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RESEARCH REPORT

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Pollution Control Options for Handicraft Villages: The Case of Duong Lieu Village in the Red River Delta, Vietnam

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This EEPSEA study from Vietnam looks at the pollution problem caused by the processing of agricultural products in the Red River Delta. It also assesses the cost-effectiveness of various pollution control options. The study is the work of Nguyen Mau Dung from Hanoi University of Agriculture and Tran Thi Thu Ha from Vietnam University of Forestry. It focuses on a village where 95% of households are engaged in cassava starch processing. It finds that this activity is a significant source of pollution, which is seriously affecting the health of local rivers and local people.

The study recommends that a wastewater treatment plant for the whole village is set up and that wastewater fees are collected from households engaged in agro-processing activities. It also recommends that the sewerage system in the village is improved, that households are involved in environmental clean-up work and that steps are taken to encourage cleaner production technologies in the agro-product processing industry. This study is timely and important because processing agricultural products is one of the most important 'handicraft' activities in Vietnam's Red River Delta. This activity provides jobs, improves household incomes and helps alleviate poverty. However, it also generates a huge amount of waste and is a source of serious pollution. Therefore, finding a solution that will cost-effectively clean up the pollution caused by agro-product processing is a vital part of sustainable development in the region.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

POLLUTION CONTROL OPTIONS FOR HANDICRAFT VILLAGES: THE CASE OF DUONG LIEU VILLAGE IN THE RED RIVER DELTA, VIETNAM

Nguyen Mau Dung and Tran Thi Thu Ha

EXECUTIVE SUMMARY

Agro-product processing is one of the major handicraft activities in the Red River Delta where more than half of the handicraft villages in Vietnam are located. Despite its important role in employment and income generation for rural households, agro-product processing generates a huge amount of waste, especially wastewater, and agro-product processing villages are considered serious polluters in the region.

This study presents an analysis of the environmental consequences of agro-product processing and the cost-effectiveness of pollution control options in the village of Duong Lieu which is famous in the Red River Delta for agro-product processing. There are currently more than 500 households in Duong Lieu engaged in agro-product processing. On average, each household produces more than one tonne of cassava starch per processing day and discharges around 15 m^3 of untreated wastewater with heavy effluents of COD, BOD and SS into the environment. The wastewater causes serious pollution in the village, leading to a high incidence of ailments such as headaches, backaches, respiratory diseases, skin irritation, stomachaches, sore eyes, and cancer.

Three pollution control options are evaluated: (1) a small treatment plant for every household; (2) a treatment plant for a group of processing households; and (3) a treatment plant for the whole village. A cost-effectiveness analysis found Option 1 to be the most cost-effective. This option is quite sensitive to increasing level of construction cost. When construction cost was increased by 10%, Option 3 became the most cost-effective. An analysis of the social acceptability of the three options was also done through focus group discussions. Option 1 which entails the construction of a 45m^3 underground tank by each household was quite difficult for most households due to limited space. Option 3 was the most widely accepted; it had the lowest treatment costs per cubic meter of wastewater and there was available space for treatment plant establishment. It was perceived to be the most likely to get financial support and completely solve the water pollution problem in the village.

Among the study's recommendations to mitigate the environmental pollution in Duong Lieu were the establishment of a wastewater treatment plant for the whole village, the collection of wastewater fees from processing households, improving the sewerage system in the village, mobilizing the participation of households in environmental sanitation activities, and encouraging the application of cleaner production technologies in the agro-product processing industry.

1.0 INTRODUCTION

1.1 Research Problem

Handicraft villages[1] are a common feature of rural Vietnam. Such villages have a high concentration of households (typically over 30%) involved in the same kind of production activities. Since the renovation of Vietnam in 1988, handicraft village development has been encouraged by the government. As a result, a number of handicraft villages have been rehabilitated and developed, especially in the Red River Delta region where cropland per farm is very small compared with other regions in the country. In 2004, the number of handicraft villages in the Red River Delta accounted for 58.9% of the whole country (Dang 2004). During the 1990-2000 period, this increased by 4.6% per annum while the total number of villages in the whole country increased by just 1.4% per annum (Do 2003).

Most handicraft villages in the Red River Delta focus on agro-product processing, carpentry, weaving, lacquering, leather processing, rattan and bamboo weaving, metal recycling, and construction material production. Of these, agro-product processing is a major activity, practised by 15.7% of the total number of handicraft villages in the region. Agro-product processing refers to the processing of agricultural products and includes rice milling; alcohol-brewing from rice or cassava; noodle-making from rice; tofu-making from soybean; vermicelli-making from canna; and cassava or canna starch processing activities.

Undoubtedly, handicraft activities in general and agro-product processing in particular in the Red River Delta have played a significant role in job generation, household income improvement, and poverty alleviation. However, two-thirds of the handicraft villages were reported to be the cause of environmental pollution (Hanoimoi Newspaper 2002). Agro-product processing activities in particular generate a huge amount of waste, including wastewater from material cleaning and starch filtering; waste air from coal use; and solid waste residue. On average, one agro-product processing village generates 0.5-1 million cubic meters of wastewater with high concentrations of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS) together with 2,000 tonnes of solid waste per year (Dang 2004). Thus, agro-product processing villages rank among the most serious polluters among all handicraft villages.

The industry has been encouraged in Red River Delta by the government (Decree No.66/2006 ND-CP issued in July 2006 and circular No. 113/2006/TT-BTC issued in December 2006 to promote rural handicraft development) with little attention paid to its impacts on the environment. Moreover, as handicraft activities are generally performed by individual households on a small scale, attempts to control the waste have been largely ineffective.

Duong Lieu is a famous agro-product processing handicraft village in the Red River Delta which mainly processes cassava to make starch. At present, more than 400 households in the village are involved in this activity and the total output of cassava starch exceeds 60,000 tonnes per year. Although agro-product processing in Duong

[1] "Handicraft villages" (or "craft villages") is the term commonly used in Vietnam to refer to villages engaged in cottage or home industry.

Lieu significantly improves household incomes, it causes serious pollution in the village. The residents of Duong Lieu perceive the wastewater and solid waste from agro-product processing as environmental health hazards that need to be addressed (Dai, Do and Dang 2000). Moreover, the pollution situation in the village has been highlighted by the local authorities and mass media. However, how to mitigate such environmental pollution remains a major challenge.

Although quite a number of studies have focused on the financial analysis of agro-product processing village development in Red River Delta, there are very few that have paid attention to the corresponding environmental impacts and pollution control options in the villages. Therefore, this study was designed to provide a clear understanding of the environmental consequences of agro-product processing and to analyze pollution control options for Duong Lieu. Its results are expected to provide a basis for policy-makers to develop more effective waste control strategies and to make the local processing households and residents pay more attention to waste treatment to control pollution in the village.

1.2 Research Objectives

The overall objective of the study was to identify the environmental consequences of agro-product processing in Duong Lieu handicraft village and to assess the cost-effectiveness of pollution control options for it.

The specific objectives included:

a) To provide an overview of the agro-product processing activities in Duong Lieu Village.

b) To identify the environmental consequences of agro-product processing activities in Duong Lieu Village.

c) To assess the cost-effectiveness of pollution control options in Duong Lieu Village.

d) To draw implications for pollution control activities in Duong Lieu Village.

1.3 Research Questions

The study sought to answer the following research questions:

a) What is the status of agro-product processing activities in Duong Lieu Village?

b) What are the environmental consequences from agro-product processing activities in Duong Lieu Village?

c) What is the best solution to mitigate the pollution in Duong Lieu Village?

1.4 Scope of the Study

Due to time and resource limitations, this study mainly focused on water pollution from agro-product processing. The reason was because agro-product processing villages generated high wastewater volumes but small air waste volumes in comparison with other types of handicraft villages (Table 1).

The wastewater from agro-product processing villages has very high concentrations of BOD, COD and SS in compared with other pollutants. One liter of the wastewater from the processing of cassava and canna contains 6,214–7,378 mg of COD (60-70 times higher than the allowed limit), 486–551 mg of BOD (10 times higher than the allowed limit), and 1,466–3,012 mg SS (14–30 times higher than the allowed limit) (Dai, Do and Dang 2000). Therefore, the pollution control options in this study only deal with BOD, COD and SS.

Table 1. Waste volumes from different types of handicraft villages

(Average for one craft village)

Type of craft activities	Wastewater volume (m^3/day)	Air waste volume (m^3/second)
1. Agro-product processing	505.9	0.903
2. Textile	256.51	0.155
3. Metal recycling	1,919.07	2.12
4. Construction materials	18.0	2.5

Source: Dang 2004

2.0 METHODOLOGY

2.1 Study Site Selection

Located in the Red River Delta, Ha Tay Province is famous for its high density of handicraft villages and diversified handicraft products. Ha Tay was therefore selected as the representative province for the Red River Delta in terms of handicraft development.

Currently, there are 120 handicraft villages in Ha Tay Province, mainly involved in carpentry, weaving, lacquering, agro-products processing, rattan and bamboo handing, and metal recycling. Of these, agro-product processing is carried out in 17 villages. Twelve of 17 focus on starch and noodle production (Ha Tay Department of Industry 2001). Duong Lieu, one of the 12 villages, was chosen as the research site as it had a very high percentage of households engaged in starch processing activities and pollution in the village was at alarming levels.

2.2 Data Collection

2.2.1 Secondary data

Secondary data on agro-product processing development and the pollution situation in Duong Lieu were gathered from related studies and available reports of various agencies (namely, the provincial Departments of Environment, Science and Technology, and Agriculture and Rural Development; and the Departments of Agriculture and Rural Development at district levels). Data on total population, households, and the number of households and labor that engaged in agro-product processing activities, the total production of agro-production processing activities, waste amounts, etc. in Duong Lieu were gathered from the statistical records of the village and Bac Ninh Province.

2.2.2 Primary data

Primary data was gathered through a household survey, focus group discussions, consultations with a technical expert, and water sample testing.

(a) Household survey

The main purposes of the household survey were to gather information on: (i) processing activities such as scale, inputs, outputs, production costs, and sales; (ii) the effects of processing activities on the environment and human health in terms of waste volumes, respondents' assessments of the changes in the quality of underground/surface water and air, and the incidence of disease; and (iii) the residents' perceptions of the pollution situation and their opinions on the pollution control options.

The stratified sampling method was used. The households in the village were divided into three groups in term of scale (large, medium, and small-scale). Then, the household samples were randomly drawn from each group. One hundred and two (102) handicraft households were finally selected for the survey (Table 2).

Table 2. Household samples by scale

Type of households	Processing Volumes	Number of households
1. Small-scale	Less than 90 tonnes per year	36
2. Medium-scale	From 90-120 tonnes per year	33
3. Large-scale	More than 120 tonnes per year	33
Total		**102**

Personal interviews with the 102 households using a standard questionnaire were carried out. At first, a draft questionnaire was developed. The questionnaire had five parts. The first part gathered data on the respondents' profile such as age, gender, education level, occupational level (handicraft skill), and family size. The second component was on agro-product processing information including investment capital, facilities, input use, output amounts, input/output prices, discharge volumes, and current treatment measures of discharge. The third part focused on the respondents' assessment of the environmental quality as affected by waste discharge (comparing between past and present or with non-handicraft villages) and included environmental indicators such as the quality of air and water, and noise pollution. The fourth section was designed to gather information on the health status of household members (diseases and frequency of occurrence, etc.). The final component sought the respondents' attitudes towards wastewater treatment options. The draft questionnaire was pre-tested with 10 households. Then the final questionnaire was developed.

(b) Focus group discussions (FGDs)

In the study, FGDs were mainly used to obtain information about changes in the environmental quality of the village compared to the past and non-handicraft villages, current policies/regulations related to environmental management, and existing and potential wastewater treatment solutions in the village. Four FGDs were organized, in which each group consisted of five to seven people with different backgrounds in terms of age, sex, social position, experience and scale of agro-product processing production.

(c) Technical expert consultation

A technical expert was invited to visit the research site to observe the processing activities; inspect the wastewater discharge, drainage systems, and pools; and develop wastewater treatment options. Thorough discussions between the technical expert and local commune staff were held to establish the current situation of wastewater pollution in the village and the conditions for treatment option development. Treatment options were then developed by the technical expert. Information on the costs and efficiency of the different options provided by the technical expert were used in a cost-effectiveness analysis of the options.

2.3 Analysis Procedures

The study used descriptive statistics, comparative analysis, and cost-effectiveness analysis. The descriptive statistics decribed the general situation of processing activities in the village such as the number and ratio of agro-processing households and workers (labor force), total agro-processing production volumes by kinds of products, and so on. This method was also used to present the general resources of each household group, the performance of agro-product processing activities by group, and the environmental consequences of the processing activities in the village.

