Recycling Plant Nutrients in Waste in Southern Thailand

Nanette Levanius Schouw
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in Southern Thailand

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Environment & Resources DTU
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PREFACE

The present thesis has been prepared as part of the fulfilment of the Ph.D. degree requirements at Environment & Resources DTU, Technical University of Denmark. The work has been carried out in the period from September 1998 to December 2002 under supervision of Professor Dr. Jens Christian Tjell, Associate Professor Dr. Hans Mosbæk, External Associate Professor Mr. Jens Lønholdt (Environment & Resources, DTU) and Assistant Professor Dr. Somtip Danteravanich (Faculty of Environmental Management, Prince of Songkhla University, Thailand). The study is based on extensive fieldwork conducted in Southern Thailand (with basis at Prince of Songkhla University) over five periods each of two-three month duration. The project is financed jointly by Danish University Consortium for Environmental Development, DUCED and the Technical University of Denmark, DTU. The thesis consists of a summary report and the following four:


All references to these papers are indicated in the text with bold roman numerals (I-IV). However, in this www-version the papers are not included. They can be obtained
As a part of my Ph.D. project I have conducted field and laboratory work in Thailand and Denmark, and contributed to International Scientific Journals. Many people were involved in this project, and it could not have been fulfilled without them.

The hospitality I was met with by staff and students at the Faculty of Environmental Management, Prince of Songkla University in Thailand is greatly acknowledged. Special thanks should be given to Rungrat Bualom, Patsorn Sawatasuk and Sasiwong Thajet, who apart from helping with some of the hard practical work, provided a friendly and home-alike atmosphere for me during my 12 month stay in Thailand. The study could not have been done without the openness and help from the citizens and authorities of Phattalung, Kuan Lang and Prik.

Thanks to all my supervisors, Hans Mosbæk, Jens Christian Tjell, Jens Lønholdt and Somtip Danteravanich, with whom it has been stimulating and a pleasure to collaborate. Especially Somtip Danteravanich should be mentioned, because she always prioritised her time to discuss my work in Thailand, and Jens Christian Tjell for his never ending interest, time and for not holding back his constructive criticism. Henrik Bregnhøj has also been a great help, and should be thanked for always commenting my work and manuscripts.

Last but not least my friends and family for helping me combining my scientific work with family life.

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Nanette Levanius Schouw

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ENGLISH SUMMARY

This Ph.D. thesis consist of a review report and four papers describing the Ph.D. project “Recycling Plant Nutrients in Waste in Southern Thailand”.

In most parts of the world problems are caused by one-way flow of plant nutrients from agriculture to water bodies via human waste. By recycling plant nutrients in waste the problems of nutrient deficiency in agriculture and pollution of water bodies might be highly reduced. The possibilities of recycling plant nutrients in waste in three case study areas, Phattalung, Kuan Lang and Prik, in Southern Thailand were studied.

Analysis of nutrient flows in waste in Phattalung, Kuan Lang and Prik showed that household waste constituted the largest recycling potential in each area. The fertiliser quality of kitchen waste, human excreta and sullage was found to be high when compared to agricultural crop’s nutrient demand, chemical fertiliser composition and international guidelines for toxic compounds. However, the recycling potential is yet far from utilised, as most nutrients in waste end up in surface water, groundwater or at disposal sites.

The economic, environmental and social feasibility of nine selected sanitation systems was studied and these results were gathered in a developed Microsoft Excel™ programme to find the most sustainable sanitation system of the nine for each area.

Recycling nutrients via a composting latrine and local watering by sullage was found to be the most environmentally feasible system in Kuan Lang. Composting toilets and waste stabilisation pond treatment of sullage was the most environmental feasible system in Phattalung. In Prik the system consisting of composting latrines and waste stabilisation treatment of sullage was as environmental feasible as the system consisting of sub surface trickle irrigation of septic tank effluent, central solid waste composting and local watering with sullage.

The existing systems were found to be the most economic feasible to the local authorities and some of the private users, as expenses to cover environmental
infrastructure were very low here. By upgrading the existing systems to comply with Thai legal framework several of the studied waste recycling sanitation systems would become more economically feasible than the upgraded existing systems. In all three areas local farmers receiving waste would potentially benefit economically from introduction of waste recycling.

It was found to be socially acceptable to recycle nutrients in waste via most of the studied systems, even though the three existing non-recycling-systems were culturally and practically most acceptable among the private users. Composting latrines were the most acceptable among the authorities of Phattalung and Kuan Lang, whereas the authority of Prik would accept composting latrines and toilets with local sub surface trickle irrigation of septic effluent equally. Thus it has been found to be socially feasible to recycle nutrients, even though the most sustainable system might not turn out to be among the nine systems studied. This latter aspect stresses the importance of making the decision process iterative.

The developed decision support tool aggregated 16 sustainability criteria with various inter-weights, and identified the most sustainable sanitation system(s) for each area of the nine studied. The existing system and the system with composting latrine and wastewater stabilisation pond treatment of sullage were found to be the most sustainable system of the studied for Phattalung. Composting latrines and local irrigation with sullage were the most sustainable system for Kuan Lang. Applying a sub surface trickle irrigation system to the existing septic tank toilet system, local irrigation with sullage and central composting of kitchen waste and septic sludge was the most sustainable system of the studied for Prik.

Therefore it can be concluded that there exist a large unutilised recycling potential in waste in Southern Thailand and that recycling potentially could result in environmental benefits and economic incentives for the farmers. Additionally there is great interest for and willingness to test waste recycling in practice among the local authorities and private users.
DANSK RESUMÉ


Denne Ph.D. afhandling omfatter en oversigtsrapport og fire artikler, der beskriver Ph.D. projektet “Recirkulering af plantenæringsstoffer i affald i det sydlige Thailand”

En-vejs-strømme af næringsstoffer fra landbrug til vandrecipienter via humant affald forårsager i de fleste dele af Verden problemer. Ved at recirkulere plantenæringsstoffer i affald kan landbrugets næringsstofmangel afhjælpes betydeligt. Muligheden for at recirkulere plantenæringsstoffer i affald i tre modelbyer, Phattalung, Kuan Lang og Prik i det sydlige Thailand blev undersøgt.

Analyse af næringsstofstrømmen i Phattalung, Kuan Lang og Prik viste at ud af alle affaldskilder genererer husholdningerne den største mængde plantenæringsstoffer i alle tre modelbyer. Gødningskvaliteten af køkkenaffaldet, de humane ekskrementer og det grå spildevand var høj ved sammenligning med stofsammensætning af afgrøder og handelsgødning samt internationale grænseværdier for miljøfremmede stoffer. Næringsstofanalyse viste dog at recirkuleringspotentialet langt fra var udnyttet i dag, idet de fleste næringsstoffer i affald endte i overfladevand, grundvand og på lossepladsen.

Den økonomiske, miljømæssige og sociale gennemførlighed (”feasibility study”) af ni sanitetssystemer blev undersøgt og resultaterne blev samlet i et udviklet Excel™ program for at identificere det mest bæredygtige system i hver af modelbyerne.

Det var mest miljøvenligt at recirkulere næringsstofferne via komposteringslatriner (humane ekskrementer og køkkenaffald) og lokal vanding med det grå spildevand i Kuan Lang. I Phattalung var komposteringslatriner samt stabiliseringsdamme til det grå spildevand mest miljøvenligt. Komposteringslatriner og stabiliseringsdamme var lige så miljøvenligt som underjordisk vanding med septik tank spildevand, et centralt komposteringsanlæg til køkkenaffald og lokal vanding med gråt spildevand.
De eksisterende sanitetssystemer var mere økonomisk fordelagtige for de lokale myndigheder og enkelte af de private brugere end recirkuleringsystemerne, idet der stort set ikke var nogle udgifter til dækning af miljøforbedrende foranstaltninger i de eksisterede systemer. Imidlertid, ville recirkuleringsystemerne blive de mest økonomisk fordelagtige, hvis de eksisterende systemer blev forbedret i henhold til det Thailandske lovgivnings anbefalinger. I alle tre modelbyer havde landmændene store økonomiske fordele ved recirkuleringsystemerne.

Der var en høj accept i samfundet af recirkulering af næringsstoffer i affald vha. de fleste af de undersøgte systemer, selvom de tre eksisterende sanitetssystemer var mest accepteret ud fra praktiske og kulturelle synsvinkler. Komposteringslatriner blev højst accepteret af de lokale myndigheder i Phattalung og Kuan Lang, mens komposteringslatrinerne og den underjordiske vanding med septik tank spildevand blev lige accepteret af myndighederne i Prik. Således kan det siges at det er socialt muligt at recirkulere affald, selvom det skal understreges her at det mest bæredygtige system i det hele taget, muligvis ikke var blandt de ni undersøgte systemer. Dette sidste synspunkt understreger vigtigheden af at gøre hele beslutningsprocessen iterativ.

