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# Nutrient Recycling: Rural On-Site Wastewater Disposal and Treatment in Can Tho City, Viet Nam

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*Rural On-Site Wastewater Disposal and Treatment in Can Tho City, Viet Nam*

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*"Tell me and I will forget, Show me and I will remember, Involve me and I will understand!"--Confucius*

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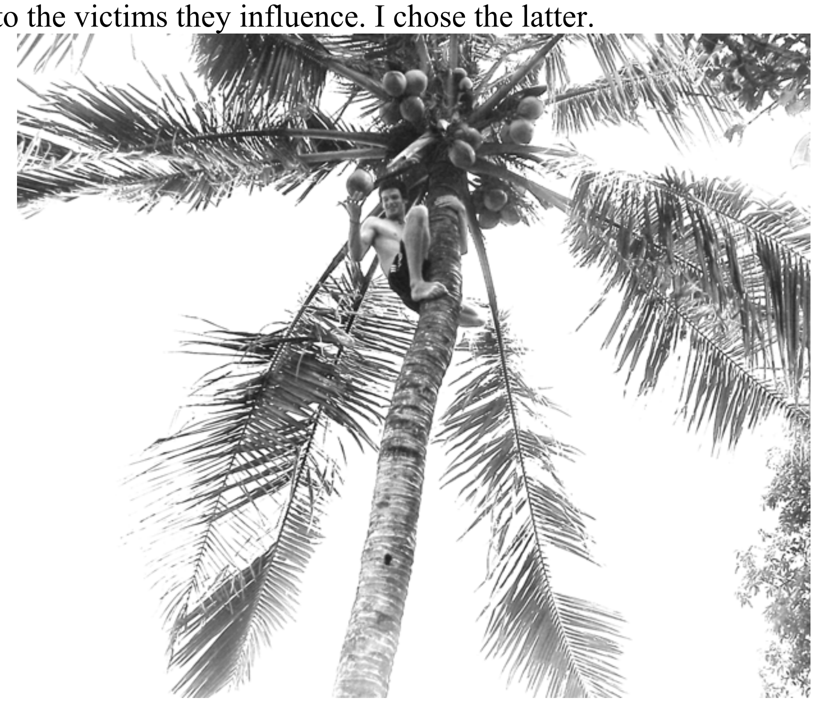
**Abstract**

In order to research a topic a holistic perspective is important. Often experiments are performed absent from the environment that is being observed. It is like thrusting one's hand into an ocean to grope around for a specimen, extract it, and examine it apart from its native habitat. Although this is possible and often primarily the method, to immerse oneself into where one is studying is to increase one's ability to obtain a more holistic perspective. I have come to believe that the more practical and accurate scientific experiments are a combination of laboratories *and* on the field. Not only should the substance be analyzed, but the surrounding community that directly or indirectly is affected should also be understood. Personal and communal perspectives, habits, traditions, understandings are often not taken into account. However, when the researcher lives with them, learns from them, and sees life from their perspective, its incorporation only enhances the final results of the analysis. How else can one help another?

This paper should not be read scientifically as the experiments were not performed within a strict, controlled environment. Contrary, this should be read as a journal or rather an extended article describing the current issues of wastewater disposal in Can Tho City, Vietnam, the present practices, health hazards, and suggestions on how can to improve the situation. A majority of my time was spent with a typical low-income farmer and his family who live in My Khanh village on the outskirts of urban Can Tho City. There I observed his approach, limitations, and understandings of the environment and how he as an individual, his family and community is contributing both negatively and positively to its future. If one truly desires to influence another's life, one must begin by stepping into their shoes and perceive life through their eyes in order to gain what they already know and conceive what they have yet to know. From there, one can pinpoint the need or area of unawareness and address it directly.

Due to time constraints, language restrictions, and selective observations, this paper can only reflect a small fraction of the wastewater situation in Can Tho City, let alone Vietnam at large. One can either approach the issue from outside and trace the adverse affects to the sources or dive within it and understand it from the inside outward beginning with the vector sources and following them to the victims they influence. I chose the latter.



“Tell me and I will forget, Show me and I will remember, Involve me and I will understand!”--Confucius

## Introduction

According to the World Health Organization, 90% of wastewater produced in the world is inadequately treated and thereby returned to the water cycle untreated. Although the earth has the capability of self-purification, there is a threshold and when exceeded, concentrations build up especially as the world’s population is increasing at rapidly. The need for wastewater treatment intensifies to protect public health, nations’ water resources including fish and aquatic life, prevent eutrophication of lakes and pollution therein, and to enhance the aesthetic quality of recreational areas. In much of the world without adequate wastewater treatment, nature often must take on the responsibility of purifying humans’ wastes. Oftentimes large bodies of water become polluted and the earth’s treatment process is too slow to keep up with the pace of pollution. As a result, the need exists to facilitate increased public awareness so that people may begin treating their own waste in a proper way as to not spread contagion. Wastewater is best if treated on the spot to minimize possibilities of leaks, contamination, and extra transportation expenses. In addition, the demands from agriculture, aquaculture, and industry on water are steadily rising causing an increasing reduction of drinking and domestic water availability. Resultantly, “[a] deterioration in the quantity and quality of existing water supplies is a major health and economic threat” (The Work 2002). The price of water will continue to raise posing financial burdens on industry, agriculture, and people. One way to lessen the costs of treatment is to prevent wastewater’s contamination of larger bodies of water. In other words, treat the wastewater as near to the source as possible. This must be the primary step and as a result will reduce needs for medical treatment, hospitalizations, cases of diarrhea, water-borne diseases and infections, skin rashes/dermatitis, and assist in increased aquatic life, aesthetic beauty, and tourism. Fortunately, “[t]he poorer the country, the more effectively waste seems to be utilized.

Therefore, the motivation for reuse of waste usually poses no major problems" (Lankinen et. al. 1994). This is often performed by direct fertilization and recycling of nutrients.

**Meeting Basic Needs**

Among Maslow's hierarchy of needs, the universal basic human physiological necessities include food, water, and excretion. Enhanced quality and additional needs and luxuries can be identified, but are dependent upon their accessibility and expense. For a nation to further develop, these basic needs must first be addressed and secured for a significant majority of the country's inhabitants. These have utmost priority while secondary expenses for comfort and environmental concerns such as wastewater treatment remain of lesser importance. Wastewater treatment at the rural level is not considered a necessity especially in Viet Nam where its treatment is only a moderately concerned issue from the locals' perspective to legislature.

In order to begin improving the water quality in Viet Nam, understanding must not only be propagated into people's minds from the top of the social ladder, but especially at the grassroots level since 80% of Vietnamese live in rural settings. "People's awareness of water supply and environmental sanitation is very limited" (National, 2000). As a result, one cannot expect a nation to immediately revolutionize its negative impact on the water if a majority of its citizens have little understanding of their influence on the water quality and vice versa, the quality o the water's affect on them.

**Food Contamination**

Due to lack of regulation from the government, food production, food handling, preparation, and marketing practices are often left up to the responsibility of the general population. Unfortunately, "[o]nly few rural people have good personal hygiene practices and in general people have low awareness of, and pay little attention to, the relation between water supply, latrine, personal hygiene practices and health" (National, 2000). As understood by various interviews with locals of Can Tho City and two surrounding villages, An Binh and My Khanh, there is an increased concern of the health and safety of food production and markets where they are sold. Much skepticism is especially centered on vegetables and meats. This concern can be well supported by the fact that according to the World Health Organization in Viet Nam approximately 90% of industries do not have wastewater treatment facilities (Vietnam). Also, although the government policy prohibits the use of human excrement as fertilizer, it is still a frequent practice. Furthermore, a majority of Vietnam's crops are watered with either urban wastewater especially those surrounding cities, or from the rivers which are being increasingly contaminated with urban and industrial runoff. Simple timing of wastewater application upon the plants and increased washing and further hygienic practices would significantly augment the health of these marketed foods. For example, vegetables especially those lying close to the ground including melons, leafy vegetables, and those harvested from ponds such as water spinach, and water lettuce, are often contaminated with wastewater and are not thoroughly cleaned and washed prior to being sold. As a result, many locals are suspicious about purchasing fresh products and the local market.

Some alternatives exist such as increasing awareness of the connection between illnesses and food intake and how the food is prepared. Another is to encourage farmers to grown home gardens thereby handing over to them the responsibility to manage the health of their own food production and how to safely fertilize the crop either with or without human excreta. For example, in large crops it is suggested to discontinue applying urea one month before harvesting. In addition, because of the high concentration of ammonia, application of urea is best not applied directly to the plant's tissue because of potential burning. Conversely, it may be sprayed close to the ground and near the roots for available uptake. Depending on the type of plant, plowing under the urea is suggested prior planting. If already planted then not plowing is advised to allow any bacteria in the urea to be destroyed by the sunlight.

**Sources of Water**

At the present, a majority of Viet Nam's population collects its domestic water supply from either rainwater, well, river and/or purchased mineral water. Rainwater is commonly collected in large jars during the rainy season and drawn upon during the dry season. Oftentimes, phen, or aluminum sulfate is mixed with the water to promote coagulation and settling of suspended solids helping to eliminate cloudiness and particles. However, since phen contains high concentrations of aluminum and often not properly filtered out, it may pose aluminum health hazards although little or no research has been conducted as to now. Although inexpensive to acquire, the poorest families are still unable to afford enough of the aluminum sulfate for treating river water, which is often relied upon heavily during the dry season. In addition, rainwater accumulates various particulates in the atmosphere as it falls to the earth. If industrial zones are nearby whose emissions are rarely filtered, these elements such as ionized aluminum and iron and other heavy metals can bond with the raindrops creating an acidic and contaminated water resource. If not properly filtered, it can pose health risks.

In Viet Nam ground water contains high amounts of iron and Manganese that requires costly treatment. An increasingly contamination of arsenic is being observed as well, which if in high enough concentrations is toxic. Often this water source is polluted due to industrial chemical residue and domestic wastes that have been disposed of near the dug well such as livestock manure, human excreta containing bacteria and pathogens, and greywater containing detergents, bathing soaps, and chemicals from food preparation. Although many of these are filtered by the soil, eventually leaching and contamination occur.

For the majority of Viet Nam's poorest, drawing water from the river for their bathing, washing, cooking, and drinking is most common. Leaching from agriculture runoff, human excrement, trash, and other water-borne disease vectors are common. Although many use aluminum sulfate and boil the water before drinking, diarrhea and gastroenteritis is prevalent in Viet Nam.