Comparative analysis was used to show the development of processing activities in the village through comparing the number/ratio of households or workers engaged in processing activities and the production of agro-processed products in the whole village by year. Comparative analysis was also used to show the differences between the household groups in terms of productive resources, the processing performance of the households, the waste volumes discharged, and the attitudes of repondents towards wastewater treatment.

Lastly, a cost-effectiveness analysis was made to select the least-cost wastewater treatment option. At first, the baseline was described. Then, the pollution control options were identified and the treatment cost per cubic meter of wastewater was calculated for each option. Finally, the least-cost solution was recommended based on the estimated costs.

3.0 LITERATURE REVIEW

3.1 Environmental Impacts in Agro-Product Processing Villages

According to the Ministry of Agriculture and Rural Development (MARD 2002), there are 197 agro-product processing villages in Vietnam, mainly (67%) located in the Red River Delta. The major products of these villages are noodles, tofu, vermicelli, alcohol, fish sauce, canna starch and cassava starch. Agro-product processing activities principally take place in households on a very small-scale using traditional knowledge and obsolete equipment.

Dang, Nguyen and Tran (2005) did a study on the environmental situation in handicraft villages in Vietnam from 2001-2005. They reported that agro-product processing activities required great quantities of water and discharged a huge amount of wastewater which contained high concentrations of organic effluents such as BOD, COD, and SS. The BOD and COD in the drains of agro-product processing villages were 5-45 times higher than the permitted standards, resulting in serious pollution of the land, water, and air in the villages (Table 3).

Table 3. Characteristics of wastewater in agro-product processing villages

Indicator	**Unit**	**Agro-product processing village**						**Standard 5945-1995 (Column B)**
		Binh Minh (Dong Nai)	**Phu Do (Ha Noi)**	**Quang Minh (Thai Binh)**	**Thon Doai (Bac Ninh)**	**Duong Lieu (Ha Tay)**	**Phong Loc (Nam Dinh)**	
pH		4,6	6,1	5,3	3,7	4,9	4,7	5,5-9
Temperature	^oC	29,7	27,7	27,5	26,5	27,2	25	40
COD	mg/l	1858	2967	1421	2993	3178	976	100
BOD	mg/l	743	1850	1008	2003	2200	642	50
SS	mg/l	926	414	1434	2671	1204	1206	100
$\sum N$	mg/l	145,6	20,9	27	121	367	31	60
$\sum P$	mg/l	27,5	2,79	14	39	41,8	4,2	6

Source: Institute of Science and Environmental Technology, University of Technology (2003)

Dai, Do and Dang (2000) in their study of agro-product processing waste management in peri-urban Hanoi reported that local residents, whether from processing or non-processing households or in processing villages or non-processing villages, were well aware of the negative effects of agro-product processing. Their interview results revealed that all respondents agreed that the drinking water during the off-season was much cleaner and that wastewater was mixed with irrigation water. Almost all the non-processing households and 84% of the processing households thought that the solid waste was harmful to their health. Most of the people in the processing villages have had solid waste dumped in front of their houses and this has been a source of conflict among the residents. In the processing villages, the non-processing household members expressed themselves freely and assertively about the pollution caused by processing activities and the negative effects on human heath. The processing households, on the other hand, were hesitant to admit the severity of the environmental problems caused by processing. The most notable impact in the non-processing villages was wastewater in the canals flowing by the non-processing villages. The residents in the non-processing villages commonly complained about the pollution and bad smell caused by the processing villages and pleaded for solutions.

According to Dang, Nguyen and Tran (2005) the common diseases of residents in cassava processing villages included gynaecological diseases (13–38%), digestive diseases (8–30%), dermatitis (4.5–23%), respiratory diseases (6–18%), and sore eyes (9–15%). The children in agro-product processing villages were commonly under-nourished and suffered from digestive diseases.

3.2 Wastewater Treatment

3.2.1 Wastewater treatment in general

Wastewater treatment is the process of removing contaminants from wastewater. It includes physical, chemical and biological processes to remove different types of contaminants. Its objective is to produce a wastewater stream of treated effluents and a solid waste or sludge suitable for resuse or discharge into the environment.

Wastewater is produced by households, processing activities, and commercial and industrial establishments. It can be treated close to where it is produced (in septic or on-site package plants), or collected and transported via a network of pipes and pump stations to a municipal treatment plant. Wastewater collection and treatment is typically subject to local or state regulations and standards. Industrial sources of wastewater often require specialized treatment processes.

Typically, wastewater treatment involves three stages: primary, secondary and tertiary treatment. In the first stage, solids are separated from the wastewater. In the secondary stage, dissolved biological matter in the wastewater is progressively converted into a solid mass by indigenous, water-borne bacteria. Finally, the biological solids are neutralized and then disposed of or reused, and the treated water may be disinfected chemically or physically (for example, by lagooning and micro-filtration). The final effluent can be discharged into a natural surface water body (e.g. stream or river) or other bodies (e.g. wetland).

There are several wastewater treatment technologies including activated sludge, aerobic granular reactors, anaerobic clarigesters, anaerobic digestion, anaerobic lagoons, cesspits, combined sewer overflow, composting toilets, constructed wetlands, expanded granular sludge bed digestion, flocculation, Imhoff tank, living machines, reed beds, septic tanks, sequencing batch reactors, sewage treatment, and upward-flow anaerobic sludge blanket (UASB) digestion. Each of these technologies could be used to treat a specific kind or several kinds of wastewater. They could also be used in combination.

3.2.2 Wastewater treatment technology application

Chisso Environment Engineering Co. Ltd. is a Japanese company that developed the reactor-bio-system (RBS) for wastewater treatment which combines the use of soil bacteria with standard activated sludge for purification. The principle of RBS is the humification process where the remains of animals and plants are decomposed and coagulated by the soil bacteria into polymers. Soil bacteria accelerate polymer coagulation of organic substances by fermentation and enzyme reaction with silicate and anaerobic (some aerobic) conditions in the soil. The RBS technology is considered very successful in treating wastewater with organic compounds such as that from food processing, livestock farming and human activity. The company has installed more than 100 wastewater treatment plants in Japan, and also in China and Thailand, and just come to Vietnam to introduce its treatment technology.

In Vietnam, several companies practise wastewater treatment. The Research Institute of Beer and Alcohol has developed and applied aerobic and anaerobic biological treatment technologies to treat the wastewater from the Hatay Food Company. The Tan Lam Coffee Company in Quang Tri Province treats their wastewater from coffee-processing using bio-technology namely, the UASB, aerobic treatment, and combined aerobic and anaerobic biological lagoons (rush, reed or water fern lagoons).

Nguyen (2006) studied treatment technologies for wastewater from cassava processing. One was bio-technology using natural bacteria. In this process, sand and solid waste are first removed from the wastewater, then the wastewater is neutralized by sodium carbonate (Na_2CO_3) to increase the pH up to 6.5 or higher. The wastewater is then treated by an anaerobic UASB reactor for 24 hours, followed by aerobic treatment for 24 hours, and a biological lagoon with water ferns for 72 hours. The effluent concentrations in the wastewater after treatment will satisfy TCVN-5945C-1995 standards.

The second technology was also bio-technology but using selected bacteria (created in a lab). Here, *Bacillus licheniformis* and *Bacillus subtilis* are used to synthesize the enzyme α-amalyza to decompose the (cassava) starch into glucoza while *Trichoderma reseii* and *Clostridium thermocellum* are selected to synthesize the enzyme xenluloza to decompose the xenlulo. After removing the sand and solid waste from the wastewater, its pH is increased to neutralize it and it is then treated in a UASB reactor for 24 hours, followed by treatment in an aerobic treatment tank for 18 hours. The wastewater is finally treated in a biological lagoon with water ferns for 60 hours to satisfy TCVN-5945C-1995 standards. The selected bacteria-based technology saves time (18 hours) and reduces treatment costs by 10% compared to the natural bacteria based technology (Nguyen 2006).

In 2005, the Chemistry Faculty of the National University of Vietnam was successful in designing a multi-purpose wastewater treatment system. This system has been piloted in Vanphuc silk craft villages and it has been reported that 90% of the effluents can be removed using this system. The system is being developed for treating other kinds of wastewater, including that from agro-product processing craft villages. It is suitable for individual households as well as for a group of households (People Newspaper 2005).

Mr. Nguyen Ty, the Director of Phuong Toan Co. Ltd. in Donghoi, Quang Binh Province, developed the biological enzyme containing the bacteria of Protaza, Lipasa, Xenluloza, Amylaza, etc., which are very effective in organic wastewater treatment. His product has been patented and used by several processing companies such as the Se Pon Cassava Processing Company, Song Dinh Cassava Processing Company, and Viet

Trung Rubber Milk Processing Company. The product is also used by cassava processing companies in China and Thailand for wastewater treatment (People Newspaper 2006).

3.3 Cost-Effectiveness Analysis and Its Applications

Cost-effectiveness analysis (CEA) is an economic evaluation tool that can be used to compare two or more programs or interventions. The products of this kind of analysis are cost-effectiveness ratios that represent the trade-offs between each program's costs (measured in dollars) and each program's outcomes (measured in appropriate units). In other words, CEA is a systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits for a given objective. A program is cost-effective if, on the basis of life cycle cost analysis of competing alternatives, it is determined to have the lowest costs expressed in present value terms for a given amount of benefits (Ashdown and Hummel 2002).

In its most common form, a new strategy is compared with current practice in the calculation of a cost-effectiveness ratio:

$$\text{CE ratio} = \frac{\text{Cost}_{\text{new strategy}} - \text{Cost}_{\text{current practice}}}{\text{Effect}_{\text{new strategy}} - \text{Effect}_{\text{current practice}}}$$

The result might be considered as the "price" of the additional outcome purchased by switching from current practice to the new strategy. If the price is low enough, the new strategy is considered "cost-effective." CEA is appropriate whenever it is unnecessary or impractical to consider the dollar value of the benefits provided by the alternatives under consideration. This is the case whenever each alternative has the same annual benefits expressed in monetary terms, or, each alternative has the same annual effects, but dollar values cannot be assigned to their benefits. CEA is closely related to cost-benefit analysis (CBA) in that both represent economic evaluations of alternative resource use and measure costs in the same way. However, CBA is used to address only those types of alternatives where the outcomes can be measured in terms of their monetary values.

The costs of an intervention are defined as the value of the resources that are given up by society to bring about the intervention. These are referred to as the ingredients of the intervention, and it is the social value of these ingredients that constitutes the overall cost of the intervention. At a later stage, the distribution of these costs among the decision-making agency/agencies and other entities can be assessed. Accordingly, a CEA sets out to systematically identify and ascertain the value of the ingredients that are required for each alternative that is under consideration.

The ingredients approach to cost estimation entails three distinct phases: (i) the identification of the ingredients; (ii) the determination of the value or cost of the ingredients and the overall costs of an intervention; and (iii) an analysis of the costs in an appropriate decision-oriented framework (Levine 2001).

Nowadays, CEA has become common in many countries and has been applied in many fields such as education, industry, healthcare, psychology, and pollution control. Mohamed, Beek and Elnawawy (2000) designed and applied a CEA in assessing the cost-effectiveness of wastewater treatment for the Nile River. His results indicated that treatment at-source may not be cost-effective if made for only a few point sources along the Nile. The European Environment Agency (2005) applied the CEA to assess the effectiveness of urban wastewater treatment policies in three selected countries; Denmark, France, and the Netherlands. The results showed that on the basis of the investment costs from 1976–1998, it was possible to conclude that the wastewater policy in the Netherlands was cost-effective and that early and consistent implementation of the polluter-pays principle in the Netherlands had resulted in a high degree of cost-effectiveness.

Van Note (1975) developed a guide for the selection of cost-effective wastewater treatment systems in which he provided guidelines for planners, engineers and decision-makers at all governmental levels to evaluate the cost-effectiveness of alternative wastewater treatment proposals. In practice, the advantages of CEA have been proven since it is conceptually and operationally simpler and does not require valuing outcomes as compared to CBA. Thus, in this study, CEA was used to assess the cost-effectiveness of proposed options to treat the wastewater from cassava processing households so that the most cost-effective pollution control option for the research site could be selected.

4.0 RESEARCH RESULTS AND DISCUSSION

4.1 Cassava Processing in Duong Lieu Village

4.1.1 Description of the study site

Duong Lieu Commune/Village[2] is located in the northwest of Hoai Duc District, Ha Tay Province. It is about 20 km from Ha Dong (the province capital) and 25 km from Ha Noi (the capital of Vietnam). Duc Giang and Duc Thuong Communes lie to the east, Cat Que Commune to the south, Lien Hiep (belongs to Phuc Tho District) to the west and Minh Khai Commune to the north.

