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RESEARCH REPORT

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Household Switching Behavior In The Use Of Groundwater In The Mekong Delta, Vietnam

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This study assesses the different water supply options available to people in Vietnam's Mekong Delta (VMD). It ascertains which source is the cleanest and most sustainable, and then sees whether people can be encouraged to switch to this source.

The study was conducted by Dr Vo Thanh Danh from the School of Economic and Business Administration at Can Tho University. He finds that there are three main sources of water in the VMD – rainwater, river water and groundwater.

Of the three options, groundwater represents the best alternative both in terms of its popularity and its cleanliness. The best method to supply this resource is through groundwater supply units or GSUs. GSUs extract water from a geological level where it is less polluted and, because users have to pay a fee for the water they use, they also encourage water conservation.

Calculations of potential supply and demand show that GSUs would be a sustainable option. The report concludes that people would be willing to switch to this popular option and recommends that the GSU program should be widely promoted by government.

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HOUSEHOLD SWITCHING BEHAVIOR IN THE USE OF GROUND WATER IN THE MEKONG DELTA, VIETNAM

Vo Thanh Danh

July, 2008

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All opinions, findings, conclusions, and recommendations expressed in this report are those of the author and do not necessarily reflect the views of EEPSEA. The author is solely responsible for any errors in this paper.

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HOUSEHOLD SWITCHING BEHAVIOR IN THE USE OF GROUND WATER IN THE MEKONG DELTA, VIETNAM

Vo Thanh Danh

EXECUTIVE SUMMARY

This report identifies the options available to households in the Mekong Delta of Vietnam (VMD) in dealing with the quality of their water sources and presents an analysis of their switching behavior across such sources.

The VMD is home to 18 million people who account for 21 per cent of the country's population. There is a huge demand for clean water by its residents. In the rural area especially, although there is a network of rivers, the use of clean water is limited due to pollution from agricultural production activities, aquaculture, and salination in the dry season. A fraction of clean water comes from ground water. Currently, ground water is mostly extracted from shallow tube-wells at the household level and ground water plants that are installed by the government via a rural development program. The objective of the rural clean water supply program in the MRD is to provide rural people with access to clean water for domestic use. The fact that the river water is highly polluted and of inferior quality in the dry season and rainwater is hard to collect and store makes ground water the best source of clean water.

Clean water supply in the MRD is complex. This study identified six possible management alternatives to deal with the problem of clean water supply using three main water sources: rainwater, surface water, and ground water in the MRD. Clean water alternatives depended on the availability of water resources and the economic condition of the households as well as the type of pollution affecting the water resources.

This study found that the water consumption of ground water supply unit (GSU) users was significantly lower compared with those using private tube-wells for their water needs. Even at the highest consumption level, the mean GSU water consumption was only at 109 liter[1]/person/day, which was less than half that of private tube-well users. This result supports the conclusion that switching from private tube-wells to GSU water would encourage water saving, thus preventing ground water resources from being over-extracted.

For non-GSU users, the probability of switching to GSU water was found to be 37 per cent. Income played an important role in encouraging households to switch to using GSU water. In addition, the interaction effects between income and the education level of the head of the household and the length of the time the household had settled in the community increased the probability of switching to GSU water.

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[1] 1 m^3 = 1,000 liters

1.0 INTRODUCTION

Vietnam's Mekong Delta (VMD) is home to 18 million people who account for 21 per cent of the country's population. There is a huge demand for clean water by its residents. A fraction of this comes from ground water. Currently, ground water is extracted in the VMD by households from shallow tube-wells with a depth of 80–120 meters (m) and ground water plants digging deep wells to a depth of 200–450 m. Michael (1994), as cited by Tuan (2004), noted that an upper section of recent alluvium and a lower section of older alluvium underlie the VMD. The older alluvium contains a permeable artesian zone called the 100-metre aquifer or upper Pleistoxen aquifer, which is the most productive ground water reservoir in Vietnam. Tested well capacities range from 33–144 m^3/hour. However, part of the 100 m aquifer is intruded by seawater. There are now more than one million shallow tube-wells. Forty per cent of them are UNICEF-made types with an extraction volume of 430,000 m^3/day.

The ground water of Can Tho Province has four layers; namely, Pleistoxen, Plioxen, Mioxen, and Holoxen. There are only three ground water layers, however, that can be extracted for clean water use purposes. The one not included is the Holoxen layer due to bio-micro pollution. However, even for the Pleistoxen layer, the high level of nitrate pollution and high chlorine concentration cause many health problems for users of the water extracted from this layer. Besides the possibility of pollution created by agricultural practices that use chemical fertilizers and pesticides, pollution also happens due to worn out tube-wells. Pollutants from the surface seep over time into ground water layers and destroy the quality of the water. Ground water pollution poses serious health risks for water consumers (Quyen 2005).

Over-extraction, saltwater intrusion, and pollution are problems linked to the ground water supply situation in the VMD. Unrestricted access increases the number of private tube-wells. As a result, over-extraction can be said to be happening in the whole delta. The phenomenon of ground water table reduction in the dry season reduces the sustainability of ground water supply and increases the cost of water pumping. Another impact of over-extraction is saltwater intrusion. The quality of the ground water aquifer gets degraded and in some cases, the saltwater intrusion also destroys the water quality of the ground water aquifer. Finally, the possibility of ground water pollution from various sources will endanger the quality of the ground water in the long run. If these adverse impacts are not prevented or eliminated, the availability of clean water supply will be severely compromised.

The objective of the Rural Clean Water Supply Program in the VMD is to provide rural people with access to clean water for domestic use. The fact that river water is highly polluted and of inferior quality in the dry season makes ground water the best source of clean water. Giving ground water high priority in the clean water supply program, however, places significant pressure on the sustainability of ground water use. Currently, ground water is extracted via small-scale household tube-wells and large-scale wells built by corporations (called ground water supply units or GSUs). Using ground water from each type of well has both advantages and disadvantages, as well as different environmental and economic impacts.

This study was developed to identify clean water use options, explore the advantages and disadvantages of each option, and analyze household switching behavior across water sources. A survey of non-GSU users (i.e., households that own private tube-wells) and GSU users (i.e., households that buy water from GSUs) was undertaken. An analysis of switching behavior from non-GSU use to GSU use was made. For current GSU users, factors that affected the choice of GSU water in terms of water quantity and quality were identified. Moreover, the reasons for the preferences in water sources were explored for both GSU and non-GSU users. Finally, the factors affecting the operation and management of GSU plants were also studied.

The specific objectives of the study were:

1. To estimate the supply of and demand for ground water.

2. To evaluate the current extraction rate relative to the sustainable yield level of ground water.

3. To measure the possibility of switching from existing sources of water to water supplied by GSUs.

4. To identify possible management alternatives to deal with the clean water supply problem.

5. To evaluate the constraints and advantages of each water use management alternative.

The analysis of household behavior of private tube-well and GSU water users, as done in this study, helped to identify the demand and supply situation of ground water. Meanwhile, the proper management of ground water is certainly necessary to prevent the possibility of deterioration of this valuable natural resource. Water pricing is the usual recommended solution to this problem. How ground water should be priced, however, is a question that should be answered in a future study on this topic.

2.0 THEORETICAL FRAMEWORK AND METHODOLOGY

2.1 Theoretical Framework

To understand the problem of ground water management in the study area, there was a need to combine both supply and demand analyses in a market-oriented framework of ground water resource management. Three major components in ground water resource management that were considered in the study were:

1. The quantity and quality of ground water supply (by GSU suppliers)

2. The quantity and quality of water demanded (by household users)

3. Pollution control

The interactions of three components are depicted in the Figure 1. There are three types of actors involved; namely, the GSU manager (or water supplier), the GSU user (or connector), and the non-GSU user. The non-GSU user is defined as a water user who owns a private tube-well. The supply-demand pattern for ground water in the figure shows that pollution factors affect the choice of tube-well and GSU water users. Water users who were neither tube-well water users nor GSU connectors were not included in this study.