Det udviklede beslutningsstøttende program samlede alle disse informationer og identificerede det mest bæredygtige system for hver modelby blandt de undersøgte ni. De eksisterende systemer og systemet med komposteringslatrin og stabiliseringsdamme var de mest bæredygtige i Phattalung. Systemet bestående af komposteringslatrin og lokal vanding med grå spildevand var mest bæredygtigt i Kuan Lang. Underjordisk vanding med septik tank spildevand, lokal vanding med grå spildevand og central komposteringsanlæg til køkkenaffald var mest bæredygtigt i Prik.

Det kan derfor konklueres at der eksisterer et uudnyttet recirkuleringspotentiale i affald i det sydlige Thailand og at indførelse af recirkuleringsystemer potentielt ville kunne medføre økonomiske fordele for landmænd og store miljøgevinster. Derudover er der en stor interesse for og villighed til at afprøve recirkuleringsystemer i praksis blandt de lokale myndigheder og private brugere.
1. INTRODUCTION

Plant nutrients and organic material are essential elements for healthy plant growth and thereby food supplies. Depletion of plant nutrients (macro nutrients and micro nutrients) or organic material may lead to severe agricultural as well as environmental problems, such as insufficient crop yield, economic recession, famine, soil erosion and desertification (Campbell, 1998; Gardner, 1997). Recycling of plant nutrients in biodegradable kitchen waste (from harvested crops and animal products) and in human waste back to agricultural areas has long way back in history been the basic method for keeping the agricultural soil fertile (Esrey, 2001). However, during the last century the extensive urbanisation, and consequently practical constraints in connection with the mentioned recycling, has led to a decreasing use of this ancient and natural method of keeping soil fertile (Gardner 1997). Plant nutrients tend to enter a “one-way flow” direction out of rural areas and into urban waste, where inadequate handling methods often results in accumulation of nutrients as well as unhygienic and polluting living conditions for the urban population (Diaz et al., 1996; Esrey, 2001). Consequently, sustainable development in relation to agriculture and urban sanitation requires a fundamental rethinking of the way modern society handle the flow of nutrients from rural areas to urban areas.

In the present PhD project the potential of recycling plant nutrients in waste back to agriculture in Southern Thailand was studied. The study was conducted by use of experiments and data collected from the three case study areas Prik, Kuan Lang and Phattalung in the provinces of Songkhla and Phattalung in Southern Thailand (see Figure 1). As in most regions of the world there is insufficient knowledge on quantity and quality of waste products in this region and their potential use as fertiliser. Therefore this Ph.D. project was initiated by a nutrient flow analysis for biodegradable waste products from all sources in the three mentioned case study

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1Sanitation of solid waste, human excreta and sullage (wastewater from kitchen and bathroom).
areas. The availability and quality of the plant nutrients were studied, and the waste fractions having the largest potential were identified. The sustainability of recycling the waste back to agricultural areas was studied holistically, taking technical, economic, environmental, social and institutional concerns into account. The feasibility of nine waste sanitation systems (three systems for each of the three areas) was studied. These feasibility results were aggregated in a developed multiple criteria decision programme and the most sustainable and feasible recycling system was identified for each case study area.

![Map of South East Asia and Southern Thailand](image)

**Figure 1: South East Asia: Myanmar, Laos, Cambodia, Vietnam, Thailand and Malaysia (small map). Southern Thailand: Songkhla and Phattalung province (enlarged map) with three case study areas: Phattalung, Kuan Lang and Prik.**

### 2. ONE-WAY NUTRIENT FLOW

The nutrient flow in typical Asian communities and the consequent problems are illustrated in Figure 2.
Figure 2: Illustration of one-way nutrient flow in typical Asian communities (text in arrows indicate transport means) and environmental problems caused (bold font).
2.1 Agricultural nutrient deficiencies

In ancient times people produced their food and recycled their waste close to where they lived, and thereby automatically closed the nutrient cycle. Today in most regions of the world the nutrient management has shifted from a recycling approach to a one-way nutrient flow, due to wider distances between urban and rural areas (Gardner, 1997). According to Esrey (2001) 80% of all natural resources are converted into waste products to be disposed of and left unavailable for recycling.

In the developing world the effects of population growth and urbanisation has started to show its impact on nutrient unbalances and thereby on the agricultural production (Johnston and Syers, 1998; Byrnes and Bumb, 1998). An attempt to feed 20% of the world’s population using only 7% of the world’s arable land has led China’s agricultural soils to be deficient in B, Zn, Mo, Mn and Cu (Xie, Xing and Zhou, 1998). Another survey by Mutert (1995) from the Asian and Pacific region also showed that the net balances for nutrients in agriculture (based on fertiliser, N-fixation, deposition, sedimentation, harvested crops, leaching, gaseous loss, and erosion) are generally negative. Vietnam, Myanmar, Indonesia and Bangladesh are among the most severely affected countries, as soils with rice and other main crops are severely deficit in N, P, K, Mg and Ca.

For Thailand the yearly shortfall in 1990 was estimated to 269,000 ton N, 442,000 ton K$_2$O, 43,000 ton MgO and 56,000 ton CaO for 90% of the agricultural soils (Mutert, 1995). Craswell and Karjalainen (1990) found additional problems of boron deficiency in Thailand. Too intensive cultivation methods have been blamed for the nutrient deficiency and consequent problems of soil erosion in Thailand (Sombatpanit et al., 1995; Tonmanee and Kanchanakool, 1999).

Also India has severe problems of nutrient deficiency, as the agricultural soils generally are deficient in N, P, K, S and Zn, and that deficiency of Mg, Fe and B are on the increase (Tandon, 1995; White and Zasoski, 1999). Thus due to the present cropping procedures many of these Asian soils are being mined for macro- and micro nutrients, and therefore may not be able to supply future demands for feeding the expected increased population (UNFPA, 2001; Johnston and Syers, 1998).
Esrey et al. (2001) estimated that there are 20-40 per cent less Ca, Fe and vitamin A and C in today’s food products compared to the level of the 1980’s, which also implies an insufficient availability of nutrients in soils. To counterbalance rising food needs of the increased population and stagnation or decline in the foundation for trading and economy more efficient and sustainable nutrient supplies have to be addressed.

In the industrialised world the immediate demand for higher agricultural production has been met by application of manufactured chemical fertilisers (Byrnes and Bumb, 1998; FAOSTAT, 2002). These fertilisers supply the soils primarily with inorganic macro nutrients (N, P and possibly K), but has the side effects of increasing the N-leachate and increasing the demand for micro nutrients (e.g. Zn, Cu, Mn, Mo, B) and organic material (I). The sudden supplement of high amounts of NP(K) changes the soil chemistry and consequently alters the micro nutrient availability and depletes the readily-available soil micro nutrient pools (White and Zasoski, 1999). Further, the chemical fertilisers are often manufactured from mined sources (e.g. phosphorous), which are finite resources and consequently termed unsustainable.

A similar short term solution is now seen in many South East Asian countries, where the import of manufactured fertilisers has increased tremendously over the last decade, with Indonesia, Malaysia, Philippines, Vietnam and Thailand as the main importers (FAOSTAT, 2002). Therefore there is an imminent need for a sustainable supply of micro nutrients, macro nutrients and organic material to the agricultural soils in these regions.

2.2 Inappropriate sanitation

As previously mentioned the one-way flow of nutrients from agriculture into the food products of the society can cause waste problems. The organic fraction of the waste attracts pathogen vectors (e.g. rodents and insects) and consequently problems of public health, aesthetics and odours are prone to occur anywhere wastes are generated, transported or accumulated (Diaz et al., 1996).
Several studies have found that solid waste collection crew members and people living at or near disposal sites in Asia suffer from respiratory diseases, gastrointestinal parasites and worms (ENSIC, 1990; Cal Recovery Systems, 1982). In addition to the putrefied organic waste comes the unsanitary disposal of infectious hospital waste in many Asian countries (ENSIC, 1990).

Drinking water is at risk of being contaminated if human excreta are discharged untreated directly to receiving waters used by the public for drinking purposes. Emsong (1999) reported that the septic tank toilet systems of Thailand are often flooded by fluctuating groundwater tables, resulting in pollution of surface and groundwater by pathogens, organic and inorganic compounds. Several cases of diarrhoea have been observed in these areas due to this phenomena (IV).

Unmanaged wastewater often results in stagnant water attracting mosquitoes, which might carry Malaria parasites (Cairncross, 1993). Prior to implementation of sewerage in Bangkok in 2000, the wastewater from toilets, kitchen and bathrooms were discharged directly to storm drains and transported to nearby surface water, which therefore suffered from the pollution (eutrophication) and unhygienic conditions (Polprasert, 1996).

2.3 Closing the cycle

![Figure 3: Closing the nutrient cycle](image)
To attain the sustainable sanitation in human settlements and the sustainable fertiliser application to agriculture, an obvious solution seems to be closing the nutrient cycle (Figure 3).