**Local Perspectives and Contributions**

To gain an insight of the locals' knowledge of wastewater and its effect on human health, I conducted a total of twenty-five surveys in three different areas, two villages and the third, residents of urban Can Tho City. (Appendix 6). Of the ten households in My Khanh, seven in An Binh, and eight in Can Tho city, the size of household ranged from one to ten with five being the average family member number. In My Khanh, the common occupation was a pig, fish or fruit tree farmer. The surveyed An Binh residents were generally merchants and within Can Tho City most were either teachers or government employees.

Surprisingly, of the twenty-five surveyed, fifteen remarked that they did not experience any diseases or ailments. This is contrary to the statistic by the World Health Organization stating that 90% of the Vietnamese population suffered from gastroenteritis. Those who admitted illnesses primarily blamed their stomachaches and diarrhea on the food they consumed such as vegetables and their skin irritations on dirty water. When asked their opinion on the causes of these diseases, only a few did not have any idea. Others mentioned their concern about the cleanliness of the food they bought at the market and how it was prepared. One made the connection between skin irritations and poor water quality. Those in the villages understood that unboiled water caused them stomachaches and as a result either boiled their water and/or applied aluminum sulfate to stick to the suspended particles in the water and cause them to sink. Those surveyed in the city had a better understanding of the contributors to their illnesses. One mentioned she knew polluted water caused diseases, but did not know which element within the water. Others blamed it on unsafe food. This response holds truth. As mentioned earlier, often foods are grown with untreated wastewater allowing metals to be absorbed and for them to be contaminated if not thoroughly washed before handling and eaten. However, washing cannot wash away absorbed heavy metals. This further reaffirms the need for treatment and application guidelines for wastewater use on plants.

As numerous impacts exist from wastewater upon health, over one-third of the villagers did not link untreated wastewater and its impact on health. (Appendix 5). To some, the river water was not dirty and need not be worried about. For the remaining villagers surveyed and almost every surveyed urban resident agreed with the relation. Some further commented on its effect on the old and young population and guessed its potential to cause digestion problems, cancer, dysentery, skin diseases, cholera, hair loss and women's health issues (Personal-Interviews, Eight). When asked their opinion of what caused polluted water, industrial fish production was a frequent response. One blamed the community further upstream for discharging too much wastewater. Another guessed that garbage from the ground polluted the river. (He also mentioned he directly flushed his wastewater into the river.) Unfortunately, sometimes people fail to realize that one's actions do have an effect upon the environment and surrounding communities. The river cannot simply wash away the waste without leaving a negative impact on its surroundings. When asked how the river could be made cleaner, one farmer suggested that it is each person's responsibility, to use water hyacynth, that wastewater should be put into a pond first to make it clean before the river, and that everyone should follow this model (Personal-Interviews, Ten).

As observed through surveys (Appendix 6), public awareness about the importance of wastewater treatment was limited in the countryside with only about one-third admitting being informed by the community Farmer's Union and Women's Club and one from the government club. With similar disagreement of the relation between health and wastewater, six out of seventeen did not believe wastewater should be treated prior discharge and support their view by flushing their waste directly into the river. Others agreed that their wastewater should be treated by referring to their usage of overhung fishpond toilets or mentioned that filtering their waste through water hyacynth or their field was their contribution to wastewater treatment. Those in the city mentioned television, newspaper, school, and radio as the main sources of information. Possibly due to heightened awareness, everyone agreed that wastewater should be treated. Unfortunately, little if any of their wastewater is treated, but rather flushed through sewer pipes and emptied into the nearest waterway as can be seen throughout the city. One resident noted "…it is necessary to make wastewater clean before being put back into the river, but there is a limitation of what can be done and what is being done" (Personal-Interviews, Seven). Another stated that he would like to treat his wastewater, but is financially unable. As a result, little is being done to treat wastewater in the city and countryside. Although locals believe their fishponds treat their waste, all too many times they are directly connected to the nearest canal or river and the tidal changes, which occurs four times daily, often carry the wastewater away before sufficient treatment. Although overhung fishpond toilets are nationally banned, eleven out of twenty-five, 44%, still use them. In the countryside, only four owned a hygienic toilet.

However, if the wastewater is filtered through a fishpond prior discharge, it may be more sanitary than hygienic toilets if directly emptying into the river.

Partially due to their toughened immune system, but also due to their limited understanding of the factors causing stomachaches and skin irritations, the river continues to be a major water source within the village for washing and especially for bathing. Some continue to use it for drinking after boiling and/or using aluminum sulfate. Only four of the village residents mentioned using rainwater as a source of drinking water though this practice is more common than reported. Those who drew water from wells still had to apply aluminum sulfate and allow time for sedimentation before use. One mentioned that his family bathed with well water because they contracted skin diseases from the river's water. For those living in urban settings, city tap water was their primary water source although two had wells in addition. Bathing was safe in the city and well water, but still needed to be boiled if to be considered drinkable water. Five out of eight purchased mineral water and two even had filters.

**Overhung Fishpond Toilets vs. Hygienic Latrines**

In the late 1980s Viet Nam banned the use of overhung toilets regarding them as unsanitary, harmful to the environment, and unsightly. The new suggestions were pit toilets and hygienic latrines that were more sophisticated and more sanitary. Pit toilets are not more sanitary due to increased waste concentration and se3page into groundwater. On the other hand, several benefits accompany the hygiene toilet approach. It supposedly helps prevents direct excreta contact with surface water, can be more private for woman, hidden from view, and can be connected to a wastewater drainage system if provided. However, several drawbacks darken this proposal. Only a small percentage of Viet Nam's households are connected to sewage systems and only a few of these systems properly treat the wastewater. Hygiene toilets may provide a more hygienic and safer setting to relieve oneself, but ultimately the excreta is emptied into the nearest open waterway undermining the initial environmental reason to introduce the toilet. In addition, hygiene toilets are expensive, costing about $75-100 USD and resultantly unaffordable to most. A simple wooden or cement platform surrounded with nylon or tin over a fishpond is more reasonably priced. As mentioned earlier, to invest money in an improved sanitation system is often considered not of highest priority. Fifty percent of rural households do not have latrines and most practice open defecation often with overhung fishpond toilets or use their neighbor's latrine or overhung toilet (National, 2000). Of the 50% that do have latrines, only 20% are hygienic while the remaining are either single or double vault latrines, open pit, pour flush latrines, or fishpond toilets in the South. The majority of the excreta often slowly seeps into the ground or must be manually removed and often times used as fertilizer. Either way, without proper treatment the human excreta is increasingly contaminating the waterways above and below ground level. Mentioned earlier, oftentimes neighbors share toilets and if not properly cleaned and maintained they can be a breeding ground for disease and infection.

As a result, although fishpond latrines have been banned in the south, there is yet a solution to hygienically dispose of waste in rural settings. It may be accurate to admit that overhung fishpond toilets are more sanitary than hygienic latrines if the latter is directly/indirectly connected to an open waterway. Because of the containment of excrement within the pond and quick ingestion by fish and/or nutrient uptake by plant aquaculture, this practice may best be allowed to continue if properly contained until proper sewage treatment facilities are available. However, one must acknowledge that this is still not a long-term solution due to disease spread within the pond and human contact with it. Also, many times these fishponds are flushed into the river emptying a high concentration of harmful waste all at once.

Either way, despite hygienic latrines or onsite treatment through fishponds, all too often domestic wastes find their way to contaminate surface water supplies. To summarize, there is yet a latrine module/system commonly being used in Viet Nam that is hygienically disposing of the waste. Until then fishpond latrines and hygienic toilets connected to the river will continue to pollute the environment and cause sanitation issues.

Universally, contact with untreated wastewater is a main contributor to diarrhea and gastroenteritis diseases, which are ranked fourth of Viet Nam's top ten causes of morbidity and tenth for causes of death (Vietnam, 2005). For instance, cases of diarrhea have increased from 300/100,000 in 1990 to 1,265/100,000 in 1997. In the Deltas, Central Highlands and North, up to 90% have intestinal worms (National, 2000). Other water-borne diseases include schistosomosis, dysentery, typhoid, bilharzias, scabies, typhus, trachoma, and dermatitis. Schistosomosis is especially high with fishermen, farmers in irrigated fields, bathing women and children, laundering, drawing water, and whoever else whose contact either by skin or mouth with contaminated water is unavoidable (Lankinen, 1994).

**Irrigating and Fertilizing with Wastewater and Human Excreta**

For centuries throughout the world, human excrement has been used to enrich the soil and wastewater to irrigate crops. In Asia, human excreta are commonly fed directly to fish. The nutrient content of urine and feces contains the same amount as the food ingested and so can effectively be used to replace the nutrients in the crop fields (Schonning, 2001). To present an example of Viet Nam's lack of wastewater treatment and its usage of wastewater for irrigation, in Viet Nam of the provinces Bac Ninh, Ha Tinh, Ha Noi, Ho Chi Minh, Ninh Binh, Thai Binh, Thanh Hoa, and Viet Tri, only Viet Tri treated its wastewater and each province had indirect uses for wastewater and almost all used wastewater in the production of rice, other cereal crops and fish (Scott et. al., 2004).

Although disregarded in most developed nations, direct fertilization with human excreta is still a frequent practice in Viet Nam despite national policy prohibiting it (Vietnam). As mentioned earlier, human excrement and urine can effectively replace much of the loss of Nitrogen, Phosphorus, and Potassium nutrients in crop fields. In fact, fields fertilized with urine resulted in as good or better yields than chemical nitrogen fertilizer (Schonning, 2001). In addition, human excrement is economical and easily available for the farmer. Conversely, when excrement undergoes conventional treatment systems Nitrogen is destroyed in the process and wasted as a potential energy such as biogas (Nhapi, 2005). Despite its value, human excrement poses health risks and to devise the most efficient use of the effluent reuse while concurrently avoiding contamination of the surrounding environment is the present need (Appendix 4, Figure 1). The complete ban by the government of human feces as fertilizer is one step too far, but the need for strict standards of employing it is a better approach. "The important thing is to help farmers with guidelines on how to compost human excreta to get fertilizer without polluting the environment and causing harmful effect on human health" (National, 2000). Composting it first rather than applying it fresh is a more sanitary implementation.

