Alternative Policies to Control Nitrogen Runoff and Its Impact on Water Resources Supply: The Case of Tai Lake Valley, China

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Abstract

The nitrogen (N) is a primary source of impairment to fresh water bodies. A linear programming (LP) model was developed in this paper to test the effectiveness of four nitrogen runoff control policies. The results indicate that all of the alternative policies take effect on reducing nitrogen runoff, but the input taxes is relatively effective and feasible if considering the transaction cost.

Keywords: NPS pollution, nitrogen fertilizer, subsidy, water quality

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Introduction

Water quality is a major environmental issue. Agricultural practices are considered the largest contributor of surface water quality degradation in terms of sediment, runoff of nutrients (such as nitrate and phosphorus), and leaching of chemicals (*Crutchfield et al., 1995*). Among the list of environmental damages, the nitrogen (N) is reported to be the primary source of impairment to fresh water bodies (*USEPA, 1998*). N in the form of NO3 is easily soluble and is transported in runoff. Excessive nitrates (NO3-) in drinking water have been linked to methemoglobinemia disease (blue baby) in animals and infants (Bower). At high levels, nitrogen in water can be toxic to humans and animals, and nitrogen in ammonia can kill or injure fish (*Miranowski, 1983*).

As technologies to control nitrogen are beginning to take shape, there is a growing need for economic analysis that can guide the selection and design of policy instruments (*Richard D. et al., 2000*). The nitrate runoff reduction policies can be designed to induce farmers to change their production practices in ways that improve the environmental and related economic consequences of production. Therefore, it is important to understand how economic incentives and other farm-level mechanisms to offset pollution are likely to influence farmer behavior. An evaluation of the farm-level consequences of such policies can provide insight into the effectiveness of these policies and suggest whether the social goal of a sustainable food supply that meets environmental demands in rural areas is attainable (*Taylor et al, 1992*).

The main goal of this paper is to assess farm-level responses to policies designed to control nitrogen effluent from farmland, with particular application to the Tai Lake Valley of China. A linear programming (LP) model was developed to simulate four alternative policies under the objective of farmer net income (NI) maximization.

The NPS pollution in Tai Lake Valley

Tai Lake valley is located in southeast China. It covers 36900 km2, which includes Southern Jiangsu province, Jiaxing city, Huzhou city, part of Hangzhou city of Zhejiang province and dominant part of Shanghai. As a typical area of South Yangzi River, Tai Lake valley is densely dotted with drainage ditches that form a waterway network. With the point source pollution generated by industry being gradually well controlled, the non-point source (NPS) pollution has become the dominant pollution source in Tai Lake valley, a developed economic region in China (*Chen, et al., 2004*). NPS pollution has been identified as the major pollution of water resources environment. It was reported that the water quality of Tai Lake valley descended one grade, from grade II to III, during the period of early 1980s and late 1990s. Meanwhile, accelerated eutrophication of water ascended two grades, which resulted in the fact that the water quality in Tai Lake valley was mainly in the eutrophic environment. The nitrogen (N) transport increased from 2.80×104 t in 1990 to 7.96×104 t in 2000, from 2000 t to 5660 t for phosphorus (P), and from 5.00×104 t to 2.82×105 t for COD transport. It was statisticed that N and P concentration generated from agricultural NPS pollution accounted for 55.1% and 27.8% of the total pollution burden, respectively. 25.1% and 60%, respectively, for that generated from living wastewater. Whereas, N and P produced by industry wastewater contributed 15.8% and 10.4% burden, respectively (*CEPB, 2000,2001*). Owing to the energetical and effective control for point source pollution induced by industry in Tai Lake valley during recent years, the NPS pollution has been becoming a dominant and threatening pollution source. The water quality of Tai Lake valley has experienced a historical period. It was still good in 1960s and 1970s. However, with the rapid economic development in Tai Lake valley, significant quantity of wastewater transported in rivers and lakes without any disposal, consequently, water pollution spread from city to country, branch to river way, river to lake, and surface water to subsurface flow in the past 30 years, eventually had affected the water source quality and people's health.

The water supplying in Tai Lake valley is mainly for living survival, agriculture and industry. The total water consume, which is supplied by water repeating using and the Yangzi River supply, is more than the total water resources in local region. In 1997, the level of modernization of city in Tai Lake valley was 49%, much higher than 30%, average level in China. It is estimated that it would achieve over 60% in 2010 and exceed 70% in 2020. Such rapid step of modernization of cities and towns in Tai Lake valley will bring forward more and more water resources requirements, not only in quantity but also in quality. Whereas, the fact is that the water quality has been gradually descending. Consequently, how to solve this conflict is among the most important and difficult problems facing water quality managers today.