Esrey (2001) estimated that in average soils, the nutrient demand of one hectare could be covered by human waste from ten people. Vietnam is one of the few countries, which have for centuries recycled human excreta to agriculture (ENSIC, 1981). The Vietnamese double-vault toilet is a classic example of dehydrating human excreta before use as fertiliser and the concept has been used in ecological sanitation systems in Central America, Mexico and Sweden. Clivus Multrum single vault toilet is an example of composting the human excreta before recycling it, and is used in Sweden, North America and Australia (Esrey et al., 1998). The costs of ecological toilets vary from 10 USD up to the price of conventional flushed toilets (Esrey, 2001). Solid biodegradable waste can either be stabilised in the composting process and thereby providing valuable nutrients and organic matter improving texture of the agricultural soils (Diaz et al., 1996) or it can be used as animal fodder (BioCycle, 1999). Sullage can be recycled via watering garden plants or irrigating agricultural crops (Henze, 1997).

3. SUSTAINABLE NUTRIENT RECYCLING

3.1 General sustainability criteria

Even though the rationale in recycling nutrients in waste for agriculture seems obvious, the one-way flow of nutrients still persist in many regions of the world. The reasons for this are uncertain, and therefore it is essential to study the concept of sustainability in the decision making process for any waste recycling programme.

Various politicians and researchers have discussed the concept and appropriate criteria for its evaluation. The World Commission on Environment and Development, WCED, required that sustainable development should “meet the needs of the present without compromising the ability of future generations to meet their own needs”
(WCED, 1987). More specifically did FAO (1991) define sustainable agriculture as being “environmentally non-degrading, economically viable and socially acceptable”. Another input to the discussion was two sustainability-criteria proposed by OECD: less reliance on dangerous forms of agro-chemicals (fertilisers and pesticides) and diverse crop rotations (OECD, 1995).

Marks (1995) analysed sustainable agriculture by the criteria: proper return on resources; proper return on assets; limit soil erosion; increase landscape attractiveness; limit nitrogen loss; increase occupational safety; and raise self-esteem of the operators. Maintenance of the resource base such as soil quality; low dependence on external inputs and lower waste generations; economic viability; and local farmers acceptability was used as sustainability criteria in environmental-economic decision-making in lowland irrigated agriculture in Thailand (Tiwari et al. 1999). It was found here that the local people’s criteria often were conflicting with the economic and environmental criteria, and the essentiality of including them in all steps of the decision-making process was stressed.

Assessment of sustainable waste management systems often only use conventional cost benefit analysis (e.g. Clarke, 2000), but few others included incommensurate parameters such as reliability, aesthetics, educational opportunities and land suitability (Cheng et al., 2002; Sawhill and Ferguson, 1998). In another case ‘efficient use of physical resources’ and ‘limiting the use of non-renewable resources’ made up the sustainability criteria in a survey on wastewater management systems (Hellström and Kärrman, 1997).

### 3.2 Specific criteria for assessing nutrient recycling

Although there is some disagreement on the definition of sustainability and the selection of criteria to evaluate agricultural and sanitation projects, some specific criteria for evaluating nutrient recycling systems have been selected in the present study (Figure 4). The 16 sub criteria all interact at some level, but for the sake of simplicity and clarity the criteria chosen have been divided into economic, social and environmental criteria.
3.2.1 Economy

Usually the conventional cost benefit analysis focus on society as a whole (Zeleny, 1982). However, when it comes to the issue of nutrient recycling it is important to study the economic consequences for the local users e.g. the farmers, who may be encouraged to shift from chemical fertilisers to organic fertilisers. The encouragement to promote the sustainable recycling could be in the form of economic incentives. This may be very effective as the annual consumption of chemical fertiliser purchases make up 20-60 % of the yearly income of an average farmer in Southern Thailand (III; Agricultural Census, 1993; Database, 1995; Database, 1998; Thai Central Chemical Public Company Ltd. 2001).

The economic criteria for studying the sustainability of recycling nutrients in Thailand therefore is limited to include cost benefit analysis of sanitation and fertilisation by private users (farmers: F and non-farmers: NF) and municipalities (THB/year, Thai
Baht currency, 1 USD ~ 45 THB). Indirect benefits, such as increased crop yield due to better soil conditions, saved governmental subsidies on chemicals, prolonged lifetime of disposal sites by recycling the organic fraction, are not included.

3.2.2 Environment
Reverting the agricultural fertilising methods and sanitation systems are expected to have impact on the environment in several ways. The environmental criteria are therefore divided into three sub-criteria: pollution index, hygiene index and the natural resources consumption (energy, water, fertiliser and organic material).

The pollution index is based on emissions of polluting agents to water, soil and air from waste products, chemical fertilisers and activities connected to the management of these (e.g. transport). The hygiene index is based on secondary research on pathogen prevalence, occurrence and transmission routes in the situations created by the nine sanitation systems studied. In each case study area estimates of resources consumption are based on total fossil energy consumption (m$^3$diesel/year and MWh electricity/year), total recyclable phosphorous as an indicator for plant nutrient potential in waste (ton P/year) and total recyclable organic material (tonnes of composted waste material/year). The water consumption is quantified for an average household in each area (m$^3$/year).

3.2.3 Society
For projects to be implemented successfully, the interests of the whole range of stakeholders are need to be taken into account, and compromises need to be actively sought between public objectives and potentially conflicting private stakeholder’s interests and objectives (Grimble and Chan 1995).

Traditionally some Thais have recycled plant nutrients from human waste by defecating/urinating directly in the agricultural fields. This habit changed with the introduction of pit latrines and later the septic tank toilets. There exist a comprehensive interest and awareness about environmental issues in Thailand, but often there is a lack of understanding of the connection between actions and

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2 Defined as people or groups who can influence or be influenced by a project
environmental consequences in the local communities (Workshop, 2001; IV). Whether it is acceptable in the Thai society to revert the resource management was studied at three levels.

The user’s cultural acceptance\(^3\) of specific sanitation systems includes religious constraints and local traditions. The practical acceptance includes concerns about inconvenience (aesthetics and odour) and difficulties in operating and managing the specific sanitation systems. These acceptances are rated as index values (with existing systems set to 1) and are based on how many of the users were accepting each of the nine specific sanitation systems (in %). The third level is the institutional acceptance: adaptation to the Thai legal framework and acceptance by local administrators, gathered in index values (with the existing systems set to 1).

4. CASE STUDIES IN SOUTHERN THAILAND

Thailand is a highly relevant country in terms of closing the nutrient circle, as their agricultural soils are depleted from nutrients, the cost of imported chemical fertilisers make up a substantial fraction of the farmer’s expenses, and urban pollution problems require new waste strategies.

4.1 Recycling possibilities in Thailand

There exist several technical solutions as to how nutrients in waste can be recycled. However, these are not all technically viable in Thailand. Therefore it is important that any recycling system meets some basic technical pre-requisites. This study is limited to assessing the same sanitation system for all households in a specific case study area.

- A technical limitation is that electricity is only accessible by 39-97% of the households (Socio Economic survey 1999; Database II 1995), consequently all solutions relying on electricity are inappropriate.

\(^3\) Percentage of all interviewed users (farmers: F and non-farmers: NF) who accept the presented systems
• Thailand has problems of water quality, but water is plentiful (EmSong, 1999; Database, 1995; Database 1998) meaning that it is possible to use water as material carrier, but also that the risk of flooding and direct contamination due to fluctuating groundwater tables should be taken into consideration.
• Several cases of sanitation related diseases have been observed, thus any sanitation systems should attain acceptable levels of hygienisation (IV).
• In terms of sanitation Thailand may be referred to as a water washer culture, meaning that water is used for anal cleansing after toilet visits. Thus toilet systems should be able to handle this water without causing water contamination.
• There is a limited resource base for skilled workers in local Thai communities (Polprasert, 1994), and consequently any system should be at such technical level that members of the local communities can operate and maintain it.

The existing toilet facilities in the rural areas could be modified by adding a subsurface trickle irrigation system to the septic tanks, and thereby returning the water and nutrient resources to the subsurface soil from where it becomes available to plants (Oron et al., 1991). In urban areas the septic tank effluent could be discharged to central waste stabilisation ponds, where the water is treated by microbial activity and plant nutrient uptake. Composting the human excreta and biodegradable kitchen waste is another possibility of recycling nutrients in waste, and can be made applicable for both rural and urban areas. The “Kerala double vault” composting latrine is an example of a system designed to water washer cultures (Esrey, 1998). Alternatively kitchen waste can be separated from other solid wastes at the source and be composted within the local community or at central plants. The sullage can either be used locally for irrigating crops or be discharged to central waste stabilisation ponds, where it can treated by microbial activity and plant uptake.

4.2 Site description
Phattalung, Kuan Lang and Prik were selected as case study areas (Figure 1) as they represent the Southern part of Thailand by their geographical location, size, occupational distribution, level of local administration and income level. Thereby the findings of this study should be applicable to most other communities of Southern Thailand to a certain extent.
Phattalung is the capital of the Phattalung province and represent the urban Southern Thailand. Kuan Lang borders Hat Yai, which is the largest city of Southern Thailand. With its combination of urban and agricultural land it represent peri-urban areas of Southern Thailand. Prik represent rural areas. Key data for all three areas are given in Table 1 and detailed descriptions can be found in I, II, III and IV.