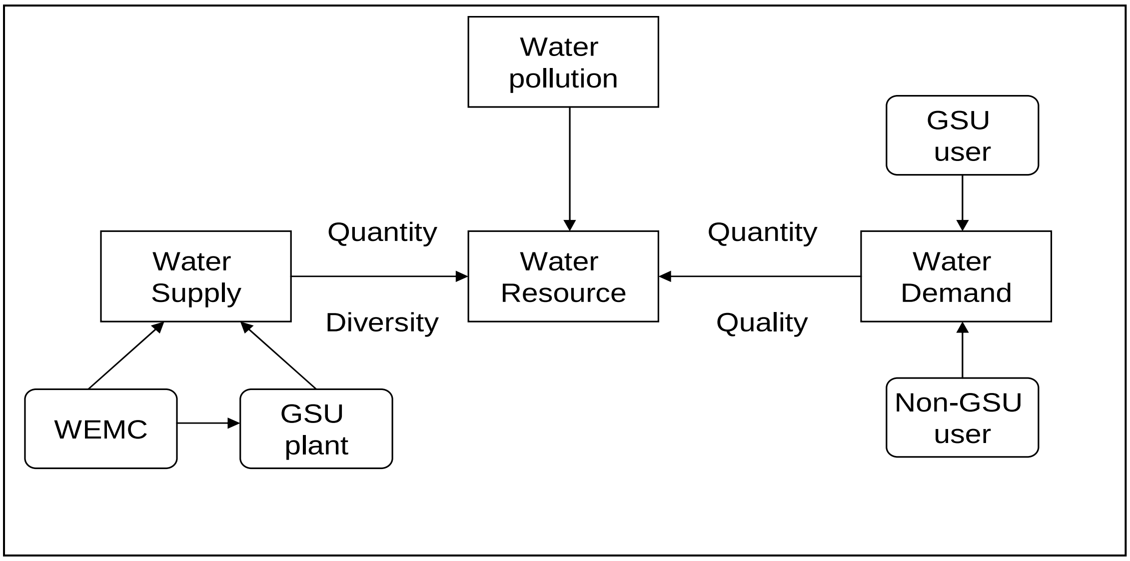

Figure 1. Theoretical framework of ground water management in the Mekong Delta

Note: WEMC = Water and Environment Management Center

2.2 Study Site and Field Methods

This study was conducted in Can Tho City and Hau Giang Province (formerly part of Can Tho Province). The study site was located in the centre of the VMD covering a total land area of 2,986 km^2. The area has two seasons a year: dry and rainy. The dry season is from December to April while the rainy season is from May to November with an average rainfall of about 92-97% of the year's total (1,635 mm per year). The average temperature is 27^oC.

Can Tho City has abundant surface water and ground water reserves. A network of rivers and canals is interlaced with a total length of 4,300 km and a density of 1.8 km/km^2. The rivers are a rich source of water in the rainy season. However, in the dry season, most rivers and canals are salinized and polluted by agro-chemicals. Consequently, surface water cannot be used for domestic purposes in the remote areas. Can Tho's total ground water reserve is about 5.5 million m^3 with a potential extractable quantity of 763,531 m^3/day, 384,562 m^3/day, and 1,450,407 m^3/day for the Pleistoxen, Plioxen, and Mioxen layers, respectively. So far, the ground water is extracted mostly from the Pleistoxen layer. In the year 2000, the total extracted amount of ground water for domestic use was about 57,000 m^3/day (Can Tho WEMC Report 2002).

Figure 2. Study site in Can Tho Province

There were three different questionnaires for three types of respondents in the survey; the GSU managers, the GSU users, and the non-GSU users. For all three types of questionnaire, there were two common sections: information about the characteristics of the respondents, and information on the supply of and demand for water. Questions about the pollution of ground water resources were asked to evaluate the effects of knowledge on pollution in selecting water sources to use. The focus group discussion method was used to design the questionnaires. Then, pre-test surveys were done to ascertain the appropriateness and level of difficulty of the questions. Based on the results of the pre-test surveys, the questionnaires were redesigned. Finally, before doing the field surveys, pilot surveys were conducted.

The GSU plant managers were interviewed on the status of ground water supply. The number of GSU plants as per the list from the WEMC was 394 at the time of the study. A fifth of this was randomly selected. On the demand side, a sample of 127 GSU users and 233 non-GSU users were interviewed. Four out of twelve districts except two urban districts were randomly selected to conduct the surveys in. These were Cai Rang, Long My, Phong Dien, and O Mon. As a first step, a GSU plant was randomly positioned in each district. Based on the number of clients that the GSU manager of the designated plant accounted for, interval sample groups with a minimum of 30 GSU-users and 60 (double the number) non-GSU users were selected in each district. To find out how many households there were in the area where GSU plants were located, the local authorities were contacted prior to the interviews. The surveys for all three questionnaires were implemented through face-to-face interviews, each taking about 40-50 minutes. To be sure that the sampling procedure was properly followed by the numerators, a team of two experienced field persons supervised the surveys. A quality check resulted in the dropping of seven from 367 questionnaires.

2.3 Methods of Analysis

To analyze the current supply and demand situation of ground water, regression models were used. The forecasting of demand and supply patterns was performed using linear probability models (LPM). To evaluate the effects of socio-economic factors on changing supply and demand patterns, the discriminant analysis (DA) method was applied.

2.3.1 Regression Models

Regression analysis allowed us to identify the key contributing factors affecting the supply and demand for ground water. There were three types of regression models used in the study; the multiple regression model, the two-step switching regression model, and the linear probability model.

Multiple Regression Model — This was used to explain the correlations between the socio-economic characteristics of GSU households and GSU managers, and GSU water expenditure and the amount of water sold, respectively. The multiple regression model is presented as follows:

$$Y_i = a_0 + a_1X_{1i} + a_2X_{2i} + \ldots + a_kX_{ki} + \ldots + a_nX_{ni} + \varepsilon_i \quad (1)$$

where

Y_i: dependent variable representing either GSU water expenditure of a GSU household) or the amount of water sold by a GSU plant

X_{ki}: explanatory variables representing the socio-economic characteristics of the k^{th} GSU household and the i^{th} GSU manager selected in the sample

a_i: estimated coefficients

ε_i: error term

Two-Step Heckman Switching Regression Model — This was used to model the decision-making behavior of households. A non-GSU household has to decide, first, whether or not to buy GSU water, and second, how much to buy. Following Maddala (1983), a statistical model was formulated as follows:

$$Y_i = a_0 + a_1X_{1i} + a_2X_{2i} + \ldots + a_kX_{ki} + \ldots + a_nX_{ni} + \varepsilon_i \quad (2)$$

Y_i is observed if and only if $b_0 + b_1X_{1i} + b_2X_{2i} + \ldots + b_kX_{ki} + \ldots + b_nX_{ni} + \gamma_i > 0$

$\mathrm{Corr}(\varepsilon_i,\gamma_i) \neq 0$

where

Y_i: dependent variable representing the demands of the i^{th} non-GSU household

X_{ki}: explanatory variables presenting socio-economic characteristics of the k^{th} non-GSU household, and the i^{th} non-GSU household selected in the sample

a_i and b_i: estimated coefficients

ε_i and γ_i: error terms

Corr: covariance

The difference between Equation (1) and (2) is that Y_i in Equation (1) is an observable variable (or actual variable) while Y_i in Equation (2) is an unobservable variable (or latent variable).

Linear Probability Model — This was used to forecast the demand or supply in the ground water market. The results of the model allow one to make a prediction about the probability of a non-GSU household switching to GSU water and the probability of a higher amount of GSU water being sold during the dry season compared with the volume sold during the rainy season as determined by specific characteristics of non-GSU households and GSU managers, respectively. The model is stated as follows:

$$Y_i = a_0 + a_1X_{1i} + a_2X_{2i} + \ldots + a_kX_{ki} + \ldots. + a_nX_{ni} + u_i \quad (3)$$

where

Y_i: dependent variable (dichotomous variable: 1 for willingness to switch to GSU water; 0 for otherwise)

X_{ki}: explanatory variables representing the socio-economic characteristics of the k^{th} non-GSU household or GSU manager and the technical nature of the i^{th} GSU plant

a_i: estimated coefficients

u_i: error term

2.3.2 Discriminant Analysis Model

To identify the factors affecting the difference in water demand by GSU households and the difference between the GSU water quantities sold in the dry season and the rainy season, the discriminant analysis (DA) model was used. It is presented below.

$$D = \alpha + \beta_1X_1 + \beta_2X_2 + \ldots.. + \beta_nX_n \quad (4)$$

where

D: discriminant or dependent variable representing either the water demand of a GSU household or water sold by a GSU plant

X_is: predictors or independent variables

α and β_is: standardized canonical discriminant coefficients[2]

The reason for using a DA function instead of a regression model to distinguish the difference in water demand by GSU households and the difference in GSU water quantities sold in the dry season and the rainy season is that the information on the quantity of water used by the consumer or sold by the supplier in the different seasons could not be collected at the time of the survey.

To estimate these models, an SPSS package was used, except that the Heckman Switching Regression model was estimated by using the STATA package since an add-in function was available.

