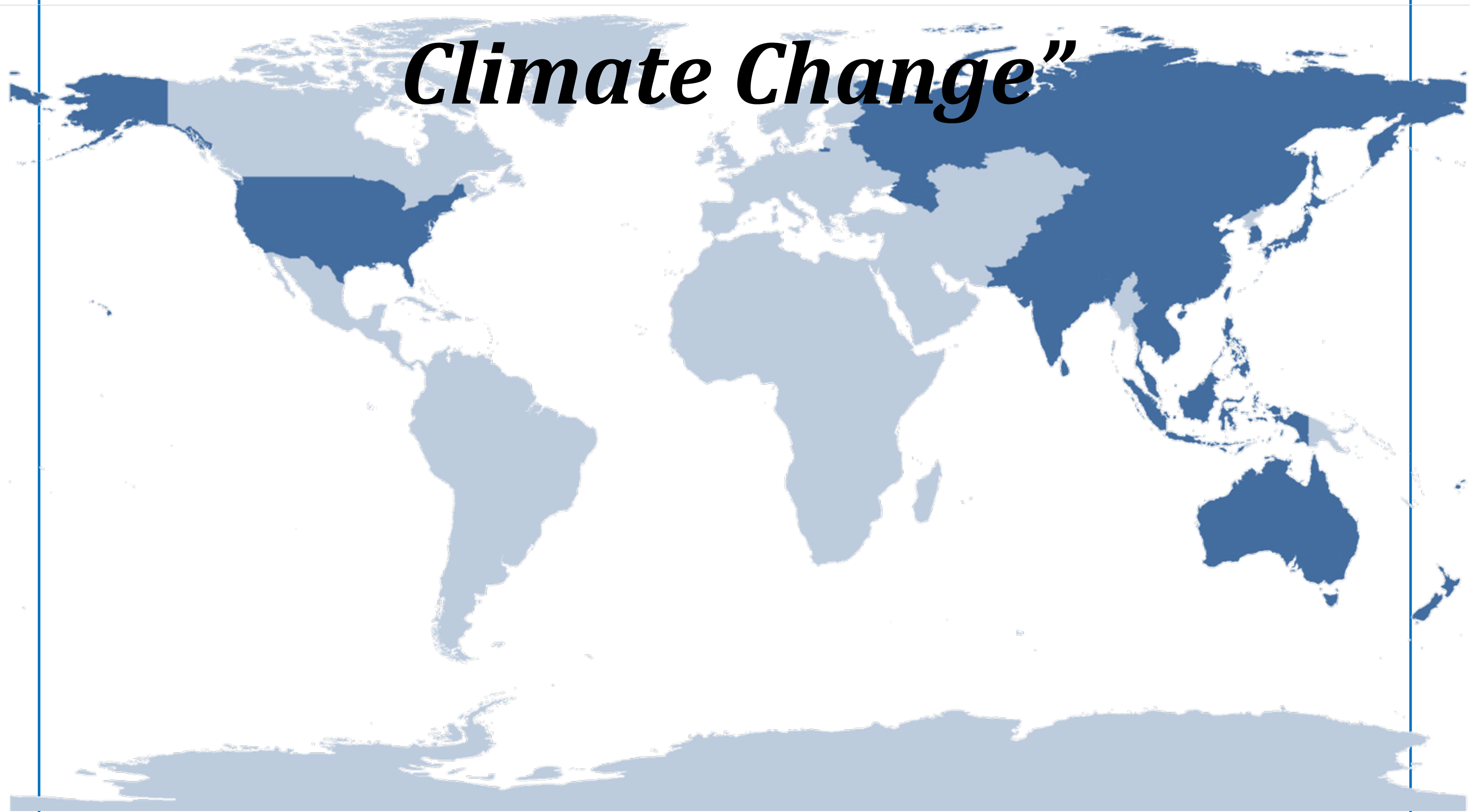
FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2011-19NSY-Koottatep

"Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases due to Climate Change"



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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

Due mainly to climate change, it is apparent that serious waterborne diseases are emerging particular to those with inadequate sanitation systems. On the contrary, the conventional sanitation systems release significant amount of Green House Gas (GHG) unless proper operation and maintenance is undertaken. In this study, two scenarios have been proposed; 1) install biogas capture at offsite sanitation and 2) decrease number of cesspools by using septic tank to reduce GHGs emissions and risks. In term of microbial health risk, the direct reuse at offsite sanitation systems is still higher than the acceptable risk in both scenarios thus disinfection process is recommended. In order to achieve sustainable sanitation development, two strategies on GHGs emission and health risks reduction was proposed though four policies such as 1) capacities building for local authority, 2) provide suitable GHGs reduction and Health risk assessment practices, 3) enhance of social learning process on GHGs reduction and health risk assessment practices and 4) develop monitoring system should be provided to evaluate GHGs reduction and Health risk assessment practice for local authorities.

Objectives

The main objectives of the project were:

1. To determine ecological sanitation systems on reductions of GHGs emissions and microbial health risks.
2. To identify affordable sanitation systems and emerging health risks according to climate change scenarios.
3. To adapt strategies for policy makers to achieve sustainable sanitation development.
4. To disseminate the lessons-learnt and appropriate guidance as “Policy Briefs” for effective sanitation planning to policy markers.

Amount received and number years supported

The Grant awarded to this project was US$ 44,550 for one year duration. However due to an unexpected serious gigantic flood over central plain of Thailand including AIT campus, we are facing difficulties in collecting of information and data from filed investigations, resulting in the delay in activity progress the planned tasks as proposed on the proposal. Thus the project was extended at no-cost extension for another 6 months.

Activity undertaken

1. Reviewed of GHGs emissions from environmental sanitation systems, health impact of waterborne diseases and pathogen (E. coli and Salmonella) treatment efficiencies of wastewater treatment systems.
2. Surveyed and collected of the missing data for model analysis and to verify the GHG emission rates and microbial health risks from sanitation systems.
3. Developed and integrated of Material Flow Analysis (MFA) and Quantitative Microbial Risk Assessment (QMRA) model.
4. Developed appropriate scenario for sanitation management to emerge health risks according to climate change.
5. The 1st stakeholder involvement was arranged in order to propose scenario of adaptive strategy with the emphases on reductions in environmental pollution and health risks. The stakeholder held at Miracle Grand Convention Hotel at 9.30 AM – 15.30 PM on Monday, January 14th, 2013. The objective of the Seminar was to discuss the proposed coping strategies with key stakeholders including policy makers and disseminate the lessons-learnt and coping strategies to public. There was 9 agencies to participate in this seminar such as Pollution Control Department, Department of Drainage and Sewerage, Department of Environmental Quality Promotion, Thailand

Institute of Scientific and Technological Research, Wastewater management Authority, Office of Natural Resource and Environmental Policy and Planning, Department of Alternative Energy Development and Efficiency, Faculty of Engineering from Mahidol University, Faculty of Engineering from Rangsit University. After two scenarios were proposed, many comments and suggestions were occurred from stakeholders. Thus the proposed scenarios were adapted according to their comments.

6. The 2nd stakeholder involvement and publish seminar were arrange in order to disseminate the adapted scenario and coping strategies to publish. The publish seminar held at Miracle Grand Convention Hotel 9.00 AM – 12.00 AM on Friday, January 18th, 2013.

Results

The study found that the existing sanitation systems release GHGs emissions and also microbial health risks with people activities. Two scenarios have been proposed; 1) install biogas capture at offsite sanitation and 2) decrease number of cesspools by using septic tank to reduce GHGs emissions and risks. It can be concluded that biogas collection installation and reduction cesspools used could reduce GHGs emissions from existing sanitation system. In term of microbial health risk, the direct reuse at offsite sanitation systems is still higher than the acceptable risk in both scenarios while others activities; collecting vegetable from the canal, fishing , swimming, irrigation of canal water on farmland the exposure are under acceptable risks except the area that directly connected to offsite sanitation systems in scenario 2. Thus, disinfection process could help to remove pathogen and people are not affected from any activities. However, there is no relationship between GHG emission and probability of infection; thus it should be identified case by case.

