Impact of Industrial Water Pollution on Rice Production in Vietnam

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1. Introduction

Vietnam has achieved the average GDP growth rate of 6.71% per year. The industrial sector has mainly contributed economic development in Vietnam, with annual growth of 12% during the period of 200-2009. In line with its industrialization and modernization policies, Vietnam has rapidly changed economic structure from agriculture base to industrial economy. The industrial and construction sector only contributed 26 percent of national GDP in 1986, but it rapidly increases to 40.3 percent in 2009.

Economic development has brought many benefits to Vietnam. Income, public transportation and, in general, quality of life have gradually improved while the percentage of people below the poverty threshold has reduced. However, there have also been many negative consequences of rapid industrialization, particularly on agriculture and ecosystem health, because of the exploitation of natural resources and pollution. The two biggest cities in Vietnam, Ha Noi and Ho Chi Minh, have been ranked as the worst cities in Asia for dust pollution (The World Bank, 2008). Within Vietnam, Ho Chi Minh, the largest city, is at the top of the national pollution list (The World Bank, 2007). This pollution, into the air, water and land, is released by various, large industries. For instance, footwear manufacturing releases 11% of the air pollution load, 10% of the land pollution load and 6% of the water pollution load, while the plastic products manufacturing industry produces 10, 13 and 9% of the air, land and water pollution load, respectively. The main pollution sources do not necessarily come from the largest industries. The cement industry, which only has 12 factories and employs 0.5% of the provincial workforce, releases 24% of the air pollution load (ICEM, 2007). Similarly, the 160 paper factories employ only 0.8% of the provincial workers but contribute 14% of the water pollution load.

According to the Department of Science, Technology, and Environment of Tay Ninh, since almost all industrial zones have not installed wastewater treatment systems in Vietnam, the existence of industrial wastewater contamination appears almost everywhere. Wastewater from thousands of industrial facilities in 30 industrial areas and from small factories and businesses in the basin is the main source of pollution in the Dong Nai river of Ho Chi Minh City [1]. The untreated wastewater contaminating oil from Hai Au concrete factory has been released directly into paddy fields approximately 200m^3/day and 1,500 m^3/day for Phuoc Long textile firm. However, it is difficult to know the actual damage and loss due to the contamination of untreated wastewater from industrial activities in Vietnam (Quang, 2001).

There have been a number of empirical agricultural studies concerning environmental problems, such as soil degradation, wind and water erosion in the world; however, few have specifically examined the impact of industrial pollution. Bai (1988) conducted field experiments in wheat lands irrigated with wastewater from the Liangshui River, the Tonghui River and the Wanquan River. He reported that wastewater irrigation caused a reduction in wheat yield by 8–17.1%. Similar studies in the Geobeidian area of the Tonghui River and the Yizhuang area of the Lianghe River reported that yields of wheat and rice cultivated in unpolluted soils in the sewage-irrigated area decrease by about 10% of the yields obtained in clean water-irrigated areas. In the sewage-irrigated area with polluted soils, yields of wheat and rice grown reduce by 40.6% and 39% of those in clean irrigation areas.

Chang *et al.* (2001) analyzed the impact of industrial pollution on agriculture, human health and industrial activities in Chongqing. To determine the effect of sewage-irrigation, they proposed expressing yield reductions as a function of the comprehensive water pollution index. Using this approach, reductions in yield due to sewage irrigation were about 10% for wheat and 30% for rice and vegetables. To evaluate the effects of polluted water irrigation, Lindhjem (2007) compared crop quality and quantity between a wastewater-irrigated area and a clean water-irrigated area. The total loss of corn and wheat production was estimated to be RMB 360 per mu, of which RMB 285 was caused by reduction in quantity, and RMB 75 was the reduction in quality. This paper also cites the study of Song (2004) that used dose-response functions to estimate the reductions in quantity and quality of crops from polluted water irrigation. Water pollution decreased rice production by 20% and quality by about 4%.

A study by The World Bank (2007) also used dose-response functions to calculate the economic losses from crop damage caused by water pollution, in terms of both reductions in crop quantity and quality (excess pollutant levels and substandard nutritional value). The economic cost of wastewater irrigation in China was estimated to be about 7 billion RMB annually for the four major crops (wheat, corn, rice, and vegetables). Reddy and Behera (2006) evaluated the impact of water pollution on rural communities in India, in terms of agricultural production, human heath, and livestock, using the effects on production, replacement costs and human capital approaches. The study estimated that the total loss per household per annum due to water pollution was \$282.5, of which \$213.2 was from agriculture, \$16.3 from livestock and \$53 from human health.

There has been some studies in recent years on industrial pollution in Vietnam such as the report written by Thong and Ngoc (2004) presented a descriptive analysis of data col-

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[1] The speech of Dr. Trinh Le, the Institute of Tropical Technology and Environmental Protection.

lected from 32 industrial estates in southern Vietnam to determine the factors affecting investment on wastewater treatment plants. It performed that water pollution was a serious problem in the big industrial estates of Ho Chi Minh City, Binh Duong, Dong Nai and Ba Ria-Vung Tau Provinces, and that financial constraints and lack of space were the main reasons why many small and medium-sized enterprises did not invest in wastewater treatment systems. Hung *et al.*(2008) studied the effects of trade liberalization on the environment, using data from the Viet Enterprise Survey of 2002 and the World Bank's Industrial Pollution Projection System. They found that trade liberalization led to greater pollution and environmental degradation but that the Vietnamese people have gradually recognized the importance of environmental protection.

However, because of a lack of information on the costs of pollution, national and local authorities in Vietnam have not paid much attention to pollution control measures. In this study, we review the literature on this topic and estimate the damage of rice production due to water pollution. Our findings could help governmental bodies enforce existing water pollution regulations, for example, TCVN 5945 on water pollution standards or Decree 67 on wastewater pollution charges, also help recognize and understand the failure of some of the current environmental policies in Vietnam. Our study could also provide useful information to authorities, such as the Natural Resources and Environment, and industries to manage water pollution and data for cost-benefit analyses of treatment projects in the industrial zones of Vietnam.

2. Evaluation concept

The total economic loss of rice production includes three factors. First, a reduction in crop quantity assumes that water pollution decreases rice yield. Second, a reduction in rice quality, which is measured as price, assumes that the lower price of rice in a particular region could reflect reduced rice quality due to water pollution. Third, an increase in input costs assumes that farms may attempt to compensate for the possible productivity losses by implementing activities that are capable of offsetting this possible loss but are more costly to implement. The expectation of the profit loss is summarized by the following formula:

$$\begin{aligned}\pi_p &= \left(\bar{P}-\Delta P\right)\left(\bar{Q}-\Delta Q\right)-\left(\bar{C}+\Delta C\right)\\ &= \bar{P}\bar{Q}-\bar{P}\times\Delta Q-\Delta P\times\bar{Q}+\Delta P\times\Delta Q-\bar{C}-\Delta C\\ &= \left(\bar{P}\bar{Q}-\bar{C}\right)-\left(\bar{P}\times\Delta Q+\Delta P\times\bar{Q}+\Delta\bar{C}\right)+\Delta P\times\Delta Q\\ &= \qquad \pi_n \qquad - \qquad \text{Profit loss}\end{aligned} \tag{1}$$

$$\begin{aligned}\Rightarrow \text{ Profit loss } &= \quad \bar{P}\times\Delta Q \quad + \quad \Delta P\times\bar{Q} \quad + \quad \Delta\bar{C}\\ &= \text{ Quantity loss } + \text{ Quality loss } + \text{ Cost increase}\end{aligned} \tag{2}$$

where π_n and π_p are the rice profits in the non-polluted and polluted areas. Because $\Delta P \times \Delta Q$ is small compared with the other parts of the equation, it can be ignored and assumed to be 0.