3.0 GROUND WATER USE IN CAN THO PROVINCE

3.1 Ground Water Reserves

Aranyossi (1972), cited by Quyen (2005), stated that the age of the ground water in the 100 m layer in the VMD is about 15,600 years old. In Can Tho Province, there are four underground layers; Holoxen, Pleistoxen, Plioxen, and Mioxen. The Holoxen covers whole areas at a depth of 54–74 m. Most water samples from this layer are polluted by bio-pollutants and risky to use. Water in the Pleistoxen layer is weak pressure ground water. It is found everywhere in the area within a range of 80–100 m. The quality of ground water in this layer is the best of the four for use and is extractable in large amounts. In the Plioxen layer, the ground water is not homogenously allocated and its quality varies from place to place as well. The depth of this layer is from 100–120 m. The ground water from this layer should not be used for drinking due to its very high mineral and chemical content. Finally, the Mioxen layer lies at 350-500 m.

Table 1 presents the ground water reserves in static, elastic, and dynamic forms[3] in the four layers, and the safe yield, designed capacity and extraction amounts of ground water in the VMD. The total ground water reserve in the VMD is about 1,375,190 m^3/day for all three forms of water reserves in which the static form has the largest amount at 1,269,520 m^3/day. The ground water in the Holoxen layer is found only in the dynamic form at 23,850 m^3/day while the three other layers have a total of 10,980 m^3/day of this form of water. Fifty two per cent of the total ground water

[2] A standardized canonical discriminant coefficient is used to compare the relative importance of the independent variables. Put another way, it indicates the partial contribution of each independent variable to the dependent variable.

[3] The static form refers to the state of stagnant ground water. The elastic form refers to the state of seasonal change of ground water. The dynamic form refers to the state of continuous flow of ground water.

reserve is stored in the Pleistoxen layer. In the VMD, the safe yield (the extraction yield that will not salinate or deplete the ground water aquifer) is about 750,584 m^3/day. Meanwhile, the capacity of the extraction pump is currently 163,558 m^3/day although the amount of ground water actually extracted is only 101,061 m^3/day.

Table 1. Details of ground water reserves in Can Tho Province

Layer	Ground water reserves (m^3/day)			Total
	Static	Elastic	Dynamic	
Holoxen	-	-	23,850	23,850
Pleistoxen	681,440	28,640	6,360	716,440
Plitoxen	349,580	10,800	920	361,300
Mioxen	238,500	31,400	3,700	273,600
Safe yield: 750,584 m^3/day				
Designed capacity: 163,558 m^3/day				
Actual extraction: 101,061 m^3/day				

Source: Can Tho DARD (2002)

3.2 Ground Water Extraction

Currently, ground water is mostly extracted from the Pleistoxen layer which has abundant water reserves. Private wells found in the area are mostly at 70-120m while GSU wells are at the 100-250 m level. Table 2 presents the current situation of ground water extraction in Can Tho Province. In 1998, there were 31,216 wells. Most of them were used for domestic and agricultural production purposes. In 2002, there were 54,250 wells with a total extraction amount of 114,000 m^3/day including 52,814 tube-wells and 201 GSU wells for domestic use, 829 wells for irrigation and livestock production, 114 wells for industrial purposes, and 292 for service purposes. In the period 1998–2002, the number of wells used for domestic purposes almost doubled while the number of wells used for agricultural production was nearly halved. Wells used for industrial purposes were mostly located in the industrial parks. The capacity of industry wells was relatively large in the range of 20–40 m^3/hour. The total extraction amount of both industrial and service users was collectively estimated at 71,600 m^3/day. However, from the 406 industrial and service wells, there were only 33 (8.13%) with licenses. Of the 201 GSU wells, 18 had a capacity of 20 m^3/hour and 183 had a capacity of 4–6m^3/hour. Medium-scale GSU wells were located in districts while small-scale GSU wells were located in villages. In 2005, there were 394 GSU wells with a depth range of 60–228 m. Presently, the private management model for GSU wells is being expanded and is considered as an efficient management model.

Table 2. Ground water use purposes in Can Tho Province, 1998-2002

Unit: number of wells

Use	1998	2002
Domestic use	28,779	53,015
Irrigation in agricultural production	1,569	829
Industrial use	94	114
Service use	285	292
Total	**30, 727**	**54,250**

Source: Can Tho DARD (2002)

3.3 Ground Water Use

As at 2002, 24 per cent of the population was using ground water. In remote areas like Long My, Chau Thanh, and Phung Hiep Districts, the rate of using ground water is very high. These areas face the serious problem of accessing clean water during the dry season since the water in rivers or canals is usually salinized at this time. Table 3 shows the state of ground water use in Can Tho Province in 2002. There is a big variation in the consumption quantities of ground water from tube-wells and GSUs. According to the Can Tho DARD's 2002 survey on the status of ground water resources, the average amount of tube-well water used by a household was 283 liters/person/day[4]. Meanwhile, calculations by the WEMC (2006) showed that the average amount of GSU water used by a household was only 30 liters/person/day. The average amount of water used by the GSU users interviewed in this study was 43 liters/person/day[5]. This study also found that pricing tends to reduce the amount of GSU water used. It is thus reasonable to assume that once more households switch to GSU ground water, over-extraction will be reduced.

Table 3. State of ground water use in Can Tho Province, 2002

District	Area (km^2)	Population ('000 people)	Number of households ('000)	Number of GW households ('000)	Number of GW users ('000)	% GW users	% GW house -holds
Can Tho	143.5	334.8	62.7	10.0	57.9	15.9	17.3
Thot Not	581.5	335.0	60.2	12.8	71.4	21.2	23.9
O Mon	545.4	305.6	53.1	14.0	71.8	26.3	23.5
Chau Thanh	177.0	121.3	23.5	4.9	26.0	20.7	31.5
Chau Thanh A	231.4	165.6	34.8	8.2	46.0	23.5	27.8
Phung Hiep	564.3	255.3	49.2	13.2	77.3	26.8	30.3
Long My	396.1	155.8	31.0	12.0	63.3	38.8	40.6
Vi Thuy	230.2	92.9	18.8	4.0	21.9	22.0	23.5
Vi Thanh	118.7	67.9	12.8	1.1	6.1	8.7	9.1
Total	**2,988.1**	**1,834.2**	**346.1**	**80.2**	**441.7**	**23.2**	**24.1**

Source: Can Tho DARD (2002)

Note: GW = Ground Water

[4] In Table 1, the rate is 229 liters/person/day (101,061,000 liters for 441,600 people)
[5] Evaluated at a mean use of 5.88 m^3 per month and a mean family size of 4.57 people.

3.4 Description of the GSU Project

A nation-wide program of clean water supply for rural areas was launched in the region in 1986. As a result, rural clean water and environment management centers (WEMCs) were established in the VMD via cooperation between the Vietnamese government and UNICEF. The main objective of the WEMCs was to help the poor in rural areas to be able to access clean water through ground water projects. Besides building private small-scale tube-wells, the program launched an impressive plan of establishing a network of ground water supply units (GSUs) covering whole rural areas. This network has been established by the WEMCs and operated by partners who are the landowners of the areas where GSU plants are located. This GSU project is expected to solve the issue of depletion of ground water caused by overuse by households — as GSU water is priced, this is expected to affect the quantity of water used which should adjust itself over time to an efficient level. This differs from the case of private tube-wells where the quantity of ground water used depends solely on the needs of the household.

The WEMC is the unit which is in charge of the management of clean water supply and environmental sanitation protection for rural areas. There are three types of GSUs; small-scale, medium-scale, and large-scale with a capacity of 4-6 m^3/hour, 10-20 m^3/hour, and up to 90 m^3/hour, respectively. However, most GSUs are small-scale. A small-scale GSU ensures supply to 100-150 household users. Figure 3 describes the components of a small-scale GSU.