As cities grow so do volumes of wastewater. Often urban expansion confiscates surrounding farmland that before was the sink of the city's wastewater. Although some of the wastewater can be used to irrigate the cities parks and other green spaces an increasingly amount is either disposed directly into the nearest waterway or transferred to nearby farmland to grow crops. Tradeoffs exist between the health of the food producers and those who live nearby, and the consumers of irrigated produce and the quality of the soil and water. Wastewater irrigation is cheaper than conventional methods due to its nutritional value, but carries with it health and environmental risks. “Irrigation with untreated wastewater can present a major threat to public health (of both humans and livestock), food safety, and environmental quality” (Scott et. al., 2004). From the perspective of the cities’ water management system, having simple and available means of ridding the wastewater is to their convenience. All in all, this irrigation practice is often unregulated and exact costs and benefits are not well understood and publicized (Scott et. al. 2004). Additionally, as urban expansion increases so does the cost of transporting wastewater out of the city as well as previous wastewater-fed aquaculture/agriculture land is confiscated. In addition, if a poor developing country has a history of using public wastewater to feed and raise aquaculture, when the country improves the sanitation system minimizing wastewater availability it can create increased hardships on farmers who may have to revert to industrial fertilizers that produce lower crop yields (Edwards).

Furthermore, not only do farmer suffer from their land being taken from them, but as countries develop so do their inhabitants’ understandings of health and food quality. As observed from locals surrounding Can Tho City, an increasing number are becoming suspicious of the safety of market produce and meats. As people become more aware of food health and safety, soon high-value fish may be preferred over low-value fish, which are often grown in wastewater ponds.

**Separation of Human Excreta**

The reasons for establishing strict regulations on fertilizing with raw sewage are because of the direct contact with produce and the produce’s ability to absorb heavy metals. Raw vegetables and fruits such as melons, salad, peppers, strawberries, that are grown close to the ground and eaten without being cooked can easily host bacteria from contact with wastewater irrigation or open defecation. Even cleansing cannot wash away all the dangers due to possibly absorbed heavy metals. Although sewage is helpful for plant growth, heavy metal content can buildup in the soil. Urban waste fertilization must be monitored because even though plants can utilize small amounts of heavy metals, they can absorb an unhealthy amount. In wastewater treatment with water hyacynth, heavy metals can be absorbed. The same with edible vegetables and when eaten can begin storing metal concentrations within the body. By determining the characteristic of the wastewater one can carefully select the type of livestock, fish, or crop to be raised so as to minimize health hazards. For examples, fruit trees are a better selection than watermelons because the fruit does not contact wastewater.

To use human feces as fertilizer is an artful procedure. First, feces and urine should be separated to avoid contamination of urine by the pathogenic substances within the feces. The sludge should next be dried and composted with soil, leaves, grass, or sawdust for about nine months before it can be safely applied as fertilizer (Pickford, 1998). There are several reasons for composting. Composting sludge helps kill and reduce pathogens that are often the leading vectors of diarrhea. Composting also concentrates nutrients, slows nitrification of Nitrogen, and reduces odor (Gruhn, 2000).

The primary reason for separating human excrement is to avoid contamination of urine, but also so that the feces may be more easily and safely transported to be composted. Also, the urine liquid tends to fill up latrines the quickest and supposedly it is the mixture of feces and urine that causes the foul smell that attracts flies generating an ideal breeding site for mosquitoes as well. By not mixing the two substances as in pit latrines, health is improved and nutrient resources become more easily available. In domestic wastewater less than 1% is urine, but urine alone contributes up to 80% of the wastewater's total Nitrogen content, 55% Phosphorous, and

60% Potassium (Schonning, 2001). As a result, this is valuable source of nutrients that must not be discarded wastefully. Urine is also lower in heavy metals than commercial fertilizers and plants can directly absorb its ammonium/ammonia content. As a result, to divert urine from being mixed with wastewater because it may be directly applied to plants without prior treatment whereas if mixed it would require prior treatment. However, care must be taken during application as to protect the applier's health in case of disease within the urine excreted from someone ill such as Salmonella typhi, Salmonella paratyphi, Schistosoma haematobium, and Leptospira interrogans.

Within urine, the higher the temperature and concentration, the greater bacteria is reduced. When spraying, applying the urine to the ground surface allows the sunlight's radiation to further kill any bacteria. When urine is exposed to the air, ionization occurs and its ammonium begins to form ammonia raising the pH level. If ammonia concentrations are high enough it is toxic to life. Fresh urine has a pH of 4.8-7.5, but can soon rise to 9.0 after excretion. As a result, when separating and storing urine, ventilation should be minimal so as to prevent odor and ammonia formation. If not, application should be hastened. Fortunately, when applied to the soil the pH rise is only negligible.

**Usage of Aquatic Plants for Nutrient and Pathogen Removal**

Where wastewater treatment systems are unavailable or inadequate, the environment receives the waste. Sunlight helps kill pathogens, microorganisms assist in organic breakdown, and plants absorb various nutrients and provide a suitable habitat for the microorganisms. Attempting to supply the world with conventional treatment systems is a farfetched aspiration due to expenses and lack of internal development. However, because nature already is capable of self-purification, learning how to concentrate it and utilize it effectively may be the most practical and promising approach to reducing contamination by wastewater.

Oftentimes the first plant noticed when looking at a river in Viet Nam is a lazily, floating mat of water hyacynth, *Eichhornia crassipes*. Locals believe its existence is adequate for the treatment of their wastewater by allowing their raw waste to flow through it. Floating, it serves as a living nutrient sink. Dead, its decomposition absorbs valuable dissolved oxygen in the water known as benthic demand. Within a massive community, it's a frequent annoyance to waterway traffic, prevents sunlight from penetrating the water, and an ideal location for disease-causing vectors, snails and mosquitoes. Optimum water habitat for this plant is in still, or slow fresh water with neutral pH, warm water temperatures of 28-30$^{o}$C, and plenty of Nitrogen, Phosphorus and Potassium elements. Water hyacynth can grow in temperature extremities and even survive frost, live in nutrient poor waterways and acidic conditions, but not it brackish or saline waters.

Although able of nutrient uptake, it presents a great threat and hindrance to waterway accessibility, fishing, plant and animal diversity, hydroelectricity, and creates "suitable breeding sites for vectors for human and animal diseases such as malaria, encephalitis, schistosomiosis (snail fever), filariasis, river blindness, and possibly cholera" as well as venomous snakes (Julien, 1999). In addition, water hyacynth transpires large amounts of water through its leaves and if in a large community of plants reduces light penetration into the water lowering oxygen levels creating anaerobic conditions unfavorable for vertebrates, invertebrates and plants in the surrounding habitat. Although it can been used as animal food, fertilizer, handicrafts, furniture, and green manure in addition to wastewater treatment, "[t]he possible advantages of utilizing water hyacynth are far outweighed by the enormous problems the weed causes throughout its introduced range. Attempts to control the weed should not therefore be compromised by any consideration of its potential use" (Julien, 1999).

In general, Nitrogen, Phosphorous, Potassium, and Carbon cause aquatic plant blooms. Often times, high Phosphorous concentrations cause excessive algae growth because it is often the limiting nutrient. Due to their high nutrient content, human waste and industrial waste are prime causes. Lake eutrophication is one example of Nitrogen and Phosphorous concentration often due to sewage leakage. In turn, algae presence inhibits sunlight from reaching underwater aquatic life altering the aquatic food cycle. Additionally, its senescence creates a rise in BOD and reduction in oxygen level thereby killing fish and other aquatic life. In order to best treat wastewater with plants, a careful selection must be made of plants that will not only improve the water quality along with other benefits, but also not create human hindrances and health risks.

**Duckweed**

Easily unnoticed as individual plant, but producing a rich-green floating mat within a large community, the duckweed plant boasts of incredible potential for wastewater treatment and to become a nutritious biological feed. Duckweed is a monocotyledon in the Lemnaceae family with the four most common species Lemna, Spirodella, Wolfia, and Wolfiella. Duckweed is flat and ovoid vegetation that is best found in waters high in organic matter content or provides high levels of nutrients. Its natural habitat is in fresh or brackish waters that must be protected from wind and wave motion to prevent layering and shading of sunlight. Otherwise, wind or wave movement causes the plants to be stranded on banks or cover up each other blocking sunlight and increasing the competition for nutrients. Due to its rapid uptake of nutrients, duckweed is considered one of the fastest growing plants in the world. One leaf can divide up to ten times in ten days producing daughter fronds before the original mother plant dies. However, as the mother plant produces daughter plants, each one becomes increasingly smaller in mass as the mother ages. Resultantly, due to their smaller mass, the daughters born later also have lower reproduction capabilities. Because of this, duckweed mats naturally expand and shrink over time and may have to be restocked with fresh duckweed after harvesting if growth diminishes (Duckweed). With daily optimal nutrients, sunlight and temperature it is capable to double its mass within sixteen to forty-eight hours (Leng, 1995). As a result of its exponential growth, if to be successfully raised duckweed must be protected from the wind, given nutrients daily, and its density managed well by regular harvesting and the remaining layer to be evenly spread densely over the pond/lagoon. This permits further growth and restricts light penetration suppressing algae growth minimizing $CO_2$ production from algae that causes pH increases. Duckweed prefers a pH range of 6.5-7.5, but can tolerate levels from 5-9. However, duckweed growth is stimulated most by sunlight and water temperature than by nutrient concentrations. For example, duckweed can grow rapidly at high temperatures even down to trace Nitrogen and Phosphorous levels. Duckweed can grow between 6-33$^{o}$C, however above 30$^{o}$C growth slows. Overall, duckweed provides protein, fat, starches, and minerals, but is limited by extremes in pH, temperature, and overcrowding of its own self within a colony (Leng, 1995).

In developing countries it is cheaper to rely on biological methods of producing feed rather than on lab equipment and chemicals (Nguyen, 1997). According to Nguyen Duc Anh's findings, duckweed protein seems to have equivalent biological value as that of soya bean meal protein. As a result, duckweed can therefore be used as a non-commercial protein replacement of soya bean meal in a duck's diet as a sole source of protein. However, its protein is utilized less efficiently than soya because its fiber content is twice as high, 10%, limiting its absorption (Nguyen, 1997). Duckweed contains high concentrations of K, P and pigments such as carotene and xanthophylls thereby making it an ideal supplement for poultry and other animals as well. Even some rural minorities in Myanmar, Laos, and in Northern Thailand in Southeast Asia consume it for its protein content and A and B vitamins.