However, it is complicated to estimate quality loss through the proxy of price because there are many other unobservable factors, excepting water pollution, which affect the price of rice. Thus, the study only calculates the three elements affected by water pollution:

- *Quantity loss:* Water pollution causes a decrease in rice yield. The production function approach is used to estimate the loss of rice yield.
- *Cost increase:* Since farms may aim and indeed be able to compensate for the possible productivity losses by implementing activities which are capable of offsetting this possible loss but are more costly to implement. In such circumstances, because it is not productivity which will be impacted, but production costs, cost function approach is applied to assess the impacts of pollution in economic terms.
- *Profit loss:* This is defined as total loss of net economic return estimated by the comparison of profit functions between two selected areas (one is considered as the polluted, other is the non-polluted area). The difference in rice profits of two regions is considered as total loss of net economic return due to industrial pollution.

3. Empirical model

We surveyed rice farmers in two areas with the assumption that they had the same natural environment conditions and social characteristics, and only differed with respect to pollution. One area was considered to be the polluted area, receiving wastewater from nearby industrial parks, while the other area was assumed to be the non-polluted area, being distant from sources of industrial pollutants. The productivity loss of rice production caused by water pollution was estimated by the difference in rice yield between the two regions (Translog production function approach). The similar calculation was applied for cost increase and profit loss due to water pollution by applying the methods of Cobb-Douglas cost function and translog profit function respectively.

3.1. Production function approach

The production function approach is that industrial activities possibly have a negative impact on the outputs, cost and profit of producers through the effect of environment. Environment affects goods or services existing in the market through the value change of their outputs, for instance, the reduced value of fish caught because of river pollution. The production function approach is often used to estimate the effect of environment change on soil erosion, deforestation, fisheries, the impact of air and water pollution on agriculture and so on (Bateman *et al.*, 2003)

A literature search on the production function approach in rice production Vietnam was conducted to make sure that relevant variables will be included in the farm survey questionnaire and to examine the suitability of existing rice production models for the research. There are a number of studies related to rice production in Vietnam. Kompas (2004) and Linh (2007) used a stochastic production frontier to estimate the technical efficiency of rice production in Vietnam. Do and Bennett (2007) used a production function approach with flood duration and relative location of upstream and downstream farmers variables to estimate the cost of changing wetland management, representing the reduced income of rice production in the Mekong River Delta. The loss of rice productivity was estimated based on the differences in rice yield between upper and lower of the Tram Chim park dyke. The results showed that the rice productivity in the lowering of park dyke decreased 0.06 tons per hectare per annum, which led to the profit loss of VND 0.07 million per hectare per annum. These three studies used the Cobb-Douglas functional form of the rice production function approach. This study uses a translog functional form and does test for checking the existence of Cobb-Douglass. The model takes the basic form:

$$Y = f(L, K, I, Z, E, F) \tag{3}$$

where Y is the rice yield of a farmer in the studied year (tones/ha), L is the number of labors for rice cultivation (man-days/ha), K is capital input (VND/ha), I is a vector of material inputs as seeds (kg/ha), fertilizers (kg/ha), herbicide (ml/ha) and pesticides (ml/ha), Z is a vector of social-economic characteristics of farmers, and E is a vector of farming conditions, and F is the relative location of farms (polluted site = 1, non-polluted site = 0)

The test for the existence of quantity loss due to water pollution is:

$$\begin{aligned} &H_0 : \text{Quantity loss} = 0 \text{ or Coef. of F} = 0 \\ &H_1 : \text{Quantity loss} > 0 \text{ or Coef. of F} < 0 \end{aligned} \tag{4}$$

The reduced yield of rice is defined as the difference in the average rice yield between the non-polluted and polluted site. It is estimated by following equation:

$$\Delta Y = f(\bar{L}, \bar{K}, \bar{I}, \bar{Z}, \bar{E}, F = 0) - f(\bar{L}, \bar{K}, \bar{I}, \bar{Z}, \bar{E}, F = 1) \tag{5}$$

where ΔY is the average yield loss caused by water pollution (kg/ha); $\bar{L}$, $\bar{K}$, $\bar{I}$, $\bar{Z}$, $\bar{E}$ are the average of labor, capital input, material inputs, social-economic characteristics, and farming conditions, respectively.

As mentioned earlier, a translog functional form is used in the study. The production functional form in the polluted and non-polluted areas is written as followed (Tim & Battese, 2005):

$$\begin{aligned} \ln(Y) = {} & \alpha_0 + \alpha_1 \ln(L) + \alpha_2 \ln(K) + \alpha_3 \ln(I) + \frac{1}{2}\alpha_{11} \left(\ln(L)\right)^2 + \alpha_{12} \ln(L)\ln(K) + \alpha_{13} \ln(L)\ln(I) + \\ & + \frac{1}{2}\alpha_{22} \left(\ln(K)\right)^2 + \alpha_{23} \ln(K)\ln(I) + \frac{1}{2}\alpha_{33} \left(\ln(I)\right)^2 + \sum_{k=1}^{5} \beta_k Z_k + \sum_{h=1}^{4} \delta_h E_h + \gamma F \end{aligned} \tag{6}$$

where Y, L, K, I, F are the same as in the above equations and Z_1, Z_2, Z_3, Z_4 are the variables of the gender (1 = male, 0 = female), the age (years), the number of school year (years), attending trainings (1 = Yes, 0 = No) of rice households, and E_1, E_2, E_3, E_4 are the variables of serious diseases happening during the study year (1 = Yes, 0 = No), rice monoculture (1 = yes, 0 = No), soil quality (1 = fertile soil, 0 = other soils), off-farm income ratio.

Some restrictions are used to check the constant returns to scale:

$$\begin{aligned} \alpha_1 + \alpha_2 + \alpha_3 &= 1 \\ \alpha_{11} + \alpha_{12} + \alpha_{13} &= 0 \\ \alpha_{12} + \alpha_{22} + \alpha_{23} &= 0 \\ \alpha_{13} + \alpha_{23} + \alpha_{33} &= 0 \end{aligned} \tag{7}$$

Then, the following restriction is applied to test the existence of Cobb-Douglass function:

$$\alpha_{11} = \alpha_{12} = \alpha_{13} = \alpha_{22} = \alpha_{23} = \alpha_{33} = 0 \tag{8}$$

3.2. Replacement Cost (RC)

Replacement cost approach is defined as payment for restoring original environment (unpolluted state) if it has already been damaged. The costs of moving away from the polluted area suffered by the victims of environmental damage or actual spending on safeguards against environmental risks are called replacement costs (Bateman *et al.*, 2003; Winpenny, 1991). In the study written by Reddy and Behera (2006), the replacement cost method is used to estimate the damage costs of pump sets due to water pollution. In this study, farmers in the polluted areas might spend more input costs for the compensation of rice productivity loss because they directly use the polluted water for irrigation. Thus, it is assumed that the costs of farmers in polluted areas are more than those in the non-polluted areas. In this case, the replacement cost is estimated by using the cost function approach. The basic form of cost function is given by:

$$C = C(W_s, W_h, W_f, W_p, Y, Z, E, F) \tag{9}$$

where C is the total cost of a farmer (VND/ha), W_s is the price of seed (VND/kg), W_h is the price of herbicide (VND/100ml), W_f is the price of fertilizers (VND/kg), W_p is the price of pesticides (VND/100ml), Y is the rice yield of a farmer in the studied year (tones/ha), Z is a vector of social-economic characteristics of farmers, and E is a vector of farming conditions, F is the relative location of farms (polluted site = 1, non-polluted site = 0)

The test for the existence of cost increase due to water pollution is:

$$\begin{aligned} &H_0 : \text{Cost increase} = 0 \text{ or Coef. of F} = 0 \\ &H_1 : \text{Cost increase} > 0 \text{ or Coef. of F} > 0 \end{aligned} \tag{10}$$

The increase in input costs is defined as the difference of the average cost between heavily polluted and less polluted areas. It is estimated by following equation:

$$\Delta C = C(\bar{W}_s, \bar{W}_h, \bar{W}_f, \bar{W}_p, \bar{Y}, \bar{Z}, \bar{E}, F=1) - C(\bar{W}_s, \bar{W}_h, \bar{W}_f, \bar{W}_p, \bar{Y}, \bar{Z}, \bar{E}, F=0) \tag{11}$$

where ΔC is the increase of the average cost per ha because of water pollution (VND/ha); $\bar{W}_s$, $\bar{W}_h$, $\bar{W}_f$, $\bar{W}_p$, $\bar{Y}$, $\bar{Z}$, $\bar{E}$ are the average price of seed, herbicide, fertilizer, pesticides, social-economic characteristics, and farming conditions, respectively.