Relevance to the APN Goals, Science Agenda and to Policy Processes

The main goal of this study is to develop affordable and sustainable sanitation approach as an adaptive strategy in dealing with emerging waterborne diseases due to climate change. The proposed proposal is relevant to:

(a) APN core strategies no. 1 is encourage research that can improve, understanding of global change and its implications for the region, and contribute to sound scientific basis for policy formulation and decision making. This research will develop coping strategies on sustainable sanitation for which policy makers realize of sanitation and global climate change.

(b) APN core strategies no. 2 is to promote activities that develop scientific capacity and improve the level of awareness on global change issues specific to the region. This research will review ecological sanitation systems with an emphasis on reduction of greenhouse gas emissions (GHGs) and microbial health risk in order to disseminate information in the Southeast Asian region.

(c) APN core strategies no. 3 is to identify and help address, in consultation with policy - makers and other end-users, present and future needs and emerging issues. This research will develop coping strategies on sustainable sanitation in consultation with relevant policy makers in address emerging waterborne diseases due to climate change.

Self evaluation

Based on the objectives, this study could achieve all proposed objective as following detail:

Objectives 1: The determination of ecological sanitation systems on reductions of GHGs emissions and microbial health risks were calculated and current situation from this region were presented.

Objective 2: Two scenarios for affordable sanitation systems and emerging health risks according to climate change were developed and proposed to government officers during stakeholder involvement. However the proposed scenarios in this study were developed as model pattern, which the real scenarios should be developing for the specific area.

Objective 3: Two strategies for policy makers were adapted to achieve sustainable sanitation development and proposed during stakeholder involvement and publish seminar.

Objective 4: Two Strategies and Four Policies were developed and disseminate the lessons-learnt and appropriate guidance for effective sanitation planning to policy markers during the publish seminar.

Potential for further work

In this study the GHGs emissions and microbial health risks model were calculate from the secondary data and gap sampling from filed investigation which still not much available such as E. coli and Salmonella contaminated. Thus in order to develop the accuracy model, in depth field investigation in the specific study area is recommended.

Acknowledgments

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Preface

Climate change is one of the defining challenges of the century, and increasingly recognized as a public health priority (WHO, 2004). Changing rainfall and temperature over the next decades are likely to make more complicated sanitation management. Reduced river flows and increase water temperature will lead to declining water as the dilution contaminants is reduced, less oxygen dissolved and microbiological activity increases. These effects could lead to major health problems. The intergovernmental Panel on Climate Change (IPCC) identified that "sustainable development can reduce vulnerability to climate change". Scenario analysis on climate change will be applied in developing of adaptive strategy with the emphases on reductions in environmental pollution and health risks.

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Chapter 1 Introduction

1.1 Introduction

The continuous greenhouse gasses emissions (GHGs) and its accumulation in the atmosphere lead to the increase in the global surface temperature known as global warming resulting in the climate change all over the world. Changing rainfall and temperature over the next decades are affecting to clean water, good sanitation and drainage. Average annual rainfall is forecast to decrease in some regions and increase in others and droughts and floods are likely to become more frequent and intense. Poor drainage in human settlements increases exposure to contaminated water and provides habitat for lack of access to clean water and sanitation are diarrhoea and other diseases caused by biological or chemical contaminants. The biggest tolls were in Africa, on the Indian subcontinent and the Southeast Asia. In Thailand, number of diarrhoea cases are approximately 1 million cases per year which no trend to reduce. E. coli and Samonnella are the major agents for this disease *(MOPH, 2009).* The IPCC (Intergovernmental Panel on Climate Change) identified that "sustainable development can reduce vulnerability to climate change". The planning or management on both environmental impact and health risk is then the concept for the advanced sanitation tool.

Generally, domestic wastewater treatment both and grey water (wastewater from kitchen, bathing, washing and etc.) and blackwater (urine and excreta) in Thailand is discharged into the onsite sanitation systems and/or drainage system because most of municipalities in Thailand and also other developing countries in Southeast Asia are not able to invest for the central wastewater collection or treatment system. Therefore, the onsite treatment systems are widely installed for partially treating or retaining the main pollutions (organic matters, nutrients and others) with limited efficiencies in removals of the excreta-related pathogens, causing the high incidences of excreta-related diseases. For instance, Weltervreden and Rissen serovars were the most common serovar isolated from human stool samples in Thailand. They were also commonly found in seafood, water and raw vegetable which may be contaminated from both faeces and water *(Bangtrakulnonth ea al., 2004)*. Two types of pathogenic organisms was also found in the major species observed from diarrhoeal patients (1,793 cases) which were 72.9% of normal flora, 10.8% of Enteropathogenic E. coli (EPEC) and 10.6% pf Salmonella app *(Pruksananonda, 2008).* This presented number could support that the preventive barriers are still inadequate in terms of sanitation barrier and behavior barrier.

The main goal of this study is to develop of methodology for assessing sustainability sanitation development and adaptation strategy to emerging water borne diseases. Therefore the rates of GHGs from domestic wastewater and faecal sludge treatment systems in Thailand and to develop mathematical model using computer software for determining appropriate managements with an emphasis on reduction of GHGs model to reduce greenhouse gas emissions. Material Flow Analysis (MFA) is applied to manage the sanitation planning in order to set up the monitoring program. E. coli and Salmonella treatment efficiencies will determine while, Quantitative Microbial Risk Assessment (QMRA) is used to determine risk of pathogens to public health according to exposure at the contaminated pathways.

1.2 Objectives of the study

- To determine ecological sanitation systems on reductions of GHGs emissions and microbial health risks.
- To identify affordable sanitation systems and emerging health risks according to Climate Change scenarios.

- To adopt strategies for policy makers to achieve sustainable sanitation development.
- To disseminate the lessons learnt and appropriate guidance as "Policy Briefs" for effective sanitation planning to policy markers.

1.3 Material Flow Analysis (MFA) concept

1.3.1 Material Flow Analysis (MFA)

Material flow analysis (MFA) is a systematic assessment of flows and stocks of material within a system defined in space and time (Baccini and Brunner, 1991). MFA connects sources, pathways, intermediate and final sinks of a material by a simple material balance comparing all inputs, stocks, and outputs.

Terms and definitions in MFA methodology are described by Brunner and Rechberger (2004), composed of substance, goods, material, process, flow and flux which can be defined as follow;

- **Substances:** In MFA field, substances are referred to the physical matter including material, matter of particular, definite chemical constitution, or matter, material of specified especially complex constitution. In addition, substance can be defined by chemical science. A substance is any (chemical) element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogenous. MFA is able to determine flows of potentially hazardous substances to the compartments such as water bodies and soils. Heavy metal (Cu, Zn) or nutrients (N, P) are also called "substances".
- **Goods:** Goods are defined as economic entities of matter with a positive or negative economic value. Goods are made of one or several substances. Examples of goods are drinking water, mineral ores, radio, garbage, concrete, sewage sludge etc. All goods are valued and financial rated by the economy.
- **Material:** Material is defined to the matter, substances, the elements, constituents or substances of which something is composed or can be made. In MFA field, material covers both substances and goods. Carbon as well as wood can be defined as material.
- **Processes:** The transformation, transport or storage of materials is called "process". In terms of consumption in a community, it refers as the private households transform goods into wastes and emissions. For example, the human bodies, where food, water and air are transformed mainly into CO_2, urine and feces. In the industrial level, the transformation takes place in the primary production processes such as in the mining and metal industry.
- **Flow and Flux:** A Flow is defined as a "material flow rate" the physical unit of this flow is "kg/sec" or "ton/year". A Flux is defined, as a flow per "Cross Section" the unit of the flux is "kg / (sec.m2). The Flux can be considered as a specific flow. In MFA, it is normally to use cross section as a person, the surface area of the system or an entity such as a private household or an enterprise.