With sufficient nutrients, duckweed can contain up to 43% crude protein, 5% lipids and digestible fiber (Leng, 1995). The fiber content is low due because it floats and does not require tissue for physical support features. However, as duckweed growth slows, fiber increases and protein decreases. Duckweed contains more essential amino acids than most vegetables and is more closely related with animal protein. Resultantly, chickens, pigs, and ruminant animals and fish can be fed duckweed as well. (Refer to Leng, 1995, for duckweed conversion into weight gain in animals.) Mature chickens can be fed it as a complete substitute for cereal grain, but chicks must have supplements or will otherwise have a small weight gain reduction. Pigs benefit well though protein efficiency is slightly less than from soya bean meal. If combined with crop residues, ruminant animals such as cows, sheep, and goats duckweed can provide a sufficient balance of nutrients as the crop residues assist in the microbial fermentative process (Leng, 1995). In fact, due to is effective sink for P and K nutrients, it is capable of concentrating Phosphorous with duckweed even up to 9-14mg/gram and can be potentially used to feed P-deficient ruminant animals often found in the tropics (Leng, 1995). In rural areas, fish production is often limited due to the accessibility and affordability of biotech-feed. It is often expensive and locally unavailable. However, duckweed is inexpensive and can be fed fresh allowing it to be eaten slowly due to its floatability compared to commercial feed that generally sinks quickly. Fish such as tilapia and carp have revealed an excellent conversion of duckweed to live weight and can be fed as a complete feed. Due to its fiber, not all fish can benefit with the same results.

The plant is an effective sink for wastewater and can permanently remove N, P, K, Ca, Na, Mg, C, and Cl elements from effluent. According to studies in Australia, protein content of duckweed increased from 20-25%→35-40% in dry matter when nitrogen from the sewage increased from <5→15 mg/liter (Nguyen, 1997). Duckweed grown in water with 10-30mg/L of Nitrogen can have protein content as high as 40% (Leng, 1995). However, when growing in nutrient-poor water it only reaches 15-25% protein and 15-30% fiber. If regularly harvested and grown in ideal conditions it produces a lower fiber content of 5-15%, an increased crude protein content of 35-43%, and 5% lipid matter as can be seen below in Table 1.

| **Table 1.** (Leng, 1995) | Crude Protein | Fat | Fibre | Ash |
|---|---|---|---|---|
| | -----------% in DM---------- | | | |
| Natural lagoon | 15-35 | 4.4 | 8-25 | 15 |
| Grown in sewage | 40-43 | 5.4 | 5 | 13 |

A prime source of nitrogen is from wastewater influent and as a result can be locally grown in polluted thereby replacing industrial feed. Duckweed has the capacity to remove mineral contaminants within wastewater from households, food processing, intensive livestock production and human excreta. Yet before being released into a duckweed pond, it is advisable for human and animal manure to undergo initial treatment such as being diluted and/or retained within an anaerobic pond or biogas digester for a few days to reduce solids and prevent the formation of a floating mat (Leng, 1995)(Appendix 4, Figure 2). Sometimes the toxic compounds accumulating in the pond cause the duckweed to die. One example is ammonia. Ammonia is preferred in its ionized state, but if pH shifts the balance from ammonium to ammonia as alkalinity increases, then ammonia moves towards its un-ionized state freeing ammonia creating toxic conditions for duckweed above 100mg $NH_3$/Liter ($NH_4^+ \rightarrow NH_3 + H^+$).

This can be observed within my own usage of duckweed to treat human excreta as will be explained later.

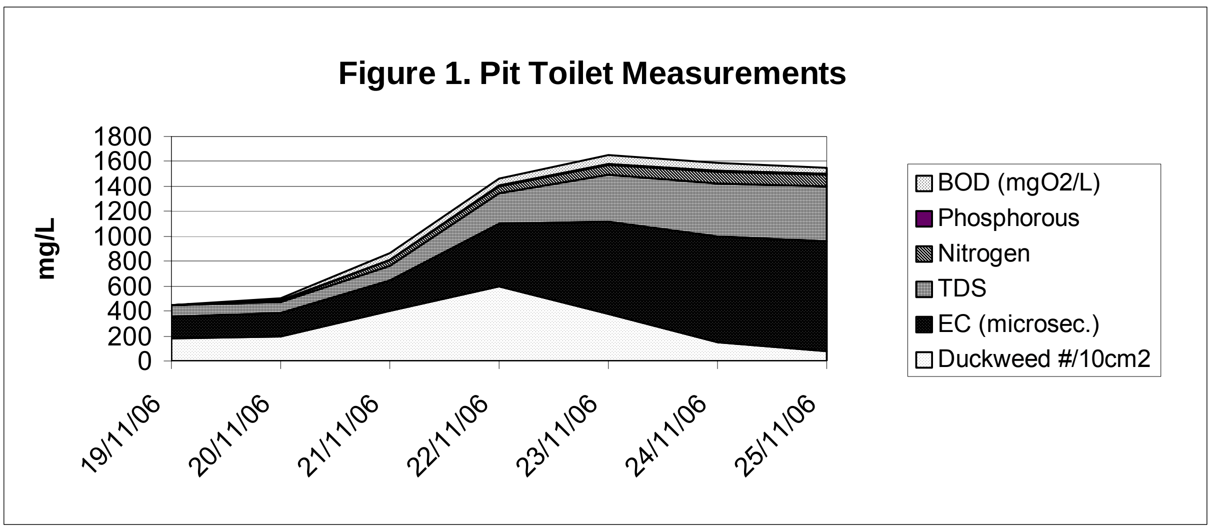
**Rural Wastewater Treatment Through Duckweed**

Mimicking Confucius's quote, "Tell me and I will forget, Show me and I will remember, Involve me and I will understand!" I not only wanted to read and be told about wastewater disposal, I wanted to see the manner of its disposal. I especially desired to be involved in wastewater contribution to better understand its need for proper treatment and disposal. In the hamlet, My Khanh, I lived for nearly two weeks with Le Hoang Thanh, a fish, pig, and fruit tree farmer along with his wife, son, daughter-in-law and their one-year old grandson. There I joined in as much daily activities as I could from helping prepare food, entertaining the baby, feeding and washing the pigs, building a new pigpen, fishing for fish, eel, and crab as well as swimming in the canal and fish pond from which I contracted a mild case of dermatitis due to its contamination.

**Experiment 1 (Pit Toilet):**

*(Methodology)*

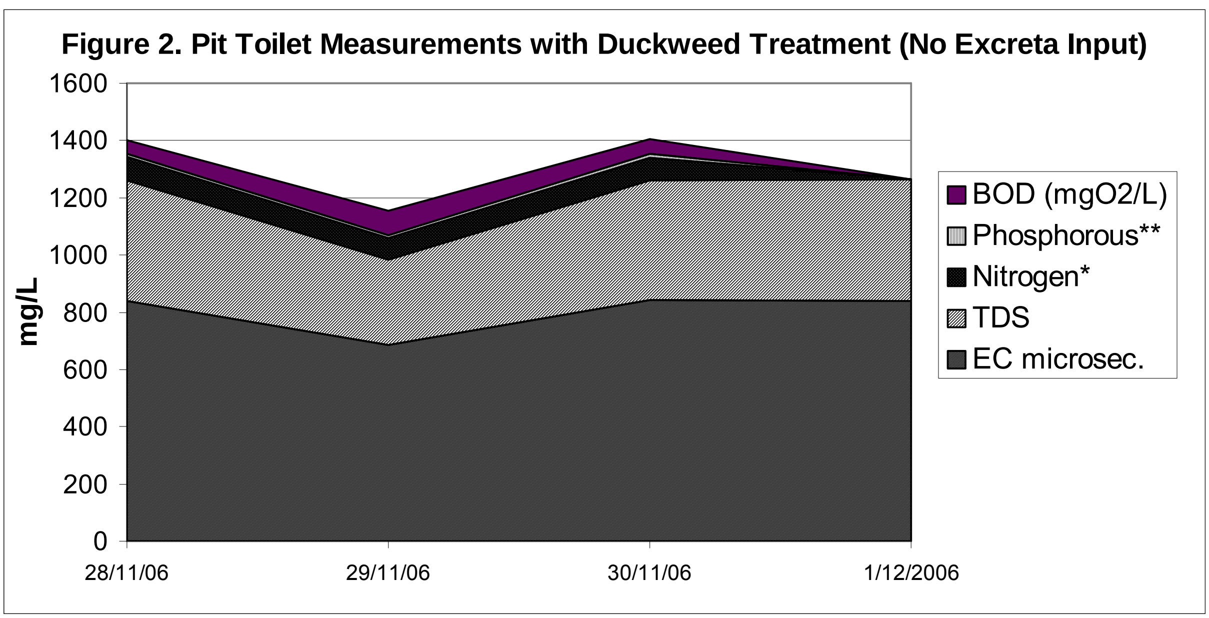
To observe quality of water exposed to human excreta contamination and the quality of public water, two experiments were conducted and numerous water samples taken. Within My Khanh, a majority of its residents continue to use overhung fishpond toilets allowing their wastewater to be directly or indirectly discharged into the nearby canal. To better understand the effect of human excreta upon the environment and how it may be treated through the use of duckweed I chose to create my own overhung toilet over a confined hole. I would measure the waste input and conduct a trial to observe if duckweed alone can keep up with the pace of my excrement input. A one cubic meter hole was dug and half-filled with water from the nearby fishpond. A density of 177 duckweed plants/10cm$^2$ was added. Daily, the time, temperature, pH, Total Dissolved Solids (TDS), and Electric Conductivity (EC) were recorded using Hanna Instruments. In addition, each day one liter of water was removed for its Nitrogen, Phosphorous and Biological Oxygen Demand (BOD) content to be analyzed at the Department for Science and Post Graduate Advanced Laboratory of Can Tho University. Immediately after removal, two liters of fishpond water were replaced to account for the one liter removed for analysis and one liter to account for daily evaporation and evapotranspiration losses. Over the following twelve days the duckweed growth and nutrient presence would be observed. In addition, the duckweed protein content would be analyzed before and after being applied to the wastewater using Kjeldalh method. (See Appendix 1)




*(Results)*

The water quality results for the pit toilet for the first six days are shown in Figure 1. For the first four days EC, TDS, Nitrogen, Phosphorous, and BOD increased rapidly as daily excrement was added. Duckweed also showed considerable growth, however quickly began dying after the fourth day. On the fifth day excrement input was discontinued as can been seen by a peak in EC, TDS, N, P, and BOD measurements. During the remaining two days their measurements declined slowly due to discontinued excrement input and significantly decreased nutrient uptake by the dying duckweed. Also, beginning on the fifth day, a mosquito larvae population of 10 larva/10cm$^2$ was counted and increased over the course of the experiment. Fish was put into the pit, but died.