The Cobb-Douglas formal function is applied to estimate the cost function in the study (Tim & Battese, 2005):

$$\ln(C) = \varphi_0 + \varphi_1 \ln(W_s) + \varphi_2 \ln(W_h) + \varphi_3 \ln(W_f) + \varphi_4 \ln(W_p) + \varphi_5 \ln(Y) + \sum_{k=1}^{3} \beta_k Z_k + \sum_{h=1}^{3} \delta_h E_h + \gamma F \tag{12}$$

where C, W_s, W_h, W_f, W_p, F are the same as in the above equation and Z_1, Z_2, Z_3, are, the age (years), the number of school year (years), attending trainings (1 = Yes, 0 = No) of rice households, and E_1, E_2, E_3, are serious diseases happening during the year (1 = Yes, 0 = No), rice monoculture (1 = yes, 0 = No), soil quality (1 = fertile soil, 0 = other soils) respectively.

3.3. Profit function approach

Net economic return is defined as revenues from rice minus the cost of producing rice. It will be identified by a profit function approach. The profit loss is estimated by the following basic profit function:

$$\pi^* = \pi\left(W^*, C, Z, E, F\right) \tag{13}$$

where π^* is normalized profit defined as gross revenue minus variable cost divided by farm-specific output price, W^* is a vector of variable input prices divided by output price, C is a vector of fixed factors of the farm, Z is a vector of social-economic characteristics of farmers, E is a vector of farming conditions, F is the relative location of farms (polluted site = 1, non-polluted site = 0).

Hypothesis for the existence of profit loss due to water pollution is:

$$\begin{aligned} &H_0 : \pi_n = \pi_p \text{ or Profit Loss = 0 or Coef. of F = 0} \\ &H_1 : \pi_n > \pi_p \text{ or Profit Loss > 0 or Coef. of F < 0} \end{aligned} \tag{14}$$

The profit loss due to water pollution is defined by the difference in profit between the polluted and non-polluted areas. It is estimated by the equation:

$$\Delta\pi^* = \pi\left(\bar{W}^*, \bar{C}, \bar{Z}, \bar{E}, F = 0\right) - \pi\left(\bar{W}^*, \bar{C}, \bar{Z}, \bar{E}, F = 1\right) \tag{15}$$

where $\Delta\pi^*$ is Profit loss in 1000 VND/ha. $\bar{W}^*$, $\bar{C}$, $\bar{Z}$, $\bar{E}$ are the average prices of inputs, the average of the fixed factors, the social-economic characteristics of farmers, the farming conditions, respectively.

We use the translog profit functional form. The formula is given as (Rahman, 2002, Surjit & Carlos, 1981)

$$\begin{aligned}\ln\pi^* = \alpha_0 + \sum_{j=1}^{4}\alpha_j \ln W_j^* + \frac{1}{2}\sum_{j=1}^{4}\sum_{k=1}^{4}\tau_{jk}\ln W_j^* \ln W_k^* + \sum_{j=1}^{4}\sum_{l=1}^{6}\phi_{jl}\ln W_j^* \ln C_l + \\ + \sum_{l=1}^{6}\beta_l \ln C_l + \frac{1}{2}\sum_{l=1}^{6}\sum_{t=1}^{6}\varphi_{lt}\ln C_l \ln C_t + \sum_{m=1}^{3}\varpi_m Z_m + \sum_{n=1}^{4}\eta_n E_n + \gamma F\end{aligned} \tag{16}$$

where π^* is the restricted profit (total revenue minus total cost of variable inputs) normalized by price of output (P); W_j^* is the price of the j^th input (W_j) normalized by the output price (P); j is the price of seed (1), the price of herbicides (2), the price of fertilizer (3), the price of pesticide (4); C_l is the quantity of fixed input, where l is total amount of seed used (1), total amount of herbicides used (2), total amount of fertilizer used (3), total amount of pesticides used (4), the number of man-days for rice production (5), the money of machines and services at all stages of rice production (6); Z_1, Z_2, Z_3 are the age (years), the number of school year (years), and attendance at training sessions (1 = Yes, 0 = No) of rice households, respectively; and E_1, E_2, E_3, E_4 are the variables of serious disease incidence happening during the study year (1 = Yes, 0 = No), rice monoculture (1 = Yes, 0 = No), soil quality (1 = fertile soil, 0 = other soils), and off-farm income ratio, respectively.

Then, the following restriction is applied to test the existence of the Cobb-Douglass function:

$$\tau_{jk} = \phi_{jl} = \varphi_{lt} = 0 \tag{17}$$

4. Study site and data description

4.1. Study site

In the Mekong River Delta, there are approximately 33 industrial parks, which constitute 9.5% of the total industrial parks of the country. Almost all of these 33 parks have no wastewater treatment system. The industrial parks in Can Tho city have released the biggest pollution loads, and the province is ranked in the top 10 most polluted provinces in Vietnam (Table 1). Can Tho is also one of the biggest rice producers in the Mekong River Delta. Because of these reasons, Can Tho was selected as the study site.

Province	Air index	Land index	Water index	Overall
Ho Chi Minh city	1	1	1	1
Hanoi	5	2	2	2
HaiPhong	2	6	4	3
Binh Duong	6	3	3	4
Dong Nai	4	4	5	5
Thai Nguyen	3	5	7	6
PhuTho	7	7	6	7
Da Nang	10	9	8	8
Ba RiaVung Tau	9	8	10	9
Can Tho	8	10	9	10

Note: The pollution loads released to air, land and water were estimated for all 64 provinces in Vietnam, and then pollution indexes were calculated and rankings were made.

Source: ICEM, 2007

Table 1. Top 10 most polluted provinces in Vietnam

Zones	Size	Main activities	Water treatments
Tra Noc 1	135 ha	Processing, electron, clothes	No [a]
Tra Noc 2	165 ha	Machinery	No [a]
Hung Phu 1	262 ha	Harbor, Store	No
Hung Phu 2	212 ha	Machinery	No
Hong Bang	38.2 ha	Consumer goods	No [a]
Thot Not	150 ha	Processing, clothes, shoes	No [a]

[a] The available decision and acceptation of local authorities to evaluate the impact of environmental pollution.

Source: Resource and Environment Department of Can Tho City (2008)

Table 2. The industrial zones in Can Tho city

There are six industrial parks in Can Tho (Table 2), which mainly comprise agricultural and fishery processing industries, clothes and consumer goods manufacturing industries. Almost none of the industrial zones and industrial corporations located near human residences have installed wastewater treatment systems. There has been little management of toxic waste or water pollution by local authorities and business. Tra Noc 1 (built in 1995) and Tra Noc 2 (built in 1999) industrial zones have only recently been acknowledged by the Department of Resources and Environment while Thot Not has been considered by Can Tho authorities to evaluate the impact of environmental pollution (Resource and Environment department of Can Tho city, 2008). As a consequence, Tra Noc 1 and 2 have released large volumes (1000s m^3) of various waste products directly into the river (Tuyen, 2010).