Located in the Red River Delta region, Duong Lieu has tropical climate characteristics. The average temperature ranges from 23.1°C to 23.5°C while rainfall fluctuates from 1.521 mm to 1.676 mm. Duong Lieu has an even and flat terrain divided into two parts, inside and outside the Day River dyke. Generally, soil in Duong Lieu is suitable for arable crops, fruits trees such as orange and pomelo, and wet rice. The total natural area of the village is 410.54 hectares, in which agricultural land accounts for 70 per cent and residential land for 13.29 per cent.

As of 2005, Duong Lieu had a total population of 12,000 people with a growth rate of 1.71 per cent per year. There are 2,680 households in Duong Lieu distributed over 12 different hamlets. Many households in the commune engage in non-agricultural activities, of which cassava processing is the leading occupation. The main road in the commune is built on the dyke of Day River, connecting the commune to other communes in the district.

[2] Duong Lieu Commune has only one village.

4.1.2 Cassava processing

Agro-product processing activities in Duong Lieu started in the 1960's. From 1960–1970, the processing technique was very simple, using only hand tools with very low productivity (30 kg of fresh cassava per working day). During the 1970–1986 period, processing tools were improved. The hand tools were replaced with leg tools, increasing productivity from 30 kg to 100 kg of fresh cassava per working day. After 1986, with the Renovation Policy, households were encouraged to engage more in craft activities. The agro-processing industry in Duong Lieu was given more attention by the government. Small machines for processing activities were gradually introduced. During the 1986–1996 period, the introduction of milling machines using gasoline increased productivity up to 300 kg per working day. In 1996, electric machines were introduced and raised productivity to 1,500–2,500 kg per working day. The development of the cassava processing craft industry has created a supply chain whereby many traders collect fresh cassava from northern provinces and sell it to the processing households in Duong Lieu.

Cassava processing has played an increasingly important role in the economy of the commune. The number of households engaged in cassava processing increased steadily from several in the 1960s to around 100 in 1990 and to more than 400 households currently. Cassava processing and its associated activities (namely, cassava cleaning services, cassava starch re-filtering, cassava solid waste trading, candy-making, and pig-raising) generate many jobs and have become the main source of livelihood for many households in the village. According to the 2005 Annual Report of the Duong Lieu Commune People's Committee, total cassava starch production reached 60,000 tonnes or 90 billion VND in that year. Aside from 25% of the households being engaged in processing cassava starch, there are approximately 6% involved in cassava starch re-filtering, 3% in cleaning services and peeling, 2% in cassava root trading, and less than 1% in cassava solid waste trading.

Despite these sound achievements, agro-product processing in Duong Lieu is carried out at the household level with very small processing areas. The processing households purchase cassava roots at cassava markets in the commune. The roots are cleaned, peeled, and ground for processing.

Principally, the processing activities are done by family members. The processing techniques are not difficult and the villagers learn from one another. Very few households in the commune hire outside labor for processing work.

4.2 Cassava Processing in the Surveyed Households

4.2.1 Profile of the surveyed households

As presented in the previous section, a total of 102 households involved in cassava processing were selected for interview. The survey results revealed that the average age of the respondents was 44.5 years and there was no significant difference among the household groups (Table 4). Most of the respondents (72%) had finished secondary school while only few (10%) had attended high school. Family size ranged from 2–11 persons, with an average of 4.8. On average, each household had 2.94 laborers/workers, of which male labor accounted for 53.4%.

Table 4. Description of the agro-product processing households

Household scale	Indicators	Age of head	Number of people	Number of males	Number of workers	Number of male workers
Small-scale (n=36)	Mean	45.75	4.86	2.67	3.03	1.61
	Std. Deviation	9.64	1.73	0.89	1.48	0.96
Medium-scale (n=33)	Mean	43.42	4.64	2.58	2.88	1.58
	Std. Deviation	10.22	0.93	0.94	1.14	0.97
Large-scale (n=33)	Mean	44.30	5.03	2.61	2.91	1.52
	Std. Deviation	10.74	1.24	0.83	1.07	0.62
All (n=102)	Mean	44.53	4.84	2.62	2.94	1.57
	Std. Deviation	10.14	1.35	0.88	1.24	0.86

Source: field survey (2006)
Note: The figures were averaged for one survey household.

4.2.2 Processing activities in the households

(a) Family labor

Each surveyed household had an average of 2.53 persons involved in its cassava processing activities (Table 5).

Table 5. Number of persons involved in processing activities in the households

Household scale	Mean	Minimum	Maximum	Std. Deviation
Small-scale	2.36	1	4	0.64
Medium-scale	2.58	2	6	0.90
Large-scale	2.67	2	5	0.85
All	2.53	1	6	0.80

Source: field survey (2006)
Note: The figures were averaged for one survey household.

The small-scale group had 77.9% of the family members or 2.36 persons (ranging from 1–4 persons) involved in processing activities while the medium and large-scale groups had 89.4% and 91.6%, respectively, ranging from 2–6 persons. Labor force is, therefore, a determining factor in the processing volume of a household. It could be said that the surveyed households had quite good experience in processing activities since 77.5% of them had started processing activities before 1995.

(b) Processing area

All the surveyed households carried out processing activities within their residential areas. The processing area was used for cleaning, peeling, and grinding roots, and accommodating several tanks to deposit the starch in. The processing area of the small-scale households was only about 32 m^2 while that of the large-scale households was around 50 m^2 (Table 6).

Table 6. Agro-product processing area by household scale

Household scale	Mean (m^2)	Minimum (m^2)	Maximum (m^2)	Std. Deviation
Small-scale	31.19	10.00	60.00	14.97
Medium-scale	38.33	15.00	80.00	16.18
Large-scale	50.33	15.00	100.00	22.36
All	39.69	10.00	100.00	19.56

Source: field survey (2006)

(c) Equipment for processing activities

Table 7 shows the main machines for cassava processing in the surveyed households i.e., cleaning and grinding machines, stirring machines and 'combinative' machines.

Table 7. Proportion (%) of households owning machines for agro-product processing activities, by scale of operation

Type of machine	By processing scale (%)			All
	Small-scale	Medium-scale	Large-scale	
Combinative	13.88	51.52	66.67	43.14
Cleaning and grinding machine	36.11	36.36	24.24	32.35
Stirring machine	86.11	51.52	33.33	57.84

Source: field survey (2006)

Before 2003, all processing households used stirring machines to process the cassava roots after grinding them. However, in 2003, a new 'combinative' machine was introduced to processing households. It integrated the functions of cleaning, grinding and stirring. The use of such machines has increased processing productivity. Nowadays, many households (43.1%) used these machines for processing, especially the large and medium-scale households. The price of the combinative machine ranges from 5–15 million VND depending on their horse power.

The development of external cleaning and grinding services resulted in many households opting to rely on these services instead of buying cleaning and grinding machines. The fee for cleaning and grinding one tonne of cassava roots was around 25,000-30,000 VND.

In addition to the mentioned machines, all the surveyed households extracted groundwater using pumps, because cassava processing requires a huge amount of water. Every household also had tanks for holding the mixture of cassava starch and water. The number of tanks varied across households, ranging from 2–5 per household, depending on the scale of processing activity.

(d) The processing of cassava starch

Processing activities take place from September to March when the cassava roots are harvested. At first, the roots are cleaned. Then they are peeled and ground. The mixture of cassava starch and water is then left for about eight hours to separate the water (starch deposition process). The black starch found floating on the surface afterwards is eliminated to get pure cassava starch. Figure 1 illustrates how cassava starch is made. On average, households can get around 450 kg of processed product from one tonne of cassava roots as shown in Table 8. This amount was not significantly different among the household groups.

Table 8. The volume of processing products by scale (2005)

Household scale	Indicator	Product volume / 1 tonne of root (kg)	Product volume per processing day (kg)	Total product volume in 2005 (kg)
Small-scale	Mean	447.2	702.3	66,440.6
	Std. Deviation	13.7	148.6	18,600.1
Medium-scale	Mean	450.0	904.6	106,000.8
	Std. Deviation	15.2	118.4	8,539.6
Large-scale	Mean	450.3	1,567.3	202,023.6
	Std. Deviation	8.8	629.6	91,025.2
All	Mean	449.1	1,047.6	123,104.6
	Std. Deviation	12.8	524.5	77,737.5

Source: field survey (2006)

However, there existed a great difference in product volume per processing day among the household groups. The processed volume of the small-scale households was around 702 kg per day while it was 904 kg for the medium-scale households and 1,567 kg for the large-scale households. The total annual product of the small-scale households was around 66 tonnes, while for the medium and large-scale households, it was 106 tonnes and 202 tonnes, respectively.

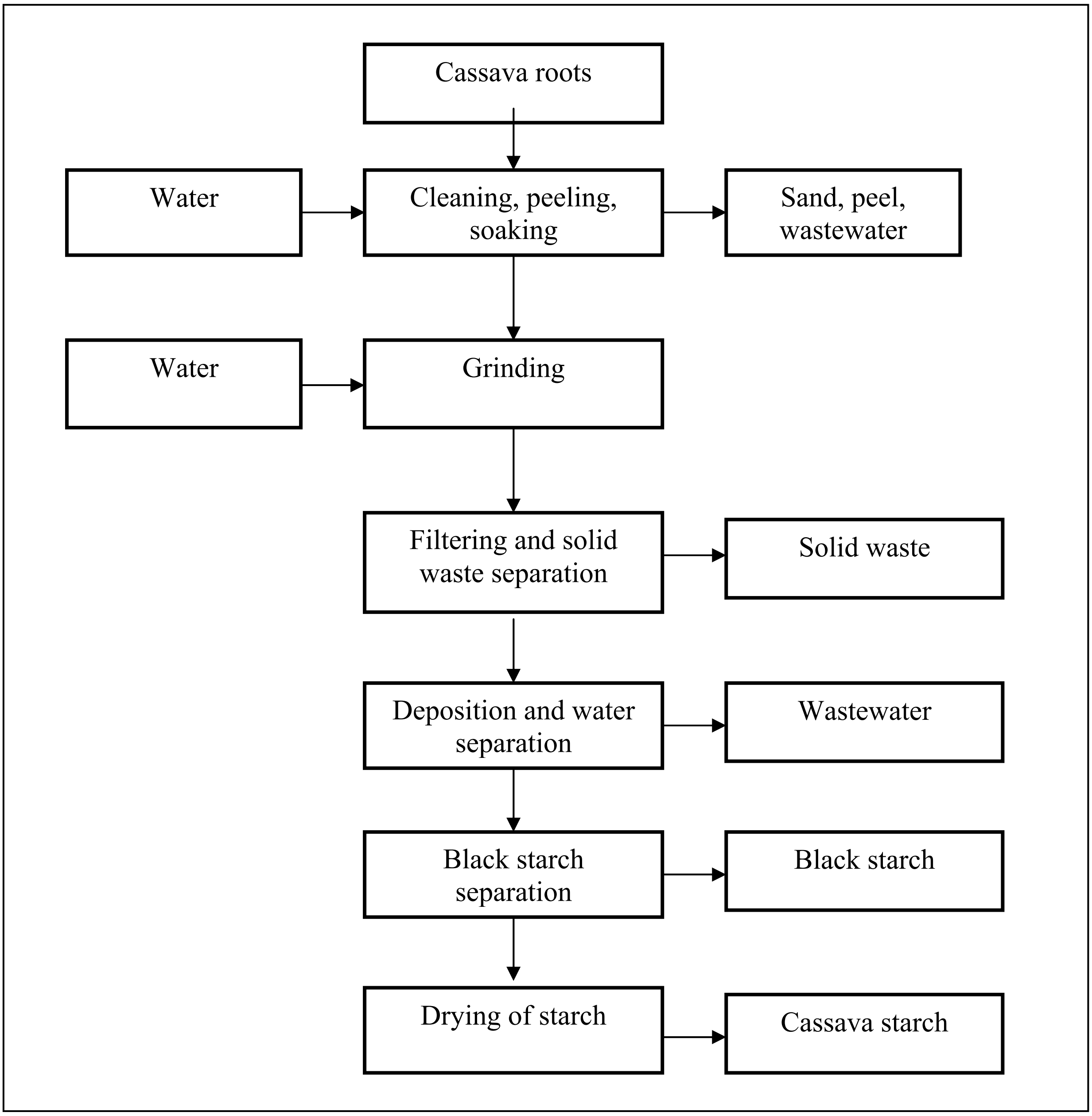


Figure 1. Flow chart for the making of cassava starch

4.2.3 Income from processing activities in households

In this study, the income earned by the household enterprises was calculated using the following formula:

$$HI = (TP \times P + BV) - (VC + A)$$

where HI is the income earned by a household enterprise;

TP is the total production of a household enterprise;

P is the selling price of the products produced by a household enterprise;

BV is the by-product value of household enterprise production;

VC is the variable cost of household enterprise production excluding family labor costs; and

A is the amortization of fixed assets used for household enterprise production.