As a result of significant amount of duckweed senescence, fresh duckweed was reapplied twice, once on the eighth day and again on the tenth day with a thick mat layer. The results of when the thick mat was applied can be seen in Figure 2. After the first day, all five measurements declined, but by the following day all had risen above the previous measurements of two days before except Nitrogen, which was only slightly lower than the two days before. Due to expenses, Nitrogen, Phosphorous, and BOD measurements were not taken after the third day contrary to what is depicted in Figure 3 from November 30-December. 1.




*(Discussion)*

As observed in Appendix 1, several problems arose that altered the results of the experiment. Near the end of the analysis, an inaccuracy of the pH Hanna Instrument was noted by questionable readings either caused by its malfunction or a miscalibration. As a result, pH measurements for the pit toilet experiment cannot be accurately relied upon.

The original idea of inputting excrement into the pit for twelve days and studying the growth rate of the original duckweed could not be fully carried out due to toxic conditions created by ammonia molecules being freed during the transition from ammonium to ammonia of the urine ($NH_4^+ \rightarrow NH_3 + H^+$). However, for the first three days the duckweed grew rapidly until its growth was sharply altered by the presence of ammonia, which begins being released beyond pH levels of 7.5. For the remaining three days the duckweed died until only a few, scattered yellow fronds remained. To prevent this, prior treatment of excrement could have been performed under anaerobic conditions to reduce pathogens and reduce floating solids, began with a denser mat of duckweed to inhibit the contact of ammonium with air, and/or a larger pit be used as to dilute the excrement lowering the concentration. Also, the first two suggestions would also help discourage mosquito breeding, which can survive in ammonia conditions as observed. When the fish were added with intention to reduce the number of mosquito larva, they died within 12 hours as a result of ammonia toxicity.

When a denser mat of duckweed was applied it flourished and half of it was harvested daily. The original protein content of the applied duckweed as 19% and its content after two days of nutrient uptake in the pit was 28%. This shows an increase in protein resulting from nutrient concentrations. However, protein content is capable of increasing up to 43% with Nitrogen availability of 10-30mg/L (Leng, 1995).

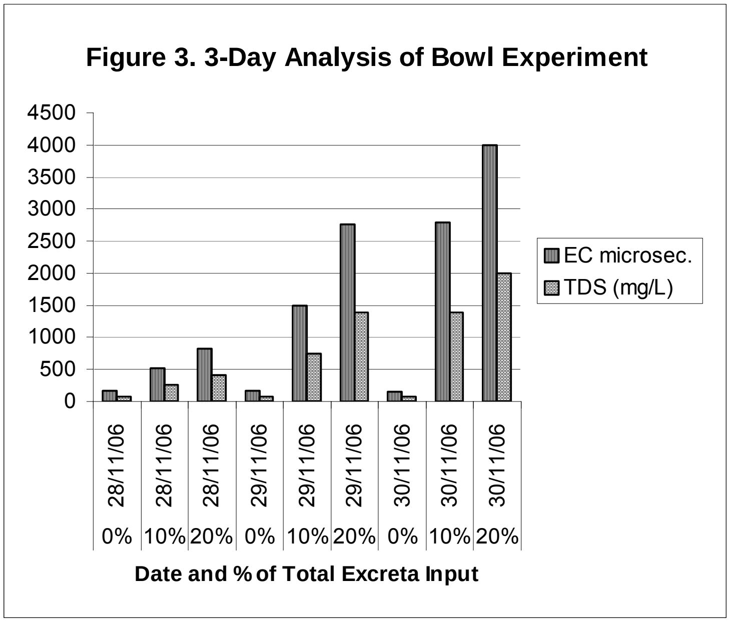
**Experiment 2 (Bowl Experiment):**

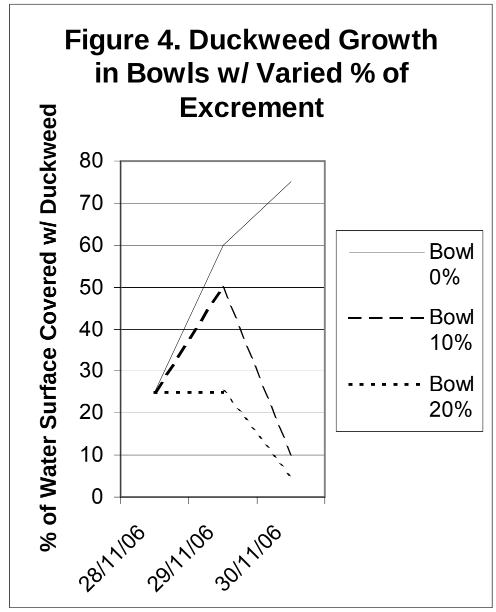
*(Methodology)*

While the second part of treatment was occurring in the pit toilet after excrement was discontinued, a second experiment was begun to better understand the nutrient uptake of duckweed with varied amounts of excrement input. Nine bowls were filled with fishpond water and its surface one-fourth (25%) covered with duckweed. Three bowls were for controlled analysis and given no excrement. Three other bowls were each given 10% of the daily total amount of excrement for three days and the third set of three bowls were provided with 20% excrement daily also for three days. Daily measurements were recorded of temperature, pH, EC, and TDS using Hanna Instruments. (Appendix 2)

*(Results)*

Results for Electric Conductivity and Total Dissolved Solids are shown in Figure 3. Under controlled conditions, EC and TDS levels remained fairly constant except for the third day when algae presence lowered them slightly. The EC and TDS of bowls with 10% and 20% excrement increased considerably with a curved slope. By the third day, the measurements of bowls with 20% excrement exceeded the Hanna Instrument's maximum EC and TDS count of 4000 and 2000 respectively. As the result, the experiment was ended. The results of duckweed growth under varied percentages of excrement as shown in Figure 4. In the controlled bowls, duckweed growth was rapid. After the first day of rapid growth the bowls with 10% excrement showed a considerable decline of duckweed presence. The bowls with 20% excrement showed no growth of duckweed, but rather a pause of growth for the first day followed by a steady senescence the second day.




*(Discussion)*

By observation, duckweed grew well in the original fishpond water without any added excrement. However, due to the size of the bowl, the water's temperature increased during the daytime causing there to be a small algae bloom raising the pH level. If more time permitted, the duckweed's growth may have slowed as a result of this in addition to competition for nutrients. The bowls that received 10% excrement quickly began dying after the second day most likely as a result of ammonia presence. In the bowls that received 20% excrement, there was no observed growth of duckweed, but rather a rapid senescence. This shows that separation of urine and feces may be a solution to avoid such toxic conditions. Also, a larger container could have assisted in diluting the excreta. In all three sets of bowls an original, denser duckweed mat would have assisted with suppressing algae growth and minimizing the ammonium's contact with air thereby reducing the chances of ammonia toxicity.

**Local Water Quality**

*(Methodology/Results/Discussion)*

To obtain a greater perspective of wastewater disposal within Can Tho City, water samples were taken from two toilet fishponds, one canal, and one intensive fish farm in An Binh; two toilet fishponds and one canal in My Khanh; and one fishpond and one canal in Can Tho City. In addition to the same measurements taken as from the pit toilet water, E. Coli presence was tested for in one fishpond from each location using Manganese peroxidase (MnP) analysis method (See Appendix 3). Contrary to expectations, the results showed no detection of E. Coli in any of the toilet fishponds. The pH of all samples were within healthy limits from 6.9-7.3. The EC and TDS in all areas were also within decent parameters except one toilet fishpond in My Khanh most likely due to excessive untreated pig wastewater, which also raised its BOD. Also, the fishpond in Can Tho City had high EC and TDS probably due to is small volume and regular use by five family members. Also the Nitrogen, Phosphorous, and BOD content of the two fishponds in My Khanh, fishpond and canal in Can Tho City was higher than normal measurements. The canal in both My Khanh and Can Tho City contained a high BOD possibly due to excess of trash or in My Khanh's case, the presence of an upstream intensive fish farm.

By comparing the results of the surveys (Appendix 5) with the water quality collected from the different sites, questions arise from possible correlations. For example, in Can Tho City, the hygiene toilet is used almost entirely. The sample collected from a city canal gave a relatively high EC, TDS and P count in addition to an exceptionally high amount of Nitrogen and BOD presence. It is possible to deduct that contamination of surface water is being caused either by uncollected trash or presence of domestic wastewater very likely through leaky septic and piping systems. In My Khanh where almost three-quarters of the residents admit to using toilet fishponds, the BOD of the canal was over nine times higher than the canal in An Binh possibly due to intensive fish farming, release of wastewater from fishponds or lack of trash collection. Trash on the river is a common site. Unfortunately, further evaluation of the results cannot be fully performed due to the lack of time since the data was given and this report written.

**Constructed Wetlands**

As observed from the above experiments, duckweed alone cannot adequately treat concentrated wastewater. Especially if the volume of wastewater is increased, a more intricate system is necessary. On the other hand, complex, centralized treatment facilities are unlikely to become available in the near future in rural areas of Viet Nam. However, it is suggested that decentralized, small-scale domestic wastewater treatment systems are possible solutions for small communities in the Mekong Delta. Although wetlands have been biological filters since the beginning of time, research and development of wastewater treatment through constructed wetlands is still a recent technology. As constructed wetlands have become increasingly popular and successful in Europe and other parts of the world so may their implementation in Viet Nam provide similar results (Le et. al. 2005).

Constructed wetlands have been designed not only for wastewater treatment and recycling of nutrients, but also for flood containment, retention of surface water runoff, and by providing a habitat for fish and wildlife. If properly designed and maintained, natural microbial, biological, physical, and chemical processes can effectively treat on-site wastewater (Tayade, 2005). Typically, an artificial wetland is composed of water, substrate, plants (vascular and algae), litter from plants, small invertebrates such as worms and insects, and microorganisms.

Constructed wetlands are most commonly fed primary and secondary domestic sewage effluent. They are capable of removing most pollutants from wastewater and contaminants such as BOD, suspended solids (SS), fecal coliform, and nutrients. A detailed design of constructed wetland in Can Tho University can be seen below in Figure 5.