### Table 1: Characteristics of the three study areas.

<table>
<thead>
<tr>
<th></th>
<th>Phattalung</th>
<th>Kuan Lang</th>
<th>Prik</th>
</tr>
</thead>
<tbody>
<tr>
<td>Province</td>
<td>Phattalung</td>
<td>Songkhla</td>
<td>Songkhla</td>
</tr>
<tr>
<td>District</td>
<td>Phattalung</td>
<td>Hat Yai</td>
<td>Sadao</td>
</tr>
<tr>
<td>Area size, km²</td>
<td>13.3</td>
<td>66.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Population size</td>
<td>37,777</td>
<td>26,266</td>
<td>5,926</td>
</tr>
<tr>
<td>Population density, capita/km²</td>
<td>2,840</td>
<td>394</td>
<td>1,235</td>
</tr>
<tr>
<td>No. of household</td>
<td>10,978</td>
<td>3,422</td>
<td>925</td>
</tr>
<tr>
<td>No. of sub-villages</td>
<td>19</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Administrative level</td>
<td>Municipality</td>
<td>TAO⁴</td>
<td>Municipality</td>
</tr>
<tr>
<td>Community level</td>
<td>Urban</td>
<td>Peri Urban</td>
<td>Rural</td>
</tr>
<tr>
<td>Industry</td>
<td>Dry food factory</td>
<td>Rubber glove and tyre, timber, charcoal, furniture</td>
<td>Timber</td>
</tr>
<tr>
<td>Income, Baht/cap/yr</td>
<td>18,874</td>
<td>23,463</td>
<td>19,996</td>
</tr>
<tr>
<td>Main occupation in area</td>
<td>Merchant and employees (&gt; 85%)</td>
<td>Owner of or employees at rubber plantation, rice farmers, fruit plantation (46%). Merchants and factory employee (51%)</td>
<td>Owner of or employees at rubber plantations (&gt;60%). Merchants 25%</td>
</tr>
</tbody>
</table>

There are crop and livestock farmers within Prik and Kuan Lang and in the bordering areas of Phattalung. Thus within reach there are potential markets for receiving the recycled waste in all three case study areas (I). Three integrated systems for handling waste products are included in this study in each of the three case study areas Phattalung (PH-), Kuan Lang (KL-) and Prik (PR-). These can be divided into: Existing system (-E), systems based on the existing facilities with modifications promoting recycling (-M), and alternative systems independent of the existing facilities with main focus on recycling (-A). These systems are illustrated in Figure 5 and described in details in III.

⁴ Tambon (~ village) Administrative Organisation
Figure 5. Illustration of existing (-E), modified (-M) and alternative (-A) sanitation systems of recycling nutrients and organic material in waste in Phattalung (PH), Kuan Lang, (KL) and Prik (PR). Italicised word: Mean of recycling. Grey line: Solid inorganic waste, which is not relevant for the specific waste fractions studied.
4.3 Methodology & Terminology

The nutrient flow analysis was based on direct measurements of nutrients generated in waste. Samples of biodegradable kitchen waste, sullage (wastewater from bathroom and kitchen activities) and human excreta from households (I; II; IV) and solid biodegradable waste and wastewater from restaurants, industries and markets (I) were collected in each of the three areas to study nutrients in waste. The vast majority of waste generating sources in each area was represented by the collected samples (I; II).

The waste samples were characterised physically, homogenised and analysed chemically (N, P, K, S, Ca, Mg, Zn, Cu, Ni, Cd, Pb, Hg, B) in accordance with standard methods (Clesceri et al., 1998). Also samples of wastewater sludge (wastewater treatment plant for Phuket Municipality, Thailand) were analysed for its content of toxic organic compounds (DEHP, PAH and NPE) on gas chromatography.

Semi-structured interviews, workshops and focus group discussions were conducted to gain knowledge about the potential users awareness, acceptance and attitude towards waste recycling in connection to the feasibility studies (IV; Mikkelsen, 1995; Robson, 1995). Representative results were obtained as all the participating users had different background (e.g. demographic, geographic, occupational and cultural) and all the studies were conducted in close collaboration with local non-governmental organisations, with specialisation in ‘public participation in environmental projects’. Due to time constraints it was chosen to prioritise quality over quantity, i.e. relatively few users participated in very detailed all-day interviews.

Other data estimations for the feasibility studies (e.g. costs, resource consumption and technical specification) were obtained from secondary sources like technical reports, yearbooks of the municipalities and statistical databases. Only the directly related consequences to the waste sanitation systems have been included in this study.

A Microsoft Excel™ programme has been developed to assess the sustainability of waste recycling. This programme is based on the fundamental principle of simple
additive weighting\(^5\) and multiple criteria decision making, MCDM (Zeleny, 1982; Yoon and Hwang, 1995). The sustainability criteria mentioned in the previous section forms the basis of this tool.

The criteria ratings (e.g. m\(^3\) diesel/year, Ton P/year, THB/year, %, Index) are normalised within each criteria and within the three sanitation systems in each case study area. According to preference profiles the criteria are inter-weighted according to their importance for sustainability, i.e. preference vectors are generated in each of the cases where the economic, the environmental and the social criteria have the major importance, and in case where they are accessed equal important. A total score can be calculated by aggregating each preference vector with the normalised rates of the criteria, and consequently a quantifiable basis for a comparison is provided.

The developed software consists of:

(I) A numerical database with background information of the three case study areas and technical specifications of the nine sanitation systems (e.g. demographic, behavioural, economic, environmental information);
(II) A qualitative description of the nine sanitation systems studied;
(III) Calculations of sub-criteria rates for each of the nine sanitation system in each case study area with reference to the worksheet with background information;
(IV) Weighing of all sub-criteria according to various preference profile’s view upon importance with respect to system sustainability;
(V) Multiple criteria decision making results: an aggregation of all criteria weights and ratings.

Details on the programme can be found in the Appendix “Multiple criteria decision making support tool – description and manual”

\(^5\) Simple additive weighting: multiplying the normalised rates of each criterion with its assigned weight, and then summing all these products over all criteria of a specific sanitation system.
4.4 Nutrient Flow Analysis

Phosphorous is one of the most important plant nutrients and is considered to be rather conservative as it does not evaporate or leach to a significant degree (Johnston and Syers, 1998). Therefore the flows of nutrients in waste in Phattalung, Kuan Lang and Prik are illustrated in Figure 6 - 8 with the size of the arrows indicating the amount of phosphorous in the specific waste stream.

4.4.1 Phattalung

In Phattalung the main nutrient sources in waste are human excreta, biodegradable kitchen waste and sullage from households. The contribution from restaurants, school canteens, hospital canteens, industry (banana chip factory) and fresh food market are insignificant (Figure 6).

Sullage from households, restaurants, canteens, markets, and industry are discharged via gutters and a river to Songkhla Lake. The toilet septic tanks are connected to conventional drainage pits, which infiltrates the liquid phase of the human excreta to the subsoil and in seasons with high water table the human excreta are mixed with the groundwater. However, the septic tanks are often connected illegally to the municipal sewer gutters, leading the liquid fraction of the human excreta directly to surface waters (EmSong, 1999). The solid phase is accumulated in the second septic tank and emptied frequently by a municipal vacuum tanker and driven to a disposal site nearby. Solid waste are collected daily by the municipal collection trucks and transported to an unprotected disposal site outside the city centre. About 1/3 of the biodegradable kitchen waste from households and most food waste from the fresh food market are collected by pig farmers around Phattalung and reused for animal fodder.

Thus nutrients in solid biodegradable waste either end up in the soil/water system of the disposal site or are recycled to livestock production, whereas the nutrients in sullage and human excreta are discharged to the Songkhla lake or the groundwater zone under Phattalung city.
4.4.2 Kuan Lang

The main waste producing sources in Kuan Lang are households and industry (Rubber glove factory, Figure 7). The restaurants, school canteens and the fresh food market generate insignificant amounts of nutrients via their waste products. Kuan Lang also uses the conventional Thai septic tank toilet system, but around 30% of the householders empty their own tanks and recycle the septic sludge in private gardens (IV). Sullage is discharged to stagnant water pools in ditches from where it slowly penetrates into the sub soil. Only 35% of the householders recycle sullage by watering their garden crops (IV). Solid household waste is mainly dumped or buried in the private gardens as the conditions of the roads does not allow municipal trucks to collect the waste (I). The industrial wastewater is discharged to river via a treatment plant reducing the organic content. Thus approximately 1/3 of the nutrients in biodegradable household waste are being accumulated within the area, but they are only partly being used as fertiliser.
Figure 7: Nutrient flow in Kuan Lang. Nutrients in waste products are indicated by arrow sizes (quantity of phosphorous), numbers at arrows (ton of N, P and K per year) and arrow colours (grey: wastewater; white: human excreta; black: solid waste). Water recipient includes groundwater and surface waters.