4.2. Data collection

The study region covers the area within and around Tra Noc 1 and Tra Noc 2 industrial zones, which are two of the greatest polluters in Can Tho. People living in this area have suffered various financial impacts from the pollution: reduced crop yields, the use of cattle and agricultural equipment such as pump sets, contamination of drinking water, and increased incidence of human diseases and deaths directly and indirectly caused by water pollution.

Farmers were randomly selected for interview from two areas (Phuoc Thoi and Thoi An) with similar social and natural conditions (e.g. the same social and farming culture, ethnicity, type of soil). The selection of the polluted and non-polluted area was based on their distance from industrial zones, and on the recommendation or suggestion of local authorities and farmers. Some of the villages in Phuoc Thoi are heavily polluted by wastewater from the TraNoc 1 and 2 industrial zones. The villages in Thoi An are further away from the industrial zones than Phuoc Thoi and deemed to represent a non-polluted area (see Figure 1).

The group of fourteen interviewers and three local guide persons includes ten final year students, four staffs of School of Economics and Business Administration, Can Tho University, one local authority from people's committee, and two local farmers.

The questionnaire composes four main parts. In the first and second parts, the personal and farming information of household such as address, age, gender, training and so on and the situation of environmental pollution were interviewed. The inputs and output of rice production were collected in the three part and income from other activities obtained in the final section of questionnaire.

The household survey took 3 months to complete from January to March 2010 and was divided into two main reporting periods. The first period was called as pilot-survey in January 2010. The aims of this interview were to check and then correct the questionnaire more clearly and concisely, and to help interviewers get used to and understand the content of questionnaire. After the interviewers were trained how to ask by using questionnaire, about 30 farmers were interviewed. The revised questionnaire was used in the second period from February to March 2010. In total, 364 rice farmers, consisting of 214 farmers in the polluted and 150 farmers in the non-polluted area, were interviewed in February and March 2010. Household data were collected on household level information related to production costs and income as well as the social and economic characteristics of the farmers, and their perceived damages and losses due to water pollution.

Table 3 showed the water quality index of the polluted and non-polluted area. The concentrations of Total Suspended Solids (TSS) in the water refer to the concentrations of solid particles that can be trapped by a filter. This can be a problem because high concentrations of TSS can block sunlight from reaching submerged vegetation. This causes a reduction in the photosynthesis rate, and therefore less dissolved oxygen released into the water by plants. If bottom dwelling plants are not exposed to some light, the plants stop producing oxygen and die. Chemical Oxygen Demand (COD) is the amount of oxygen used during the oxidation of organic matter and inorganic chemicals such as ammonia nitrogen (NH3-N). High COD indicates a greater pollution load.

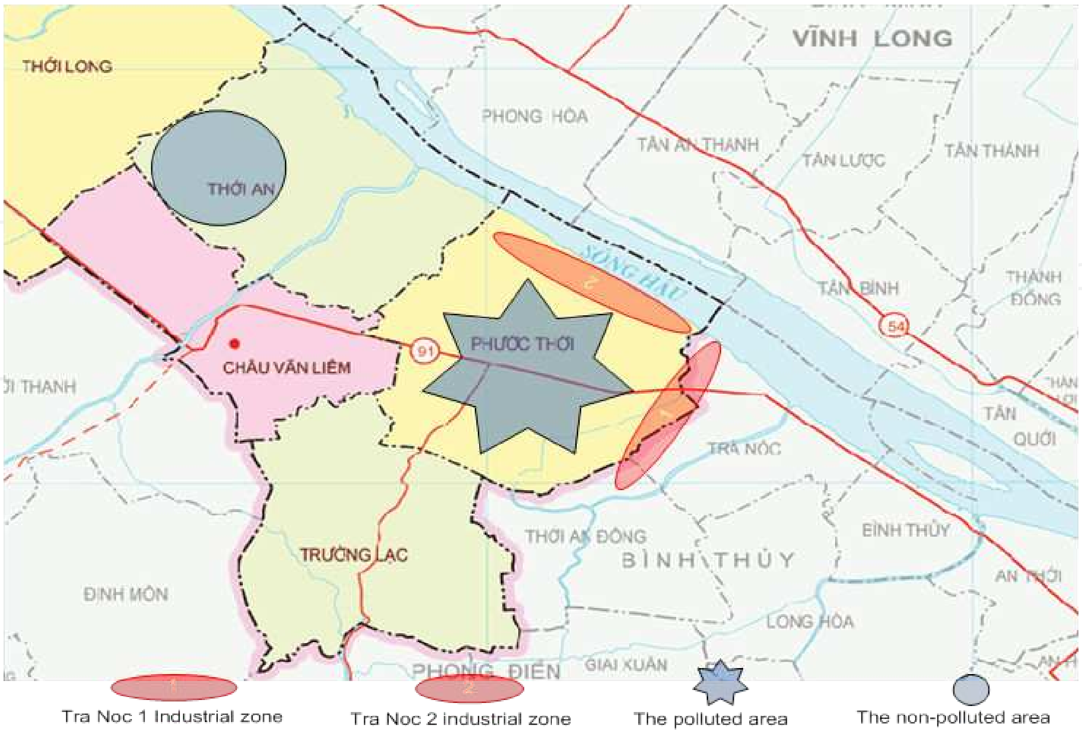

Figure 1. Map of the Study Site

	TSS (mg/l)	COD (mg/l)	NH3-N (mg/l)
The polluted area (PhuocThoi) (1)			
- Sewer mouth	145	720	13.29
- Primary affected water source (2)	50	50	1.23
- Secondary affected water source (3)	60	48	0.63
The non-polluted area (Thoi An)(4)	22	5.1	0.16
Limitation value (TCVN5942,1995)			
- Class A (5)	20	10	0.05
- Class B (6)	80	35	1

Notes:

(1) Measured on January 17th, 2007 (Nga *et al.*, 2008)

(2) The region receives wastewater directly from the industrial park.

(3) The region receives polluted water from the primary affected water source regions.

(4) Measured on January 27th, 2007 (Lang *et al.*, 2009)

(5) Values in Class A are from the surface water used for domestic water supply with appropriate treatments.

(6) Values in Class B are from the surface water used for purposes other than domestic water supply. Water quality criteria for aquatic life are specified in a separate index.

Table 3. Water quality of the polluted and non-polluted area

In the polluted area, the concentrations of TSS, COD and NH3-H in the sewer mouth, the primary affected water source and the secondary affected water source regions were mostly much higher than those of the standard water quality (see Table 3). This indicated that our selected pollution area site was heavily polluted. The concentrations of TSS, COD and NH3-N in the sewer mouth region were nearly 2-fold, over 20-fold and 13-fold higher than those of the standard water quality of class B, respectively.

Differences in the water quality index between the polluted and non-polluted area indicate that the water quality in the non-polluted area was much higher than that in the polluted area. However, the concentrations of TSS and NH3-N in the non-polluted were slightly higher than those of the Class A standard. This may be caused by non-point source pollutants, for instance, fertilizer, herbicide and pesticide released by agricultural activities in the region.