Material flows between various processes Pi and Pj. In which i,j = 1,…, n, are modeled by transfer-coefficients (kij, i,j=1,..,n). They are defined as the proportions of the total inputs into the process Pi and transferred to the other processes Pj, whereas $\sum$ kij =1 (Binder et al., 2001). Figure 1.1 shows the example of MFA system.

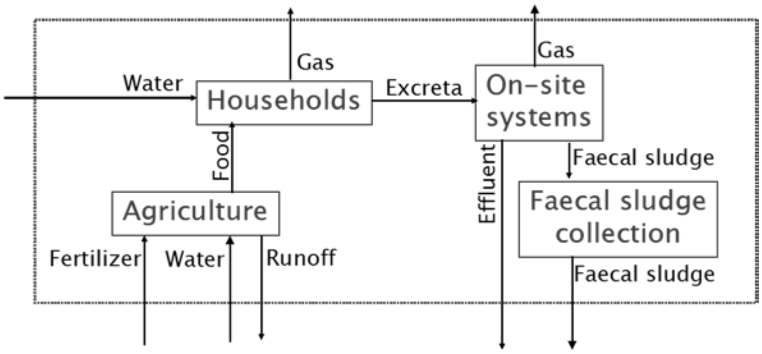


Figure 1.1 Example of MFA system for environmental

MFA has been applied in the field of environmental sanitation many years ago. The first MFA was developed and validated for subsystem of water, food and durables in Tunja municipality, Columbia. This application had results in (a) setting up monitoring concepts, (b) the early recognition of resource demand and environmental impacts, and (c) evaluating the effect of technical measures in mitigating these impacts *(Binder et al. 1997). Binder and Patzel (2001)* applied MFA to describe carbon fluxes in organic wastes between the rural and the urban areas of the municipality of Tunja and estimated the effect of waste reuse on soil organic matter. Then, MFA was applied in the city (urban and peri-urban area) of Kumasi (Ghana) in order to estimate how much of the nitrogen and phosphorous demand in urban and peri-urban agriculture could be covered by compost produced with urban solid waste and excreta *(Belevi et al., 2000 and Belevi, 2002).* MFA was also used for environmental sanitation planning for water and wastewater flows, and nutrients flows in Hanoi (Veitnam) *(Montangero et al. 2004).* In Thailand, MFA was applied to analyze flows of domestic solid waste and wastewater management in Pak Kret municipality *(Sinsupan et al. 2005).*

1.4 Quantitative Microbial Risk Assessment (QMRA) concept

1.4.1 Quantitative Microbial Risk Assessment (QMRA)

Microbial risk assessment was first developed for determination of health risk in drinking waters (Regli et al., 1991) and later it has been applied to practices such as irrigation crops and discharge to recreational impoundments (Shuval et al., 1997; Tanaka et al., 1998; Ashbolt, 1999). Rose and Gerba (1991) stated that use of the models to establish potential health risks have many applications which used relative risks for quantitative comparing.

Quantitative Microbial Risk assessment (QMRA) is a method to predict the consequences of potential or actual exposure to infectious microorganisms (Haas et al. 1999). It is used to calculate risk from what is known, or can be inferred, about the distribution and concentration of particular pathogens in the system of concern along with the information of the infectivity of those pathogens to determine risks to public health. QMRA's methodology is based on the chemical risk assessment concept (National Research Council, 1983) however, pathogens differ from toxic chemicals because the living organisms and their characteristics: 1) Pathogens possess the potential to evolve and alter their ability to cause disease (virulence) as well as their persistence in various environments, including human host; 2) Pathogens may be capable of multiplying within affected individuals; 3) Exact symptoms and severity of illness depend on host factors such as the health of the person, their pre-existing immunity and pathogen dose; 4) Pathogens can be passed from one person to many (secondary spread), from either healthy but infected (asymptomatic) or ill (symptomatic); 5) Pathogens are generally not evenly suspended in water (Fane et al., 2002 and Hunter et al., 2003). QMRA's process consists of 4 steps as: 1) Hazard identification; 2) Exposure assessment; 3) Dose-response assessment; 4) Risk characterization. Their specific responsibilities are stated as follow;

- ***Hazard identification:*** To describe acute and chronic human health effects associated with any particular hazard, including toxicity, carcinogenicity, mutagen city, developmental toxicity, reproductive toxicity, and neurotoxicity. However, in QMRA, the hazard identification means to identify the pathogenic microorganisms which can cause the infectious diseases upon the exposure on the organism; virus, bacteria, protozoa and helminthes Haas et al., 1999. There are a number of possible outcomes once the infection begins; including asymptomatic illness, various levels of acute and chronic disease and potentially to mortality. Moreover, these outcomes are also dependent on the sensitive populations, women during pregnancy, young or elderly people, the immune compromised, socio-economical situation and hygienic behavior practices.
- ***Exposure assessment:*** To determine the size and nature of the population exposed and the route, concentrations, frequency, and distribution of the microorganisms and the duration of the exposure (Haas et al., 1999). It needs to determine the concentration or the number of organisms or, the presence or absence of organisms in the set samples and its medium food or water through the exposure pathways as shows in figure 1.2. However, conceptually all microorganism occurrence distributions are measured is the Poisson distribution when the organisms are distributed randomly.

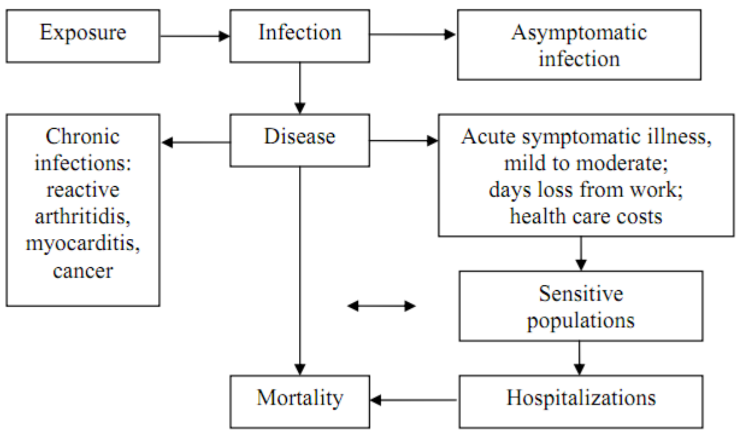


Figure 1.2 Outcomes of the infection process for quantification (Source: Haas et al., 1999)

- ***Does-response assessment***: To develop a relationship between the level of microbial exposure and the likelihood of occurrence of an adverse consequence. In general, dose-response analysis would not be necessary if the microbial risk level is high enough to be acceptable to conduct the experiment on human or animal. But in most cases the risk level from a single exposure is much lower than 1/1000, it will become impractical to assess the risk from direct experiment (Haas et al., 1999). Dose-response model is a mathematical function which yields the probability of the particular adverse effect, which is bounded by zero (no effect) and one (complete conversion to adverse state) as shows in figure 1.3.