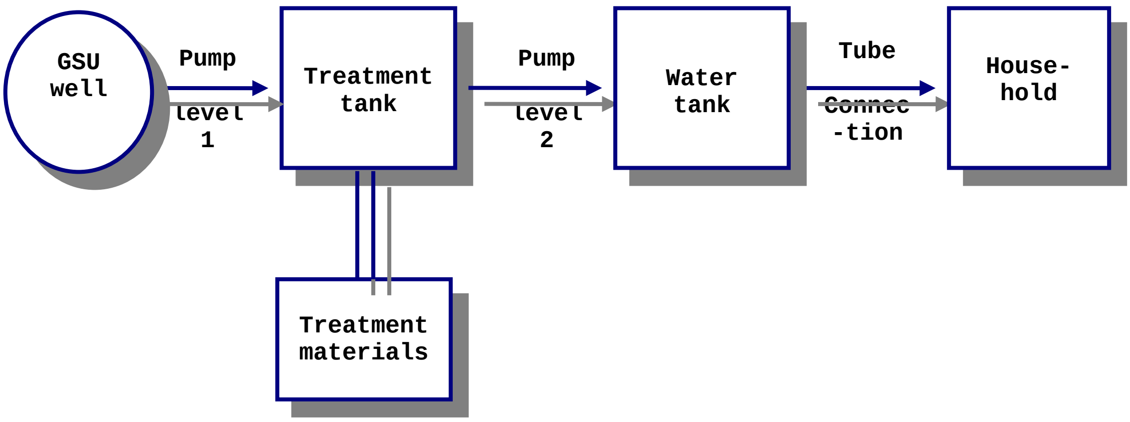

Figure 3. Components of a small-scale GSU

The small GSU wells have the depth of 100-120 m. The type of tube used is 49-60 mm in diameter and it allows a maximum capacity of 6 m^3/hour. Ground water is pumped to a treatment tank which removes bad odors and pollutants; the cleaned water then flows to a water container. The treatment tank has a volume of 16 m^3. It has three components; a carbon filter, a sand filter, and a treated water container. The water container has a volume of 4 m^3 and is placed at a height of 6 m to create pressure for the water distribution system. The length of the main distribution system is about 1,500–2,000 m along the roads and rivers. The amount of clean water designated for household users is about 60-80 liters/person/day.

3.5 Ground Water Resource Management

3.5.1 Extraction Rights

Extraction rights were defined in the "Temporary Decision on Permits for Extraction of Ground Water and Licensing of Drilling Companies" circulated in 1996; later the contents of this regulation were embedded in the Law on Water Resources 1999. It is stated that permit holders have the right to exploit and use ground water resources for purposes of living, agriculture, forestry and industrial production, mining, electricity generation, water transport, aquaculture, sea fishery, salt-making, medicine production, health rehabilitation, recreation, sports, tourism, scientific research and other purposes.

The criteria for the issuance of permits are defined as follows:

- Anyone who implements ground water exploration or ground water extraction for any purpose must have a permit except for some subjects as indicated below.

- Ground water dewatering required during the construction or excavation of construction materials also requires a permit.

- Owners of ground water extraction facilities that wish to expand the facilities for larger extraction or to change the purpose of water use must apply for a permit.

Subjects that do not need to apply for a permit are:

- Families that can establish a small-scale ground water extraction within a household for the purposes of domestic use, gardening, aquaculture, handicraft-making, and other non-business purposes.

- Any rehabilitation of ground water extraction facilities that does not change the content of the original permit.

However, in recent years, many are clamoring for household ground water extraction to be regulated as well. There are currently three kinds of ground water wells; private tube-wells made by private drilling teams, private or community tube-wells provided by the UNICEF program, and GSU plants mostly established by the WEMCs. While the government implemented regulations for community tube-wells and GSU plants, the private tube-wells which comprised the biggest number of ground water wells were not controlled. If private tube-wells are not controlled appropriately, the state of ground water pollution and subsidence (lowering of the ground water table) cannot be controlled as well. The management of ground water resources is thus a problem faced by the local authorities, especially at the lower level. Table 4 shows the management units for ground water resources at Cai Rang district. There are five units delegated to administer the distribution of ground water for seven precincts in the district. However, they lack the expertise required to properly manage water resources and one can therefore say that effectively, there is no real management of ground water resources taking place.

Table 4. Management units in charge of ground water distribution in Cai Rang District

Precinct	Management unit
Le Binh	Red Cross
Ba Lang	Department of Culture-Information
Thuong Thanh	Department of Agriculture
Hung Phu	Department of Socio-Culture
Hung Thanh	Department of Agriculture
Phu Thu	Department of Agriculture
Tan Phu	People's Committee

Source: Quyen (2005)

3.5.2 Water Pricing

In Vietnam, water prices are controlled by the government which changes them from time to time. Generally, the water price set for domestic use is lower than the price for industrial purposes. There is no price differentiation between ground water and surface water. The prices also do not reflect the environmental and depletion costs of ground water extraction. Table 5 presents the schedule of water prices applied in the country.

Table 5. Schedule of the new tap water prices (effective from March 2000)

Water user	Consumption rate m^3/month	Old charges VND/m^3	New charges VND/m^3
Household size (number of persons)	up to 4 4 – 6 6 – 10 over 10	1,300 1,300 1,500 1,500	1,700 2,500 3,200 4,000
Governmental agencies and organizations	1 to <10 10 to >10	1,300 1,300	2,200 3,000
Industrial users	over 10	3,100	4,000
Business and service users	over 10	5,200	6,500

Source: Tuan (2004)

Note: Surcharges added include: (1) water use VAT (5%), and (2) sewerage fee (180 VND/m^3)

4.0 FINDINGS AND DISCUSSION

4.1 Descriptive Statistics

Among the 441 respondents in the survey, there were 127 GSU users, 233 non-GSU users, and 81 GSU managers. Generally, the demographic characteristics of water users sampled were similar in age, education status, years of residence in the study site, and household size. However, there was a difference in the mean household incomes of GSU users and non-GSU users. The non-GSU users' average household income was significantly higher than the GSU users' average household income. For the water supply side, the mean education level of the GSU managers was secondary school level and the designed capacity (number of households) of the GSUs ranged from 45–90. Table 6 provides the descriptive statistics of water actors in the survey.

Table 6. Descriptive statistics of water actors

Characteristic	Mean	Minimum	Maximum	Standard deviation
Non-GSU users				
Age (in years)	48	17	82	13.5
Education level [a]	3	1	5	0.86
Number of years of residence	32	1	79	16.65
Number of family members	5	1	12	1.87
Income per month (million VND)	3.27	0.25	25.0	3.72
GSU users				
Age (in years)	45	17	86	14.8
Education level [a]	3	1	5	0.81
Number of years of residence	31	1	85	17.14
Number of family members	5	1	12	1.62
Income per month (million VND)	2.28	0.25	14.0	1.75
GSU managers				
Age (in years)	43	19	69	12.55
Education level [a]	3	2	5	0.77
Designed capacity (number of households)	157	90	450	65.67
Number of years GSU established (up to 2006)	3	1	7	1.71

Note: [a] 1, 2, 3, 4, and 5 stand for illiterate, primary level (1-5 years), secondary level (6-9 years), high school (10-12 years), and tertiary level (>12 years), respectively.

Some of the socio-economic variables were used to analyze the water supply situation of GSU plants and water demand situation of both the current GSU users and the non-GSU users (potential GSU users). These economic variables with their definitions are presented in Table 7.

Table 7. Definitions of variables used in the study

Variable	Definition
General sample and Non-GSU user sample	
SWITCH	Dummy variable of switching (1 for willingness-to-switch; otherwise 0)
SEX	Sex (1 for male; otherwise 0)
AGE	Age in years
EDUCATION	Educational level (1, 2, 3, 4, and 5 for illiterate, primary, secondary, high school, and tertiary level, respectively)
OCCUPATION	Dummy variable of occupation (1 for farmer; otherwise 0)
ETHNIC	Ethnic (1 for Kinh; otherwise 0)
RESIDENCE	Years of residence in the study site
FAMILY NUMBER	Number of family members
INCOME	Monthly household income (million VND)
DISTANCE	Distance from household to nearest GSU (km)
GSU user sample	
DISTRICT-D1	District (1 for Phong Dien District; otherwise 0)
DISTRICT-D2	District (1 for Cai Rang District; otherwise 0)
DISTRICT-D3	District (1 for O Mon District; otherwise 0)
EDUCATION-D1	Educational level (1 for illiteracy or primary school; otherwise 0)
EDUCATION-D2	Educational level (1 for secondary school; otherwise 0)
RESIDENCE-D1	Years of residence (1 for prior to 1976; otherwise 0)
RESIDENCE-D2	Years of residence (1 for 1976-1985; otherwise 0)
RESIDENCE-D3	Years of residence (1 for 1986-1995; otherwise 0)
AMOUNT 1	GSU water amount bought monthly
GSU manager sample	
DEPTH	Depth of GSU well (m)
MANAGER EDUCATION	Dummy variable of educational level (1 for high school or tertiary; otherwise 0)
YEARS GSU ESTABLISHED	Number of years the GSU plant has been established (up to 2006)
AMOUNT 2	GSU water quantity sold monthly (m^3)
CAPACITY	Designed capacity (number of households)

4.2 Ground Water Demand Analysis

There were 127 households using ground water supplied by GSU plants and 233 households using ground water from their own private tube-wells. Three main sources of water could be found in the study area. Generally, the preference of the households for the different water sources was ranked as follows: 52.4 per cent, 24.5 per cent, 21 per cent, and 2.1 per cent for tube-wells, rain water, GSU water, and river water, respectively. The results showed that ground water was the most preferred water source. Rain water ranked second while river water was hardly preferred at all. As mentioned in the earlier sections, the serious pollution of the rivers in recent years has discouraged people from using river water. Meanwhile, rain water presented problems of air pollution, reliability and storage. It can be stated that for domestic purposes, people in the VMD prefer to use ground water over other water sources. However, they still use other water sources like rain water and river water for their daily activities. Nearly two-thirds of the households believed that using ground water would allow them to avoid health hazards. The reliability of ground water sources was also appreciated by the households. For rain water and river water, availability and reliability were cited as the most important reasons for continued domestic use. Table 8 presents the main reasons for the households' choice of water sources for domestic use.