The main agricultural NPS pollution sources in Tai Lake valley are domestic animals manure, fertilizer, domestic living pollution, runoff and pesticide, etc, which has become the key factors constraining the sustainable development of the agriculture and environment in this region. In order to settle this problem, series of methods has been put forward. Among which the most prominent were conservation buffer strips including buffer wetlands, buffer forest strips and buffer grass strips (*Ni, et al., 2002*). These techniques could prevent NPS pollution and protect the agro-environment, in the other hand, contribute to agricultural landscaping. Moreover, a series of techniques to control NPS pollution such as optimal fertilization technique, pesticide application design, agricultural waste disposal and integrative utilization, control of water and soil runoff. These techniques were integrated and tested in Xindai County, a typical area in Tai Lake valley, and showed satisfied results.

Although the technologies to control agricultural NPS pollution have taken shape in the testing area, they haven't been applied in practice by most of the farmer. In other words, farmers have no incentive to adopt the new technologies or to reduce the pollution. Thus, the agricultural NPS pollution in Tai Lake valley is still very serious. There is little literature in China to guide the design of agricultural NPS pollution control policies. The economic analysis of farmer activities involving NPS pollution is lacking too.

Methodology

A linear programming (LP) model was developed here to quantify the economic and environmental quality impacts from differential restrictions. The LP model was applied in Xindai Town, Pinghu County, Zhejiang province, south edge of Tai Lake Valley (Fig.1). Pinghu County was the main commercial-grain-base of Zhejiang province with 71.2% of its total land is arable land. Xindai Town ranks in the hignest category of chemical oxygen demand (CODcr), total phosphorus levels (TP) and total nitrogen levels (TN) around the county, which are shown in table 1.

After elaborate investigation, the 13rd Group in Tongxin village was selected for the study case in this study. The basic data of 13rd Group are in table 2. Rice (*Oryza sativa*) is a dominant crop in this area. The other main crops include wheat, rape and bean. The dominant cultivation patterns are paddy-wheat rotation and paddy-rape rotation. NH_4HCO_3, $(NH)_2CO$, KCl and $Ca(H_2PO_4)_2.H_2O$ are mainly applied in farmland. As to the livestock in this group, the dominating livestock are sows and piglets. The sows live on wheat and part of paddy, however, the feedstuff bought for piglets.

Five policy scenarios are designed. These include: (1) a tax on nitrogen fertilizer, implemented as a tax equal to 50% of the cost of nitrogen; (2) a ban of spring fertilizer applications to reduce summer runoff; (3) a requirement for use of CA fertilizer, a kind of new fertilizer; and (4) per unit land subsidy for using manure, implemented by land rent free or paying 100 to 200 RMB subsidy per mu ($667m^2$).

Results

Table 2 provides a summary of results for the base run or current situation (unrestricted scenario). The solutions generated represent the most profitable crop and livestock mixes given the resources, soils, and production constraints. Paddies was planted as hobby main-food and feed feeding piglets mainly but a kind of commodity. Although the study region was the main commercial-grain-base of Zhejiang province, most farmers haven't sell grains since the grain marketlization reform began in 2001. Rape is the only crop for selling because farmer can't consume rapeseed directly. The other reason for planting rape is that farmers have no more choices in spring period. Local farmers also plant other crops such as barely, potato and all kinds of vegetables, which aren't considered in the model because the quantity is very small. For example, only one family plants barely in 2003, with total 0.08ha.

With the price of pork going up, it arouses the enthusiasm of farmers at large to sell piglets, which can bring considerable revenue for them. That's why averagely every family has a sow (to procreate piglet). But compared to off-farm benefit, farm benefit is still low. Therefore, more than 50% of the labor forces are full-time worker at factory initiated by village or town; 26% of the labor forces are part-time worker who work out of farmland during the non-farming period; and only less than 20% of the labor force are full-time farmer, most of them are old-women. Both the activities of farming and feeding result in nitrogen runoff, which includes organic nitrogen (from fertilizer) and inorganic nitrogen (from brute manure).