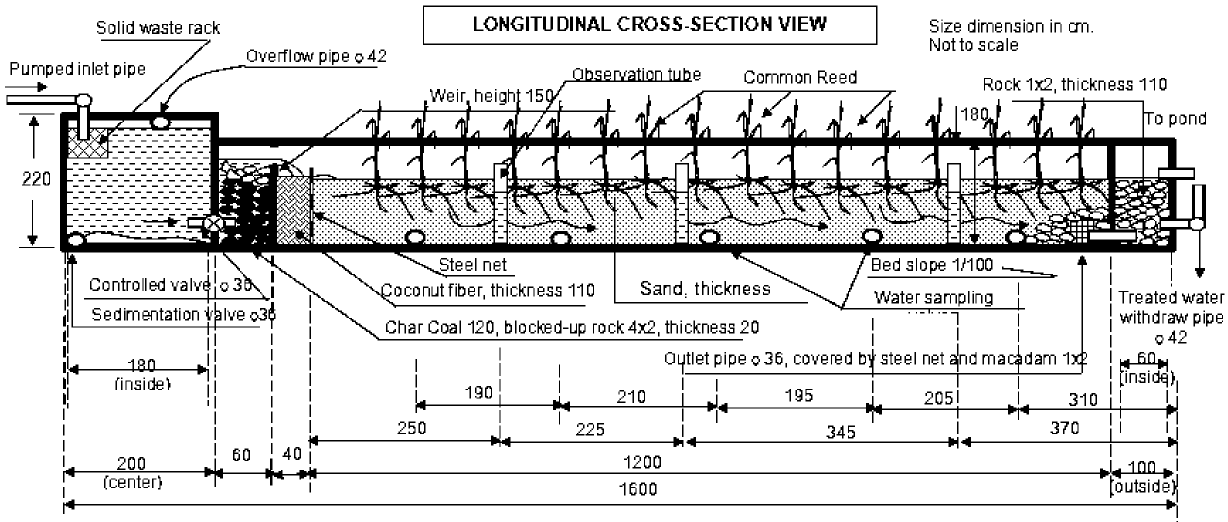



**Figure 5** (Le et. al. 2005)

The primary characteristic of a constructed wetland is to provide an environment where wastewater can flow through slowly allowing biological microbial processes to occur, contaminants retained, and its C, N, P, and K nutrients to be filtered and absorbed by growing plants. The slow movement of water caused by substrates such as rocks, sand, and coconut husks encourage sedimentation of suspended solids which will further decompose under anaerobic conditions, oxygen to leak in improving the oxygen level, and underwater anoxic conditions to assist in the removal of Nitrogen, ammonium, and metals. Charcoal adds carbon nutrition while simultaneously helping reduce odor. The roots and stems of the vegetation that can be collected locally provide habitat for microbes to breakdown organic matter and reduce pathogen. The vegetation must be able to slow water movement and be well adapted to saturated conditions. It is also advisable to use vegetation that can be harvested and used for multiple purposes. At Can Tho University's experimental constructed wetland in Campus 1, the common reed is grown, but is limited in further uses other than fuel. However, the benefit of growing a common plant is that there is less concern for over-harvesting and since humans do not consume it the spread of disease is minimized.

At Can Tho University's constructed wetland, it is currently treating the raw wastewater from fifteen local households. It is concluded by the designer of the model, Professor Le Anh Tuan, that the constructed wetland has a high efficiency in removing pollutants (Le et. al., 2005). Constructed wetland sizes and types differ depending on the amount of wastewater being treated and what species of aquatic plants are being raised. Although the university's wetland is constructed from cement and brick, cheaper designs are available.

Two types of constructed wetlands exist: subsurface flow (SSF) and surface flow (SF) systems. The former is better suited because it requires a smaller amount of land and can better eliminate odor and pest such as mosquito breeding. The porous mediums/substrate allow for a greater area of contact for treatment. As a result these can be constructed above ground or below however both require liners such as nylon, plastic, or cement, to prevent seepage into underground water.

As with all other wastewater treatment systems, the constructed wetland poses benefits and limitations. The constructed wetland can be less expensive than other systems and the operational costs are minimal and uptake simple. They are able to withstand water flow fluctuations. Due to their natural composition, they visually and environmentally blend in with the surroundings and are aesthetically pleasing to the eye. Finally, as a result of its slow movement, it creates a habitat for wetland organisms and the recycling of nutrients.

Conversely, land is required for its construction, though can be reduced with an appropriate design. A constructed wetland is only cheaper than conventional systems where land is available and affordable. Thinking globally, constructed wetlands vary in performance with seasonal and temperature changes. There also must be at least a minimal input of water daily. It cannot dry out. They cannot be entirely dependent over a long period of time if the quality of water input does not meet specific standards such as the absence of excess chemicals, metals, and pesticides which are destructive to the system's biological organisms. As a result, it is possible to combine a constructed wetland with conventional treatment systems for complete water rejuvenation.

Due to its relatively recent use as wastewater treatment, constructed wetlands still have issues in need of further research. For example, the rate of bio-toxicity is not yet documented. How much contamination and metals the system can withstand before its efficiency weakens is also still unknown (Davis). When a constructed wetland's capacity for Phosphorous and metals reaches its limit, it must be emptied and replaced with new substrate. However, the question remains, where does the emptied substance go then?

**Conclusion**

To provide the entire world with sewers and wastewater treatment is nearly an impossible feat. However, for individuals to take responsibility for their own waste and to treat it at the home level may be a more achievable goal. Constructed wetlands and biogas digestion have been proved as effective methods of helping to treat wastewater. The effluent, especially from the biogas digester can then be deposited into a pond to grow vegetation such as duckweed, which not only has wastewater treatment qualities, but also animal feed value. Although the environment has natural processes to treat wastewater such as by vegetation, as observed in the experiments, wastes must be separated and receive pre-treatment before given to vegetation to absorb its nutrients. Careful handling of wastewater is of high importance as to not further contaminate clean water. However, increasing public awareness and changing people's minds on wastewater issues is a slow and tedious process. “People just observe by eye,” but not understand. “Farmers like to see something,” not just hear something (Nguyen, 2006). Not only must a change of view take place at the grassroots level, but also in the minds of those who lead the country. According to Innocent Nhapi, the cost of disposing one cubic meter of wastewater is more expensive than the cost of creating one cubic meter of potable water. As a result, “[i]n developing countries, the situation is more desperate as investments have focused more on clean water provision than on sanitation services” (Nhapi, 2005). As population increases so does wastewater. Soon one choice may remain, to treat the wastewater because that is the only source of water left available.

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# Appendix 1

## Results of Pit Toilet

| Day | Time | Water Temp.◦C | pH | Duckweed #/10cm2 | EC microsec. | TDS (mg/L) | Nitrogen* (mg/L) | Phosphorous** (mg/L) | BOD (mgO2/L) | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|
| 19/11/06 | 12:30pm | 31.8 | 8.1 | 177 | 179 | 90 | | | | Began experiment (Fishpond water input) |
| 20/11/06 | 9:15pm | 29.6 | 7.5 | ~200 | 182 | 91 | 8.40 | 2.86 | 18 | Began excrement input |
| 21/11/06 | 7:45am | 28.2 | 7.1 | Not Counted | 244 | 122 | 42.00 | 5.28 | 52 | 1 frog noticed |
| 22/11/06 | 7:15am | 27.4 | 8.2 | ~600 | 497 | 246 | 58.80 | 6.97 | 52 | One dead fish |
| 23/11/06 | 4:00pm | 30.7 | 8.1 | Sig. decline | 745 | 376 | 75.60 | 9.70 | 72 | Counted 10 mosquito larvae/10cm2 |
| 24/11/06 | 10:45am | 31.5 | 7.9 | ~150 | 847 | 423 | 98.00 | 6.17 | 63 | Ended excrement input |
| 25/11/06 | 1:15pm | 29.9 | 7.8 | ~80 | 876 | 447 | 88.20 | 10.75 | 46 | Added 1 fish; scum causes DW to clump |
| 26/11/06 | 9:45am | 28.5 | 7.8 | ~200 | 878 | 437 | 89.60 | 10.77 | 46 | Added fresh DW (Duckweed); one dead fish |
| 27/11/06 | 7:45am | 27.7 | 7.8 | Not Counted | 867 | 433 | 84.00 | 10.61 | 36 | Brought weekend samples in for sampling |
| 28/11/06 | 8:00am | 27.7 | 7.6 | ~750 | 841 | 420 | 81.20 | 11.21 | 48 | Covered water with fresh, thick mat of DW |
| 29/11/06 | 6:30am | 26.8 | 7.8 | | 685 | 299 | 75.60 | 10.29 | 84 | Added 2 fish |
| 30/11/06 | 7:00am | 27.4 | 7.4 | | 842 | 420 | 78.40 | 11.27 | 52 | Harvested half of DW |
| 1/12/2006 | 8:15am | 27.3 | 7.4 | | 840 | 425 | | | | 1 dead frog; 2 dead fish; ended experiment |

11/28/2006 Original fresh layer of duckweed protein content(wet)>>1.33%---(dry***)>>19%

1/12/2006 Harvested duckweed protein content(wet)>>1.93%---(dry***)>>28%

Analysis Method:

Temperature, pH, EC, TDS : Hanna Instruments
Nitrogen* : Kjeldalh
Phosphorous** : Colorimetric
Dry*** : Assuming wet duckweed is 93% water and only 7% substance remains when dry
EC : Electric Conductivity
TDS : Total Dissolved Solids
BOD : Biological Oxygen Demand

# Appendix 2

## Water Quality Results of Varying Excrement Input

| | Date | Time | Water Temp.◦C | pH | EC microsec. | TDS (mg/L) | DW % |
|---|---|---|---|---|---|---|---|
| Av. of 3 Bowls (0% excrement each) | 28/11/06 | 7:30pm | 27.2 | 9.1 | 165 | 83 | 25% |
| Av. of 3 Bowls (10% excrement each) | " | " | 26.4 | 8.4 | 518 | 259 | 25% |
| Av. of 3 bowls (20% excrement each) | " | " | 26.3 | 8.4 | 818 | 414 | 25% |
| Av. of 3 Bowls (0% excrement each) | 29/11/06 | 7:30pm | 28.0 | 9.2 | 163 | 83 | 60% |
| Av. of 3 Bowls (10% excrement each) | " | " | 27.2 | 8.2 | 1488 | 750 | 50% |
| Av. of 3 bowls (20% excrement each) | " | " | 27.2 | 8.2 | 2768 | 1394 | 25% |
| Av. of 3 Bowls (0% excrement each) | 30/11/06 | 8:00pm | 26.9 | 9.2 | 155 | 77 | 75% (algae) |
| Av. of 3 Bowls (10% excrement each) | " | " | 25.8 | 8.3 | 2796 | 1395 | 10% |
| Av. of 3 bowls (20% excrement each) | " | " | 25.5 | 8.2 | >4000 | >2000 | 5% |