Variable	Description	Unit
Y	Total yield per hectare	Ton/hectare
P	Price of rice	Thousand VND/ton
C	Total cost	Thousand VND/ha
π	Total profit	Thousand VND/ha
C_s	Total amount of seed used	Kg/ha
C_h	Total amount of herbicides used	Equivalent unit of 100 ml/ha
C_f	Total amount of fertilizer used	Kg/ha
C_p	Total amount of pesticide used	Equivalent unit of 100 ml/ha
C_l	The number of man-days for rice production	day/ha
C_c	The money of machines and services at all stages of rice production	Thousand VND/ha
W_s	Price of seed	Thousand VND/kg
W_h	Price of herbicide	Thousand VND/100ml
W_f	Price of fertilizer	Thousand VND/kg
W_p	Price of pesticide	Thousand VND/100ml
Age	The age of respondents	Years
Education	The number of school year of respondents	Years
Training	Respondents attending trainings	1= Yes, 0 = No
Mono	Rice monoculture	1= Yes, 0 = No
Diseases	Diseases happening during the study year	1= Yes, 0 = No
Off-farm ratio	The ratio of off-farm income	
Soil	Soil quality	1 = fertile soil, 0 = other soils

Table 4. Description of variables used in rice production models

Table 4 showed the descriptions of variables in rice production models. The volumes of herbicide and pesticide used have measurement units of equivalent units of 100 ml per hectare per crop, based on farmers' reports and experts' recommendations. This is because farmers use various types of herbicides and pesticides (mixed with water or as a powder), and sometimes mix them together, which means that it is difficult to estimate exact amounts.

Variables	**Non-polluted area**	**Polluted area**	**t-value**
Y	5.88	4.99	-7.31***
P	4,157.79	4,060.89	-3.06***
C	10,909.44	10,563.61	-0.84
π	13,623.91	9,759.35	-8.37***
C_s	224.41	206.42	-2.37**
C_h	10.43	11.70	1.33
C_f	475.87	463.76	-0.53
C_p	77.26	70.23	-1.24
C_l	29.03	32.95	1.39
C_c	3283.02	3436.20	1.06
W_s	5.46	5.21	-1.34
W_h	32.79	32.47	0.21
W_f	9.42	9.54	0.92
W_p	24.86	21.70	-1.85*
Age	48.04	48.99	0.81
Education	6.33	6.07	-0.87
Training	0.49	0.35	-2.72***$^{\psi}$
Mono	0.60	0.58	-0.39$^{\psi}$
Diseases	0.40	0.42	-0.39$^{\psi}$
Off-farm ratio	0.20	0.37	4.72***$^{\psi}$
Soil	0.63	0.75	2.35**$^{\psi}$

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively

$^{\psi}$ Z-test for the equality of two proportions

Source: Own estimates; data appendix available from authors.

Table 5. Descriptive Statistics of Rice Production per hectare per crop

Table 5 showed the descriptive statistics of the main variables in the rice production model for the polluted and non-polluted areas. Although soil quality in the non-polluted area was significantly ($P < 0.05$) lower than that in the polluted area, rice productivity and profit in the non-polluted area was significantly ($P < 0.01$) higher than those in the polluted area. The price of rice in the polluted area was significantly ($P < 0.01$) lower than that in the non-polluted area. This indicated that water pollution might have reduced crop quality, and in turn its price. The difference in the off-farm income ratio between the two areas suggests that farmers are aware of the reduced profit from rice cultivation in polluted soil, and therefore have a tendency to find additional work in nearby industrial parks to supplement their income.

Other variables measured did not significantly differ between the two regions (Table 5), except the percentage of respondents attending training. The results also showed that, on average, farmers were 48 years old, have had 6 years of education and 60 % of them grew rice in a monoculture.

5. Estimated results

5.1. Impact of water pollution on rice productivity

Table 6 showed the Ordinary Least Squares (OLS) result of rice production function in translog form. The variables estimated in the model were statistically significant at 1 percent level. The estimated R-square was equal to 0.64, revealing the 64 percent change of rice yield possibly explained by independent variables in the model.

Variables	Coef.	t-value	Variables	Coef.	t-value
$\ln(C_s)$	0.696	0.87	$\ln(C_h)\times\ln(C_p)$	0.007	0.7
$\ln(C_h)$	-0.123	-0.8	$\ln(C_h)\times\ln(C_l)$	0.021	1.49
$\ln(C_f)$	0.465	0.84	$\ln(C_h)\times\ln(C_c)$	0.008	0.35
$\ln(C_p)$	-0.157	-0.59	$\ln(C_f)\times\ln(C_p)$	0.060	1.5
$\ln(C_l)$	0.851**	2.55	$\ln(C_f)\times\ln(C_l)$	-0.026	-0.56
$\ln(C_c)$	0.572	1.3	$\ln(C_f)\times\ln(C_c)$	-0.022	-0.27
$½ \ln(C_s)^2$	0.532***	2.72	$\ln(C_p)\times\ln(C_l)$	-0.031	-1.41
$½ \ln(C_h)^2$	0.000	0.03	$\ln(C_p)\times\ln(C_c)$	0.029	0.71
$½ \ln(C_f)^2$	0.037	1.13	$\ln(C_l)\times\ln(C_c)$	-0.023	-0.58
$½ \ln(C_p)^2$	-0.011	-0.66	*Age*	-0.002**	-2.07
$½ \ln(C_l)^2$	0.059*	1.81	*Education*	0.004	1.1
$½ \ln(C_c)^2$	0.075	1.07	*Training*	0.039**	2.07
$\ln(C_s)\times\ln(C_h)$	0.014	0.54	*Disease*	-0.012	-0.67
$\ln(C_s)\times\ln(C_f)$	-0.132	-1.34	*Mono*	0.016	0.7
$\ln(C_s)\times\ln(C_p)$	-0.057	-1.08	*Soil*	0.031	1.64
$\ln(C_s)\times\ln(C_l))$	-0.105*	-1.83	*Off-farm ratio*	-0.054*	-1.93
$\ln(C_s)\times\ln(C_c)$	-0.216*	-1.87	*Pollution*	-0.127***	-6.68
$\ln(C_h)\times\ln(C_f)$	-0.025	-0.7	Constant	-5.615**	-2.26
R-square					0.64
Included observation					364

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively

Source: Own estimates; data appendix available from authors.

Table 6. The OLS regression of rice production function

The study also examined the null hypothesis in (7) that there was a proportional output change when inputs in the model were varied or farms produce rice with constant returns to scale. The restricted least squares regression with the null hypothesis of constant returns to scale was estimated. The computed F statistic was 37.09 more than the critical value F (7, 327) of 2.69 at

1 percent level of significance 1). Thus, the null hypothesis was rejected and the study concluded that technology did not exhibit constant returns to scale.

The second test was applied to check the Cobb-Douglass formal existence of the production function. The restricted function was estimated with the null hypothesis of jointed parameters in (8) equal to 0. The computed F statistic of 1.94 was more than the critical F(21,327) of 1.91 at 1 percent level of significance 1). Thus, the null hypothesis was rejected, meaning that the translog functional form was suitably applied for the data of rice production in the study.

The results of Table 6 showed that there was no multicollinearity in the independent variables of production function because the correlations of these independent variables estimated by using the correlation matrix were less than 70 percent. The null hypothesis homoscedasticity was also accepted by using Breusch-Pagan test because the estimated LM of 49.72 was less than the critical $\chi^2_{36}$of 57.34 at the level of 1 percent 2).

Table 6 showed that the rice productivity in the polluted was lower than in the non-polluted area because the coefficient of *Pollution* variable was significantly negative at 1 percent level. In addition, the study also revealed that training courses partly contributed an increase in rice yield since the coefficient of *Training* variable was significantly positive.

Moreover, the model also showed that farmer age ($P < 0.05$) and the ratio of off-farm income ($P < 0.1$) explained variation in rice yield. The effect of age might have been caused by declines in the health of older farmers leading to less efficient cultivation. Farmers who earned more off-farm income were associated with less profitable rice cultivation. Our interviews with the farmers in the polluted region suggested that when rice production was no longer profitable, farmers tended to sell their land as construction land or rent their land to farmers from other regions. Local farmers also attempted to secure employment in the nearby industrial parks, from which they could earn more money than compared to rice cultivation. The study also discovered that water pollution made farmers change rice cultivation and crop intensification techniques. Before their income was mainly from rice production with three rice crops per year, now they do rice farming as part-time jobs, only grow one or two crops per year and harvest rice just enough for home consumption. These possibly were the suitable explanations for the negative impact of off-farm income on rice productivity.