4.4.3 Prik

The sawdust from the timber factory and the household waste fractions are the dominant nutrients sources in Prik, as the contributions from restaurants, school canteens and fresh food market are negligible (Figure 8). The industrial sawdust is deposited together with the main fraction of the solid household waste at a landfill site outside Prik, but holds a potential as soil amendment or filler at a composting plant. The human excreta are handled in similar ways as in Kuan Lang and Phattalung, only with a minor fraction (6%) being reused for fertilising fruit trees in private gardens (IV). Sullage is recycled as irrigation water by 30% of the households in Prik, and the remaining fraction is infiltrating the soil or discharged via ditches to rivers (IV).
Figure 8: Nutrient flow in Prik. Nutrients in waste products are indicated by arrow sizes (quantity of phosphorous), numbers at arrows (ton of N, P and K per year) and arrow colours (grey: wastewater; white: human excreta; black: solid waste). Water recipient includes groundwater and surface waters.

Generally, the vast majority of plant nutrients are generated in the household waste, which, apart from the recycled waste, mostly end up in water bodies. Nutrients in human excreta are discharged via deep drainage pits in the septic tank systems. The sullage are discharged via open gutters, ditches and rivers. Most of the biodegradable kitchen waste is disposed of in pits at the unprotected landfill sites, where the groundwater and surface water often comes in direct contact with the waste.

4.5 Recycling potential
4.5.1 Quantity
The total generation rates of macro and micro nutrients in all waste fractions are given in Table 2. From the nutrient flow analysis it was found that the main recycling potential is within the household waste: human excreta, sullage and biodegradable kitchen waste. The amount of N / P / K in household waste produced by respectively
17 / 17 / 11 persons could cover the recommended fertiliser rate of one hectare. The amount of N / P / K in household waste produced by respectively 8 / 9 / 3 persons could replace the actual consumption of chemical fertiliser on one hectare (Agricultural census, 1993). In average 7 persons are living per hectare agricultural land area in Phattalung and Songkhla Province (Database, 1995). Consequently about half of the nutrient demand could potentially be met by recycling all household waste, and all chemical fertiliser consumed in 1993 could be substituted by recycled household waste.

Table 2: Total generation rate of nutrients in biodegradable waste in Phattalung, Kuan Lang and Prik, ton/year (I; II)

<table>
<thead>
<tr>
<th></th>
<th>Phattalung</th>
<th>Kuan Lang</th>
<th>Prik</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>158</td>
<td>138</td>
<td>25</td>
</tr>
<tr>
<td>P</td>
<td>75</td>
<td>83</td>
<td>9</td>
</tr>
<tr>
<td>K</td>
<td>72</td>
<td>149</td>
<td>21</td>
</tr>
<tr>
<td>S</td>
<td>35</td>
<td>93</td>
<td>11</td>
</tr>
<tr>
<td>Ca</td>
<td>57</td>
<td>258</td>
<td>16</td>
</tr>
<tr>
<td>Mg</td>
<td>21</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>Zn</td>
<td>1.2</td>
<td>3.7</td>
<td>0.25</td>
</tr>
<tr>
<td>Cu</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

4.5.2 Quality

The quality of the household waste depends partly on its fertiliser value and partly on the concentrations of various unwanted components, such as organic xenobiotic chemicals, heavy metals and pathogens. The latter will be dealt with via the hygienic criteria of the feasibility study.

4.5.2.1 Chemical composition

The fertiliser value depends on the organic content and the concentration of macro- and micro nutrients. Figure 9 shows the chemical composition of the household waste products as well as the total generation rate per capita per day.

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6 N/P/K in household waste could cover the nutrient demand of respectively 4066/4030/6470 hectare agricultural soils, based on the sum of NPK in household waste: 270 ton N/year; 130 ton P/year; 201 ton K/year (I; II) divided by recommended application rates for various crops and fertiliser formulation (N-P2O5-K2O): 1 kg/rubber tree (15-15-15); 240 kg/hectare rice field (16-20-0); 180 kg/hectare vegetables (15-15-15). (Agricultural Census, 1993; Workshop, 2001)
Figure 9: Percentage distribution of elements in waste: sullage (domestic grey wastewater), domestic kitchen waste, faeces and urine. Data are based on total generation per capita per day (I; II).

Most nutrients are discharged via sullage and human excreta (the soluble compounds via urine and the metals via faeces). Biodegradable kitchen waste and human faeces provide organic material, which can be used to improve the soil texture, moisture content, micro nutrient availability (Cu, Fe, Mn), and thereby increasing the soil fertility (Shuman, 1998).

The distribution among the nutrients should be similar to the plant needs to avoid either of the macro nutrients or micro nutrients to reach inadequate, inhibiting or toxic levels. In Figure 10 the generated amounts of nutrients in the most common crops in Thailand are compared to the nutrient composition of biodegradable waste and chemical fertilisers.
Using biodegradable wastes as fertiliser could in fact supply agriculture with an appropriate relative concentration of nutrients compared to the nutrient demand of the crops. The chemical composition of the chemical fertilisers is more unbalanced compared to the mentioned crop needs, as K, Ca and Mg are highly “under-supplied”. Thus the biodegradable waste has a superior quality with respect to plant nutrient composition.

### 4.5.2.2 Organic xenobiotic compounds

There exist very little knowledge on the use of organic xenobiotic compounds in Thailand and the residual concentrations in the waste fractions. In the present study collected wastewater sludge samples were screened for some indicating organic xenobiotic compounds (PAH, NPE and phthalates), as one would expect the compounds – if any - to be accumulated in this “sink” of the society (Table 3).

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7 Estimation based on production of rice, cassava, maize, sorghum, peanut, mungbean and pineapple in region of Southern Thailand (Putthacharoen et al., 1998; IRRI, 1992; Agricultural census, 1993)
8 Estimation based on produced amounts of domestic sullage, biodegradable kitchen waste and human excreta in Southern Thailand (I; II)
9 Estimation based on yearly consumption of the three most frequently used chemical fertilisers in Southern Thailand: Hua Wua Khan Thai N-P2O5-K2O: 16-20-0 (A), Hua Wua Khan Thai 15-15-15 (C) produced by Thai Central Chemical Public Co. Ltd. and Pui Thai 16-20-0 (B) produced by Thai Fertiliser Co. Ltd. (I; Agricultural census, 1993)
Table 3: Content of organic xenobiotic indicator compounds in Thai sewage sludge, mg/kg dry matter

<table>
<thead>
<tr>
<th></th>
<th>Thai sewage sludge$^{10}$</th>
<th>DK limit$^{11}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEHP (di(2-ethylhexyl)phthalates)</td>
<td>52</td>
<td>50</td>
</tr>
<tr>
<td>PAH (Poly cyclic aromatic hydrocarbon)</td>
<td>Non detectable</td>
<td>3</td>
</tr>
<tr>
<td>NPE (Nonylphenol ethoxylates)</td>
<td>Non detectable</td>
<td>10</td>
</tr>
</tbody>
</table>

It was found that PAH and NPE were below detection limit, for which reason it is assumed that these compounds do not constitute an environmental problem in connection to waste recycling. DEHP, on the other hand, was quantified to 52 ppm (dry matter basis, DM) of wastewater sludge, which is the same level as the Danish threshold limit of 50 ppm DM (Miljø- og Energimnisteriet, 1996). Thus it might seem that DEHP constitute a potential environmental problem for Thailand. However, it is not likely that the sorted household waste dealt with in this study obtain the same toxic levels of DEHP as the wastewater sludge, which is expected to accumulate slowly degradable compounds.

4.5.2.3 Faecal contamination

It is assumed that all the waste fractions contain pathogens, which hold the potential of causing disease outbreaks if recycling within a community (especially the human excreta). Therefore it is important to take precautions when recycling the waste products. WHO (1989) recommend that one or more of the following means are used to reduce the risk of faecal contamination when recycling waste to agriculture and aquaculture:

- Adequate waste treatment; e.g. high temperatures over long time
- Crop restriction; e.g. use waste as fertiliser on non-edible crops
- Appropriate waste application method; e.g. sub soil application
- Reduce human exposure; e.g. proper clothing, gloves

$^{10}$ PAH, NPE and Phthalates were analysed at E&R DTU by liquid extraction of the samples using dichloromethane (5 ml to 0.1 - 0.5 g of solid). After separation the extraction solvent were analysed using GC-FID (Hewlett Packard 5890, column HP-5, 30 m, 0.32 mm ID. The detection limits for the individual compounds corresponded to 2 mg/kg. 12 samples of municipal wastewater sludge were collected at Phuket treatment plant. 95% confidence interval: 19% $^{11}$ Criteria for use of waste products in agriculture (Miljø- og energimnisteriet, 1996)
4.5.2.4 Heavy metals

The concentrations of heavy metals in biodegradable kitchen waste, sullage and human excreta collected in Phattalung, Kuan Lang and Prik are compared to international limits and guidelines and to the contents of chemical fertilisers, Table 4 (dry matter basis, DM) and Table 5 (phosphorous basis).