It should be noted here that the above equation represents a calculation of the entire income of one household enterprise. This income is not confined to agro-product processing but includes earnings from other activites such as crop production and animal raising. Table 9 gives the breakdown of household income sources.

Table 9. Household income from processing activities and other sources

Unit: million VND

Household scales	Indicator	Income from crop production	Income from livestock	Income from agro-processing	Wages	Other income	Total income
Small-scale	Mean (mil.vnd)	2,100.0	9,440.0	8,580.0	7,540.0	4,300.0	31,960.0
	%	6.6	29.5	26.8	23.6	13.5	100.0
Medium-scale	Mean (mil.vnd)	2,180.0	10,310.0	13,090.0	3,470.0	4,000.0	33,050.0
	%	6.6	31.2	39.6	10.5	12.1	100.0
Large-scale	Mean (mil.vnd)	1,690.0	16,150.0	24,670.0	3,560.0	3,050.0	49,120.0
	%	3.4	32.9	50.2	7.3	6.2	100.0
All	Mean (mil.vnd)	1,990.0	11,890.0	15,250.0	4,940.0	3,800.0	37,870.0
	%	5.3	31.4	40.3	13.0	10.0	100.0

Source: field survey (2006)
Note: The income figures were averaged for one survey household.

On average, income from cassava processing accounted for 40.3% of the total household income. It varied by processing scale, the largest percentage (50.2%) being for large-scale households and the lowest (26.8%) for small-scale households. Cassava processing also generated feed for pigs, resulting in many households increasing the number of pigs reared. Pig-raising contributed a significant share (31.4%) to the total household income. Therefore, it could be said that cassava processing helped increase the incomes of households in Duong Lieu, which were higher than those of households in the non-processing villages in the same district.

4.3 Environmental Consequences of Processing Activities

4.3.1 Waste from cassava-processing

Although cassava processing helped the households in the village earn considerably higher incomes and made a big contribution to the economic development of the area, it generated a considerable amount of waste, mainly solid waste and wastewater (Table 10).

Table 10. Material inputs, outputs and waste from processing one tonne of cassava roots

Processing stage	Inputs	Outputs	Waste
1. Cleaning and peeling	• 1,000 kg of cassava roots • 0.8-1.2 m^3 of water • 1.5 Kwh of electricity	• 950 kg of peeled cassava roots	• 0.8 – 1.2 m^3 of wastewater • 50 kg of peels and send
2. Soaking	• 950 kg of peeled cassava roots • 0.5 m^3 of water	• 950 kg of peeled cassava roots	• 0.5 m^3 of wastewater
3. Grinding	• 950 kg of peeled cassava roots • 2.5 Kwh of electricity	• 950 kg of very wet cassava starch (W=68%)	
4. Filtering the solid waste	• 950 kg of very wet cassava starch (W=68%) • 4-5m^3 of water • 2.5 Kwh of electricity	• Starch milk	• 3.8-4.8 m^3 of wastewater • 404 kg of wet solid waste
5. Filtering the cassava starch	• Starch milk	• 500-520 kg of wet cassava starch (W =55%)	• 60 kg of black starch (w = 70%)
6. Drying the cassava starch	• 500-520 kg of wet cassava starch (W =55%) • 30 kg of dried coal residuals	• 450-470 kg of cassava starch (W = 50%)	• 80 kg of wet coal residuals

Source: field survey (2006)
Note: W = degree of wetness or the percentage of water in the starch

Although cassava processing helped the households in the village earn considerably higher incomes and made a big contribution to the economic development of the area, it generated a considerable amount of waste, mainly solid waste and wastewater. The survey results showed that the processing of one tonne of fresh cassava roots required 5.5–6.5 m^3 of water and generated 450–470 kg of wet cassava starch product. However, it also discharged 50 kg of cassava peels and sand, 350–420 kg of wet solid cassava waste, 60 kg of wet black starch, 80 kg of wet coal residue, and 5.05–6.3 m^3 of wastewater. The wet solid cassava waste/residue was sold to several companies to produce animal feed, and the wet black starch was used by the households for feeding pigs or sold to other pig-raising households in the village or nearby communes. The coal residue was reused for processing after being dried. Thus, it was the wastewater from the processing that was freely discharged to the drains in the village without any treatment. Therefore, the wastewater was the principal source of environmental pollution and health hazards for the local and neighboring communities.

The discharged wastewater volume per day varied across the different household groups. On average, one small-scale household discharged nearly 10 m^3 of wastewater per day while the medium and large-scale ones discharged 12.3 m^3 and 21.8 m^3 per day. The minimum wastewater volume was 5 m^3 per day while the maximum was 50 m^3 per day (Table 11).

Table 11. Wastewater volume per day by household scale

Household scale	Mean (m^3)	Minimum (m^3)	Maximum (m^3)	Std. Deviation
Small-scale	9.67	5.00	14.00	2.60
Medium-scale	12.25	7.00	18.00	2.30
Large-scale	21.76	10.00	50.00	9.34
All	14.41	5.00	50.00	7.67

Source: field survey (2006)

4.3.2 Effluents in wastewater from cassava processing

Tests by the Institute of Science and Environmental Technology, University of Technology in 2003 in Duong Lieu Village found that the concentrations of COD, BOD, and SS in wastewater from all the processing steps were over the standards (Table 12). These effluents were especially high in wastewater separated from deposited starch. The COD and BOD concentrations in the wastewater from cleaning and soaking were around 10-12 times higher than the standards while the wastewater from the starch deposition process had COD and BOD concentrations of more than 120 times higher. The free discharge of untreated wastewater, especially from the starch deposition process, thus led to environmental pollution in the village.

Table 12. Effluents in wastewater from cassava processing in Duong Lieu

Indicators	Unit	Wastewater produced per processing step		
		Wastewater from cleaning and peeling	Wastewater from soaking roots after peeling	Wastewater from starch deposition
pH	-	6.8	6.5	3.9
COD	mg/l	856	982	12,289
BOD	mg/l	550	660	6,400
SS	mg/l	42	52	1,186

Source: Institute of Science and Environmental Technology, University of Technology (2003)

4.3.3 Awareness of environmental problems

Wastewater with high concentrations of COD and BOD was the main reason for the environmental pollution in Duong Lieu. Meanwhile, solid waste was being dumped on the roadside before being sold to feed companies, giving off a bad smell in the village. The Chairperson of Duong Lieu's People's Committee reported that environmental pollution had existed in Duong Lieu for a long time due to the untreated waste from processing activities, but up to now, there was still no solution to the problem (People Newspaper 2005).

The survey results showed that almost 75% of the households reported that wastewater from cassava processing seriously polluted the environment (Table 13). Only about 2% of the surveyed households reported that wastewater had no effects on the ambient environment.

As for solid waste, 27.5% of the respondents reported that it had no effect on the environment while 65.7% admitted it was an environmental nuisance. The wastewater from processing activities also polluted surface water bodies in the village. Almost all the interviewees reported that the pond water in the village could not be used for cleaning and washing any longer. About 80% of them said that the water in the ponds during processing seasons was dirtier than in non-processing seasons. Solid waste was generated during root cleaning and peeling. It comprised root skin, fibrous residue, and black starch. Root skin waste accounted for around 5% of root weight. Two to three days after processing, the fibrous residue would begin to ferment, change color from beige to brown, and give off a foul smell. Many respondents (88%) reported that the solid waste on the roadside looked very unsightly and 83% of them said that it was smelly.

Cassava processing activities were also likely to have resulted in the degradation and depletion of groundwater in the area. The majority of the respondents (74%) conceded that many households had to dig deeper wells than before because the groundwater was being depleted. It was very difficult for the people to pump water during the processing season when every processing household was using a lot of groundwater for cassava processing. Several processing households reported that to get enough water, they had to get up very early in the morning to pump the water. The quality of groundwater was worse than before; 22% of the households reported that they had to wash their water filter tanks more often than in the past.

According to the processing households, their neighbors did not complain about the waste, noise, and pollution in the village. This is possibly because the neighbors were also processing households or they understood that processing was a source of income for many villagers. However, residents in the nearby communes that the wastewater flowed through often complained about the environmental pollution caused by cassava processing in Duong Lieu. A number of them have sued Duong Lieu starch producers for the pollution and demanded the intervention of the local district authorities. The local newspaper in Ha Tay Province also publicised this situation and appealed for solutions. However, the problem remains unsolved.

Table 13. Awareness of villagers about environmental problems

Unit: percentage

Survey questions	Opinions	Household scale			Total
		Small-scale	Medium-scale	Large-scale	
1. How serious are the effects of wastewater?	Very serious	27.78	18.18	36.36	27.45
	Serious	52.78	51.52	36.36	47.06
	Little serious	16.67	27.27	27.27	23.53
	No effects	2.78	3.03	0.0	1.96
2. How serious are the effects of solid waste?	Very serious	2.78	3.03	0.0	1.96
	Serious	2.78	0.0	12.12	4.90
	Little serious	72.22	54.55	69.70	65.69
	No effects	22.22	42.42	18.18	27.45
3. Is the water in the ponds still usable?	Yes	5.56	6.06	3.03	4.90
	No	94.44	93.94	96.97	95.10
	No answer	0.00	0.00	0.00	0.00
4. Is the water in the ponds dirtier in the processing season?	Yes	77.78	84.85	75.76	79.41
	No	22.22	15.15	24.24	20.59
	No answer	0.00	0.00	0.00	0.00
5. Have you noticed plants by the canals (filled with wastewater) dying?	Yes	16.67	30.30	36.36	27.45
	No	83.33	66.67	63.64	71.57
	No answer	0.00	3.03	0.00	0.98
6. Does the solid waste look unsightly?	Yes	91.67	84.85	87.88	88.24
	No	5.56	12.12	12.12	9.80
	No answer	2.78	3.03	0.00	1.96
7. Is there a bad smell from the solid waste?	Yes	80.56	81.82	87.88	83.33
	No	16.67	6.06	3.03	8.82
	No answer	2.78	12.12	9.09	7.84
8. What is the quality of groundwater compared to the past?	Better than before	2.77	0.00	0.00	0.98
	The same	72.22	90.90	69.69	77.45
	Worse than before	25.00	9.09	30.30	21.56
9. Is the groundwater deeper than before?	Yes	77.78	69.70	72.73	73.53
	No	22.22	30.30	27.27	26.47
	No answer	0.00	0.00	0.00	0.00
10. Are there complaints from your neighbors?	Yes	0.00	3.03	0.00	0.99
	No	100.00	96.97	96.97	98.02
	No answer	0.00	0.00	3.03	0.99
11. Are there complaints from other villages?	Yes	50.00	51.52	72.73	57.84
	No	5.56	3.03	12.12	6.86
	No answer	44.44	45.45	15.15	35.29

Source: field survey (2006)

4.3.4 Incidence of disease

Undoubtedly, the pollution caused by cassava processing activities in the village have had negative impacts on the environment and the local people's health. According to the interviewees, the common illnesses in Duong Lieu Village were headaches (52%), backaches (43%), respiratory diseases (38%), and skin irritation (36%). Stomachaches, sore eyes and cancer were also considered common diseases by around 16-20 % of the respondents (Table 14). The noise made by machines also had negative impacts on the workers, causing them nervous tension, fatigue, and respiratory diseases (Dang, Nguyen and Tran 2005).

Table 14. Common illnesses reported by the respondents

Unit: percentage

Illnesses	Small-scale	Medium-scale	Large-scale	Total
Headache	61.11	42.42	51.52	51.96
Backache	44.44	33.33	51.52	43.14
Respiratory diseases	30.56	54.55	30.30	38.24
Skin irritation	36.11	42.42	30.30	36.27
Sore eyes	25.00	9.09	21.21	18.63
Cancer	25.00	15.15	9.09	16.67
Stomachache	16.67	18.18	24.24	19.61
Allergy	2.78	9.09	6.06	5.88
Vomitting	2.78	0.00	0.00	0.98

Source: field survey (2006)

The survey also asked the respondents which illnesses they believed were caused by environmental pollution in the village. Several of them (14%) admitted that the headaches, skin irritation, and cancer were possibly caused by environmental pollution in the village but less than 10% thought that stomachaches, sore eyes, respiratory diseases, and rheumatism were due to pollution (Table 15). It is possible that the villagers understated the linkage because they were afraid that their processing businesses would be stopped or impeded if the pollution in the village was seen to the cause of disease and illness.