Table 8. Reasons for choice of water sources for domestic use of the average household in the VMD

Unit: %

Reasons for choice	Sources of water		
	Ground water	Rain water	River water
Reliability	67.4	16.9	41.2
Availability	27.9	62.8	71.9
Convenience	15.9	25.0	-
Health concerns	63.9	35.8	1.8
Other water source polluted	78.1	20.3	-
Low cost	36.9	25.0	36.8

Source: Survey 2006

Ground water was the most important source used by GSU users and non-GSU users for different activities such as cooking, drinking, bathing, washing, and gardening. Table 9 shows the ranking of water sources used for different kinds of activities.

Table 9. Ranking of water source by purpose of use

Unit: %

Water sources	Purpose of use					
	Drinking	Cooking	Bathing	Washing	Gardening	Other
Non-GSU users						
Ground water	61.8	90.4	97.9	93.6	39.3	24.5
Rain water	57.7	24.4	3.4	3.0	-	-
River water	6.7	9.8	8.5	25.2	-	6.4
GSU users						
Ground water	74.8	100.0	100.0	77.2	3.1	4.7
Rain water	41.7	18.9	-	-	-	-
River water	-	-	11.0	37.8	34.6	7.9

Source: Survey 2006

4.3 Demand of Non-GSU Users

To measure the demand for GSU water in the VMD, two categories of water users were interviewed in the study. These were the current GSU users and non-GSU users. This section discusses the non-GSU users' demand, forecasting their willingness-to-switch to using GSU water and estimating their demand for GSU water.

To predict the switching pattern of non-GSU households, a linear probability model (LPM) was used in the study. The results of the LPM estimation in Table 10 were used to evaluate factors affecting the change in the probability of switching. In the study, demographic characteristics of the household head included in the model were gender, age, education status, and occupation. Firstly, at the significance level of 10%, if the head of the household was male, the probability of switching was 5.3 per cent higher than if the head was female. The head's age was also an important factor. The probability of switching by younger people was significantly higher than for older ones. It was found that if the head of the household was 40 years old or younger, the probability of switching was 17 per cent higher than if the head was over 60 years of age. Education status had a positive relationship with willingness-to-switch. A head with a high school education had a higher probability of 9.8% and 5.7% of switching than one who had finished only primary school and secondary school, respectively. However, the result for the latter was not statistically significant. The occupation of the household head did not significantly affect the probability of switching to GSU water.

Other household characteristics that were taken into account in the decision to switch to GSU water included: the time/year of settlement (to indicate the years of residence in the area), household size, and household income. The probability of switching of a household which had settled prior to 1976 was 18 per cent lower than that of a household which had settled from 1996–2005. In the same manner, the probability of switching of a household which had settled in the period 1976-1985 was 11 per cent lower than that of a household which had settled from 1996–2005. It is probable that the quality of ground water from the private tube-wells that were built prior to 1986 was better so much so the households preferred tube-well water to GSU water. The longer the household had settled in the area, the lower the probability of switching was, except for the 1986-1995 period. Secondly, the size of the household had a positive relationship with the probability of switching to GSU water. As the size of the household increased, the probability of switching increased. A household that had fewer than four people had a lower probability of switching than a household with more than four people. Lastly, households with low incomes were most likely to switch. At the 5 per cent significance level, households with a mean monthly income of 2–5 million VND and higher than 5 million VND had a lower probability of switching at 6.2 per cent and 19.5 per cent, respectively, as compared with those with mean monthly incomes of less than 2 million VND. This showed that poor households, which had no access to ground water treatment systems[6], had the highest demand of the three income groups for GSU water and that they had the capacity to pay for it.

[6] In the survey, 4.4 per cent, 10.6 per cent, and 19.8 per cent of households having a clean groundwater treatment system had mean monthly incomes of below 2 million VND, 2-5 million VND, and over 5 million VND respectively.

Table 10. Results of LPM estimation on non-GSU users switching to GSU water use (Dependent Variable: SWITCH)

Explanatory variable	Coefficient	t-value
Constant	0.853	5.028***
SEX		
Female	……..	…….
Male	0.053	1.746*
AGE		
≤ 40 years	……..	…….
41-60 years	-0.118	-1.622ns
≥ 61 years	-0.17	-1.869*
EDUCATION		
High school and above	…….	….
Primary school	-0.098	-1.741*
Secondary school	-0.057	-1.423ns
OCCUPATION		
Other careers	…….	…….
Farmers	0.019	1.156ns
RESIDENCE		
1996-2005	…….	……
< 1976	-0.181	-1.86*
1976-1985	-0.1	-1.571ns
1986-1995	0.025	1.743*
FAMILY NUMBER		
≤ 3 persons	…….	…….
4-5 persons	0.041	1.591ns
6-7 persons	0.039	1.906*
≥ 8 persons	0.058	1.719*
INCOME		
< 2 million VND	…….	…….
2-5 million VND	-0.062	-2.256**
> 5 million VND	-0.195	-2.561**
R^2: 0.210		
Number of observations: 233		

Notes:

***, **, *, indicate significance at 1, 5, and 10 per cent levels, respectively

ns = not significant

The results of the LPM model showed that a representative household[7] had a 37.4% probability of switching to GSU water. However, the households were heterogeneous in nature. A combination of factors or the interaction effects of

[7] The base case was a representative/average household having a female head who was a farmer and 48 years old with secondary level education, having resided in the area for 32 years, having 5 persons in the family, and earning a monthly income of 3.27 million VND.

different household characteristic need to be considered in predicting the probability of non-GSU users switching to GSU water. Table 11 presents the sensitivity analysis of households under different scenarios in terms of age (of the head), education level (of the head), the year of taking residence, the size of the household, and the monthly income, as well as shows the interaction effects between income, education, and the year of taking up residence variables.

Compared to the base case (see footnote 6), if the head was under 40 years of age, the probability of switching would be 49.2 per cent. If the head had high school or tertiary education, the probability of switching would be 41.5 per cent. If the household took up residence during the periods 1976-1985, 1986-1995, and 1996-2005, the probability of switching would be 45.5 per cent, 53 per cent, and 55.5 per cent respectively. The probability of switching would be 39.1 per cent if the number of persons in the household was greater than seven and it would be 33.3 per cent if number of persons was fewer than four. The probability of switching would be 56.9 per cent and 50.7 per cent if the household's monthly income was less than 2 million VND and greater than 5 million VND, respectively. This showed that both the rich and the poor were likely to switch, but probably for different reasons. The poor most likely wanted to switch because they had no access to GSU water – GSU water would actually be cheaper for them than costly groundwater treatment systems. The rich, however, were more probably more interested in health reasons as GSU water was considered cleaner than that from other sources.

In order to evaluate the income effect on the other important demographic variables, the interaction effect between monthly income and education status and time of resettlement was used in the analysis. The interaction effect enhanced the probability of switching.

For the poorer households, the impact of education status became greater. The probability of switching of households with monthly incomes from 2-5 million VND was 50.4 per cent, 37.4 per cent, and 63.8 per cent if the head had received primary, secondary, and high school and tertiary education respectively. However, for the richer households, the impact of education status was not as great. The probability of switching of households with monthly incomes of more than 5 million VND was 31.7 per cent, 29.3 per cent, and 35.4 per cent for household heads with primary, secondary, and the high school and tertiary education respectively.

For the impact of the monthly income on the time of settlement variable, the results showed that households with monthly incomes of 2-5 million VND had a very high probability of switching, at 71.3 per cent, when the time of resettlement was between 1996 and 2005 while the probability of switching remained generally unchanged if the household settled prior to 1996. For households with monthly incomes of more than 5 million VND, those which had settled in the area prior to 1986 and after 1995 had higher probabilities of switching than those which had settled from 1986-1995. Households which had settled prior to 1976, from 1976-1985 and from 1996-2005 had 61.3 per cent, 59.9 per cent, and 50.7 per cent probabilities of switching respectively. Meanwhile, households which had settled from 1986-1995 had a low probability of switching at 9.9 per cent. The period 1986–1995 was the time when the UNICEF rural sanitary water program was successfully deployed. It could be that the tube-wells installed under the program were of a higher technical standard, thus the households with these tube-wells did not feel the need to switch to GSU water.