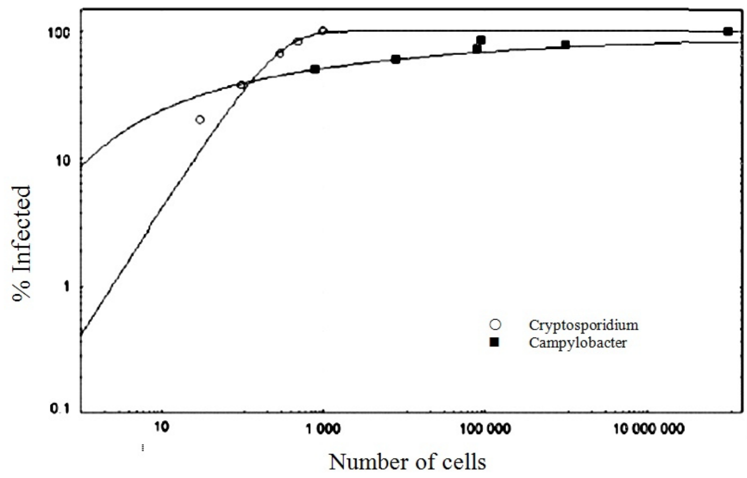


Figure 1.3 Examples of dose-response models for Cryptosporidium and Campylobacter (Source: Haas et al., 1999)

- ***Risk characterization:*** To integrate the information from exposure, dose-response, and health steps in order to estimate the magnitude of the public health problem and to evaluate variability and uncertainty. Moreover, it is also evaluated the types and the magnitude of the health risk posed to the public which is normally described in infections per year, and either for individual or in a population. Those factors are used in the evaluation of the risk assessment which is one of the most important factors to put into account for the decision makers and other stakeholders. Once characterize the distribution of a risk quantity, usually the higher is the exposure, the higher is the risk. For example, in figure 1.4, the more technology is implemented to reduce risks, the more the exposure is reduced (Hass et al., 1999).

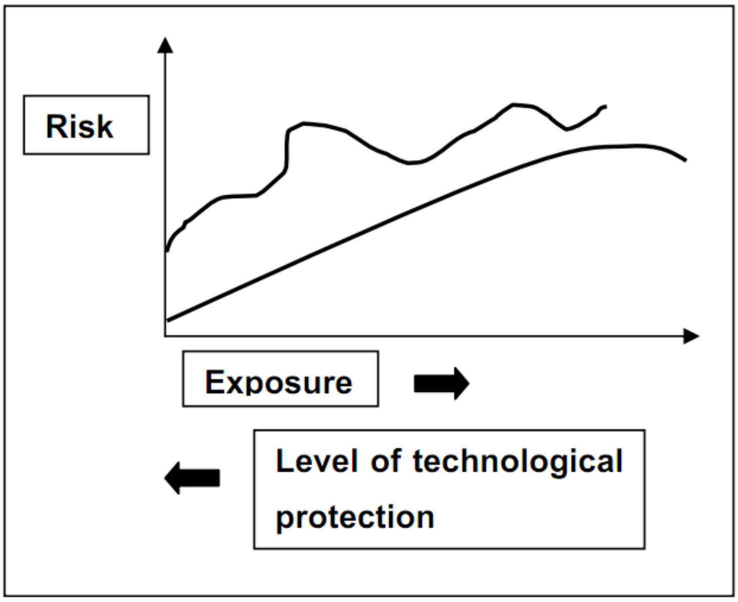


Figure 1.4 QMRA graphic summary (Source: Hass et al., 1999)

In the calculation process of microbial health risk, exposure assessment and dose-response parameters are very important, which are shown in Table 1.1 and 1.2. Based on the results of infectious risk, USEPA has defined the acceptable risk of 1 infection per 10,000 people per year, using Giardia, which is known to be more resistant to disinfection than other microbial pathogens, as reference organism (Macler and Regil, 1993). Considering such a high variability in actual illness after infection with the types and strains of microorganisms as well as host age and other host factors, acceptable risks of 1 infection per 10,000 people per year has been established for risk of infection rather than illness (Gerba et al., 1996).

Table 1.1 Involuntary ingestion volumes based on the intensity of water contact per event

Contact intensity	Intake volumes	Events	References
Full-body immersion	100 mL swallowed/ event	- Swimming activities - Children playing in water - Body-washing	DWAF (1996) WHO (1998) Genthe and Rodda (1999) Haas et al., (1999)
Intermediate	50mL swallowed/ event	- Repeated immersion during skiing, surfing, canoeing	Medema et al. (2001)
Other	10mL swallowed/ event	- Laundry - Fishing - Ingestion related to irrigation in agri- and horticulture	Genthe and Rodda (1999) Medema et al., (2001)

Source: Cited by Steyn et al. (2004)

Table 1.2 Best-Fit Dose-Response Parameters (Human)

Organism	Exponential	Beta Poisson		Reference
	K	N50	α	
Poliovirus I (Minor)	109.87			Minor et al., 1981
Rotavirus		6.17	0.2531	Haas et al, 1993
Hepatitus A virus [(a)]	1.8229			Ward et al.,1958
Adenovirus 4	2.397			Couch et al., 1966
Echovirus 12	78.3			Akin 1981
Coxsackie [(b)]	69.1			Couch et al.1965; Sutel, 1963
Salmonella [(c)]		23,600	0.3126	Haas et al.,1999
Samonella typhosa		$3.60x10^6$	0.1086	Hornick et al 1966
Shigella [(d)]		1120	0.2100	Haas et al., 1999
Escherichia coli [(e)]		$8.60x10^7$	0.1778	Haas et al., 1999
Campylobacter jejuni		896	0.145	Medema et al., 1996
Vibrio cholera		243	0.25	Haas et al., 1999
Entamoeba coli		341	0.1008	Rendtorff 1954
Cryptosporidium parvum	238			Haas et al., 1996; Dupont et al., 1995
Giardia lamblia	50.23			Rose et al., 1991

Source: Cited by Haas & Eisenberg (2001)

Remarks: (a) Dose in grams of feces (of excreting infected individuals)
(b) B4 and A21 strains pooled
(c) Multiple (non-typhoid) pathogenic strains (S. pullorum excluded)
(d) Flexnerii and dysenteriae pooled
(e) Nonenterohaemorrhagic strains (except O111)

Likely to the sophisticated epidemiological investigations, QMRA has increasingly applied to risks associated with bacteria, protozoa, viruses and helminthes. *Asano et al (1992)* estimated the risk of infection from viruses in various scenarios such as wastewater use in irrigation, golf courses, recreational of contaminated water and ground water recharge. *Hoglund et al. (2002)* applied microbial risk assessment of source-separation urine used in agriculture. *Westrell et al. (2004)* approached QMRA and Hazard Analysis of Critical Control Point (HACCP) for management of pathogens in wastewater and sewage sludge treatment and reuse. *Howard and Pedley (2004)* studied on Kampala's drinking water for risk assessments of the piped water supply were under taken for *E. coli*. In Thailand, health risks of *E. coli* in water supply of urban, peri-urban and rural area were comparable *(Watanabe et al. 2006). Yajima (2005)* used QMRA for the comparative health impact assessments on faecal sludge management practices between two sub-districts, Tha Khlong and Klong Luang. The health risks assessment of infection by QMRA in food waste and market waste management in Klong Luang was also reported *(Kyaw Swar, 2006).*

One of the definitions of acceptable risk, widely accepted by environmental regulation although is not relevant to microbiological parameters, is a person's chance of developing cancer by one chance in a million or less *(Hunter and Fewtrell, 2001).* Based on this definition, USEPA uses a target reference risk range of 10^{-4} to 10^{-6} for carcinogens in drinking water in line with WHO drinking water quality guideline *(WHO, 1993).* Due to there is no acceptable standard in developing countries, the acceptable risk proposed by USEPA is used in many studies and is currently discussing whether the risk of infection higher than 10^{-4} should be accepted or not *(Watanabe, 2006).*