<u>Analysis Method</u>

Temperature, pH, EC, TDS : Hanna Instruments

EC: Electric Conductivity

TDS: Total Dissolved Solids

# Appendix 3

## An Binh, My Khanh, and Can Tho City Site Water Quality Results

| Location | Site | Date | Time | Av.Water Temp.°C | Av.pH | E. coli | EC range microsec. | TDS range (mg/L) | Nitrogen* (mg/L) | Phosphorous** (mg/L) | BOD ($mgO_2/L$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| An Binh | Toilet fishpond | 23/11/06 | 8:00am | 28.4 | 7.2 | ND | 171;165;189 | 85;82;84 | 8.40 | 2.00 | 10 |
| | Toilet fishpond | 23/11/06 | 8:30am | 28.4 | 7.1 | ND | 164;158;134 | 82;78;67 | 2.80 | 0.94 | 4 |
| | Canal | 23/11/06 | 8:45am | 29.5 | 7 | (-) | 122 | 62 | 5.60 | 0.53 | 3 |
| | Intestive fishfarm | 23/11/06 | 8:15am | 29.7 | 7.1 | (-) | 172;169;171 | 86;84;83 | 11.20 | 1.13 | 14 |
| My Khanh | Toilet fishpond | 30/11/06 | 6:45am | 27.3 | 7 | (-) | 197;195;195 | 98;97;98 | 11.20 | 1.91 | 22 |
| | Toilet fishpond | 30/11/06 | 7:15am | 28.1 | 6.9 | ND | 200;239;166 | 100;119;84 | 14.00 | 3.42 | 44 |
| | Canal | 30/11/06 | 7:00am | 29.2 | 7 | (-) | 117 | 58 | 5.60 | 0.50 | 28 |
| Can Tho | Toilet fishpond | 1/12/2006 | 12:40pm | 27.5 | 7.1 | ND | 531;530;633 | 264;265;315 | 22.40 | 2.06 | 22 |
| | Canal | 1/13/2006 | 10:30am | 28 | 7.3 | (-) | 195;386;670 | 95;192;333 | 19.60 | 1.58 | 30 |

Note:

Analysis method:

Temperature, pH, EC, TDS : Hanna Instruments

N : Kjeldalh

P : Colorimetric

E. coli : MnP

ND : Not Detected

(-) : Not Analyzed

Av. : Average of three samples

Range : Measurement of three samples

# Appendix 4

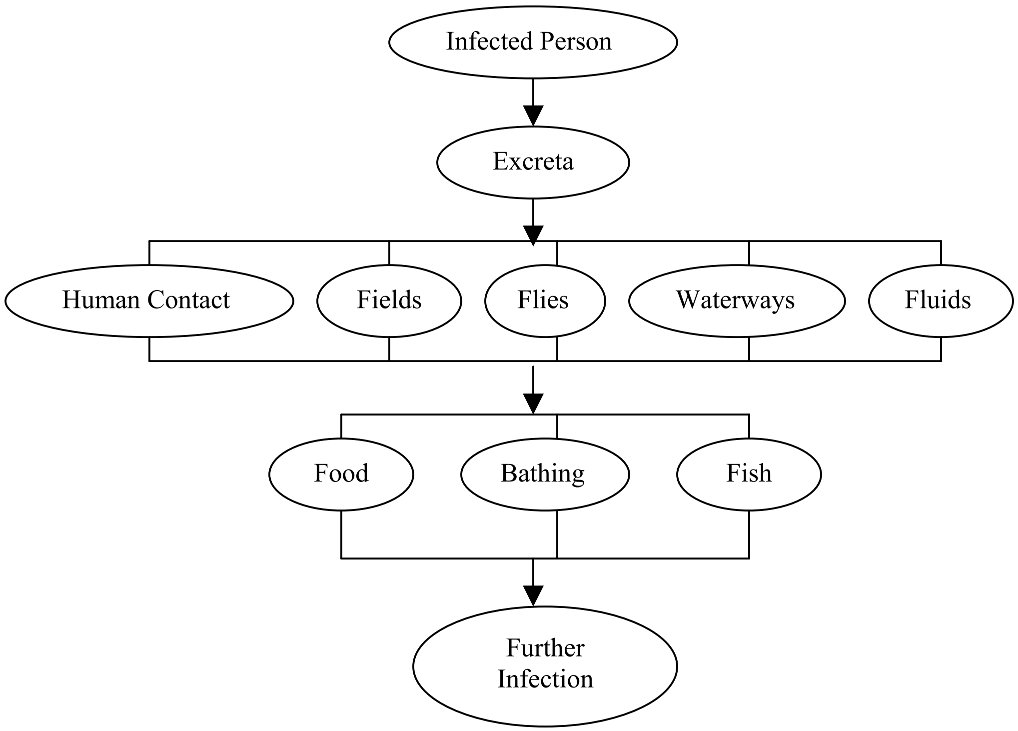



**Figure 1.** (Dalsgaard, 1995)

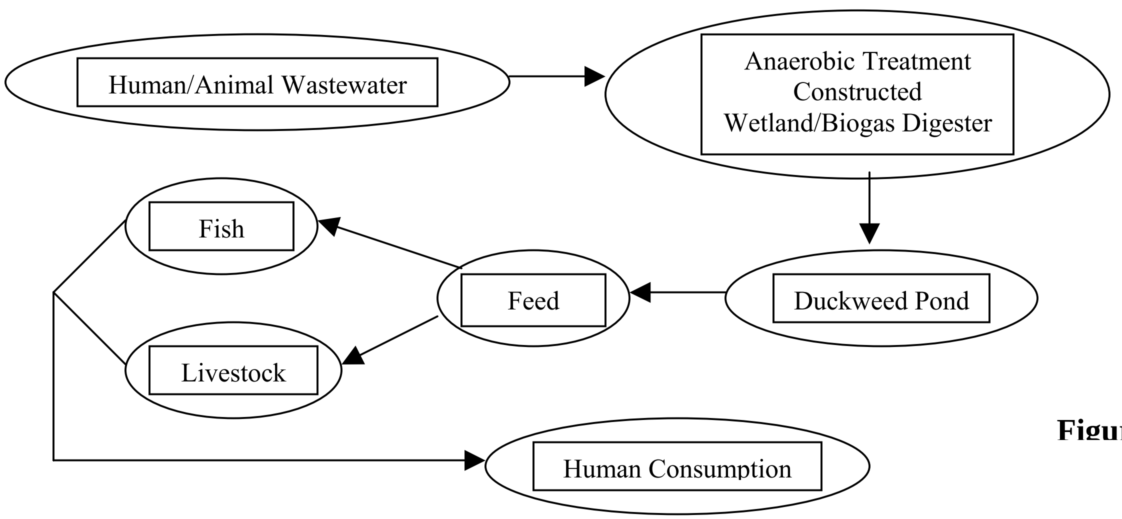
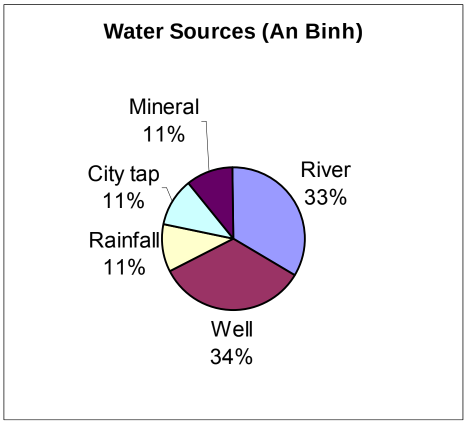
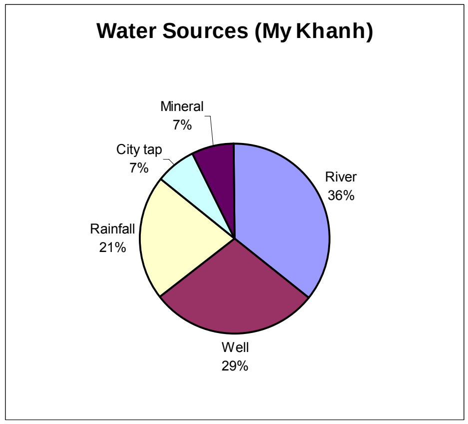
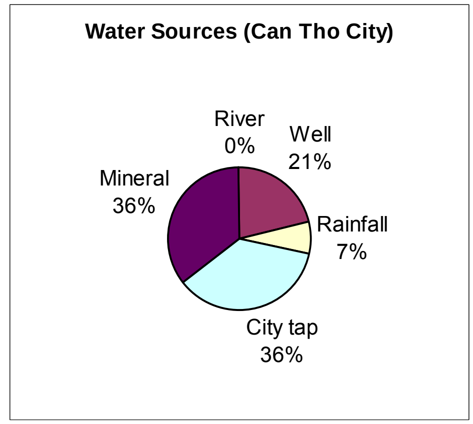