Table 11. Sensitivity analysis of predicted probability of switching to GSU water use

Interaction form	Base line[a]	Scenario: Young people (age ≤ 40)	High school & Tertiary education	Year of taking residence: 1976 -1985	1986-1995	1996-2005	Number of persons in household: ≤ 3	6-7	≥ 8	Income of household: < 2 mil VND	> 5 mil VND
No interaction effect	0.374	0.492	0.415	0.455	0.530	0.555	0.333	0.372	0.391	0.569	0.507

Interaction effect	Education: Primary School	Secondary school	High school & Tertiary	Year of taking up residence: Prior to 1976	1976-1985	1986-1995	1996-2005
Income at:							
2-5 million VND	0.504	0.374	0.638	0.374	0.344	0.387	0.713
Higher than 5 million VND	0.317	0.293	0.354	0.613	0.599	0.099	0.507

Note: [a] = base line is evaluated according to the mean numbers given in Table 6

To predict the demand for GSU water by non-GSU households, the two-step Heckman Switching Regression (HSR) decision model was used. According to the model, the decision to switch to GSU water by a non-GSU household is logically a two-step process. Firstly, if a non-GSU household decides to connect to a GSU, it will then have to decide how much GSU water to buy. The first step in switching was analyzed in terms of probability. The second step of forecasting the quantity of water demanded was described in Equation (2). The results of estimating the model is presented in Table 12.

All variables used in the LPM model were repeated in the HSR model. In addition, a distance variable from the house to the nearest GSU plant was incorporated into the model. The estimated coefficient, however, was not statistically significant although the sign of the coefficient was consistent with the hypothesis that the further the household was from the GSU plant, the less amount of water was demanded. In the model, there were only two variables—education status and occupation—that turned out to be statistically significant. Therefore, they can be used to forecast the demand for GSU water by a non-GSU household. The marginal contribution of the number of school-going years was 5,546 VND (or 2.22 m^3). Meanwhile, it was found that farmers demanded more GSU water (6,833 VND or 2.73 m^3 more) than non-farmers.

This forecasting allows the GSU manager to make optimistic forecasts on the current mean monthly amount of GSU water sold (about 4.3 m^3) (WEMC 2005) for higher educated users and farmers.

Table 12. Results of the two-step Heckman Switching Regression estimation on GSU water demand

Unit: thousand VND

Explanatory variable	Coefficient	z	P > z ab
Constant	4.95	0.31	0.756
DISTANCE	-.008	-0.48	0.623
SEX	5.14	1.05	0.295
AGE	-5.86	-0.02	0.981
EDUCATION[a]	5.55	1.71	0.087
OCCUPATION	6.83	1.73	0.083
RESIDENCE	-.002	-1.31	0.192
FAMILY NUMBER	.002	0.19	0.849
INCOME	.009	1.28	0.202
Wald chi-square (8) 18.76			
Number of observations 195			

Note: [a] = number of school-going years

4.4 Demand for GSU water

One hundred and twenty seven (127) GSU households were interviewed in the survey. Before switching to using GSU water, they had used water from different sources such as rivers, tube-wells, and the rain. There were 82 per cent of them using river water; 74.8 per cent using rain water; and 32.3 per cent of them using tube-wells. The fact that a high number of GSU users used to own private tube-wells shows that the GSU program had successfully attracted people. After switching to GSU water, there was a change in the water use pattern of the households. More than one-third of the households which had previously used water from the river stopped doing so while more than 41.2 per cent which had previously used water from private tube-wells abandoned them. Moreover, the number of households which had been using rain water decreased by about 40 per cent. The preferred water sources of GSU households were GSUs, the rain, and tube-wells at the levels of 81.7 per cent, 14.3 per cent, and 1.6 per cent, respectively. In addition, other water sources such as bottled water and vendor water were preferred only at the 2.4 per cent level. Thus, ground water was found to be the most preferred choice of GSU households.

On average, GSU households consumed 5.88 m^3 of GSU water per month or nearly 43 liters/person/day. This consumption level was still very low in comparison with the WHO standard on clean water consumption in rural areas, which was 120 liters/person/day. This shows that once domestic water was charged, the amount of clean water used became less than the consumption levels of those using private tube-wells. For the rural sector, it could be that the income and price effects were important factors in determining how much water was bought. In addition, there was a difference in consumption levels in the rainy season and the dry season. Nearly two-thirds of the households used much more GSU water in the dry season than during the rainy season. The factors affecting the difference in the use of water is presented in Table 13, and they were analyzed using the discriminant analysis (DA) model. The DA function (Equation 4) identifies the factors that affect seasonal use of water.

Table 13. Results of the discriminant analysis of the difference in GSU water use in the dry and rainy seasons

Variable	Standardized canonical discriminant coefficient	Structure matrix coefficient
INCOME	.754	.281
FAMILY NUMBER	-.543	-.114
RESIDENCE	.516	.412
R_c	0.272	
Wilks' Lambda	0.905 (sig = 0.004)	

The results showed that household income and the time of settlement were the most important factors contributing to the difference in water consumption between the two seasons. The results did not, however, show a strong correlation between seasonal water consumption and the size of the household although the partial contribution of the latter was large enough to explain the difference in water consumption between the two seasons.

The mean monthly cost of GSU water consumption was about 14,700 VND. To evaluate the marginal contribution of variables (representing the characteristics of the GSU household) to the cost of water consumption, a regression function was used in the study. The estimation showed that all the variables were not statistically significant so they could not be used to explain the change in the cost of water consumption. However, dummy variables indicated a very big difference in the cost of water consumption depending on the location and the time of settlement of the household. In the areas where rivers are seriously salinized during the dry season like in the Long My District of Hau Giang Province, people are heavily dependent on ground water. This could be the reason why the households located in Long My spent more money on GSU water consumption than those located in the districts of O Mon, Phong Dien, and Cai Rang of Can Tho City. The households living in Hau Giang Province paid an additional 13,700–15,000 VND per month for GSU water consumption compared with the households living in Can Tho City. The availability of water resources is different from place to place in the VMD so we can expect that ground water consumption will also be different from area to area. The results in Table 14 also show that the cost of water consumption is not the same if the time of settlement is different. People who had settled in the area during the period 1996–2005 spent less money on GSU water consumption than those who had settled earlier.

Table 14. Results of the regression analysis of monthly water cost paid by GSU users

Unit: thousand VND

Explanatory variable	Coefficient	t-value
(Constant)	-32.40	-.985
DISTRICT-D1	-14.97	-3.957***
DISTRICT-D2	-13.72	-3.329***
DISTRICT-D3	-15.16	-3.749***
Ln (FAMILY NUMBER)	5.77	.631
Ln (INCOME)	2.93	.656
OCCUPATION	0.25	.082
SEX	-0.36	-.120
Ln (AGE)	18.62	1.583
EDUCATION-D1	-1.03	-.241
EDUCATION-D2	0.10	.030
RESIDENCE-D1	4.49	1.999**
RESIDENCE-D2	10.19	2.194**
RESIDENCE-D3	3.91	.823
R^2 0.214		
F-test 4.134 (sig = .0000)		

Note: ***, **, * = significant at 1, 5, and 10 per cent levels, respectively

4.5 Ground Water Supply Analysis

In 2005, there were 394 GSU plants in Can Tho City. Wells of these GSUs had a depth of 60–228 m, the average being 110 m. The mean number of users per GSU was 69 households with a maximum of 351. Meanwhile, the designed capacity of GSUs ranged from 90-450 households at a mean level of 157 households per GSU. On average, the used capacity in terms of number of households served was 44 per cent. This result is actually not good. It indicates that there is still more to be done to attract people to the program.

In terms of the amount of water sold monthly, the mean quantity was about 331 m^3 per month. However, the distribution of water quantity sold was highly skewed. While 88.6% of the GSUs sold less than 600 m^3/month with a mean quantity of 247 m^3/month, 9.1 per cent of them sold 600–1,000 m^3/month with a mean quantity of 739 m^3/month, and 2.3 per cent sold more than 1,000 m^3/month with a mean quantity of 1,944 m^3/month. In terms of water consumption, the monthly average per household was about 4.29 m^3. There were 72.6 per cent and 27.4 per cent of the GSUs performing at average volumes of less than 5 m^3 (with a mean of 3.2 m^3 /household/month) and more than 5 m^3 (with a mean of 7 m^3/household/month), respectively. In general, the performance level of GSUs in terms of the quantity supplied to the households was still very low.