1.4.2 E. coli and Salmonella

1.4.2.1 Escherichia coli (E. coli)

Escherichia coli (E. coli) is a family of bacteria named Enterobacteriaceae, which is informally referred to as enteric bacteria, normally inhabiting in the intestinal tracts of healthy animals such as cattle, chickens, deer, sheep and pigs as well as humans. E. coli has been widely recognized as the leading cause of bloody diarrhoea. Typical clinical features of *E. coli* infection are watery or bloody diarrhoea and abdominal cramps, with or without fever. There are, at least, four types of E. coli pathogenic to humans: Enterotoxigenic (ETEC), Enterohaemorrhagic (EHEC) – O157: H7, Enteropathogenic (EPEC), and Enteroinvasive (EIEC). Fatalities due to ETEC, EIEC and EHEC infections are between 0.1 to 0.2 %, while that of EPEC infection can be up to 16% for newly born babies *(Haas et al., 1999).*

E. coli infection can mainly occur through eating uncooked ground meat, drinking fecally contaminated water, drinking unpasteurized milk or fruit juices, eating contaminated raw vegetables and working with cattle. Outbreaks can also occur through person-to-person transmission of the bacteria at home or settings such as daycare center and hospitals *(CDC, 2004).* In the United States, there are estimated to be 200,000 cases of infection and 400 death per year attributed to pathogenic E. coli *(Haas et al, 1999).* According to the review of medical reports in the United States *(Craun, 1991),* the percentage of hospitalized cases in total cases of waterborne outbreaks due to E. coli is estimated to be 12.7%. The disappearance rate of E. coli is found to be between 0.23 and 0.46 % per day in surface water and between 0.063 and 0.36 % per day in groundwater, whereas time for 50 % concentration reduction in surface water is between 1.5 and 3 days *(Medema et al., 2003),* depending on a variety of environmental stressors such as hight emperature, pH and sunlight intensity.

1.4.2.2 Salmonella spp

Salmonella is one of the most common enteric infectious bacteria. It is gram-negative, flagellated and facultative anaerobic bacilli, characterized by O, H, and Vi antigens. The intestines of healthy animals such as chickens, turkey, pigs and cattle are the main reservoir. Nevertheless, its transmission tends to involve person-to-person contact since this specie practically lacks animal reservoirs *(WHO, 2004).*

Fecally contaminated water is believed to be the major transmission media. In the United States, reported incidence of salmonella illnesses are about 17 cases per each 100,000 people, though this figure might only represent a small part of the true occurrence of salmonella infection *(Salmonellosis)* since only about 3 % of cases are said to be officially reported while many milder cases are never diagnosed *(CDC, 2004).* More than 2300 Salmonella serotypes are known to exist. Typhoid fever, a life-threatening illness, is caused by a particular strain called Salmonella typhi. In the United States, 400 cases occur per year, while in developing countries 12.5 million persons have been affected per year *(CDC, 2004).* Salmonellosis, which is an illness caused by other salmonella strains, is also common with its cases estimated to be 2 million to 5 million per year in the United States *(Haas et al, 1999).*

Salmonellosis clinically ranges from the common Salmonella gastroenteritis such as diarrhoea, abdominal cramps and fever to enteric fevers. According to the review of medical reports in the United States *(Craun, 1991),* the percentage of hospitalized cases in total cases of waterborne outbreaks due to Salmonella is estimated to be 4.1%. In this study, non-typhoid strains were employed, which is the cause of general diarrhoea of various degrees at higher frequencies than in the case of Salmonella typhoid. The disappearance rate of *Salmonella spp*. is found to be between 1 and 7 % per day in surface water and between 0.13 and 0.22 % per day in groundwater, whereas time for 50 % concentration reduction in surface water is between 0.1 and 0.67 days *(Medema et al., 2003),* depending on a variety of environmental stressors such as temperature, pH and sunlight intensity.

Chapter 2 Methodology

2.1 Concept frame work

2.1.1 Detailed framework

An overall research framework is shown in Figure 2.1. Descriptions of each research objective including methods and main research activities are show in Table 2.1.