The reduced productivity of rice was calculated based on findings from Table 6. After the equation (5) was used to eliminate the effects of other factors, the estimated yield in the non-polluted area was about 5.61 tons and around 4.94 tons for the polluted region. Then, the loss of rice yield due to polluted water irrigation was estimated by subtracting the yield in the polluted from yield in the non-polluted region (equation 5). Using this approach, the estimated result was about 0.67 tons per hectare per crop (5.61 tons – 4.94 tons).

5.2. Increase in rice production cost due to water pollution

Table 7 showed R-square was equal to 0.56, revealing the variation of total rice costs of 56 percent was explained by independent variables in the model. The study also showed that the multicollinearity among the independent variables in cost function did not exist because the results estimated by correlation matrix approach showed that there were no correlations in these independent variables higher than 70 percent. The result of Breusch-Pagan test performed that the estimated LM of 14.96 was less than the critical $\chi^2_{12}$of 26.22 at the level of 1 percent, revealing the absence of heterscedasticity in the estimate of cost function 2).

Variables	Coefficient	t-value
$\ln(W_s)$	0.195***	3.95
$\ln(W_h)$	0.021	0.84
$\ln(W_f)$	0.431***	5.5
$\ln(W_p)$	0.007	0.27
$\ln(Y)$	0.918***	14.79
Age	0.002*	1.9
Education	-0.008	-1.55
Training	-0.058**	-2.02
Diseases	0.045	1.62
Rice monoculture	0.143***	4.72
Soil	-0.032	-1.08
Pollution	0.098***	3.3
Constant	6.140***	22.84
Statistic summary		
R-square	0.56	
Included observation	364	

Notes: ***, **, * indicate statistical significance at the 0.01, 0.05 and 0.1 level respectively

Source: Own estimates; data appendix available from authors.

Table 7. The OLS regression of rice cost function

The coefficient of *Pollution* variable was statistically significant positive at level of 1 percent, performing rice costs in the polluted region was higher than one in the non-polluted region. Moreover, farmers, who were older, managed their production cost more highly and less efficiently, performed by the positive effect of *Age* variable on total costs at 10 percent level. The significantly positive coefficient of *Rice monoculture* variable ($P < 0.01$) revealed that farmers who grew rice monoculture cost more than ones who cultivated rice rotation or intercropping. Possible explanation is that the cropping system of rice monoculture decreased the fertility of soil.

Like the calculation of yield loss, cost increase due to water pollution was estimated using the coefficients performed in Table 7. After the effect of other factors were eliminated, total cost was estimated about VND 10.37 million for rice production in the polluted area and VND 9.4

per ha per crop for that in the non-polluted area. Cost increase was estimated by subtracting the rice cost in the non-polluted region by the rice cost in the polluted area (equation 11). Using this approach, an increase in cost due to water pollution was calculated around VND 0.97 million per ha per crop (See Table 10).

5.3. Total loss of net economic return

Table 8 showed the coefficients from the OLS regression of the rice profit model using the translog profit functional form (equation 16). The full model was statistically significant at the 1% level. The estimated R-square revealed that 50% of the variation in the rice profit was explained by the model.

Next, we tested the null hypothesis of the Cobb-Douglass functional form. The restricted function was estimated assuming the null hypothesis that the joint parameters in (17) are 0. The computed F statistic of 1.78 was more than the critical F(55,283) value of 1.57 at the 1 percent level [1)]. The null hypothesis was therefore rejected, which supported the use of the translog functional form in this study. The estimate of profit function also showed the absence of multicollinearity (the correlations of independent variables less than 70 percent) and of heterscedasticity (Breusch-Pagan test showed the critical χ^2_{74} of 105.2 at the level of 1 percent higher than the computed LM of 100.24) [2)].

The coefficient of *Pollution* variable representing the effect of pollution was negative and significant ($P < 0.01$), which confirmed that water pollution reduced the profit of rice cultivation. The reduction in rice profit was calculated using the coefficients presented in Table 8. The estimated profit was approximately VND 9.14 million for rice cultivation in the polluted area and VND 12.34 million for that in the non-polluted area after the influences of other factors were eliminated. The loss of rice profit due to wastewater irrigation was estimated by subtracting the rice profit in the polluted region by the rice profit in the non-polluted region (equation 15). Using this approach, the loss of profit was calculated to be approximately VND 3.2 million per hectare per crop (see Table 10).

Like the results of rice yield loss, this model also performed that farmer age ($P < 0.01$), attending training ($P < 0.01$) and the ratio of off-farm income ($P < 0.1$) explained variation in profit. Moreover, soil quality was also an important factor affecting profit ($P<0.1$).

We also used the same estimate of profit loss due to water pollution to calculate reductions in profit caused by other factors as presented in Table 9. Cultivation in non-fertile soil, instead of fertile soil, could reduce rice profit by 8.24%. Farmers whose main sources of income were from non-agricultural sectors obtained 11.45% less rice profit than those who only had an agricultural income. Participating in trainings was estimated to increase profit by 13.03%. Profit loss caused by water pollution was much higher than the profit loss caused by other factors, which demonstrates that environment pollution has a great significance for rice farmers near industrial parks. Because of this, we suggest that the Vietnamese authorities should place a greater importance on the development and implementation of pollution control policies.

Variables	**Coef.**	**t-value**	**Variables**	**Coef.**	**t-value**
$\ln(W_s^*)$	-0.111	-0.02	$\ln(W_p^*)\times\ln(C_c)$	0.162	0.92
$\ln(W_h^*)$	1.211	0.54	$\ln(C_s)$	-3.393	-0.72
$\ln(W_f^*)$	-3.869	-0.71	$\ln(C_h)$	-0.540	-0.34
$\ln(W_p^*)$	-0.698	-0.29	$\ln(C_f)$	3.341	0.99
$\frac{1}{2}\ln(W_s^*)^2$	0.322	0.68	$\ln(C_p)$	-2.241	-1.16
$\frac{1}{2}\ln(W_h^*)^2$	-0.019	-0.15	$\ln(C_l)$	2.890	1.51
$\frac{1}{2}\ln(W_f^*)^2$	-1.245**	-1.99	$\ln(C_c)$	1.432	0.37
$\frac{1}{2}\ln(W_p^*)^2$	0.223	1.58	$\frac{1}{2}\ln(C_s)^2$	0.338	0.61
$\ln(W_s^*)\times\ln(W_h^*)$	-0.017	-0.09	$\frac{1}{2}\ln(C_h)^2$	0.012	0.18
$\ln(W_s^*)\times\ln(W_f^*)$	-0.257	-0.50	$\frac{1}{2}\ln(C_f)^2$	-0.117	-0.47
$\ln(W_s^*)\times\ln(W_p^*)$	-0.042	-0.22	$\frac{1}{2}\ln(C_p)^2$	0.013	0.18
$\ln(W_h^*)\times\ln(W_f^*)$	0.231	0.91	$\frac{1}{2}\ln(C_l)^2$	0.123	1.44
$\ln(W_h^*)\times\ln(W_p^*)$	0.030	0.28	$\frac{1}{2}\ln(C_c)^2$	-0.107	-0.52
$\ln(W_f^*)\times\ln(W_p^*)$	0.005	0.02	$\ln(C_s)\times\ln(C_h)$	-0.113	-0.80
$\ln(W_s^*)\times\ln(C_s)$	-0.648*	-1.96	$\ln(C_s)\times\ln(C_f)$	0.500*	1.73
$\ln(W_s^*)\times\ln(C_h)$	0.181	1.32	$\ln(C_s)\times\ln(C_p)$	0.013	0.06
$\ln(W_s^*)\times\ln(C_f)$	0.586**	2.01	$\ln(C_s)\times\ln(C_l))$	-0.250	-1.56
$\ln(W_s^*)\times\ln(C_p)$	-0.165	-0.96	$\ln(C_s)\times\ln(C_c)$	-0.149	-0.48
$\ln(W_s^*)\times\ln(C_l)$	0.079	0.56	$\ln(C_h)\times\ln(C_f)$	-0.130	-1.19
$\ln(W_s^*)\times\ln(C_c)$	0.029	0.08	$\ln(C_h)\times\ln(C_p)$	0.054	0.93
$\ln(W_h^*)\times\ln(C_s)$	-0.314	-1.62	$\ln(C_h)\times\ln(C_l)$	0.148**	2.33
$\ln(W_h^*)\times\ln(C_h)$	-0.064	-0.80	$\ln(C_h)\times\ln(C_c)$	0.012	0.10
$\ln(W_h^*)\times\ln(C_f)$	-0.124	-0.84	$\ln(C_f)\times\ln(C_p)$	-0.137	-1.08
$\ln(W_h^*)\times\ln(C_p)$	0.087	0.89	$\ln(C_f)\times\ln(C_l)$	-0.055	-0.41
$\ln(W_h^*)\times\ln(C_l)$	0.115	1.41	$\ln(C_f)\times\ln(C_c)$	-0.568**	-2.46
$\ln(W_h^*)\times\ln(C_c)$	0.244	1.63	$\ln(C_p)\times\ln(C_l)$	-0.140**	-2.07
$\ln(W_s^*)\times\ln(C_s)$	0.533	1.01	$\ln(C_p)\times\ln(C_c)$	0.192	1.45
$\ln(W_f^*)\times\ln(C_h)$	-0.376*	-1.83	$\ln(C_l)\times\ln(C_c)$	-0.025	-0.22
$\ln(W_f^*)\times\ln(C_f)$	-0.609	-1.63	*Age*	-0.006***	-2.63
$\ln(W_f^*)\times\ln(C_p)$	-0.104	-0.45	*Education*	0.010	1.22
$\ln(W_f^*)\times\ln(C_l)$	0.106	0.47	*Training*	0.140***	2.90
$\ln(W_f^*)\times\ln(C_c)$	-0.529	-1.26	*Disease*	0.016	0.35
$\ln(W_p^*)\times\ln(C_s)$	0.025	0.12	*Mono*	0.003	0.06