To measure the impact of factors affecting the quantity of water sold by GSU plants, a regression function was used. The three variables shown in Table 15 are: the distance from the GSU plant to the center of the village or commune; the education level of the GSU manager; and the number of years the GSU plant had been established. All coefficient signs estimated were consistent with the hypotheses. Distance did not have a large effect on the amount of water sold although the estimation showed that the further the GSU plant was from the center of the village, the less water quantity was sold. It can thus be said that distance was not an important factor affecting the quantity of water sold. Meanwhile, managers who had tertiary education were found to sell much more water than those with less education. Therefore, it can be surmised that the education level of the GSU manager played an important role in the success of the GSU. Specifically, the mean amount of water sold by the higher educated managers was more than that sold by the less educated ones by 150 m^3/month. Finally, the number of years of establishment of the GSU had a positive impact on the water quantity sold with a partial contribution of 61.5 m^3.

Table 15. Results of the regression analysis of the amount of water sold monthly by GSU plants

Explanatory variable	Coefficient	t-value
(Constant)	234.9	3.191***
DISTANCE	-26.0	-2.202**
MANAGER EDUCATION	150.2	2.400**
YEARS GSU ESTABLISHED	61.5	4.050***
R^2 0.296		
F-test 10.391 (sig = .0000)		

Note: ***, ** = significant at 1 and 5 per cent levels, respectively

To identify the factors affecting the difference in water quantity sold in the dry and rainy seasons, a discriminant analysis (DA) function with four predictor variables was used in the study. The reason for using the DA approach instead of a regression analysis was because the quantitative data on water sold in the dry season and the rainy season was not collected in the survey. The results in Table 16 show that three variables namely, distance from the GSU plant to the center of the village or commune, the depth of the GSU well, and the designed capacity in terms of the number of households that the GSU could serve, were important factors in explaining the difference in water quantity sold in the two seasons. Meanwhile, there was no strong support found for the existence of a relationship between the education level and the performance of the GSU in terms of the amount of water sold in the dry and rainy seasons.

Table 16. Results of the discriminant analysis of the difference in amount of GSU water sold in the dry and rainy seasons

Variable	Standardized canonical discriminant coefficient	Structure matrix coefficient
DISTANCE	.558	.601
DEPTH	-.829	-.497
MANAGER EDUCATION	-.142	-.190
CAPACITY	.755	.298
R_c 0.269		
Wilks' Lambda 0.900 (sig = 0.002)		

In order to forecast the probability of higher performance of GSUs in the dry season, a linear probability model (LPM) analysis was used in the study. The model used four predictors: the education status of the GSU manager, the years of establishment of the GSU (based on the time the GSU was built), the designed capacity, and the distance from the GSU to the center of the village or commune.

The results showed that for the representative GSU[8], the probability of selling more water in the dry season was very high at 93 per cent, i.e., most the GSUs did better business in the dry season than in the rainy season. The results also showed that GSU managers with high school or tertiary education had a lower probability of better performance than those with secondary or primary education. As mentioned earlier (Table 15), the number of years that a GSU plant had been in existence was related to the amount of water sold and the number of customers. These results suggest that GSU managers with lower educational levels had gotten their jobs earlier and had therefore had a longer time to establish a strong customer base. However, there could be other factors affecting the GSU managers' performance that cannot be explained by the model. Next, the time the GSU had been established had an effect on its performance in that GSUs built prior to 2002 had a higher probability of better performance compared with those established in the period 2002-2006. For instance, GSUs established in the period 2005-2006 had a lower probability of good performance at 13.5 per cent compared with those set up prior to 2005. The LPM forecasts are given in Table 17.

Table 17. LPM forecasts of GSU performance in the dry and rainy seasons

Variable		Coefficient	t-value
Constant		0.51	7.321***
MANAGER EDUCATION	High school and above	…..	…..
	Secondary	0.135	2.654***
	Primary	0.133	1.186
YEARS GSU ESTABLISHED	Prior to 2002	…..	…..
	2002 – 2004	-0.033	-0.354
	2005 – 2006	-0.135	-1.968 **
CAPACITY	More than 150 households	…..	…..
	Less than 150 households	0.076	0.909
DISTANCE	More than 3 km	…..	…..
	Less than 3 km	0.033	0.384
R^2 0.265			

Note: ***, ** = significant at 1 and 5 per cent levels, respectively

4.6 Sustainability of Ground Water Supply

In Can Tho Province, the ground water is extracted from the Pleistoxen layer for both GSU plants and private tube-wells. Table 18 shows the calculation of the

[8] In the survey, a representative GSU was described by the following characteristics (mean values): GSU manager at secondary school education level, the GSU was built in the period 2002-2004, the designed capacity was less than 150 households, and the distance to the center of the village was more than 3 km.

extraction : safe yield ratios for different water suppliers. If the GSU is the main supplier, the sustainability of ground water extraction will be maintained. However, if the water is extracted mainly via private tube-wells, then the exhaustion of ground water is likely.

Table 18. Ground water extraction : safe yield ratios for different water suppliers

Items	WHO standard	Water supplier	
		GSU	Private
Consumption per capita (liters/day)	120	43	284
Total demand (m^3/day) [a]	231,120	82,818	545,058
Extraction : safe yield ratio (time) [b]	0.58	0.21	1.37

Notes:

[a] = total consumption estimated with the 2005 population of 1,926,000 persons
[b] = the estimation is based on the assumption that the ground water extracted from the Pleistoxen layer is at a safe yield of 398,000 m^3/day

4.7 Analysis of Clean Water Use Options

In the VMD, water for domestic purposes comprises river water, ground water, and rain water. The dependence of households on specific water sources differs from time to time in a year and from place to place. Rain water is mostly used in the rural and sub-urban areas while urban people do not like to collect it because it is inconvenient. Even among rural households, very few have the financial ability to invest in storage facilities for the whole year. Rain water is also never treated for drinking and we know that users can face health problems since rain water can contain pollutants such as acid and air-dust. Rain water samples collected in the months of April and May had reportedly higher acidity levels than in other months (Tuan 2004). For the small number that collects rain water, there are two collection systems being used: (a) small-scale terracotta jars or two cement-brick tanks and (b) three large-scale containers. The first system is more common among poor households. For both systems, no water treatment is carried out. The use of filter equipment should therefore be explored.

Water can also be obtained from surface water sources like rivers and canals. Although the VMD is characterized by an interlacing network of rivers, fresh water can be easily collected only in the rainy season. It is difficult to do so in the lower part of the delta in the dry season. During such time, the water quality is poor because of high levels of pollution and salinity. Surface water is commonly collected and treated before being used, depending on the water quality and the financial ability of the household to buy water treatment materials and equipment. If the water has a high level of suspension particles, aluminum sulphate coagulation and sand filtration together with chloric-disinfection is recommended. It is common in the VMD for most poor rural households to use this water treatment technique. However, it is expected that such treatment cannot completely remove all bacteria and toxic material from the water. If the water has either high salinity or a high toxin concentration, advanced water treatment is necessary – this is provided by large-scale water supply plants in rural areas managed by either local WEMCs or private investors.

Ground water is the main water source for residents living in poor water distribution places such as coastal areas and the lower parts of the VMD. The allocation and quality of ground water in the VMD varies from place to place. In some places in the provinces of Soc Trang, Dong Thap, Ben Tre, and Kien Giang, ground water does not exist or cannot be used due to the high level of salinity. A common characteristic of ground water in the delta is its high iron content giving it a metallic taste and unpleasant odour. At the household level, the ground water is pumped out and used immediately or treated by aeration, and sand and/or carbonate filtration. Alternatively, households can also use clean ground water supplied by GSU plants managed by WEMCs or private businesses. The clean ground water is ensured by the treatment processes according to the UNICEF technique (Can Tho WEMC 2005).

The problem of obtaining clean water supply in the VMD is a complex one. Choosing clean water sources mainly depends on their availability and the water quality as well as the economic condition of the household. Table 19 shows the opportunities and constraints of the options.

Table 19. Summary of water treatment techniques, advantages and constraints of different water sources in the Mekong Delta

Water sources	**Type of pollution**	**Water storage/extraction options**	**Water treatment techniques**	**Advantages**	**Constraints**
Rain water	- Acidity - Air-dust - Other pollutants deposited on house-roofs	Small-scale terracotta jars or cement-brick tanks	- Porous porcelain filter equipment - Drying - Boiling	- Very cheap water source - Covers a wide area - Easily available in the rainy season - Easy to collect - Suitable for the majority, especially the poor	- Unreliability in the dry season - Time-consuming to treat
		Large-scale containers	- Porous porcelain filter equipment - Drying - Boiling	- Very cheap water source - High quality - Covers a wide area - Easily available in the rainy season - Easy to collect	- Unreliability in the dry season - Low affordability in buying the containers - Time-consuming to treat
Surface water (water from rivers, lakes, etc,)	- Suspended solids/ particles - Salinity - Toxic chemicals - High acidity - Other pollutants	Cement or brick containers	- Treatment with aluminum sulfate - Slow sand filtration - Chloric disinfectant	- Cheap water source - Easily available - Preferred by households	- Time consuming to collect - High pollution in the dry season - No full removal of bacterial contamination.
		GSU plants	- Advanced treatment techniques	- Cheap water source - Widely available	- High cost to remove pollutants

Table 19 continued.