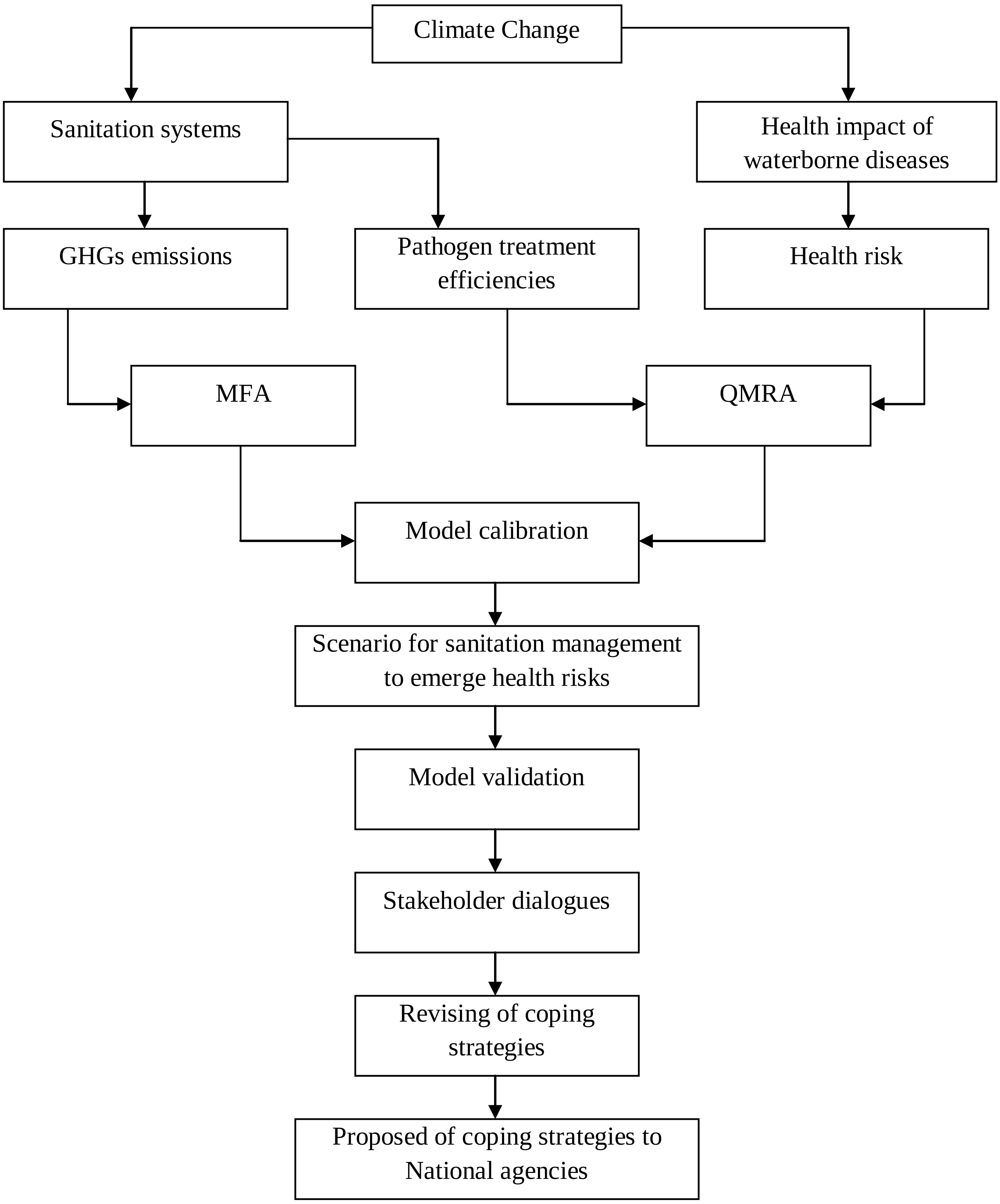


Figure 2.1 Conceptual research framework

Table 2.1 Research works

Objectives	Methods	Activities
1. To determine ecological sanitation systems on reductions of GHGs emissions and microbial health risks.	1. Reviews of GHGs emissions from environmental sanitation systems. 2. Reviews of health impact of waterborne diseases due to climate change. 3. Reviews *E. coli* and *Salmonella* treatment efficiencies of wastewater treatment systems. 4. Questionnaires and interviews. 5. Field investigation and lab analysis. 6. Application of conventional MFA and QMRA methodology.	1. Survey and collection data of environmental sanitation systems such as water treatment system, onsite treatment systems, faecal sludge treatment systems, wastewater treatment systems, etc. on GHGs emissions. 2. Survey data of health impact of waterborne diseases due to climate change. 3. Survey and collection data of *E. coli* and *Salmonella* in each process above in order to evaluate health risk. 4. Field and lad analyze. 5. Determining and selecting ecological systems on reductions of GHGs emissions and microbial health risks.
2. To identify affordable sanitation systems and emerging health risks according to climate change scenarios.	1. Application of conventional MFA and QMRA methodology.	1. Development and integrated of MFA and QMRA model. 2. Development sanitation systems and emerging health risks according to climate change scenarios. 3. Analysing appropriate scenario for sanitation management to emerge health risks according to climate change.
3. To adapt strategies for policy makers to achieve sustainable sanitation development.	1. Reviews of strategies to achieve sustainable sanitation development. 2. Integrate of strategies from literature review and scenario from this study. 3. Developing coping strategies through stakeholder dialogues.	1. Survey and collection information of strategies for sustainable sanitation development. 2. Integrated of strategies from literature review and scenario from this study in order to develop existing strategies. 3. Arranging stakeholder involvement, to discuss on the proposed coping strategies for policy makers. 4. Reviewing of coping strategies according to comments and suggestions from stakeholder involvement.
4. To disseminate the lessons-learnt and appropriate guidance as "Policy Briefs" for effective sanitation planning to policy markers.	1. Public seminar	1. Disseminate the lessons-learnt and appropriate guidance through training workshops/seminars. 2. Proposed of coping strategies to government officers as an effective sanitation planning to policy markers.

2.2 Concept of model development

2.2.1 Concept of the MFA and QMRA integrated method

Concept of the integrated method is shown in Figure 2.2, consisting of 2 compartments: MFA and QMRA. In principle, a step by step of MFA includes:

- Model set-up: model equation and input data are prepared according to interested pathway and pathogen.
- Model calibration: comparing model results with data from field experiments or the available set of measurement in Thailand and Vietnam. Differences are calculated for the fitness of model such as correlation coefficient (r) and geometric mean for the trend and magnitude. If the results of fitness are not satisfaction, parameters in model set-up are needed to adjust.
- Model validation: testing the model by using a observed data or measurement. Again validation process will inform the accuracy of prediction compared with the observed value from the uncontrolled field.

Model results: results of the model application with various scenarios can be further used in the QMRA process which consists of 3 processes:

- Model set-up: similar to MFA model, model equation of QMRA and input data are prepared. Input data are activity, type of indicator or pathogen, exposure dose, frequency of exposure, and dose-response parameter. Concentrations of indicator are obtained from the MFA part and the reduction according to management practice.
- Model application: simulation for the probability of infection risk. Result can be single infection risk or yearly infection risk.
- Model result: results will be compared with acceptable risk. Scenarios for the intervention in management plan such as pre and post treatments or health barriers can be proposed as the options with the risk improvements.

Modelling in this study is a dynamic type which needs to be developed and validated on case by case basis using STELLA software program.

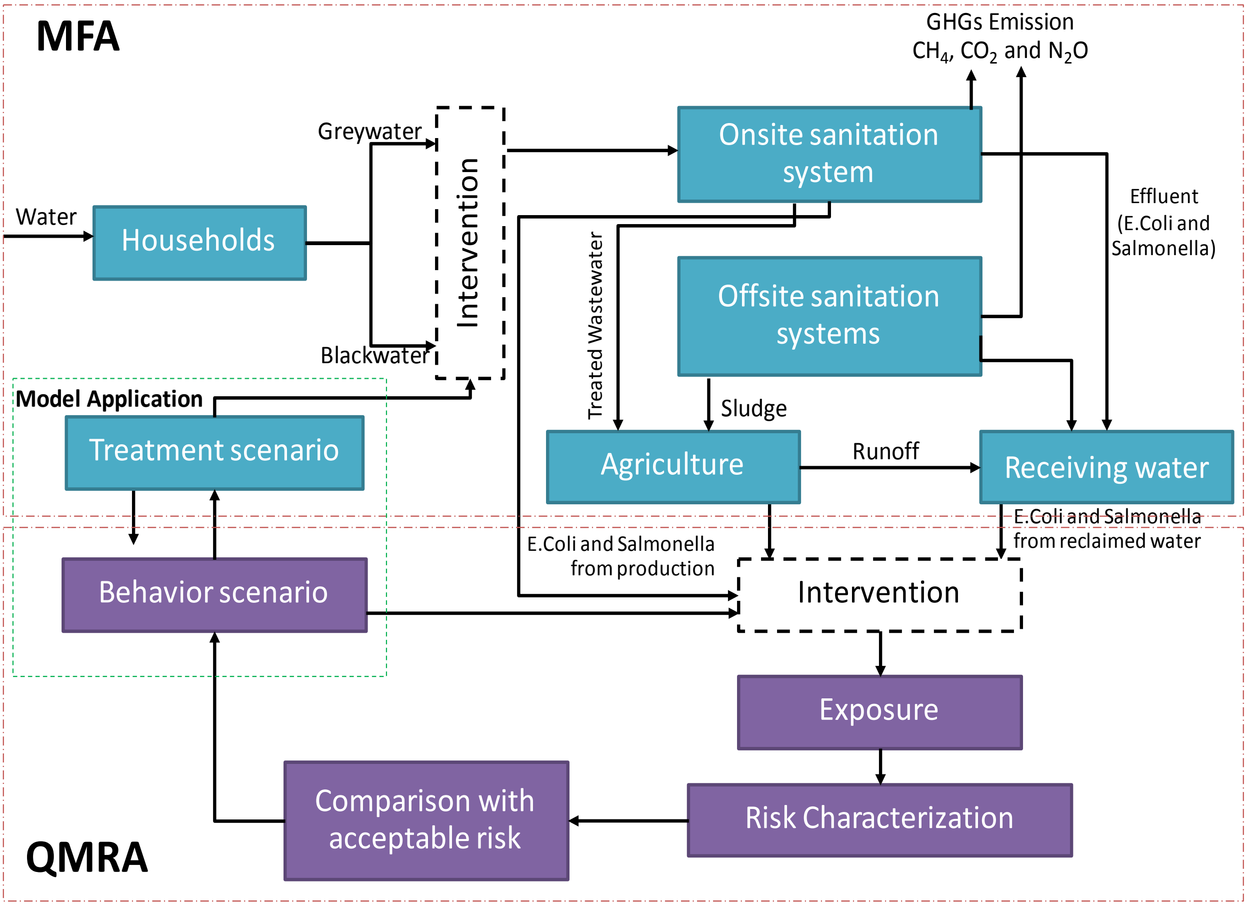


Figure 2.2 Conceptual of MFA and QMRA model development

2.2.2 Parameters

MFA and QMRA were conducted in Thailand in order to systematically access environmental sanitation systems and microbial risks thought water born disease. Relevant data were collected according to frameworks as shown in Table 2.2.