Variables	Coef.	t-value	Variables	Coef.	t-value
$\ln(W_p^*)\times\ln(C_h)$	-0.010	-0.15	*Soil*	0.086*	1.75
$\ln(W_p^*)\times\ln(C_f)$	-0.164	-1.11	*Off-farm ratio*	-0.126*	-1.73
$\ln(W_p^*)\times\ln(C_p)$	0.107	1.14	*Pollution*	-0.300***	-5.81
$\ln(W_p^*)\times\ln(C_l)$	-0.098	-1.22	Constant	-20.213	-0.60
R-square			0.50		
Included observation			364		

Table 8. The OLS regression of rice profit function

Factors	Reduced profit (Thousand VND)	Percentage of reduced profit (%)
Polluted vs. Non-polluted area	3,203	25.95
Non-fertile vs. Fertile soil	874	8.24
Non-training vs. Training	1,465	13.03
The highest off-farm vs. Zero off-farm income ratio	1,229	11.45

Source: Own estimates; data appendix available from authors.

Table 9. Reduced profit in rice farming and key constraints

Table 10 summarized the total loss of rice production due to water pollution. The estimated results showed there were about 26 percent of profit loss, including around 12 percent of reduced quantity (yield loss) and 9 percent of cost increase, adversely caused by industrial water pollution. In this study, we also observed that farmers in the polluted area use water irrigation from the highest water tide level to reduce the effects of wastewater on rice production. This was because the farmers thought the water at the high tide level looked less polluted than the waters at other times, despite the fact that the water was always heavily polluted near the industrial parks.

	Amount	Percent
Quantity loss	0.67 tons/ha	12%
Cost increase	0.97 million VND/ha	9%
Total loss of net economic return	3.2 million VND/ha	26%

Source: Own estimates; data appendix available from authors.

Table 10. Impact of water pollution on rice production

Moreover, the use of polluted water also caused the farmers to change their cultivation management. In previous years, three rice crops were produced annually and rice cultivation was the main income source. However, because of pollution, only one or two rice crops is now cultivated in the polluted area each year, and farmers treat rice cultivation as a part-time job, producing rice sufficient only for household consumption.

During our study, we also received reports of skin diseases on the farmers working in the polluted region. For instance, a farmer in the polluted area reported that he had suffered from skin disease 5 days per year, and the treatment cost VND 500,000. The diseases also caused the loss of 2.5 workdays, equivalent to VND 250,000. Therefore, the estimate of total economic loss is underestimated if indirect costs such as the health costs suffered by farmers are not included.

6. Conclusions and policy implication

Local authorities in Vietnam have recently removed or reduced some of the environmental impact requirements to attract industrial investments to their province. Although industrial investments with low environmental standards might increase gross domestic product and create more jobs for local households, they may also bring many problems including water, air and soil pollution. This study provides an example of the negative impacts that arise from pollution by industries.

In this study, we surveyed rice farmers in two areas with the same natural environment conditions, social characteristics (e.g. the same social and farming culture, ethnicity, type of soil), and only differed with respect to pollution. One area was considered to be the polluted area, receiving wastewater from nearby industrial parks, while the other area was assumed to be the non-polluted area, being distant from sources of industrial pollutants. The productivity loss of rice production caused by water pollution was estimated by the difference in rice yield between the two regions. The similar calculation was applied for cost increase and profit loss for using wastewater irrigation. The results showed that the yield loss of rice was about 0.67 tons per hectare per crop, VND 0.97 million for cost increase and totally 26 percent of profit loss due to water pollution. Therefore, since the study includes 214 farmers in the polluted area and these 214 farmers cultivate rice in 148 hectare as a whole, their total cost increase per crop because of water pollution could be estimated about VND 144 million (VND 0.97 * 148ha) and approximately VND 474 million (VND 3.2 million * 148ha) for their total net economic loss.

According to The World Bank (2007), the development of rice roots and seedlings could be influenced by using wastewater for irrigation. Polluted water irrigation causes the reduction of height, leaf area and dry matter. Decrease in leaf surface area leads to the reduction of photosynthesis. These facts have directly impact on rice production. In other words, the impacts of polluted water on rice productivity mainly reduce the number of ears unit area, number of seed per ear and seed weight. The study estimated water pollution caused yield reduction about 12 percent. This result is nearly equal to the reduced yield of 10 percent in the sewage-irrigated area in comparison with clear water-irrigated areas estimated by Bai (2004), but much lower than the rice reduced productivity of 20 percent calculated by Song (2004) in the study of Lindhjem (2007) and 30 percent by Chang *et al.* (2001).

Economic developments that cause damage to natural resources and the environment are unsustainable. We suggest that the Vietnamese government needs to develop policies that ensure sustainable development. Similar to environmental policies in developed countries, the Vietnamese government could consider increasing the current environmental standards and raising environmental taxes. The increase of environmental taxes could not only encourage industries to apply new technologies that reduce environmental pollution, but also generate money to compensate farmers near industrial areas for the damage to their agricultural production and health and to build wastewater treatment facilities in industrial parks. Compensation could be provided directly in cash to the farmers, or indirectly by means such as funding training or activities related to new technologies and the management of agricultural inputs and expenditure. Our study showed that training helped farmers increase their profit, which might partly offset some of the losses caused by environmental pollution.