Table 4: Heavy metal concentrations in waste products, chemical fertilisers and quality criteria of recycling waste for agricultural purposes from USA, EU and Denmark, mg/kg dry matter

<table>
<thead>
<tr>
<th></th>
<th>Actual concentration</th>
<th>Guideline limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodegradable kitchen waste</td>
<td>Human excreta</td>
<td>Chemical fertiliser</td>
</tr>
<tr>
<td>Zn</td>
<td>51</td>
<td>138</td>
</tr>
<tr>
<td>Cu</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Ni</td>
<td>0.37</td>
<td>3</td>
</tr>
<tr>
<td>Pb</td>
<td>0.15</td>
<td>1.2</td>
</tr>
<tr>
<td>Cd</td>
<td>0.65</td>
<td>0.26</td>
</tr>
<tr>
<td>Hg</td>
<td>0.04</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 5: Heavy metal concentration in waste products, chemical fertilisers and quality criteria of recycling waste for agricultural purposes in Denmark, mg/kg phosphorous

<table>
<thead>
<tr>
<th></th>
<th>Actual concentration</th>
<th>Guideline limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodegradable kitchen waste</td>
<td>Human excreta</td>
<td>Sullage</td>
</tr>
<tr>
<td>Zn</td>
<td>42884</td>
<td>7518</td>
</tr>
<tr>
<td>Cu</td>
<td>1804</td>
<td>881</td>
</tr>
<tr>
<td>Ni</td>
<td>311</td>
<td>182</td>
</tr>
<tr>
<td>Pb</td>
<td>123</td>
<td>63</td>
</tr>
<tr>
<td>Cd</td>
<td>539</td>
<td>15</td>
</tr>
<tr>
<td>Hg</td>
<td>35</td>
<td>6</td>
</tr>
</tbody>
</table>

It is evident that there is a remarkable difference in the threshold limits of the different countries; Danish regulation being the strictest and the regulation of USA being the least strict. Holding the heavy metal values (in DM) against the limits show that chemical fertiliser application exceeds the EU and DK limits for Zn, Ni, Cd and Hg, while only the cadmium in biodegradable kitchen waste exceed the limit (in bold letter). The relative (to P) content of Pb, Zn and Cu is lower in chemical fertiliser than the three waste fractions, but none of them exceed the limits. In an international study from 1990 severe zinc and copper deficiencies were observed in most agricultural soils in Thailand (Sillanpää, 1990). Applying waste products to agricultural soils

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12 Criteria for use of waste products in agriculture (Miljø- og energiministeriet, 1996)
13 Criteria for composted material – stabilised waste (EC, 2001)
14 US EPA, 2000
would therefore potentially be more beneficial with respect to micro nutrients than the chemical fertilisers.

4.6 Feasibility study

Nutrients in biodegradable kitchen waste, sullage and human excreta could contribute considerably to the fertiliser demand and use in Thailand, and the quality is acceptable both in comparison with chemical fertiliser products and international threshold limits. However, at present the recycling potential is far from utilised.

A feasibility study has been carried out to study the possibility of recycling nutrients in waste back to agriculture. The feasibilities of the nine sanitation systems (Figure 5; III) were evaluated by use of a multiple criteria analysis to induce the sustainability and viability of any potential recycling project. The processed rates for the 16 sub-criteria are gathered in Table 6.

Table 6: Sustainability sub-criteria rating estimates at selected society levels\(^{17}\) (III; IV)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost benefit, F</td>
<td>1000 THB/HH/year</td>
<td>5.9</td>
<td>6.2</td>
<td>5.6</td>
<td>2.9</td>
<td>3.4</td>
<td>12.8</td>
<td>11.0</td>
<td>11.4</td>
</tr>
<tr>
<td>Cost benefit, NF</td>
<td>1000 THB/HH/year</td>
<td>2.1</td>
<td>2.4</td>
<td>2.7</td>
<td>1.0</td>
<td>1.3</td>
<td>1.4</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Cost benefit, I</td>
<td>1000 THB/year</td>
<td>34.1</td>
<td>60.9</td>
<td>61.5</td>
<td>0.3</td>
<td>27.9</td>
<td>0.1</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Water pollution</td>
<td>Index</td>
<td>1.00</td>
<td>0.99</td>
<td>0.59</td>
<td>1.00</td>
<td>0.72</td>
<td>0.01</td>
<td>1.00</td>
<td>0.002</td>
</tr>
<tr>
<td>Soil pollution</td>
<td>Index</td>
<td>1.00</td>
<td>0.98</td>
<td>0.66</td>
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<td>0.60</td>
<td>0.87</td>
<td>1.00</td>
<td>0.93</td>
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<tr>
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<td>1.03</td>
<td>0.78</td>
<td>1.00</td>
<td>0.65</td>
<td>0.53</td>
<td>1.00</td>
<td>0.96</td>
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<tr>
<td>Hygiene</td>
<td>Index</td>
<td>1.00</td>
<td>1.10</td>
<td>1.06</td>
<td>1.00</td>
<td>1.22</td>
<td>1.13</td>
<td>1.00</td>
<td>1.14</td>
</tr>
<tr>
<td>Energy Resource</td>
<td>MWh/year</td>
<td>6759</td>
<td>7020</td>
<td>5188</td>
<td>947</td>
<td>670</td>
<td>524</td>
<td>498</td>
<td>427</td>
</tr>
<tr>
<td>Water Resource</td>
<td>m(^3)/year</td>
<td>167</td>
<td>167</td>
<td>101</td>
<td>451</td>
<td>451</td>
<td>422</td>
<td>257</td>
<td>233</td>
</tr>
<tr>
<td>Nutrient Resource</td>
<td>Ton P/year</td>
<td>1.1</td>
<td>3.4</td>
<td>25.6</td>
<td>17.8</td>
<td>30.0</td>
<td>51.8</td>
<td>7.9</td>
<td>5.3</td>
</tr>
<tr>
<td>Organic Resource</td>
<td>Ton/year</td>
<td>36</td>
<td>1038</td>
<td>1651</td>
<td>155</td>
<td>531</td>
<td>956</td>
<td>84</td>
<td>180</td>
</tr>
<tr>
<td>Cultural accept, NF</td>
<td>Index</td>
<td>1.00</td>
<td>0.93</td>
<td>0.85</td>
<td>1.00</td>
<td>0.74</td>
<td>0.67</td>
<td>1.00</td>
<td>0.83</td>
</tr>
<tr>
<td>Cultural accept, F</td>
<td>Index</td>
<td>1.00</td>
<td>0.92</td>
<td>0.75</td>
<td>1.00</td>
<td>0.76</td>
<td>0.65</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>Practical accept, NF</td>
<td>Index</td>
<td>1.00</td>
<td>0.85</td>
<td>0.59</td>
<td>1.00</td>
<td>0.33</td>
<td>0.33</td>
<td>1.00</td>
<td>0.67</td>
</tr>
<tr>
<td>Practical accept, F</td>
<td>Index</td>
<td>1.00</td>
<td>0.71</td>
<td>0.75</td>
<td>1.00</td>
<td>0.82</td>
<td>0.71</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>Inst. accept, I</td>
<td>Index</td>
<td>1.00</td>
<td>1.17</td>
<td>1.50</td>
<td>1.00</td>
<td>1.10</td>
<td>1.67</td>
<td>1.00</td>
<td>1.83</td>
</tr>
</tbody>
</table>

4.6.1 Economic feasibility

The economic consequence for farmers, who shift from conventional systems (PH-E; KL-E; PR-E) to the modified (PH-M; KL-M; PR-M) or alternative (PH-A; KL-A; PR-A) recycling system is favourable. This is mainly due to the substitution of expensive

\(^{17}\) HH: household; F: Private user: farmer; NF: Private user: non-farmers (people with other occupations than agriculture); I: Institution: Phattalung municipal, Kuan Lang administrative organisation and Prik municipality.

Index: 1: Exiting systems as point of references. (>1). Increased emission/hygiene/acceptance. (<1) Lower emission/hygiene/acceptance.

\(^{18}\) To calculate the primary energy consumption (based on fossils), two conversion factors are used: 2.5 MWh/MWh Electricity and 10 MWh/m\(^3\) Diesel (Hall et al., 1982).
chemical fertiliser to cheap organic recycled waste\textsuperscript{19}. Other private users (NF) and the local municipalities/administration will generally have increased expenses, as waste recycling requires construction of new facilities (e.g. composting plants, wastewater stabilisation ponds, gutters, composting toilets, subsurface trickle irrigation drains) and increased service fees (wastewater).

However the economic comparison between the nine systems are carried out on what might be assessed as slightly unequal terms. The existing systems are not completely living up to the recommendations given in the Thai legal framework on reducing pollution from waste products, and the existing user fees are symbolic and do not cover the actual service costs (\textsuperscript{III}; Danteravanich and Siri Wong, 1998).

Phattalung has just decided to upgrade their wastewater system after having recognised the existing system’s environmental impact on the surrounding water recipients (Pakawan Chufamanee pers. comm. Oct. 2002). Changing the point of reference hypothetically according to this new situation in Phattalung will result in the “existing” system being the most expensive of the three studied for Phattalung municipality (\textsuperscript{III}). The consequence for private users might eventually also change as the concepts of cost recovery and polluters-pay-principle are expected to be essential in the future system of Phattalung (Em Song, 1999).