Table 2.2 Relevant parameters need for the conventional MFA and QMRA application

Model	Procedure	Parameter	Data collection
MFA	Sanitation systems	- Type of onsite treatment systems in developing countries	- Literatures reviews -Questionnaires and interviews
		- Onsite treatment processes	- Literatures reviews
		- Wastewater and faecal sludge characteristics in term of organic matter (COD) and nutrient (P and N) concentration	- Literatures reviews - Reconnaissance survey
		- GHGs (CH4, CO2 and N2O)emission from onsite treatment processes	- Literatures reviews - Reconnaissance survey
		- Pathogen (E. coli and Salmonella) emission from onsite treatment processes	- Literatures reviews - Reconnaissance survey
QMRA	Hazard identification	- Activities related to contaminated sources of receiving water (E. coli and Salmonella)	- Literature reviews - Questionnaires
	Exposure assessment	- Number of population in each activity - Number of exposures in year - Concentrations of E. coli and Salmonella in each exposure	-Questionnaires and interview -Assumption based on the in-depth interviews
	Dose-response analysis	- Dose response parameters	- Literature reviews

2.3 Material Flow Analysis (MFA) research works

2.3.1 MFA research framework

The overall MFA research framework is shows in figure 2.3. It consists of data collection, both literature review and field sampling, and then available data were used to develop the MFA model on GHGs emissions from sanitation systems in Thailand.

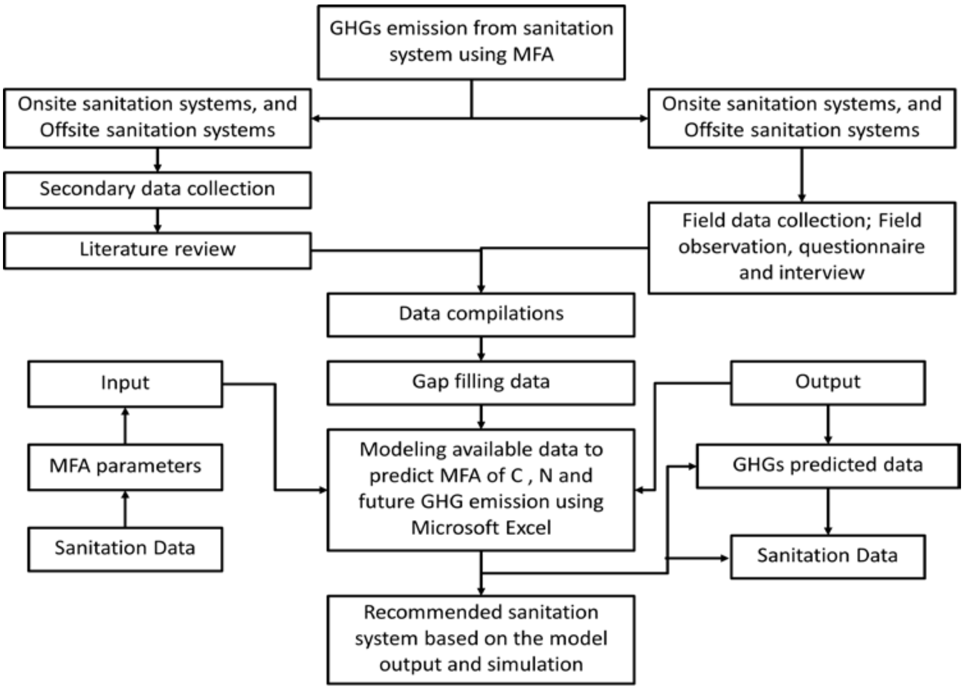


Figure 2.3 Overall MFA research framework

2.3.2 System boundary identification

To estimate GHGs emission from sanitation systems in Thailand a system boundary are showed in figure 2.4.

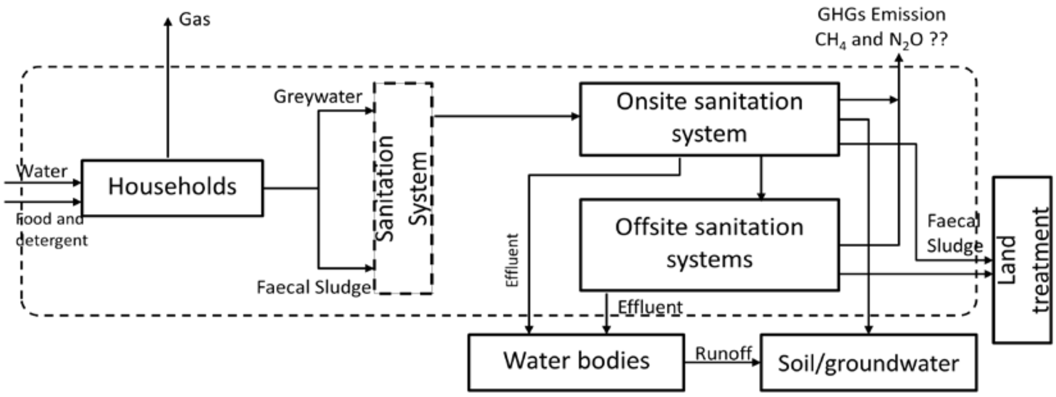


Figure 2.4 MFA system boundary in Thailand

2.3.3 Establishing MFA Model

After the survey, necessary modification of MFA model was made, however some processes were not considered. Thus, an improved MFA model was framed and analyzed using EXCEL. All the process and sub process, equations were generated to show the balance of nutrients (N or C) in their respective flows. Defining the parameter assessment and then calculating the model parameters and its distribution were determined.

2.3.3.1 Formulation of balance and the model equations

System analysis is the base frame for the mathematical model, where each flow or stock change rate is a variable expressed as a function of the parameter involved. Thus, two types of equations are used for the model; model and balance equations. The model equations are based on the scientific knowledge and expert knowledge that determine the various parameters determining the flows (variables) in the system. In this study, IPCC domestic waste equation and the law of mass conservations were governed the balancing equations for each of the process because it is highly desirable to formulate the equations in such a way that the necessity to collect many data is reduced. Hence, the number of parameters that are involved in the formulation of MFA should be minimized without compromising on the quality of the data. A balance equation based on the law of mass conservation (Equation 2.1), it formulated for individual process enclosing the system boundary. The equations were developed to show the different parameters interact to determine the variables within the system boundary. The model equation were developed using equations available from the literature review, IPCC (2006) and expert advice.

$$\frac{dMi^{j}}{dt} = \sum A_{i,r-j} - \sum A_{i,j-s} \qquad \text{(Equation 2.1)}$$

The left side of the equation indicates the rate of stock change of a substance *i* within the process *j*. The right side stand for the difference between the input and the output flows of the substance *i* to and from the process *j*.

2.3.3.2 Formulation of plausibility criteria

Plausibility criteria are representing variables (flows) and parameters were defined to enable us to determine plausibility of model input parameters and model outputs. The plausibility criteria were derived from reliable sources (literature reviews). Thus the plausibility criteria include target accuracies for key parameters based on "priority" sensitivity analysis for a given model equation. This sensitivity analysis provides insight into determining parameters.

2.3.3.3 Parameter assessments

A general parameter analysis is necessary before proceeding with further research when data collected are limited. Moreover, the data uncertainty should be taken into account; therefore the parameters were expressed as probability distribution.

2.3.3.4 Calculation of model variables and parameters

The variables, flow as well as stock rate changes within each process, were calculated using respective equations and parameters. Variable uncertainty was assessed by using Monte Carlo simulation, where a set of values are calculated for each of the variable by choosing a random parameter values based on their probability distribution by applying the model equation. Excel statistical formula were used to calculate the random values for each parameter influencing the variable depending on the parameters probability distribution.

The standard deviation and the variable mean were calculated for "n". The number of iterations was set as 1000, thereby resulting in a 0.01% difference between average of "n" values and the average of "n-1" values. The model information output increases by working with the probability distribution. While comparing different scenarios the knowledge of probability distribution allows us to determine the impact factor of different scenarios lie within a certain range or deviate significantly.

