framework using the results of a SWAT model. It can be concluded that:

- The SWAT is a promising approach for modeling small lake-basin watersheds, analyzing crop yields, and calculating export coefficients and the effectiveness of BMPs. In order to consider the concerns of low-income farmers in WLA, it is emphasized that crop yield assessment and economic analysis of BMPs are necessary at the farm scale.
- The WLA in a WQT framework is more cost effective than the conventional TMDL approach. Because the ability of BMPs for nutrient reduction and the income rate of farmers are limited, WQT may lose its efficiency. This emphasizes the requirement to use supportive trading rules and conditions for market enhancement, particularly for NPS pollution reduction.
- Multiple-pollutants TDP can enhance market pricing and support market deals. In this study, the main trades belong to N permits, while P is the limiting factor. Discount factors, subsidies, and fund reallocations are also available to support farmers buying unaffordable credits.

These approaches increase the robustness of the market and its economic incentives.

- An institution is required to manage the market, reallocate the funds, and, more importantly, ensure the income and benefits of farmers in WQT. An informative trade can attract participants, such as alfalfa and barley farmers, to risk investing for pollution reduction even more than their income to turn a market on the brink of failure into a cost-effective and successful approach.

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