\textbf{4.6.2 Environmental feasibility}

The negative environmental impact is reduced in all the proposed modified and alternative sanitation systems with respect to all environmental sub-criteria compared to present systems.

As most elements are discharged via the human excreta, the groundwater pollution could be greatly reduced by replacing the conventional deep drainage pit after the septic tank with a sub surface trickle irrigator (30 cm below surface) or by transportation via gutters to waste stabilisation ponds (PH-M; PH-A; KL-M; PR-A). The human excreta contamination of surface- and groundwater could be totally eliminated by implementing the composting latrine (PH-A; KL-A; PR-A).

\textsuperscript{19} Market price for chemical fertiliser: 15 THB/kg; Accepted price for composted waste: 1 THB/kg (Thai Central Chemical Public Company Ltd. 2001; Workshop, 2001)
The hygiene could also be considerably improved by preventing direct contamination of groundwater, which is a dominating drinking water source (Database, 1995). Other measures for improving the hygienic conditions are reducing the amount of putrefying waste at open dumping sites (PH-M; PH-A; KL-M; KL-A; PR-M; PR-A) and reducing the amount of stagnant water (KL-M; PR-A).

The air emission index and energy consumption are in all nine systems most influenced by the transport of fertiliser and waste. These are therefore least in systems with local recycling possibilities e.g. community composting plants (KL-M) and composting latrines (PH-A; KL-A; PR-A). Least water resources are consumed in the systems where the septic tank toilet system is replaced by the relatively dry composting latrine.

Recovery of plant nutrients in waste (represented by P) is largest in systems where wastewater is directly applied to crops (KL-A; PR-M) and systems where all nutrients in human excreta are recycled via the composting toilet (PH-A; KL-A; PR-A), as other processes might result in lechate-loss to a water recipient.

Organic material can primarily be recycled in systems with high recycling degree of biodegradable kitchen waste, as in the composting latrine.

4.6.3 Social feasibility
Generally there was a high level of acceptance among the private stakeholders towards waste recycling to livestock (pig), agriculture (crop) and aquaculture (fish), which is essential for any future recycling initiatives.

All the nine sanitation systems were also accepted at an institutional level and in line with the Thai laws and regulations, although the existing systems were not fully meeting the Thai recommendations on reducing pollution. From an institutional point of view the proposed future sanitation systems with the highest degree of independence and autonomy (e.g. composting latrine and community based
composting) were the most favourable, and therefore institutionally feasible (PH-A; KL-A; PR-M; PR-A).

The potential waste producers (NF) and waste receivers (F) showed in general more positive attitudes towards the existing sanitation systems (PH-E; KL-E; PR-E) than the proposed recycling systems (PH-M; PH-A; KL-M; KL-A; PR-M; PR-A).

There appear to be conflicting interest towards the nine systems among the stakeholders, although they all did express positive attitudes towards changes (environmental improvements), and were all interested in several of the proposed recycling technologies (Workshop, 2001; IV).

Even though it seems socially feasible to recycle waste in the local communities, the most socially sustainable system might not have been found yet, pointing at the importance of making any such decision processes iterative. The next process step could therefore be to present all the feasibility results to the local stakeholders, who might change their perception towards the systems or come up with new proposals to be included in the survey programme.

4.7 Multiple Criteria Decision Making
A PC-based decision programme has been developed to support the selection of the most appropriate sanitation system in the three case study areas.

4.7.1 Results
Figure 11 shows the results of the MCDM support tool; the sanitation system with the highest score (based on simple additive weighting of criteria ratings and criteria weights) is the most sustainable (black) of the three studied for each case study area under the specific conditions studied. The conditions studied include specific ratings of the 16 sub-criteria (III; IV) and various preference profiles weights of the criteria according to their perceived importance.
Figure 11: Results of MCDM analysis by use of various preference profile’s fictive weights of the criteria (with social, economic and environmental priority and equal priority) and actual weights of the criteria (municipalities’ priority and private stakeholders’ priority).

If all the main criteria (social, environmental and economic) were weighted equally then the alternative system with composting latrine would be most sustainable for Phattalung and Kuan Lang and the modified system with sub surface trickle irrigation of human excreta would be most sustainable for Prik. The same results are found in the case of the municipalities priorities, environmental priorities and the social priority. In the case where stakeholders’ priority and economic priority is given the majority weight the result changes only for Phattalung; now the existing low-recycling system is the most sustainable. All the results are gathered in Table 7.

---

20 (Social criteria: economic criteria: environmental criteria): ΣNormalised ratings of socio cultural acceptance, practical acceptance and institutional acceptance: Σnormalised ratings of cost benefit analysis of farmers, non-farmers and local authority: Σnormalised ratings of soil pollution, water pollution, air pollution, energy resource, water resource, nutrient resource, organic material resource, hygiene:
- Equal priority: (0.34: 0.33: 0.33)
- Social priority: (0.75: 0.10: 0.15)
- Environmental priority: (0.15: 0.10: 0.75)
- Economic priority: (0.15: 0.75: 0.10)
- Municipalities’ priority: (0.17: 0.40: 0.43)
- Stakeholders priority: various: Ranked criteria’s importance according to private users of Phattalung: Practical acceptance, economy, hygiene, pollution, natural resources; Kuan Lang: Pollution, hygiene, economy, practical acceptance, natural resources; and Prik: Practical acceptance, hygiene, pollution, economy, natural resources (Workshop, 2001)
Table 7: Overall result of Multiple Criteria Decision Making analysis based on various preference profiles (III; IV).

<table>
<thead>
<tr>
<th>Preference profile</th>
<th>Phattalung</th>
<th>Kuan Lang</th>
<th>Prik</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social priority</td>
<td>PH-A</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
<tr>
<td>Economical priority</td>
<td>PH-E</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
<tr>
<td>Environmental priority</td>
<td>PH-A</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
<tr>
<td>Stakeholders priority</td>
<td>PH-A/E</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
<tr>
<td>Municipality’s priority</td>
<td>PH-A</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
<tr>
<td>Equal priority</td>
<td>PH-A</td>
<td>KL-A</td>
<td>PR-M</td>
</tr>
</tbody>
</table>

In Phattalung two sanitation systems seems to be most appropriate with respect to the sustainability criteria selected for this study. The alternative system with integrated recycling of human excreta and biodegradable kitchen waste in composting latrines and sullage treatment has environmental advantages, acceptance among the users and could be accommodated within the Thai legal framework (PH-A). The existing system with low solid waste recycling and no recycling of sullage and human excreta has economic advantages (PH-E).

In Kuan Lang the community based recycling system with local sullage recycling and composting latrines is the most sustainable when all the criteria and preference profile’s weights are aggregated (KL-A).

The system with local human excreta recycling (sub surface trickle irrigation of toilet effluents), local sullage recycling and central composting of biodegradable kitchen waste and septic sludge are most appropriate for Prik on the basis of all the criteria (PR-M).

4.7.2 Parameter sensitivity analysis

The sensitivity of the programme is tested by variating several key parameters. The price of the chemical fertiliser could be hypothetically changed from 15 THB/kg to 30 THB/kg by regulating the economic political incentive tools, e.g. by removing the governmental subsidy or raising the taxes of chemical fertiliser. Under these conditions farmers (F) could in this case save 3000-4000 THB/year by replacing chemical fertilisers with recycled waste, but there would be no consequence for the overall MCDM result. However, combining this situation with increased market prices of composted waste products from 1 THB/kg (acceptable price in Kuan Lang)
to 7 THB/kg (acceptable price in Prik), would change the cost benefit results (Workshop, 2001). Farmers (F) could then save 500 – 3500 THB/year and the non-farmers (NF) could save 550 – 1100 THB/year by changing from the existing systems to the proposed recycling systems in Kuan Lang and Prik. The economic deficit of the three local administrators and the non-farmers (NF) of Phattalung when recycling waste could similarly be reduced under these conditions. If these economic incentives were included in the MCDM support tool, the sanitation systems, PH-A, KL-A and PR-M, would clearly become the most sustainable of the nine.

The programme can also be used to identify which part of the integrated sanitation system is the most dominant with respect to cost benefit, nutrient recycling rate and organic material recycling rate. It is found that local recycling of human excreta is the cheapest way of returning a high fraction of the nutrients in waste to agriculture. Recycling sullage and biodegradable kitchen waste through large central plants are the most expensive ways of recycling a minor fraction of nutrients in waste. However, as mentioned in the introduction, it is not only a question of solving the problem of nutrient deficiency in agriculture, it is also a question of solving the environmental problems caused by the unmanaged waste. Therefore an integrated solution should be sought, and this study found that local waste recycling is more sustainable than centralised systems for this kind of communities.