Table 15. Illnesses perceived by the respondents to be caused by environmental pollution

Unit: percentage

Illnesses	Small-scale	Medium-scale	Large-scale	Total
Headache	19.44	9.09	12.12	14.28
Skin irritation	19.44	21.21	0.00	14.28
Cancer	19.44	9.09	12.12	14.28
Stomachache	11.11	3.03	9.09	8.16
Sore eyes	5.56	0.00	12.12	6.12
Rheumatism	8.33	3.03	3.03	5.10
Respiratory diseases	0.00	9.09	3.03	4.08
Allergy	5.56	3.03	0.00	3.06

Source: field survey (2006)

4.3.5 Local efforts to mitigate the pollution in Duong Lieu

Due to the serious environmental consequences caused by agro-product processing in Duong Lieu, the local government and residents have adopted several measures to try to mitigate the pollution.

(a) At the village level

- *Issuance of environmental protection regulations:* In March 2000, the Duong Lieu People's Committee designed and issued environmental protection regulations which specified the responsibilities of processing households and local stakeholders (the People's Committee, women's union, youth union, farmers' alliance, etc.) for environmental protection in the village/commune. According to the regulations, each person in the commune had to contribute 3,000 VND/month towards a village Environmental Sanitary Fund. In addition, each cassava processing household had to contribute 50,000 VND/year to the fund. Since 2005, an environmental sanitary team has been established in the commune with the main responsibilities of collecting the domestic solid waste and cleaning the roads and drains in the village.
- *Upgrade of the drainage system in Duong Lieu:* Each year, the authorities invest around 20 million VND to upkeep the village drainage system. The drains are quite old as they were built in 1990. Therefore, sometimes they get broken and clogged up with wastewater and waste.
- *Dissemination of environmental protection information to the villagers:* This is done via a village meeting once or twice a year to raise the awareness of the villagers, but not all attend. Also, those who do attend the meetings often do not share the information with their household members. Moreover, the speakers are usually local commune staff who are not specialized in environmental management and are unable to provide much information on pollution mitigation measures. Thus, the effectiveness of this outreach is very

limited. There are still no households which treat their wastewater before discharge.

(b) At the household level

In order to reduce the pollution in their own private area, many households have upgraded their drains so that the wastewater from their households can flow into the village drainage system as quickly as possible. Moreover, as the local residents are well aware that the serious pollution in the village can degrade the quality of the groundwater, almost all the households in Duong Lieu have built tanks to store rainwater for drinking purposes (rather than drink the groundwater).

4.4 Pollution Control Options for Duong Lieu

4.4.1 Design of pollution control options

At present, the wastewater from cassava processing households in Duong Lieu flows untreated into the drains to a common pool, then through a drainage canal to the Nhue River (Figure 2).

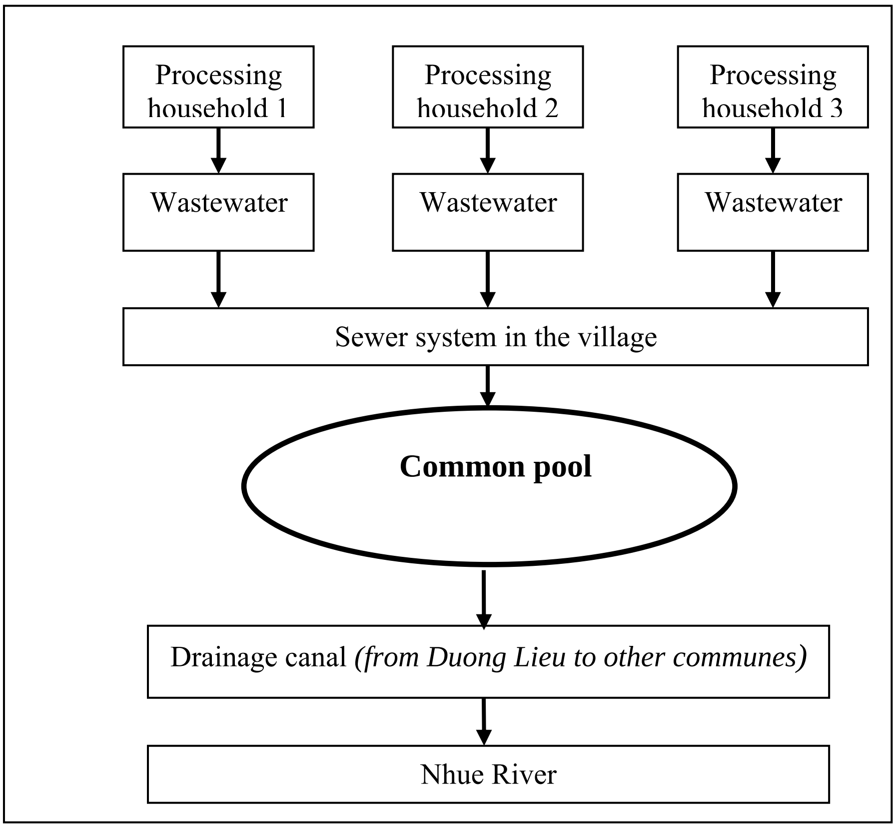


Figure 2. Wastewater flow in Duong Lieu

One of the ways to mitigate the environmental pollution in Duong Lieu is to treat the wastewater from the processing activities. In order to establish what treatment technology should be applied and how the treatment plant should be designed, we invited a technical expert on wastewater treatment to join this research. Field trips to Duong Lieu Village by the technical expert and researchers were arranged. The technical expert visited the processing households and observed the drainage system and the common pools in the village. A meeting between the technical expert, researchers, and village leaders was held in which questions relating to the current drainage system and common pools were raised by the technical expert and answered by the village leaders. Based on his observations and the information gathered on wastewater in the village, the technical expert designed three options to treat the wastewater in the village (Table 16).

Table 16. Description of pollution control options for Duong Lieu

Options	Description
Option 1	Establishment of a small treatment system for individual processing households
Option 2	Establishment of a wastewater treatment system for a group of processing households
Option 3	Establishment of wastewater treatment system for the whole village

(a) Option 1: Small treatment plant for an individual household

Since the average volume of wastewater from a processing household was around 14-15 m^3/day, a small treatment plant with the capacity to treat 15 m^3 per day was designed. Based on the contents of the wastewater from the processing households, an anaerobic tank was selected. For effective treatment, it would be necessary to increase the pH from 4.64 to 7.5. In order to bring the BOD effluent concentration down to 50 mg/l (the standard) after treatment, the duration for the wastewater treatment (flowing from inlet to outlet) should be 72 hours. Figure 3 shows the design of the treatment tank.

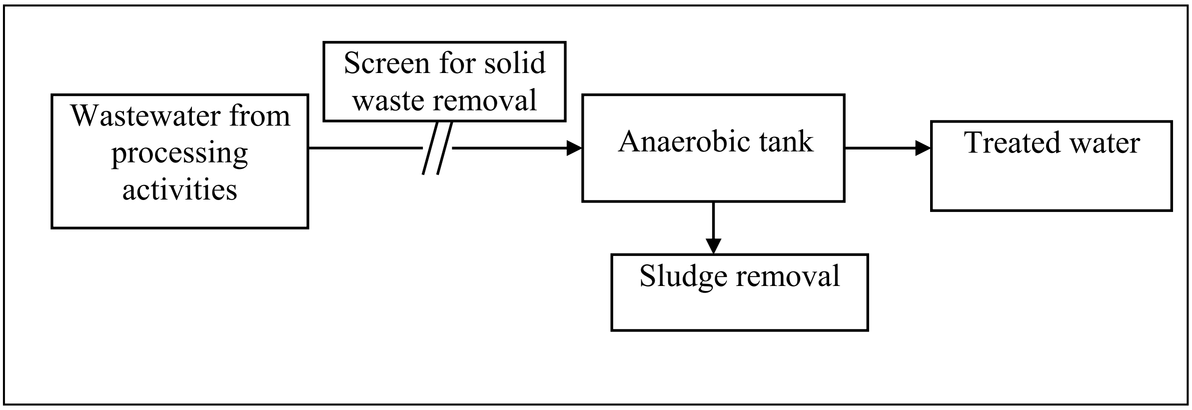


Figure 3. The wastewater treatment system for a single household (Option 1)

Lime solution ($Ca(OH)_2$ or calcium hydroxide) is first added to the wastewater from which solid waste (such as cassava peel, fibers, and sand) has been removed. The wastewater is then channeled into an anaerobic tank (Figure 4). Lime solution is used to increase the pH up to 7.5—it is cheap and highly effective. The sludge in the anaerobic tank should be periodically removed using a pump. The capacity of the anaerobic tank should be 45 m^3 (for treating 15 m^3 of wastewater per day). The tank should lie underground due to limited household area. Supplementary materials required for this option are a barrel of lime solution, PVC pipes, and valves.

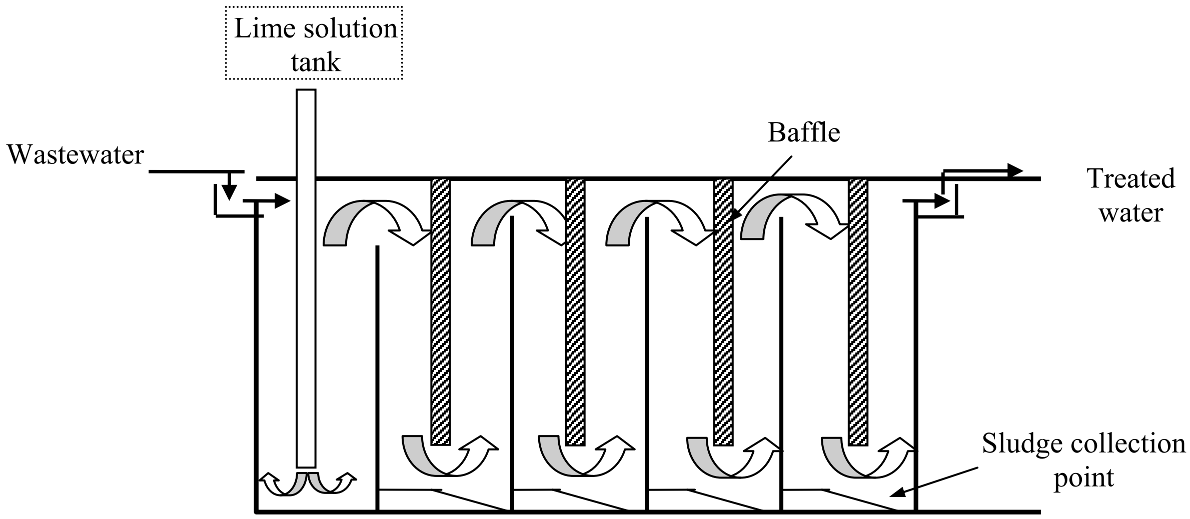


Figure 4. The anaerobic tank for wastewater treatment for a single household (Option 1)

(b) Option 2: Establishment of a treatment system for a household group

In this option, the wastewater from a group of 10-15 processing households located near to one another will be collected for treatment. The wastewater volume treated by the treatment plant will be around 200 m^3/day. This option uses biological and chemical treatment technology and is presented in Figure 5.

The wastewater first flows through the screen tank to remove all big-sized solid materials such as rubbish in the inflow. It then goes through the sand sedimentation tank for the removing of pellets with diameters more than 0.2 mm. The wastewater then flows into the equalization tank and stays in the tank for eight hours for polluted effluent stabilization. After that, it is pumped to the mixing tank (the pump is used to stabilize the inflow for the treatment system).

Sodium hydroxide (NaOH) is injected into the coagulation tank by a volumetric pump in order to increase the pH of the wastewater up to 7.5, a favorable condition for the treatment steps that follow (sludge activation and biological treatment). The NaOH pump is automatically monitored and stops when the pH reaches 7.5. A powered activated carbon (PAC) reagent is then mixed into the coagulation tank. After that, the mixture of wastewater and PAC flows into the flocculation tank.