Four specific control policy scenarios are tested; and the results of farmer's net income and nitrogen runoff are summarized in figure 2. Apparently, input taxes of 50% of the price of nitrogen fertilizer (S1) reduce nitrogen applications; meanwhile the farmers' net income has a little bit increase. Compared with the S1, a ban of spring fertilizer applications to reduce summer runoff (S2) is more effective to control the nitrogen runoff; however farmers' net income goes down rapidly at the same time. The effect of S3 (a requirement for use of CA fertilizer) is close to but not as good as S1. If local government compensates 150RMB per mu (equal to 667m^2) cultivated land to those farmers who use sow and piglet manure to fertilize soil, the computer-run result is just as figure 2 showed. It seems that S4 is the most effective policy both in abating pollution and increasing farmers' net income. But except for S1, all the other three N-runoff control measures have highly monitoring difficulty and implementation costs. Since inclusion of transaction costs in policy evaluation is very important, input taxes is a relatively effective and feasible policy as a whole.

Conclusions

This research tested the effectiveness of agricultural NPS pollution control policies based on the LP model in developed rural area in China. The analyses above indicate that all of the scenarios designed here take effect on reducing nitrogen runoff, but the scenario of input taxes is relatively effective and feasible if considering the transaction cost. This conclusion is also applicable in the other types of NPS pollution control. An obvious characteristic of the study area is that the commercial rate of agricultural products are very low, and 85.3% of farmers' income from non-agriculture. In order to examine further the effectiveness of the NPS pollution control policy, a high commercial rate case is needed to compare with this study case.

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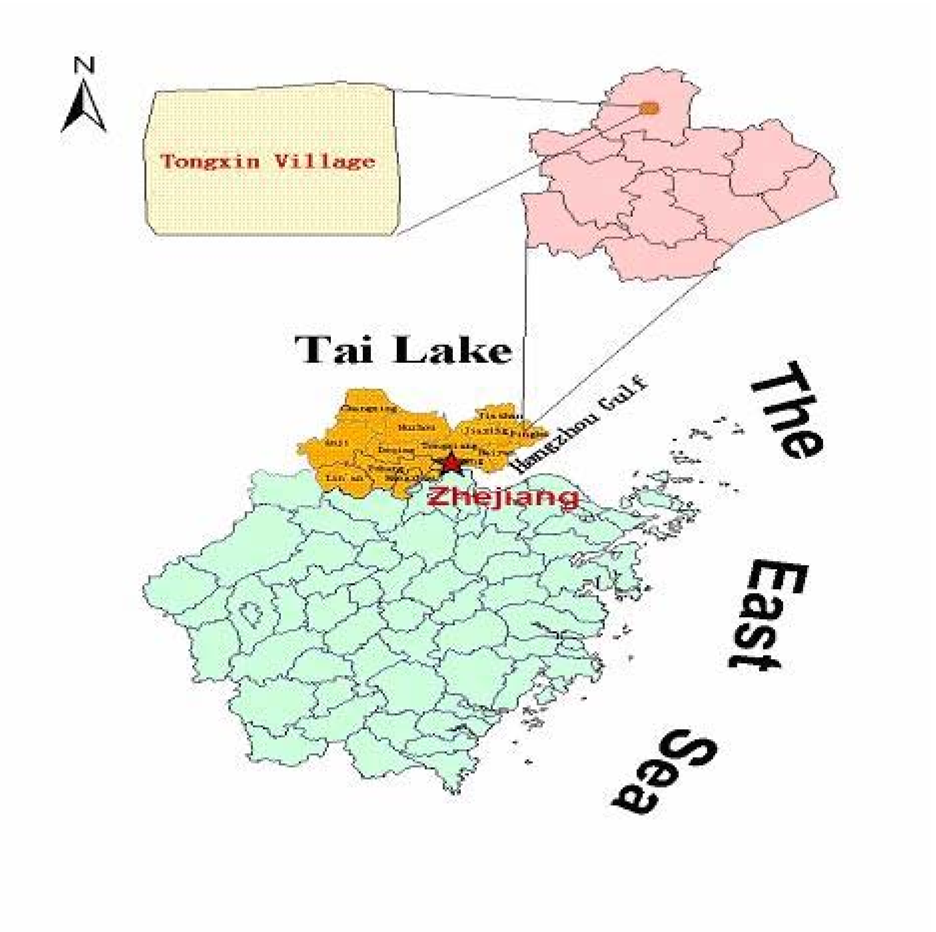