Water sources	Type of pollution	Water storage/extraction options	Water treatment techniques	Advantages	Constraints
Ground water	- Salinity - High iron content - High acidity - Other contamination	Private tube-wells	- Sand and/or carbonate filtration	- Suitable for remote areas - Reasonable cost	- Household's economic constraints; poverty - High density wells could lead to subsidence of land - No full removal of pollutants
		GSU plants	- Rapid/Slow filtration - Aeration by water diffusing tray - Other advanced treatment techniques	- Helps to manage ground water resources - Use controlled by market prices	- Household's economic constraints - High cost to remove pollutants

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has described several ways to deal with the problem of clean water use for three main water sources; rain water, surface water, and ground water in the VMD. The advantages and constraints of and water treatment techniques for each source were comparatively evaluated to provide a summary of clean water use options for the households of the delta. The final choice of water source and treatment options was found to depend on the availability and quality of the different sources and the economic situation of the household.

There are four ground water layers found in Can Tho Province; the Holoxen, Pleistoxen, Plioxen, and Mioxen layers. The ground water in the Pleistoxen layer is the most suitable for extraction for domestic use. It is weak pressure ground water and can be found everywhere in the area at a depth of 80-100 m. Extracting ground water is currently done by private households, and the private and state sectors with three main types of ground water wells; private tube-wells, community wells, and GSU wells.

Much of the ground water used for domestic purposes in Can Tho Province is drawn from privately owned shallow tube-wells while a lesser quantity is drawn from deeper GSU wells. Water withdrawals from the shallow aquifers will deplete ground water resources. The water here is also polluted with agricultural chemicals posing significant health risks to those who consume it. GSU water, on the other hand, has better quality as it is treated before delivery. So, it represents a safe and clean source of water for domestic purposes.

Non-GSU users extract ground water free of charge. They also tend to use water from other free sources such as rivers and the rain. The use of rain water is now not popular, limited by the problem of storage. In these circumstances, ground water is the most suitable choice. If all the ground water required for domestic purposes were to be extracted from the privately owned tube-wells, ground water would soon be completely depleted. However, GSU users have to pay a price for the water they buy. This is a good thing since pricing the water tends to reduce the volume of water demanded. A survey of GSU managers found that the probability of consumers switching to GSU water was higher during the dry season as compared to the wet season. The fact that GSU water becomes more popular during the dry season also implies that the use of this resource would help relieve extraction from the shallow aquifers and rivers, thus resulting in improved environmental conditions in the region. Especially in the dry season, the water in the rivers of the VMD is seriously polluted and presents health hazards for users.

Almost all GSU wells are small-scale ones with a designed capacity of 4-6 m^3/hour and a depth of 60-228 m (an average of 110 m). While the designed capacity for households is about 60-80 liters/person/day (0.06-0.08 m^3/person/day), the actual extraction is only 43 liters/person/day. However, this is dependent on the season in that most GSU plants sell much more water in the dry season than in the rainy season. The results showed that three factors affected the quantity of water sold; the distance from GSU plant to the center of the village or commune, the education status of the GSU manager, and the time the GSU plant was built.

Meanwhile, the factors which were found to affect the difference in the water quantities sold in the dry and rainy seasons were the distance from the GSU plant to the centre of the village or commune, the depth of the GSU well, and the designed capacity of the GSU (number of households that the GSU could serve). Among the factors forecasted to contribute to higher quantities of water sold in the dry season (as compared with the rainy season) was the education status of the GSU manager. It was predicted that GSU managers who had lower levels of education (secondary and primary school) would perform better than those with high school or tertiary education. This was a surprising result indicating that some factors like customer relationships were important but not considered in this study.

Ground water was the water source most preferred by non-GSU households (with more than half the interviewees selecting it) as well as by GSU households. The main reason for choosing ground water was quality, in terms of cleanliness, good taste, and safety. For GSU users, only GSU water was used for drinking and cooking. Rain water was preferred next. However, with limited knowledge on pollution, the public faced health risks in using rain water without treatment. Table 20 summarizes the details of GSU water consumption by households in the study.

Non-GSU households showed a change in their water use patterns after switching to GSU water. More than one-third of them which had previously used water from the river stopped doing so and more than 41 per cent which had previously used water from private tube-wells abandoned them. The study also revealed that water consumption levels reduced dramatically after the switch compared with former levels of use with private tube-wells. Even at the highest consumption level, the mean amount of water consumed was only 109 liters/person/day. This was less than half the previous level of tube-well water consumption[9]. This surprising result supports the conclusion that switching from private tube-wells to GSU water would be the best solution to prevent the over-extraction of ground water. In terms of water use, there was a difference in consumption levels between the dry season and the rainy season. Factors affecting the difference in water quantity used in the two seasons included household income and the time the household had settled in the area. The former implies that pricing GSU water has an impact on consumption levels. In addition, the study found that ground water consumption was different from place to place in the region. The difference was very significant; 13,700-15,000 VND/household/month or about 6 m^3/household/month.

Study analyses also showed that the probability of non-GSU users switching to GSU water was relatively high at the rate of 37 per cent. Poor households (earning less than 2 million VND per month) were the most likely to switch. Income was obviously not a constraining factor to switching and poorer households would switch to GSUs if they were given access to them. In addition, a strong interaction effect between income and the time of settlement was found in predicting the demand for GSU water by non-GSU households. Households with monthly incomes of 2-5

[9] According to the Can Tho Department of Agriculture and Rural Development (Can Tho DARD survey, 2002), the average amount of tube-well water used by a household was estimated at 283 liters/person/day. It is assumed that the user who already has a tube-well will buy less GSU water than the one who does not own a tube-well.

million VND showed a very high probability of switching (71.3 per cent) when the time of resettlement was from 1996-2005 while the probability of switching remained generally unchanged if the household had settled prior to 1996. For households with monthly incomes of more than 5 million VND, those which had settled in the area before 1986 and after 1995 had much higher probabilities of switching than those which had settled from 1986-1995. Meanwhile, household size had a positive relationship with the probability of switching; the larger the household, the higher the probability of switching.

Table 20. Mean GSU water consumption

Monthly water consumption per household	**Proportion of households in the sample (%)**	**Daily water consumption per person [a] (liters)**
Less than 2 m^3	6.6	14.6
From 2- 5 m^3	66.2	25.5
More than 5- 8 m^3	22.1	47.4
More than 8 - 10 m^3	3.3	65.6
More than 10 m^3	1.8	109.4
Total / Mean respectively	100.0	43.0

Note: [a] = the calculation is based on a household's mean water consumption evaluated at the midpoint with a mean family size of 4.57

5.2 Recommendations

Besides ground water and river water, rain water is also considered as a potential water source of the Rural Clean Water Supply Program in the VMD. However, the awareness of the public about pollution of untreated rain water is limited. Each source of water has economic and environmental advantages and disadvantages. Any proposal on water source options should take into account the problem of water pollution, appropriate treatment techniques, and economic factors. It is recommended that in-depth economic analyses of the cost effectiveness of the different management alternatives be conducted in order to identify the best options for the residents of the delta.

Analyzing the demand and supply situation and the management of ground water resources in the VMD helped identify the problems. Ground water plays an important role in supplying clean water for the majority of the residents especially in the rural area. Ground water extraction and uses should therefore be managed so as to be sustainable and efficient.

In order to ensure this, it is recommended that in Can Tho Province, ground water to be used for domestic uses should be extracted only from the Pleistoxen layer. Extracting ground water from the other layers is not recommended until an official survey at the national level is conducted to ascertain the quantities and quality of ground water resources in these layers.

Among current GSU water users, two-fifths of them used to have their own private tube-wells before switching to GSU water. This result proves that the GSU program is attractive to households. Therefore, the WEMCs should promote the program to every non-GSU household, especially private tube-well owners. The fact that the water consumption is reduced with GSUs indicates that the right way towards sustainable ground water management is by getting more private tube-well users into the program. Household income and size were found to be two main factors affecting non-GSU to GSU switching decisions. It is therefore recommended that the WEMCs target large households with low incomes as they had limited access to GSU water but possessed the capacity to pay for it. The WEMCs should also target large high income non-GSU households which had settled in the area prior to 1986 or after 1995.

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