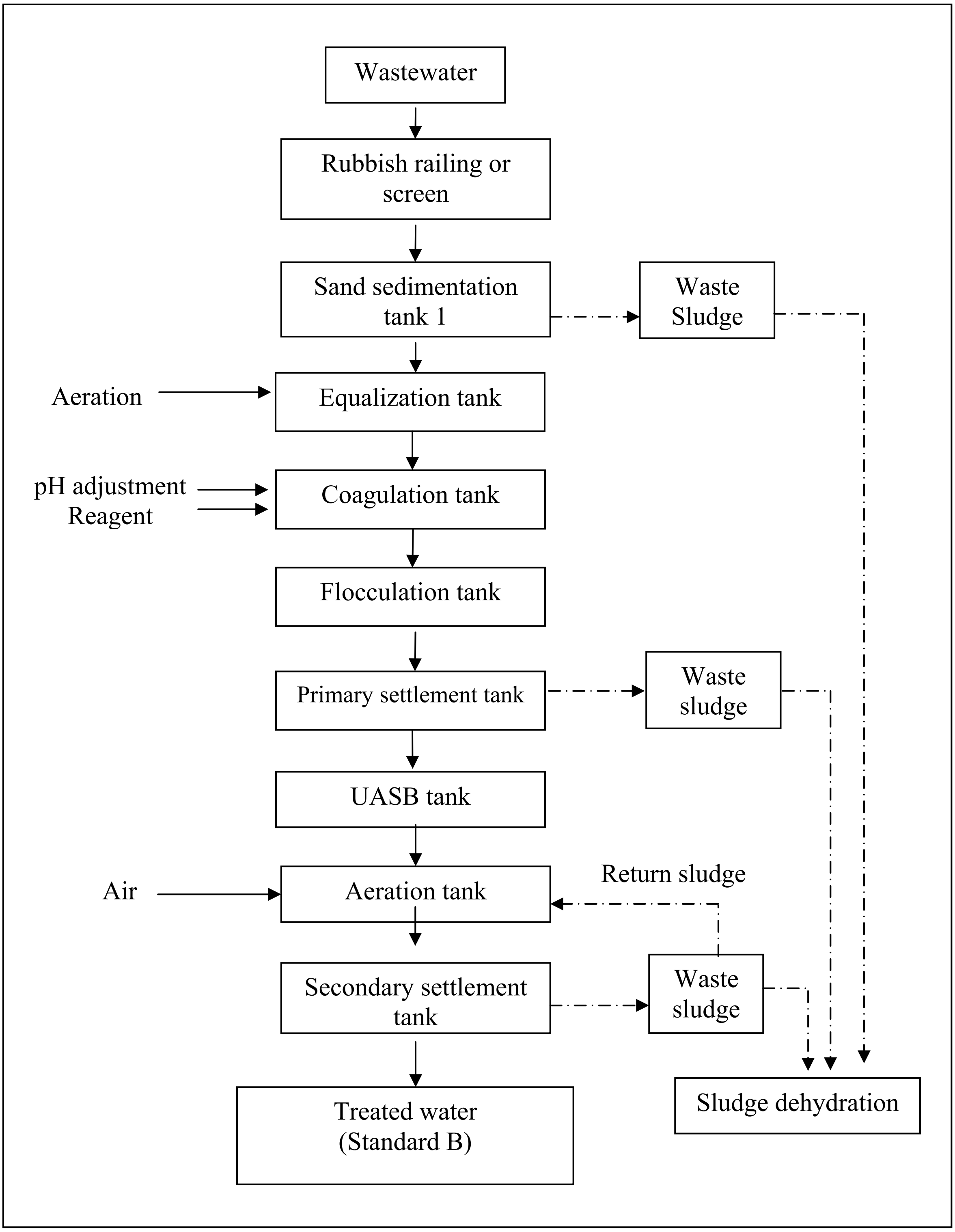


Figure 5. The wastewater treatment system for a household group (Option 2)

In the flocculation tank, the mixture is slowly stirred for floccule[3] creation (with a retention time of between 15-30 minutes). When the floccules reach a certain size and weight, they will move to the primary settlement tank and settle there. The remaining water (with high COD content) will then flow to the upward-flow anaerobic sludge blanket reactor (UASB) tank. The water will stay in the UASB tank for a while in order for the COD concentration in the water to fall to 500 mg/l, suitable for aeration treatment.

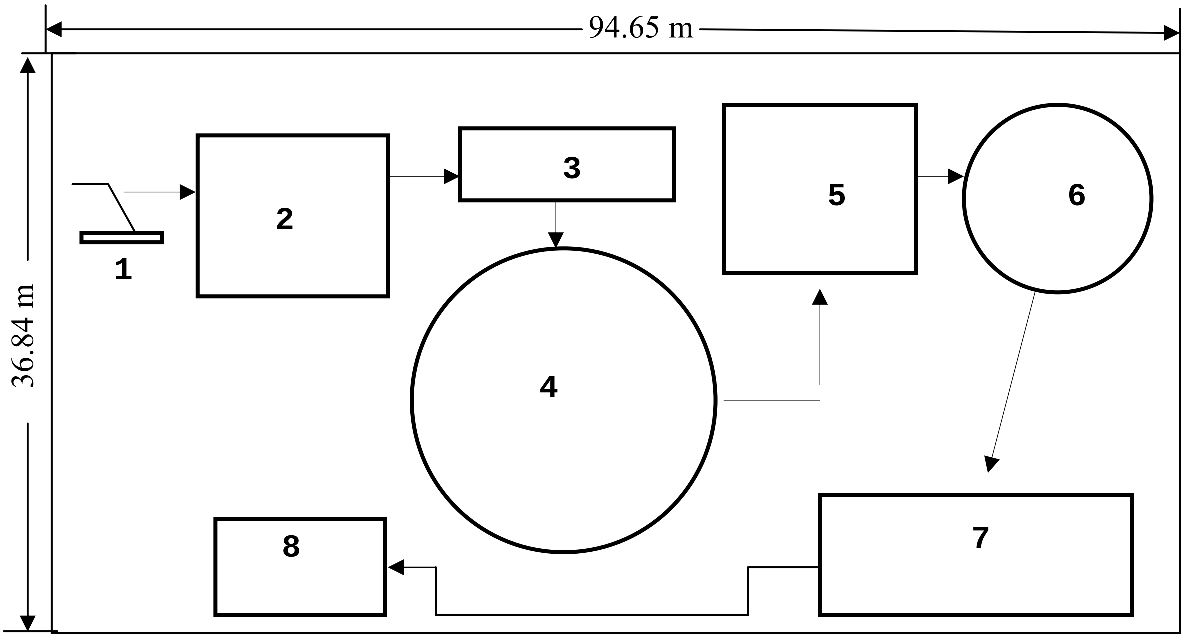
After the UASB tank, the wastewater will flow through the aeration tank. The remaining organic matter will be digested by aerobic micro-organisms. Dissolved oxygen (DO) in the aeration tank will be kept at 1.5-2 mg/l through a DO automatic controller. After this, the water will flow to the secondary tank, then to the common drain in the village. The water quality will satisfy Standard B according to environmental regulation TCVN 5945-1995-Column B (MOSTE 2002). The waste sludge in the sand sedimentation, primary settlement, and secondary settlement tanks should be regularly pumped out.

Option 3: Establishment of a treatment system for the whole village

Duong Lieu Village is divided into two separate parts by a dyke. There are 217 processing households outside the dyke and more than 200 processing households inside the dyke. All the wastewater from the processing households outside the dyke flows into one common pool through the village drainage and canal system. Similarly, all the wastewater from the processing households inside the dyke flows into another common pool in the village.

Based on the number of processing households and their daily wastewater volume, it was estimated that the wastewater volume flowing from processing households to each common pool was around 2,000-2,500 m^3 per day. Based on this volume and the BOD, COD, and SS concentrations in the wastewater in the village drains, a common system was designed with the aim of setting up two plants in the village, each to treat 2,500 m^3 of wastewater per day. The treatment technology in this option is the same as that in Option 2. Only the wastewater volume per day is different. In this option, a part of each common pool has to be used to build the treatment plants. Figure 6 refers.

[3] A small, loosely held mass of fine particles either suspended in or precipitated from a solution.



1) Sand sedimentation tank
2) Equalization tank
3) Coagulation, flocculation and primary settlement tanks
4) UASB tank
5) Aeration tank
6) Secondary settlement tank
7) Sludge dehydration
8) Operation house and reagent storage

Figure 6. The wastewater treatment system for the whole village (Option 3)

4.4.2 Cost estimates for the three options

The total wastewater treatment costs for all options include fixed costs and variable costs. The fixed costs in all the options consist of plant construction costs, management costs, and equipment costs while the variable costs comprise the costs of chemicals or reagents and electricity.

For Option 1, a 45-m^3 anaerobic tank will be constructed underground with an operation duration of 15 years. Equipment such as sludge pumps, a rubbish screen, barrels, and pipes are necessary for the operation. The cost of plant construction was estimated based on current construction prices. The costs of equipment, reagents, electricity, and labor were also estimated based on the current prices. The cost items in Option 2 and Option 3 were similarly estimated. The detailed costs of all three options are presented in Table 17. However, due to the different treatment capacities and technologies, the costs among options are very different.

Table 17. Cost estimates for the three pollution control options

Cost items	Cost ('000 VND)	Details
1. Option 1: Small treatment system for an individual household (15 m^3/day)		
1.1. Plant construction	34,918	The treatment plant can last for 15 years.
1.2. Equipment	8,216	The equipment can last for 5 years.
1.3. Reagents	1.875	This reagent cost is for daily treatment of 15 m^3 of wastewater.
1.4. Electricity	2.4	This electricity cost is for daily treatment of 15 m^3 of wastewater.
1.5. Labor	100	This is the monthly labor cost (30 days) for plant operation and management.
2. Option 2: Treatment system for a household group (200 m^3/day)		
2.1. Plant construction	139,932	The treatment plant can last for 20 years.
2.2. Equipment	376,425	The equipment can last for 5 years.
2.3. Reagents	100.1	This reagent cost is for daily treatment of 200 m^3 of wastewater.
2.4. Electricity	292	This electricity cost is for daily treatment of 200 m^3 of wastewater.
2.5. Labor	1,400	This is the monthly labor cost (30 days) for plant operation and management.
3. Option 3: Treatment system for the whole village (2,500 m^3/day)		
3.1. Plant construction	2,110,611	The treatment plant can last for 20 years.
3.2. Equipment	1,386,000	The equipment can last for 5 years.
3.3. Reagents	1,251.5	This reagent cost is for daily treatment of 2,500 m^3 of wastewater.
3.4. Electricity	1,402	This electricity cost is for daily treatment of 2,500 m^3 of wastewater.
3.5. Labor	7,200	This is the monthly labor cost (30 days) for plant operation and management.

Source: estimated by the technical expert
Note: The estimates are for one plant under each option.

4.4.3 Cost-effectiveness analysis and sensitivity analysis

Based on the cost estimates for the three options, the average treatment cost for wastewater was calculated. The average treatment cost for Option 1 was the lowest, followed by Option 3 and Option 2, which was the highest (Table 18). Thus, it could be said that Option 1 was most cost-effective wastewater treatment. This is because the technology in Option 1 (small-scale treatment) is quite simple and does not require modern equipment. The costs of equipment and electricity for the treatment of one cubic meter of wastewater were very small compared to the other options.

A sensitivity analysis was done of the options to see the effects of changes in construction, equipment, and reagent costs. It was found that if the construction costs in all options increased by 10% or 20%, the average treatment cost for wastewater in Option 3 would become the lowest (2,031 VND/m^3 or 2,054 VND/m^3, respectively). So if construction costs increase, Option 3 will become the least-cost treatment technology. However, if equipment or reagent costs increased, there would be no change in the ranking of the average treatment cost among systems, the lowest still being Option 1 and the most expensive being Option 2. So if only the treatment cost is considered, wastewater treatment at the individual household level should be selected, but if construction costs were to rise, then the establishment of a treatment system for the whole village would be the most cost-effective option.

Table 18. Sensitivity analysis of the average wastewater treatment cost by option

Unit: (VND/m^3)

	Option 1	**Option 2**	**Option 3**
1. Base case (no change in cost items)	1,978	4,480	2,008
2. If construction costs increase			
- by 10%	2,064	4,498	2,031
- by 20%	2,150	4,518	2,054
3. If equipment costs increase			
- by 10%	2,039	4,689	2,070
- by 20%	2,100	4,898	2,131
4. If reagent costs increase			
- by 10%	1,990	4,529	2,058
- by 20%	2,003	4,580	2,108

Source: Please refer to Appendices 1, 2 and 3.

4.4.4 Social acceptability of the options

The cost-effectiveness analysis of the options would not be sufficient grounds to make a decision on the best option; the social acceptability of the options had to also be considered. The concept of social acceptability can be traced back to the work of rural sociologist, Firey (1960), who was interested in understanding why certain resource practices and prescriptions in different societies persisted, whereas others did not. He concluded that the adoption and retention of any particular resource program or action depended on the extent to which such action satisfied three key prerequisites: (a) being physically possible or practices consistent with ecological processes, (b) being economically feasible or practices that generated revenue in excess of costs, and (c) being culturally adoptable or practices that were consistent with prevailing social customs and norms. Clawson (1975) introduced a similar premise which focused directly on forest environments but provided a more detailed set of criteria than Firey by arguing that successful policies must meet five conditions: (a) biological and physical feasibility, (b) economic efficiency, (c) economic welfare or equity, (d) social or cultural acceptability, and (e) operational or administrative practicality. Both frameworks acknowledge and agree on one fundamental notion: policies and practices lacking societal acceptance and approval will ultimately fail. This will occur even if they are supported by sound science (physically possible) and are profitable (economically feasible).