Figure 1. Location of the study area

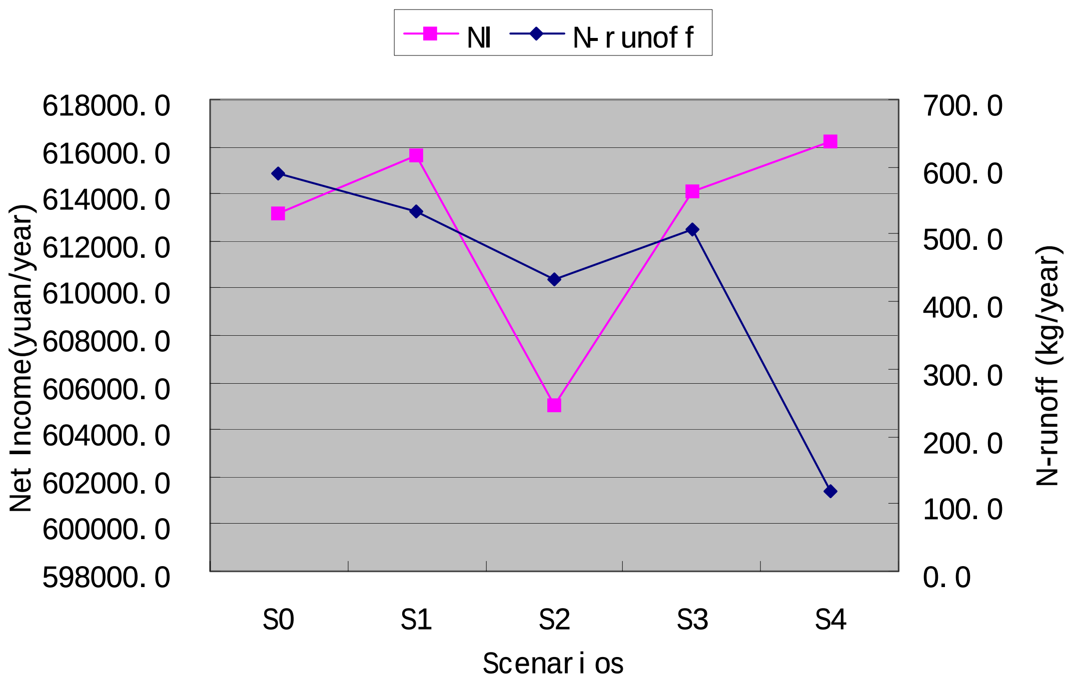

Figure 2. Location of the study area

Table 1 **Various Sorts of Pollution Sources in Tongxin Village in 2000**

Pollution Sources	Pollution Capacity (kg)				Equal-standard Drainage Capacity (m^3)	Contribution Rate (%)
	CODcr	TN	TP	Total		
Brute Manure	1876.61	683.89	191.47	2751.97	2.72	20.22
Domestic Pollution	6032.72	603.27	150.82	6786.81	2.51	18.66
Human Manure	2045.34	316.1	54.13	2415.57	0.99	7.36
Village Runoff	875.86	59.37	17.09	952.32	0.29	2.16
Paddy Field Runoff	9002.57	1281.52	207.15	10491.24	3.95	29.37
Upland Runoff	1598.51	137.55	23.36	1759.42	0.48	3.57
Paddy Field Leakage	5441.64	1064.72	66.82	6573.18	2.10	15.61
Food-supplied Fishpond	1132.4	153.52	16.72	1302.64	0.40	2.97
Total	28005.65	4299.94	727.56	33033.15	13.45	100
Equal-standard Drainage Capacity	1.87	4.30	7.28	13.45		

Source: Qian and Xu, 2002

Table 2 **Results of Base Run Solution**

Categories	Variable	Unit	Base Run
Production	Paddy	mu	89.7
	Wheat	mu	56.5
	Rape	mu	56.5
	Bean	mu	9.9
Livestock	Sow	head	26.6
	Piglet	head	612.3
Sell	Paddy	kg	0.0
	Rape	kg	7824.3
	Soy-bean	kg	0.0
	Piglet	head	612.3
Self-consumption	Rice	kg	28350.0
	Soybean	kg	560.0
Purchase	Urea	kg	3203.0
	Ammonium bicarbonate	kg	4925.8
	superphosphate	kg	3954.8
	Potassium Chloride	kg	672.6
	Pesticide	yuan	3608.0
Self-supply	Paddy Feed	kg	16559.5
	Wheat Feed	kg	8333.0
	Manure	kg	56294.3
Land supply	Paddy field	mu	89.7
	Upland	mu	3.8
Labor supply	Farm labor	person	13.0
	Off-farm labor yearly	person	40.0
	Off-farm labor monthly	person	19.0
NPS pollution	Nitrogen Runoff	kg/year	591.5

Note: mu=667m^2