4.7.3 Programme delimitation

The present PC programme is based on background data for the three case study areas and is as such specific mainly for the local conditions ruling here. The software is in the progress of being developed to fit other areas, and could relatively easily be changed to fit most sets of local conditions elsewhere - especially in Asia. A future version could therefore serve as a powerful tool for evaluating alternative recycling technologies and thereby ensuring sustainable agriculture and sanitation, but should not be the only tool. It can be used for gathering, structuring and comparing knowledge and data for various sustainability criteria and thereby testing the sustainability of specific technical solutions under specific conditions. However, it should be stressed that it is essential to supplement this “deskwork” with “fieldwork” (e.g. workshops and focus group discussions with stakeholder groups) and making the
decision process iterative. It can be downloaded for free from
www.er.dtu.dk/projects/mcdm-sanitation

5. CONCLUSION

Plant nutrients in biodegradable kitchen waste, sullage and human excreta constitute a large fertiliser potential with respect to both quantity and quality, but is presently not utilised in Southern Thailand. In any potential recycling program, frequent monitoring of faecal indicators, cadmium and DEHP is recommended, as these might create environmental problems in the future.

In general local recycling of plant nutrients in waste was found to be more social, economic and environmental feasible in the rural areas, Kuan Lang and Prik, than in urban areas, Phattalung, where a combination of local and centralised systems were most feasible.

The developed multiple criteria decision making programme combined the economic, environmental and social evaluations of nine sanitation systems, and the most sustainable systems were identified. It was most sustainable to discharge sullage to waste stabilisation pond system in Phattalung, whereas it should be recycled directly to garden crops in Prik and Kuan Lang. Human excreta could be recycled via composting latrines in Phattalung and Kuan Lang with large economic and environmental benefits. This solution was not culturally accepted in the Moslem area, Prik, and therefore a modification of the existing septic tank toilet was proposed here, including recycling of septic effluent in a sub surface irrigation system. Biodegradable kitchen waste could be co-composted with human excreta in the latrines of Phattalung and Kuan Lang and be composted at a central plant in Prik.

Though there might exist more feasible systems than the studied, it can be concluded that it is possible to identify sustainable integrated sanitation systems to recycle nutrients in waste in Southern Thailand by use of multiple criteria decision making.
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APPENDIX

Multiple criteria decision making support tool
- description and manual
Multiple criteria decision making support tool

-description and manual

Background and Delimitation
The tool for supporting the multiple criteria decision making (MCDM) process of the Ph.D. project was developed in Microsoft Excel™ by Nanette Levanius Schouw. The programme determines the sustainability of the nine specific sanitation systems of the three specific case study areas, and estimation methods are based on the current availability of specific data here of. It does not have a high quality user interface, and it is therefore quite difficult, at its current development state, to be used by other people. The programme should mainly be viewed as an appendix to the MCDM calculations of this PhD abstract report. It is possible to change a limited number of the data to test the MCDM process under various circumstances, but the programme has not yet been fully developed for this use. You are most welcome to study the programme, but I cannot take full responsibility for the outcome of these new calculations.

Tool Description
A Microsoft Excel™ programme has been developed to assess the sustainability of nine sanitation systems in Phattalung, Kuan Lang and Prik.

Basic principle
This programme is based on the basic principle of multiple criteria decision making (MCDM) and simple additive weighting (SAW) (Zeleny, 1982; Yoon and Hwang, 1995). In the MCDM process 3 main criteria are selected, which are expected to have significant influence on the sustainability of the studied systems: economic, environmental and social criteria. These main criteria are divided into 16 sub-criteria (sc: Cost benefit F, Cost benefit NF, Cost benefit I, Water pollution, Soil pollution, Air pollution, Hygiene, Primary energy resource, Water resource, Nutrient resource, Organic resource, Cultural acceptance NF, Cultural acceptance F, Practical acceptance NF, Practical acceptance F, Legal acceptance I), which are weighted,
according to their importance with respect to sustainability in the different contexts, as described in the PhD report. As different stakeholders might view sustainability differently, various preference profiles will result in different sets of weight in the preference vectors.

\[
W_{\text{total}} = \sum_{SC=1}^{16} W_{SC} = 1
\]  
(I)

Thereafter the sub-criteria are rated either at a quantitative scale (e.g. kWh/year and Thai Bath currency/year) or qualitative scale (e.g. very bad/bad/medium/good/very good, or worse/in balance/improved). The qualitative scale is changed into a semi quantitative scale (e.g. 0 – 1 or percentage). All the rates (R) are then normalised (NR) within each sub-criteria (sc) and within the three compared sanitation systems of each case study area (ss).

\[
NR_{SC1,SS1} = \frac{R_{SC1,SS1}}{\sum_{SS=1}^{3} R_{SC1,SS}}
\]  
(II)

\[
\sum_{SS=1}^{3} NR_{SC1,SS,Phattalung} = \sum_{SS=4}^{6} NR_{SC1,SS,KuanLang} = \sum_{SS=7}^{9} NR_{SC1,SS,Pr ik} = 1
\]  
(III)

\[ss \in (1 : 3), (4 : 6), (7 : 9) \quad \text{and} \quad sc \in (1 : 16)\]

The SAW method multiplies the normalised rates of each sub-criterion with its assigned weight (W_{SC}), and then sums up all these products over all criteria of a specific sanitation system.

\[
SAW_{SS1} = \sum_{SC=1}^{16} W_{SC,SS1} \cdot NR_{SC,SS1}
\]  
(IV)

\[
\sum_{SS=1}^{3} SAW_{SS,Phattalung} = \sum_{SS=4}^{6} SAW_{SS,KuanLang} = \sum_{SS=7}^{9} SAW_{SS,Pr ik} = 1
\]  
(V)

The outcome of this calculation is a quantification of the difference between the sustainability of the three systems of each area. The sanitation system with highest
SAW-score within each case study area is regarded as the most sustainable system under the specifically selected sustainability criteria, weights and rates.

**Tool Set-up**

The programme consist of:

- A worksheet consisting of a numerical database with background information of the three case study areas and technical specifications of the nine sanitation systems (e.g. demographic, behavioural, economic, environmental information), #1 "Background data".
- A worksheet describing the nine sanitation systems studied, #2 "Systems studied".
- A worksheet for each criterion, where specific rates are calculated for each of the nine sanitation system in each case study area with reference to the worksheet with background data, #3 “CBA”, #4 “Hygiene”, #5 “Energy Resource”, #6 “Pollution, air”, #7 “Pollution soil&water”, #8 “Nutrient&organic Resource”, #9 “Water Resource”, #10 “Acceptance”.
- A worksheet where all main criteria and sub criteria can be inter-weighted (i.e. according to their importance with respect to system sustainability), #11 “Criteria weights”.
- An aggregating worksheet where all sub-criteria weights and ratings are multiplied and the SAW-scores are used for the final decision making, #12 “MCDM results”.
- A worksheet where the used terms and colour scales are explained, #13 “Explanation “.
- A worksheet with all references for the specific data, #14 “References”.

Grey buttons have been inserted at central places of the worksheet to direct the user to more detailed information on e.g. the sanitation system and criteria rate. Comment boxes (red corner of cell) are added to a number of the cells to provide the user with detailed information about calculation method, references or technical assumptions.
Manual

If the user wants to change the data to test the MCDM results for different conditions than chosen in the PhD report, the following methods should be used. When manipulating the programme, always remember to save it under a new name, as equations might be deleted from the cells when new values are inserted!

Changing the weights of the criteria:
- Go to worksheet #11 “Criteria Weight”
- Change the weights of the 16 sub-criteria in the cells with black background and red font (B5: Q5).
- Go to #12 “MCDM results” to see the new SAW-scores of the nine sanitation systems (E21: M21)

Changing the rates for sub-criteria
- Go to #1 “Background data”.
- Change the values of the background information or technical specifications in the worksheet.
- These new values are then used for generating the new rates of the sub-criteria, which can be viewed in worksheet #3 - #10.
- Go to #12 “MCDM results” to see the new SAW-scores of the nine sanitation systems (E21: M21)

Or
- Go directly to the criteria, which is to be changed (#3-#10).
- Change the specific sub-criteria values.
- Go to #12 “MCDM results” to see the new SAW-scores of the nine sanitation systems (E21: M21)

Errors
Mainly two types of errors might occur when the data is changed to determine the sustainability for other sets of conditions than the ones studied:
• Not all the intended sub-criteria rates are covered by a change in the specific background data.
• Other sub-criteria rates than the intended ones are changing when new background data are inserted

The main reasons for these errors are opaqueness of the calculation methods in the programme and an unfriendly user interface. The methods for estimating the criteria rates were, wherever possible, the same for the three case study areas and the nine sanitation systems. However, in some cases, the calculation methods differ due to differences in the availability of data. A example of this is the municipal cost of solid waste management: existing sanitation systems are mainly based directly on official budgets whereas the modified and alternative systems are estimated from new values of waste amounts, transport distances, diesel consumption etc. An isolated change in the value for diesel market price in “Background data” will in this case not have the intended influence on the calculations of all the system’s new economic and energetic rates. Therefore the user should be careful about making conclusions solely based on manipulated data in the programme.