In this study, the social acceptability of the various wastewater treatment options was considered in terms of physical feasibility, financing capability, cultural acceptability, and operational or administrative capacity. First of all, the technical expert clearly presented the three wastewater treatment options—flip-charts about the option designs were shown together with diagrams of the wastewater treatment systems. The researchers then explained about the costs of each option. A table was presented showing the costs of plant construction, equipment, reagents, electricity, and labor for each option. The average treatment cost per cubic meter of wastewater for each option was calculated and also presented to the participants. Next, a discussion between the local people, technical expert and researchers was held. Each of the options was discussed in detail and questions raised by the villagers were answered by the research group. Lastly, to rank the options, a "voting game" was conducted with the participation of 15 local people including two commune staff and a representative from each of the 13 processing households in which each participant had the right to select his/her favorite option from his/her point of view. The social acceptability of the options was then assessed by the sums of the individual choices.

At the beginning, the voting game and scoring method were both considered for selecting the options. However, after discussion with the participants, it became quite clear that the scoring method was too complicated for them—they would face difficulties in assessing and assigning scores to each attribute of the options. They preferred to play the "voting game" where they only needed to answer "yes" or "no" in selecting the options, which was easier for them. To guard against cursory or careless answers, the participants were requested to write down the reasons why they selected or did not select an option.

Physical feasibility

Through discussions, several problems on the physical feasibility of the options were revealed. As proposed for Option 1, an underground tank of 45 m^3 had to be constructed for treating 15 m^3 of wastewater per day. The volume of the treatment tank would have to be larger if the wastewater volume was more. However, the residential area of processing households in Duong Lieu was very small. Most of the households had a very tiny backyard for processing and no garden. The establishment of a 45 m^3 underground tank in the household area was therefore quite difficult. For households with larger wastewater volumes, the establishment of bigger tanks would be impossible due to lack of space. The impossibility of installing a big tank for a large-scale processing household would certainly result in non-homogeneity in wastewater treatment among the individual households. Consequently, the physical feasibility of Option 1 was not good. Option 2 proposed the construction of several small treatment plants for household groups. However, the problem was that the plants had to be constructed on agricultural land as there was no common land to use. This required a change in the current land policy involving agricultural land use and would take a long time to settle. Even if the land policy constraint was eventually resolved, time and other transaction costs would be needed to first convince the land owners to leave their agricultural land to make way for the construction of the plants and then, to pay them compensation which would be another problem in itself. In Option 3, however, there was no problem in terms of plant construction area as the two plants would be built in the common pools in the commune (one inside and one outside the dyke).

Financing feasibility

It was clear that the treatment plants could not be established based totally on the contributions of the households in Duong Lieu because the construction and operation costs for the three options were huge and beyond the capacity of the individual households. Although the processing households agreed to contribute around 10% of their annual income from processing activities, this contribution could make up only from 2.9–7.5% of the initial construction and equipment costs. Financial support from the local government and other donors was thus essential. Currently, environmental pollution in agro-processing villages was an issue of very high concern to the government. A pilot wastewater treatment project in an agro-processing village could have a high possibility of receiving financial support from the local government and donors. Therefore, projects based on the proposed options should be designed to solicit such support. According to the participants, Option 3 was more feasible than Options 1 and 2, especially in terms of investment management, whereas for Option 1, it would be difficult to allocate funding to individual households as well as to control the quality of the treatment system. In Option 3, the whole investment budget was used for only one large treatment system under the supervision of construction experts. The quality of the constructed plant and use of investment budget were perceived as much easier to control.

Cultural acceptability

Many participants expressed the view that it would be difficult to persuade the households to establish an underground 45 m^3 tank in their backyards for wastewater treatment. One of the reasons was that many local people believed that the establishment of a wide and deep ditch very close to their homes (and their altars) would bring them bad luck in their life and business. Therefore, Option 1 was not really suitable for the households with their small residential area. Only households with large residential areas or gardens could accept the proposal. For Option 2, participants also thought that the establishment of 15 or so small wastewater treatment plants in the village was not culturally acceptable.

Operational or administrative capacity

The treatment technology in Option 1 was simple and easily transferable to the households. Although the households could manage this technology easily, it would be quite difficult to investigate whether they would follow all the technical guidelines and be able to control the quality of water outflow. Problems with the treatment tank would also be difficult to settle since the tank was underground and external technical support would be necessary. Meanwhile, the treatment techniques in Options 2 and 3 were complicated and modern but as the plants would be managed by technicians, there would be no problems with their operation. The quality of water outflow would be controlled by the technicians.

The results of the social acceptability assessment are shown in Table 19. The reasons why participants selected or did not select an option in the “voting game” are also given in the table. Only 13% of the villagers agreed to adopt Option 1 with the main reasons being that the treatment cost per cubic meter was the cheapest and it was quite easy for individual households to manage and operate. However, this 13% were better-off and had enough space for the tank. The remaining 87% believed that not all households in the village could afford this system due to the high cost and limited area of their residence. Also, wastewater pollution would not be solved if only a few households treated their wastewater while others did not. Furthermore, it was more difficult to get and manage the funding for Option 1 than for the other options. The system was also not culturally acceptable and its lifetime was relatively short.

Table 19. Social acceptability assessment of the proposed wastewater treatment options

Option	Accepted/ Not accepted	Ratio (%)	Reasons for being accepted or not accepted
Option 1	Accepted	13.3	- Lowest cost of treatment per m^3 - The equipment, reagent, electricity and labor costs are low - Easy to manage and operate by individual households
	Not accepted	86.7	- The space for construction is limited in each household - Not all households in the village can afford this system - Difficult to get financial support for every processing household and to manage the support - Not culturally acceptable - The lifetime of the system is too short
Option 2	Accepted	0	- The lifetime of the system is long - Salvaging of the present drainage, canal and common pool system in the village
	Not accepted	100	- Very high cost of treatment per m^3 - Difficult to find space to install the system - The equipment cost is very high compared to the other options - Quite difficult to get financial support - Low cultural acceptability - Requires high technical support for implementation and management
Option 3	Accepted	86.7	- Low cost of treatment per m^3 - Available space for treatment plant establishment - Easier to get financial support - Culturally acceptable - Salvaging of the present drainage, canal and common pool system in the village. - Able to completely solve the water pollution problem in the village
	Not accepted	13.3	- Requires high technical support for implementation and management

Source: field survey 2007

All the participants rejected Option 2 mainly due to its very high average treatment cost (4,480 VND/m^3) compared with the other options. It was also very difficult to find the space to set up the plants and cultural acceptability of the system was very low.

Most of the participants (87%) were keen on Option 3 or the establishment of a treatment system for the whole village. Although the average treatment cost for wastewater in Option 3 was a little bit higher than that in Option 1, it was still low (2,008 VND/ m^3) and could become the lowest if construction costs increased. The advantages of Option 3 included available space for system establishment, high cultural acceptability, and financing feasibility. Option 3 could utilize the existing system of drains, canals and common pools, and completely solve the water pollution problem in the village. The disadvantage of the system was that it required high technical support for implementation and management. However, this would not be a problem since technicians would be operating the system.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Handicraft activities in general and agro-product processing in particular, in the Red River Delta have played a significant role in contributing to job opportunity generation, household income improvement and poverty alleviation. However, agro-product processing activities generate a huge amount of waste and are considered as a source of serious pollution. This study was therefore designed to describe the environmental consequences of agro-product processing and to assess the cost-effectiveness of pollution control options in an agro-product processing handicraft village with a focus on water pollution. Duong Lieu, a famous agro-product processing village with a very high percentage (95%) of households engaged in cassava starch processing activities, was selected as the research site. Secondary data on socio-economic factors, processing activities and environmental problems in Duong Lieu were gathered from available reports of various agencies. In addition, primary data on processing activities, environmental consequences and the villagers' attitudes on pollution control options were gathered through direct interviews with 102 small, medium and large-scale processing households and through focus group discussions. Descriptive statistics, comparative analysis, and cost-effectiveness analysis were the main methods of analysis used in this study.

Agro-product processing in Duong Lieu has had a long history since the 1960s. At the time of the study, more than 400 households in the village were engaged in this industry, producing around 60,000 tonnes of cassava starch (90 billion VND) annually. On average, each processing household had 2.5 persons involved in cassava processing, 39.7 m^2 of processing area, several processing machines, and 1,047.6 kg of cassava starch generated per processing day.

There were certainly differences in labor input, processing area, machines used and product volumes among household groups. The small-scale households produced 66 tonnes of starch products in 2005 while this figure was 106 tonnes for medium households and 202 tonnes for large-scale households. The income from processing activities accounted for 40.4% of the total household income on average (50.3% for the large-scale and 27% for the small-scale households).

Although the processing helped the households in Duong Lieu earn considerably higher incomes, it generated a significant amount of waste, especially untreated wastewater, into the environment. On average, one small-scale household discharged nearly 10 m^3 of wastewater per day while the volumes for medium and large-scale households were 12.3 m^3 and 21.8 m^3, respectively. The COD, BOD, and SS concentrations in the wastewater in all stages of processing were 10–120 times over the standards, causing serious environmental degradation and negative impacts on human health. A large percentage (75%) of the villagers believed that the common illnesses in the village were due to the serious pollution caused by cassava processing.

To mitigate the environmental pollution in Duong Lieu, three pollution control options were designed to treat the wastewater in the village. These options were: the establishment of a small treatment plant for each individual household (Option 1); a treatment plant for a group of processing households (Option 2); and a treatment plant for the whole village (Option 3). The costs of plant construction, equipment, reagents, electricity, and labor were estimated. Option 1 had the smallest treatment cost per cubic meter of wastewater (1,978 VND/m^3), followed by Option 3 (2,008 VND/m^3), with the highest being Option 2 (4,480 VND/m^3). In other words, Option 1 was most cost-effective option.

The sensitivity analysis indicated that Option 3 would become the most cost-effective if the construction costs in all the options increased. An analysis of the social acceptability of the three options was made according to various indicators through focus group discussions and a "voting game" in which each participant selected the most appropriate option from his/her individual viewpoint. The results showed that Option 3 was the most widely accepted because it had low treatment costs per cubic meter of wastewater, available space for the establishment of the treatment plant, a higher likelihood of securing financial support and having that support efficiently managed, and higher culturally acceptability; and it could solve the water pollution problem in the village completely.

5.2 Recommendations

In order to mitigate the environmental pollution in Duong Lieu Village, a number of recommendations are proposed.

a) Establishing a wastewater treatment plant for the whole village

The results of the cost-effectiveness analysis and social acceptability assessment show that the establishment of a treatment system for the whole village would be the most viable wastewater treatment option to resolve the pollution problems in the village. However, the initial investment costs for construction and equipment are heavy and beyond the contribution capacity of processing households although they are willing to contribute up to 10% of their annual income from processing activities. Financial support from the government or foreign sponsors is thus necessary. First of all, a proper wastewater treatment project proposal for funding support based on Option 3 should be drawn-up in further consultation with the technical expert and researchers. The project proposal, with a detailed design of the wastewater treatment plant and description of its operation, should make clear the contribution share from the processing households in the village and the required share of financial support from the donors. A cost-benefit analysis should also be included to show the benefits of project implementation so as to convince donors to support the project. The proposal should be sent to the Department of Science and Technology in Ha Tay Province so that it may source for funding from local and international organizations.

b) Collecting wastewater fees from processing households

Although Decree 67/2003/ND-CP on environmental protection charges for wastewater follows the "polluter pays" principle and has been in effect since 2004, the processing households in Duong Lieu have still not paid for their wastewater discharge. This is because the processing activities are performed by many small-scale households and the measurement of wastewater volumes from every household is an impossible task. Without data on the wastewater volumes produced by the processing households, it is impossible to calculate the wastewater fees that they should pay. The focus group discussions with the local staff in Duong Lieu Village, however, revealed the possibility of calculating the wastewater volumes of the processing households through their monthly electricity use as all households possessed electricity meters. The survey results showed that the processing of one tonne of fresh cassava required around 6.5 kilowatts of electricity and discharged 5.5–6.5 m^3 of wastewater. Therefore, the approximate volumes of wastewater discharge could be estimated and the wastewater fees could be calculated and collected using the available electricity data. The collection of wastewater fees from the processing households would create a source of finance to support the operation of the treatment system and help raise awareness of the importance of environmental protection among the processing households in the village.

c) Raising the villagers' awareness of the importance of environmental protection

Although the local residents in the village perceived wastewater and solid waste from agro-processing activities as environmental health hazards that need to be addressed, their awareness of the importance of environmental protection was still poor. Many processing households disposed of a mixture of wastewater and cassava peels into the drainage system of the village. They also dumped the processing residues along the roads in a disorderly fashion and these residues sometimes fell into the nearby drains and blocked them up, worsening the pollution situation. Educating the villagers on environmental pollution, especially the processing households, is therefore essential. Classes on pollution prevention and treatment should be held for the processing households. Moreover, an environmental education program should be developed and implemented to raise the villagers' understanding of environmental problems and solutions, especially regarding the wastewater produced in the village.

d) Improving the drainage system in the village

The drainage system in the village was constructed in 1990 and has degraded considerably since. The drains were broken and badly clogged with waste in several places. The repair and improvement of the drainage system in the villages is therefore necessary.

e) Mobilizing the participation of households in environmental protection activities

The environmental sanitation team in the village was formed in 2006. The team has 15 workers and each worker is responsible for the environmental sanitation in one small hamlet. The specific tasks of the team are to collect the rubbish from daily village activities, clean the hamlet roads, and clear the drains. While rubbish collection is done every day, the drains are cleared usually only once every three months due to resource limitations. To clean the drains more often, the participation of the villagers is necessary. The Village Management Board should organize a collective village activity involving everyone in the cleaning of the roads and drains once a month.

f) Encouraging the application of cleaner production technologies

The goal of cleaner production is to avoid pollution by utilizing resources and raw materials to the maximum. This means that a higher percentage of the raw materials are turned into valuable products instead of being wasted. For cassava processing, cleaner production could be made possible by replacing old processing machines with modern ones, reusing the wastewater from filtering to clean cassava roots, and using cassava residues to produce bio-fertilizers or materials for mushroom cultivation.