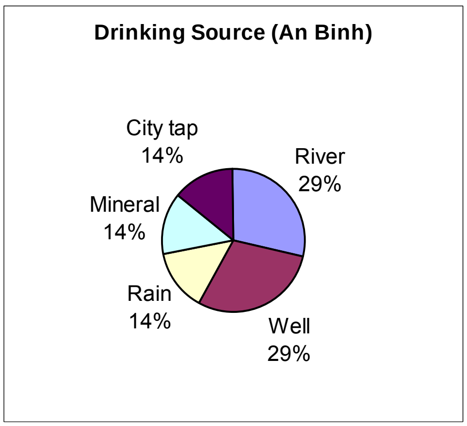

**Figure 2.**

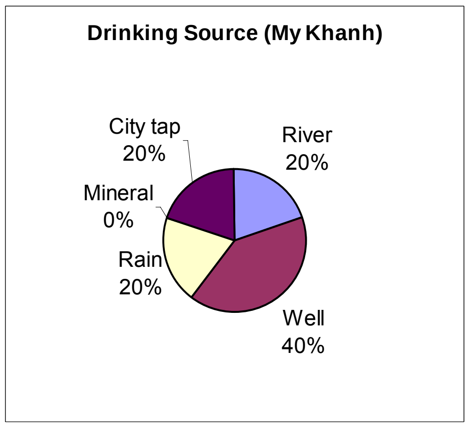
# Appendix 5

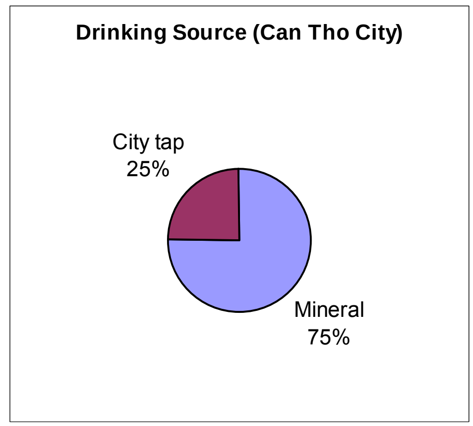

Water Sources (An Binh)
Mineral 11%
City tap 11%
Rainfall 11%
River 33%
Well 34%

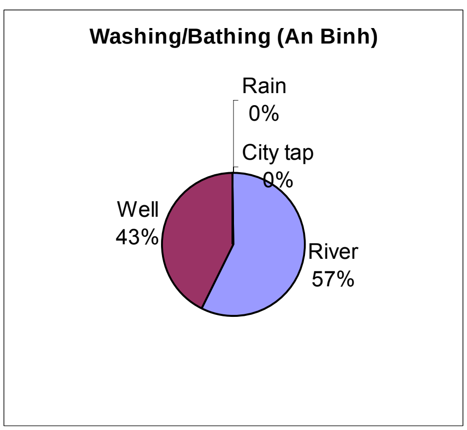

Water Sources (My Khanh)
Mineral 7%
City tap 7%
Rainfall 21%
River 36%
Well 29%

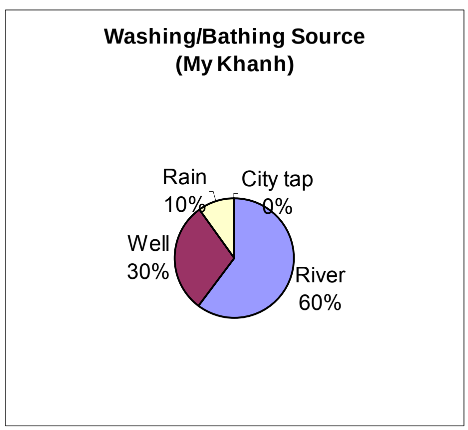

Water Sources (Can Tho City)
River 0%
Well 21%
Mineral 36%
Rainfall 7%
City tap 36%

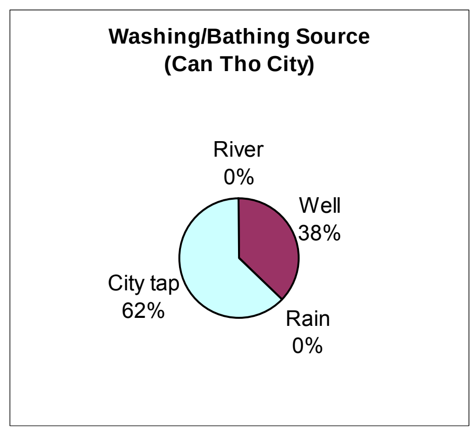

Drinking Source (An Binh)
City tap 14%
River 29%
Mineral 14%
Rain 14%
Well 29%

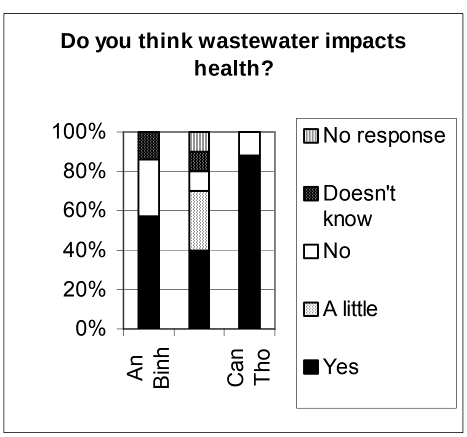

Drinking Source (My Khanh)
City tap 20%
River 20%
Mineral 0%
Rain 20%
Well 40%

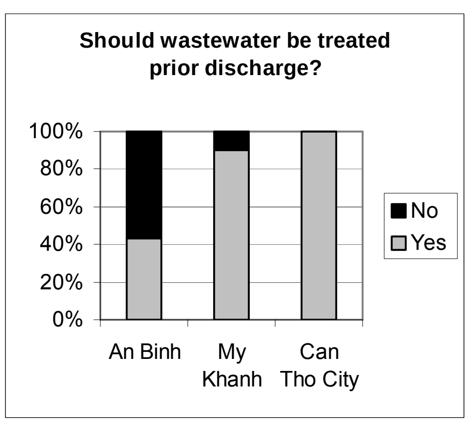

Drinking Source (Can Tho City)
City tap 25%
Mineral 75%

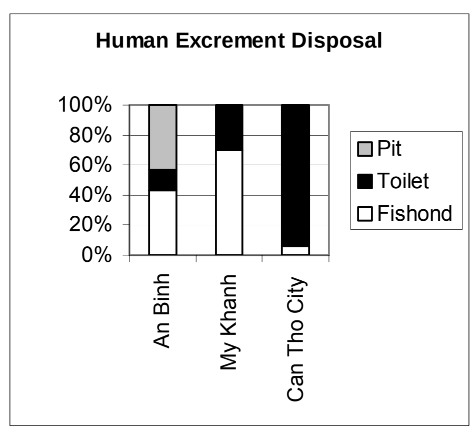

Washing/Bathing (An Binh)
Rain 0%
City tap 0%
Well 43%
River 57%


Washing/Bathing Source (My Khanh)
Rain 10%
City tap 0%
Well 30%
River 60%


Washing/Bathing Source (Can Tho City)
River 0%
Well 38%
City tap 62%
Rain 0%


Do you think wastewater impacts health?
100%
80%
60%
40%
20%
0%
An Binh
Can Tho
No response
Doesn't know
No
A little
Yes


Should wastewater be treated prior discharge?
100%
80%
60%
40%
20%
0%
An Binh
My Khanh
Can Tho City
No
Yes


Human Excrement Disposal
100%
80%
60%
40%
20%
0%
An Binh
My Khanh
Can Tho City
Pit
Toilet
Fishond

# Appendix 6

B¶ng C©u Hái Pháng VÊn Hé Gia §×nh

Xin chµo,
Em tªn Micah vµ lµ ngêi Mü. Em hiÖn ®ang lµ sinh viªn cña trêng §¹i Häc CÇn th¬ ®ang häc tËp vÒ Bé M«n M«i Trêng. Em ®ang tiÕn hµnh mét dù ¸n nghiªn cøu vÒ xö lý níc th¶i ë c¸c x· Mü Kh¸nh, An B×nh vµ néi thÞ thµnh phè CÇn th¬. Em sÏ rÊt biÕt ¬n nÕu nh Anh/ChÞ ®äc vµ tr¶ lêi mét sè c©u hái cña em díi ®©y. Em còng xin phÐp ®îc sö dông c¸c c©u tr¶ lêi cña Anh/ChÞ trong mét b¶n b¸o c¸o. Em sÏ kh«ng ®a tªn gäi cña Anh/ChÞ vµo trong b¶n b¸o c¸o. Em xin tr©n träng c¶m ¬n.

*(Hello, my name is Micah and I am from the United States. I am a student at Can Tho University studying Environment. I am studying wastewater treatment in My Khanh, An Binh, and Can Tho City. I appreciate if you would to read and answer my questions. I ask your permission to use your responses in a report. I will not mention your names. Thank you very much!)*

1. Gia ®×nh nhµ ta cã bao nhiªu ngêi? Cã mÊy trÎ em, ngêi lín vµ «ng bµ ...?
(How many members are in your household? How many children, adults, grandparents…?)

2. C¸c c«ng viÖc chÝnh cña c¸c thµnh viªn trong gia ®×nh lµ g×?
(What are the occupations of the members in the household?)

3. Gia ®×nh nhµ ta së h÷u bao nhiªu mÐt vu«ng ®Êt?
(How many square meters of land do you own?)

4. C¸c bÖnh tËt th«ng thêng mµ gia ®×nh ®· gÆp ph¶i (bÖnh vÒ da, bÖnh tiªu ch¶y, ®au bông ...)
(What are some of the common illnesses your household has had? (skin irritations, diarrhea, stomach pains…))

5. Anh/ChÞ cã biÕt g× vÒ nh÷ng nguyªn nh©n cña c¸c bÖnh tËt ®ã kh«ng?
(What do you think the causes of these illnesses were?)

6. Anh/ChÞ lÊy nguån níc uèng vµ níc t¾m giÆt ë ®©u?
(Where do you get your drinking and bathing water?)

7. Anh/ChÞ cã xö lý níc kh«ng? NÕu cã th× Anh/ChÞ xö lý níc nh thÕ nµo? B»ng ph¬ng ph¸p g×?
(Do you treat the water? How? (which method))

8. Anh/ChÞ ®· tiÕn hµnh xö lý níc vµo khi nµo? V× sao?
(When did you begin treating your water? Why?)

9. Anh/ChÞ ®· häc hái ®îc vÒ tÇm quan träng cña xö lý níc nh thÕ nµo? (Qua Héi N«ng D©n hay Héi Phô N÷) (How did you learn about the importance of treating water? (Farmer Assoc., Women's Union))

10. Anh ChÞ cã nghÜ lµ níc th¶i cÇn ®îc xö lý tríc khi ch¶y ra s«ng r¹ch vµ ao hå kh«ng?
(Do you think wastewater should be treated before being discharged into the river/canal/pond?)

11. Nhµ Anh/ChÞ cã lo¹i h×nh nhµ vÖ sinh g×? (What kind of toilet do you have? (over fish pond, hygiene toilet, pit))

CÇu tiªu trªn ao c¸ □ (Toilet over fishpond)
Nhµ vÖ sinh □ (Hygiene toilet)
Hè tiªu □ (Pit)

12. Anh/ChÞ cã nghÜ r»ng níc th¶i cã ¶nh hëng ®Õn vÊn ®Ò søc kháe kh«ng? Nh thÕ nµo
(Do you think wastewater can cause health problems? How?)

Xin c¶m ¬n sù tr¶ lêi cña Anh/ChÞ. (Thank for your responses)