To reduce polluted water from the industrial parks, an increase in the effectiveness of implementation of Decision 64 and Circular 07 should be recommended. A public disclosure system for the environmental performance of polluters mentioned in Article 104 of the Law on Environmental Protection (dated 2005) and Article 23 of Degree No. 80/2006ND-CP should be considered as one of the best ways to increase the efficiency of Decision 64 and Circular 07.

Article 104 requires polluters to report and publicize the information and data about the environment as follows:

- Reports on the environmental impact assessment, decision on approval for reports on the environmental impact assessment and plan for the implementation of requirements stipulated in the decision on approval for reports on the environmental impact assessment;
- List of and information about sources of wastes, pollutants that seem potentially harmful to people’s health and environment;
- Areas where environment is polluted and degraded seriously and extremely seriously, areas in danger of the environmental pollution.
- Report on the environmental situation at the provincial level, report on environmental impact assessment by industries, fields and the national report on the environment
- It is essential to ensure unrestricted access to publicized information
- Agencies publicizing information about the environment have to take responsibility on accuracy, honesty and objectivity of announced information before legal agencies.

Article 23 provides details and instructions on how to implement Article 104 of the Law on Environmental Protection. These details and instructions include:

- The Ministry of Natural Resources and Environment have responsibility for announcing information and data about the national environment;

- Ministries and ministerial-level agencies, government agencies shoulder responsibility for exposing information and data about the environment in industries and areas under their management;
- Agencies in charge of the environmental protection of People's Committees at all levels bear responsibility for make information and data about the environment in the area under their management publicly;
- Management board of economic zones, industrial parks, export processing zones, managers of manufacturing and service units accept responsibility for publicizing information and data about the environment in the area under their management;
- Publicity of information and data about the environment is stipulated as follows:
- Information and data about the environment is publicized in form of books, news in newspapers or post on units' websites;
- Information and data about the environment is publicized in form of books, news in newspapers or post on units' websites (if any), reported in people's council meetings, announced on notice boards in residential quarter meetings, or listed in headquarters of units or headquarters of commune, ward, town people's committee where units are in operation.

The requirements of these above public disclosure system illustrate a new and significant approach for environmental authorities to force environmental laws and regulations in strong manner by increasing environmental awareness and permitting the large public to put pressure on polluters to solve current environmental problems. Such public disclosure requirements also create significant pressure on environmental authorities themselves as their own decision failures might also be widely recognized by such requirements. However, the implementation of these requirements in a clear, precise, and systematic manner is strongly needed.

Since water treatment facilities in these industrial parks must be built as soon as possible, the study on their cost effectiveness could be needed and seriously considered to decide whether we should build the water treatment facilities in every individual factory or for the whole industrial parks. Moreover, we suggest that the government should not use high-yield agricultural land for the construction of new industrial parks unless they include the latest pollution treatment technologies. The impact of environmental pollution should continue to be evaluated.

Notes

1) Calculated by the formula $F = \frac{(\mathrm{RSS}_R - \mathrm{RSS}_U)/J}{RSS_U/(N-K)}$, where RSS_R and RSS_U are the restricted and unrestricted sums of squared residuals, J is the number of restrictions, N is the number of observations, and K is the number of parameters in an unrestricted function.

(2) Breusch-Pagan test for heterscedasticity:

$$LM = nR^2 \sim X^2_k$$

where: n is the number of observations

R^2 is the R-Square of $|\hat{u}_i| = \delta_0 + \delta_1 X_{1i} + \delta_2 X_{2i} + ... + \delta_k X_{ki} + \tilde{v}_i$

k is the number of restricted factors

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References

[1] Bai, Y. (1988). Pollution of irrigation water and its effects, Beijing, China, Beijing Agriculture University Press: Beijing Agriculture University Press.

[2] Bateman, I. J, Carson, R. T, Day, B, Hanemann, M, Hanley, N, Hett, T, Lee, M. J, Loomes, G, Mourato, S, Ozdemiroglu, E, Pearce, D. W, Sugden, R, & Swanson, J. (2003). Economic Valuation With Stated Preference Techniques Edward Elgar Publishing, London.

[3] Chang, Y, Hans, M. S, & Haakon, V. (2001). The Environmental Cost of Water Pollution in Chongqing, China. Environment and Development Economics , 6(313-333)

[4] Do, T. N, & Bennett, J. Would wet biodiversity conservation improve social welfare? A case study in Vietnam's Mekong River Delta, International Conference on Sustainable Development: Challanges and Opportunities for GMS,

[5] Hung, P. T, Tuan, B. A, & Chinh, N. T. (2008). The Impact of Trade Liberalization on Industrial Pollution: Empirical Evidence from Vietnam the Economy and Environment Program for Southeast Asia (EEPSEA).

[6] ICEM ((2007). Analysis of Pollution from Manufacturing Sectors in Vietnam International Centre for Environmental Management, Indooroopily, Queenland.

[7] Khai, H. V, & Yabe, M. (2011). Evaluation of the Impact of Water Pollution on Rice Production in the Mekong Delta, Vietnam. The International Journal of Environmental, Cultural, Economic and Social Sustainability , 7(5)

[8] Khai, H. V, & Yabe, M. (2012). Rice Yield Loss Due to Industrial Pollution in Vietnam. Journal of US-China Public Administration , 9(3)

[9] Kompas, T. (2004). Market Reform, Productivity and Efficiency in Vietnamese Rice Production. International and Development Economics Working Papers, Asia Pacific School of Economics and Governmnet, Australian National University, Australia.

[10] Lang, V. T, Vinh, K. Q, & Truc, N. T. T. (2009). Environmental Consequences of and Pollution Control Options for Pond "Tra" Fish Production in Thotnot District, Can Tho city, Vietnam The Economy and Environment Program for Southeast Asia (EEPSEA).

[11] Lindhjem, H. (2007). Emvironmental Economic Impact Assessment in China: Problems and Prospects. Environmnetal Impact Assessment Review , 27(1)

[12] Linh, H. V. (2007). Efficiency of Rice Farming Households in Vietnam: A DEA With Bootstrap and Stochastic Frontier Application. University of Minnessota, Minesota, USA.

[13] Nga, B. T, Giao, N. T, & Nu, P. V. (2008). Effects of Waste Water From Tra Noc Industrial Zone on Adjacent Rivers in Can Tho City. Scientific journal of Can Tho University , 9(2)

[14] Quang, M. N. (2001). An Evaluation of the Chemical Pollution in Vietnam.Retrieved May 19, 2011, from http://www.mekonginfo.org/mrc_en/doclib.nsf/38bfa13a79f297d2c72566170044aaf9/1d952c500be72dc587256b74000703c8?OpenDocument

[15] Rahman, S. (2002). Profit Efficiency Among Bangladeshi Rice Farmers. Food Policy , 28(5-6)

[16] Reddy, V. R, & Behera, B. (2006). Impact of Water Pollution on Rural Communities: An Economic Analysis. Ecological Economics , 58(3)

[17] Resource and Environment department of Can Tho city ((2008). Report on the situation of Environment in Can Tho City.

[18] Surjit, S. S, & Carlos, A. B. (1981). Estimating Farm-Level Input Demand and Wheat Supply in the Indian Punjab Using a Translog Profit Function. American Journal of Agricultural Economics , 63(2)

[19] The World Bank ((2007). Cost of Pollution in China- Economic Estimates of Physical Damages.

[20] The World Bank ((2008). Handling Serious Environmnetal Polluters in Vietnam: Review of Implementation and Recommendations.

[21] Thong, L. Q, & Ngoc, N. A. (2004). Incentives for Wastewater Management in Industrial Estates in Vietnam the Economy and Environment Program for Southeast Asia (EEPSEA).

[22] Tim, C. D. S. P, & Battese, G. E. (2005). An Introduction to Efficiency and Productivity Analysis, New York, Springer Science.

[23] Tuyen, B. C. (2010). Strategy of Vietnam towards addressing Environment and Climate risks.

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