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APPENDICES

Appendix 1. Treatment Costs for Option 1

The total costs for Option 1 include the costs of construction, supplies and operations. The tables show the costs of treating 15 m^3 of wastewater.

1.1 Costs of construction and supplies

The construction and supply costs are estimated in the Table 1A. The duration of the tank is 15 years while the lifetime of supplies is five years.

Table 1A. Costs of construction and supplies in Option 1

Cost item	Unit	Quantity	Unit price ('000 VND)	Estimated cost ('000 VND)
1. Construction costs				**34,918**
1.1. Preparing the areas for tank construction (soil removal)	m^3	45	100	4,500
1.2. Tank construction	m^3	45	639	28,755
1.3. VAT (5%)				1,663
2. Costs of Supplies				**8,216**
2.1. Sludge pump	pump	1	3000	3,000
2.2. Screen	-	1	1200	1,200
2.3. $Ca(OH)_2$ barrel	barrel	1	1000	1,000
2.4. PVC pipe	m	25	20	1,125
2.5. Baffle	baffle	5	100	500
2.6. Others	-			1,000
2.7. VAT (5%)				391

Source: estimated by the technical expert (2007)

1.2 Operational costs

Operational costs include the cost of $Ca(OH)_2$, electricity and family labor to operate the sludge pump. It is estimated that the treatment of 15 m^3 of wastewater will need 7.5 kg $Ca(OH)_2$. The electricity needed to operate the sludge pump is around 2 KW per day, equivalent to 2,400 VND per day. The family labor cost is around 100,000 VND per month. The treatment system will operate when cassava processing activities are carried out. This means that the treatment system will be operated for 6 months or 180 days per year.

1.3 Treatment cost for 1 m^3 of wastewater

This is calculated as follows:

- Depreciation of construction cost:

34,918,000 VND/ (15 years x180 days/year x 15 m^3/day) = 862.2 VND

- Depreciation of supplies:

8,216,000 VND/ (5 years x 180 days/year x 15 m^3/day) = 608.6 VND

- Operational cost:
  - Cost for Ca(OH)2: 7.5 kg x 250 VND /15 m^3 = 125 VND
  - Cost for electricity: 2400 VND/15 m^3 = 160 VND
- Labor cost: 100,000 VND/30 days/15 m^3 = 222.2 VND

1.4 Total treatment cost for Option 1

Thus, total treatment cost for 1 m^3 of wastewater in the households is **1,978 VND** (862.2 VND + 608.6 VND + 125 VND + 160 VND + 222.2VND) = 1,978 VND).

Appendix 2. Treatment Costs for Option 2

The costs shown in the tables below are for the treatment of 200 m^3 of wastewater in Option 2.

2.1 Construction costs

Table 2A. Construction costs in Option 2

Cost item	Unit	Quantity	Unit price ('000VND)	Estimated cost ('000 VND)
1. Preparing the areas for plant construction				3,000
2. Sand sedimentation tank	m^3	0.12	1000	250
3. Equalization tank	m^3	50	639	31,950
4. Mixing tank	m^3	0.045	1000	200
5. Flocculation tank	m^3	2.16	639	1,380
6. Primary settlement tank	m^3	6.75	639	4,313
7. UASB tank	m^3	42	639	26,838
8. Aeroten tank	m^3	63	639	40,257
9. Secondary settlement tank	m^3	10	639	6,390
10. Sludge dehydration tank	m^3	9	410	3,690
11. Opportunity cost of land area for plant (336m^3)	year	20	750	15,000
12. VAT (5%)				6,663
Total construction cost				**139,932**

Source: estimated by the technical expert (2007)

The plant is estimated to operate for 20 years. Each year, the system will operate for 6 months or 180 days. Thus, the cost per cubic meter of wastewater equals to 194.4 VND (139,932,000 VND/20 years/180 days/200 m^3)

2.2 Costs of supplies

Table 3A. Costs of supplies in Option 2

Cost item	Quantity	Unit price ('000 VND)	Estimated cost ('000 VND)
1. Slow mixer	1	10,000	10,000
2. Rapid mixer	1	10,000	10,000
3. Slow mixer for settlement tank 2	1	20,000	20,000
4. Air blower	3	20,000	60,000
5. Wastewater pump	2	15,000	30,000
6. pH probe	1	5,000	5,000
7. DO probe	1	5,000	5,000
8. Volumetric pumps	4	10,000	40,000
9. Sludge pumps	4	15,000	60,000
10. Screen machine	1	7,500	7,500
11. Reagent storage tank	3	2,000	6,000
12. Water pipe, valve, connector	-	25,000	25,000
13. Air pipe, valve, connector	-	20,000	20,000
14. Electric wire and equipments	-	20,000	20,000
15. Main control box	1	30,000	30,000
16. Others	-	10,000	10,000
17. VAT (5%)			17,925
Total supply cost			**376,425**

Source: estimated by the technical expert (2007)

The supplies are estimated to operate for five years. Thus, the cost per cubic meter of wastewater equals to 2091.3 VND (376,425,000VND/5 years/180 days/200m^3).

2.3 Costs of chemicals

Table 4A. Costs of chemicals in Option 2

Chemicals	Quantity (kg)	Unit price ('000 VND)	Estimated cost ('000 VND)
1. NaOH	0.003	6.0	0.02
2. PAC	10.0	5.2	52.00
3. Polymer	0.2	70.0	14.00
4. CaO	100.0	0.3	25.00
5. VAT (10%)			9.10
Total chemical cost			**100.12**

Source: estimated by the technical expert (2007)

Thus, the total chemical treatment cost for 1 m^3 equals to 500.6 VND (100,120 VND/200 m^3).

2.4 Electricity costs

Table 5A. Electricity costs in Option 2

Equipment	Quantity	Power (/h)	Estimated cost ('000 VND)
1. Slow mixer	1	0.75	21.6
2. Rapid mixer	1	0.75	21.6
3. Wastewater Pump	2	2	57.6
4. Blower	2	2	57.6
5. Volumetric pump	3	0.75	21.6
6. Mixer in settlement tank 2	1	3	86.4
7. VAT(10%)			26.6
Total electricity cost			**292.0**

Source: estimated by the technical expert (2007)

The total estimated cost of electricity is 292,000 VND for the treatment of 200 m^3 of wastewater. Thus, the cost of treatment for 1 m^3 will be 1,460 VND.

2.5 Labor costs

To operate the plant, there needs to be one environmental engineer, one electrician, and one general worker. They could work on two other similar plants in the village in the same time. The monthly wages for the three staff are estimated at 4.2 mil VND (2 mil. VND/environmental engineer + 1.2 mil. VND/electrician + 1 mil. VND/general worker) for three similar plants or 1.4 million per plant. Thus the labor cost for the treatment of 1 m^3 of wastewater will be 233.3 VND (1,400,000 VND/30 days/200 m^3)

2.6 Total treatment cost for Option 2

Thus, the total cost for the treatment of 1 m^3 of wastewater is 4,480 VND.

$$194.4 + 2,091.3 + 500.6 + 1,460 + 233.3 = 4,480 \text{ (VND)}$$

Appendix 3. Treatment Costs for Option 3

The costs shown in the tables below are for the treatment of 2,500 m^3 of wastewater in Option 3.

3.1 Construction costs

Table 6A. Construction costs in Option 3

Cost item	Unit	Quantity	Unit price ('000 VND)	Estimated cost ('000 VND)
1. Preparing the areas for plant construction				40,000
2. Sand sedimentation tank	m^3	2	410	820
3. Equalization tank	m^3	855	639	546,345
4. Mixing tank	m^3	0.64	1000	640
5. Flocculation tank	m^3	27	639	17,253
6. Primary settlement tank	m^3	109	639	69,651
7. UASB tank	m^3	706	639	451,134
8. Aeroten tank	m^3	980	639	626,220
9. Secondary settlement tank	m^3	237	639	151,443
10. Sludge dehydration tank	m^3	260	410	106,600
11. Opportunity cost of land area for plant (336m2)	Year	0	0	-
12. VAT (5%)				100,505
Total construction cost				**2,110,611**

Source: estimated by the technical expert (2007)

The plant is estimated to operate for 20 years. The system will be operated for 6 months or 180 days per year during cassava processing activity. Thus, the cost per cubic meter of wastewater equals to 234.5 VND (2,110,611,000 VND/20 years/180 days/2,500 m^3).

3.2 Costs of supplies

Table 7A. Costs of supplies in Option 3

Cost item	Quantity	Unit price ('000 VND)	Estimated cost ('000 VND)
1. Slow mixer	1	35,000	35,000
2. Rapid mixer	1	35,000	35,000
3. Slow mixer for settlement tank 2	1	85,000	85,000
4. Air blower	3	90,000	270,000
5. Wastewater pump	2	85,000	170,000
6. pH probe	1	15,000	15,000
7. DO probe	1	15,000	15,000
8. Volumetric pumps	4	25,000	100,000
9. Sludge pumps	4	45,000	180,000
10. Screen machine	1	30,000	30,000
11. Reagent storage tank	3	5,000	15,000
12. Water pipe, valve, connector	-	110,000	110,000
13. Air pipe, valve, connector	-	70,000	70,000
14. Electric wire and equipments	-	65,000	65,000
15. Main control box	1	75,000	75,000
16. Others	-	50,000	50,000
17. VAT (5%)			66,000
Total supply cost			**1,386,000**

Source: estimated by the technical expert (2007)

The supplies are estimated to operate for five years. Thus, the cost per cubic meter of wastewater equals to 616.0 VND (1,386,000,000 VND/5 years/180 days/2,500 m^3).

3.3 Costs of chemicals

Table 8A. Costs of chemicals in Option 3

Chemicals	Quantity (kg)	Unit price ('000 VND)	Estimated cost ('000 VND)
1. NaOH	0.0	6.0	0.2
2. PAC	125.0	5.2	650.0
3. Polymer	2.5	70.0	175.0
4. CaO	1,250.0	0.3	312.5
5. VAT (10%)			113.8
Total chemical cost			**1,251.5**

Source: estimated by the technical expert (2007)

The cost of chemicals for 1 m^3 of wastewater equals to 500.6 VND (1,251,500 VND/2,500m^3).

3.4 Electricity costs

Table 9A. Costs of electricity in Option 3

Equipment	Quantity	Power (KW/h)	Estimated cost ('000 VND)
1. Slow mixer	1	1	28.8
2. Rapid mixer	1	3	86.4
3. Wastewater Pump	2	4	230.4
4. Blower	2	12	691.2
5. Volumetric pump	3	0.75	64.8
6. Mixer in settlement tank 2	1	3	172.8
7. VAT(10%)			127.4
Total electricity cost			**1,402**

Source: estimated by the technical expert (2007)

The total estimated cost of electricity is 1,402,000 VND for the treatment of 2,500 m^3 of wastewater. Thus, the cost for the treatment of 1 m^3 will be 560.8 VND.

3.5 Labor costs

Option 3 requires one environmental engineer, one electrician and four general workers. The monthly wages for the six staff are estimated at 7.2 mil VND (2 mil. VND/engineer + 1.2 mil. VND/ electrician + 1 mil. VND x 4 regular workers). Thus, the treatment cost for 1 m^3 of wastewater will be 96.0 VND (7,200,000 VND/30 days/2,500 m^3).

3.6 Total treatment cost for Option 3

Thus, the total cost for the treatment of 1 m^3 of wastewater is **2008 VND.**

$$234.5 + 616.0 + 500.6 + 560.8 + 96.0 = 2,007.9 \approx 2,008 \text{ VND}$$