2.3.4 Data collection

The primary data collection methods include field observation, household survey, and interviews with key informants.

2.3.4.1 Survey questionnaire

A set of structured questionnaire were used for the survey, which included household general information, sanitation system, and sanitation conditions in terms of onsite wastewater management system. The questionnaire was designed with both open ended and closed ended questions.

2.3.4.2 Key informant's interviews

Key informants interviews were made with related department, organization, local authorities and people who had deep knowledge of the existing general situation and sanitation situation.

2.3.5 Parameter Assessment

Parameter assessment is an iterative process. Flows calculations were made based on the first parameter analysis. The plausibility of parameter values and model outcomes were subsequently analyzed. Differential literature review and survey were carried out to obtain a more accurate assessment of the sensitive parameters**.** Monte Carlo simulation is used to assess the model outcome and parameter values. If 68.27% of the values assessed lie within the range then only they are accepted because 68% of the values lie within one standard deviation of the mean.

2.3.6 MFA model simulation

2.3.6.1 Conducting sensitivity, uncertainty analysis and calibration of MFA model

This step compares parameter values and model outcomes with the reliable ranges determined for the plausibility criteria. If plausibility criteria were not met or variable, uncertainty was larger than targeted accuracy, parameter assessment and uncertainty analysis should be repeated. Once the model parameter and outcomes are plausible and target accuracy was reached, material flow is used to identify the problem and subsequently scenarios were developed.

2.3.6.2 Simulating scenarios, interpretation and documentation

The data reliability was verified according to the collection methods. Mass and indicator flows (C, N) were determined with respect to transfer co-efficient and collected data. The transfer co-efficient which is depending on similarity of various factors such as data availability, similarity of process, geography and etc were determined using; typical transfer co-efficient, related research and calculation methods or mass balance.

By balancing the flow of input and output in each sub processes and establishing a connection between all the sub processes in the system, a graphical representation to visualize the result was generated. The equation 2.2 shows the input and output flow balancing equation.

$$TC\ (S, P, O) = \frac{Flow\ substance\ S\ in\ output\ goods\ O}{Total\ input\ flow\ substance\ S\ in\ procsee\ P} \qquad \text{(Equation 2.2)}$$

2.3.7 Methane Emission from Wastewater

There are three tier methods used in IPCC (2006) for categorizing the CH_4 emission factors from any country. Tier 1 was used in this study because it assigns default values for the emission factor and parameters due to less data availability in Thailand. The relevant parameters that were used in MFA are show in table 2.3.

Table 2.3: The relevant parameters for the conventional MFA application

Model	Procedure	Parameter	Data collection
MFA & IPCC	Sanitation systems	- Type of onsite treatment systems in developing countries	- Literatures reviews - Questionnaires and Interviews
		- Wastewater and faecal sludge characteristics in term of organic matter (COD) and nutrient	- Literatures reviews - Reconnaissance survey
		- GHG's (NH_4 and N_2O) emission from onsite treatment processes	- Literatures reviews - Reconnaissance survey
	CH_4 Inventories	CH_4 Emissions, TOW, S, U_i, $T_{i,j}$, i, j, EF_j, R, Ef_j, B_0, MCFj, P, BOD, I	- Literatures reviews - Survey - Secondary data from government - Field experiments
	N_2O Inventories	$N_{effluent}$, P, Protein, F_{npr}, $F_{non-con}$, $F_{ind-com}$, N_{sludge}	- Literatures reviews - Survey - Secondary data from government - Field experiments

2.3.7.1 Methane (CH_4) Emission

The general equation to estimate CH_4 emissions from domestic wastewater is as follows (Equation 2.3).

$$CH_4 = \left[\sum_{i,j}(U_i \times T_{i,j} \times EF)\right](TOW - S) - R \qquad \text{(Equation 2.3)}$$

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr

TOW = Total organics in wastewater in inventory year, kg BOD/yr

S = Organic component removed as sludge in inventory year, kg BOD/yr

U_i = Fraction of population in income group i in inventory year

$T_{i,j}$ = Degree of utilization of treatment/discharge pathway or system, j, for each income group fraction i in inventory year
i = Income group: rural, urban high income and urban low income
j = Each treatment/discharge pathway or system
EF_j = Emission factor, kg CH_4 / kg BOD
R = Amount of CH_4 recovered in inventory year, kg CH_4/yr

Moreover, the B_0 is the maximum amount of CH_4 that can be produced from a given quantity of organics (as expressed in BOD or COD) in the wastewater. The methane correction factor (MCF) indicates the extent to which the CH_4 producing capacity (B_0) is realized in each type of treatment and discharge pathway and system. Thus, it is an indication of the degree to which the system is anaerobic. The CH_4 emission factor for each domestic wastewater treatment/discharge pathway or system can be calculated from Equation 2.4.

$$Ef_j = B_0 \times MCF_j \qquad \text{(Equation 2.4)}$$

Where:
Ef_j = Emission factor, kg CH_4/kg BOD
B_0 = Maximum CH_4 producing capacity, kg CH_4/kg BOD, (Default value of 0.6 kg CH_4/kg BOD or 0.25 CH_4/kg COD)
MCF_j = Methane correction factor (fraction), (0.05)
j = Each treatment/discharge pathway or system

The parameter for this source category is the total amount of organically degradable material in the wastewater (TOW). This parameter is a function of human population and BOD generation per person. It is expressed in terms of biochemical oxygen demand (kg BOD/year). The Equation 2.5 is used to determine TOW.

$$TOW = P \times BOD \times 0.001 \times I \times 365 \qquad \text{(Equation 2.5)}$$

Where:
TOW = Total organics in wastewater in inventory year, kg BOD/yr
P = Country population in inventory year, (person)
BOD = Country-specific per capita BOD in inventory year, g/person/day
0.001 = Conversion from grams BOD to kg BOD
I = Correction factor for additional industrial BOD discharged into sewers (For collected the default is 1.25, for uncollected the default is 1.00)

2.3.7.2 Nitrous oxide (N_2O) emissions from wastewater

Nitrous oxide (N_2O) emissions can occur as direct emissions from treatment plants or from indirect emissions from wastewater after disposal of effluent into canal. It can be determined from equation 2.6.

$$N_2O\ emission = E_{effluent} \times Ef_{effluent} \times \frac{44}{28} \qquad \text{(Equation 2.6)}$$

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr
$N_{effluent}$ = Nitrogen in the effluent discharged to aquatic environments, kg N/yr
$Ef_{effluent}$ = Emission factor for N_2O emissions from discharged to wastewater, kg N_2O-n/kg n
44/28 = The conversion factor of kg N_2O-n into kg N_2O.

The default IPCC emission factor for N_2O emissions from domestic wastewater nitrogen effluent is 0.005 (0.0005 - 0.25) kg N_2O-n/kg n. This emission factor is based on limited field data and on specific assumptions regarding the occurrence of nitrification and denitrification in rivers and in estuaries. The assumption is that all nitrogen is discharged with the effluent.

The parameters that are needed for estimating N_2O emissions are nitrogen content in the wastewater effluent of the population and average annual per capita protein generation (kg/person/yr). Per capita protein generation consists of intake (consumption) which is available from the food and agriculture organization (FAO, 200 multiplied by factors to account for additional 'non-consumed' protein and for industrial protein discharged in the sewer system. Food (waste) that is not consumed may be washed down the drain (e.g., as result of the use garbage disposals in some developed countries) and bath and laundry water can be expected to contribute nitrogen loadings. The total nitrogen in the effluent was estimated from equation 2.7.

$$N_{effluent} = \left(P \times protein \times F_{npr} \times F_{non-con} \times F_{ind-com}\right) - N_{sludge} \quad \text{(Equation 2.7)}$$

Where:
$N_{effluent}$ = Total annual amount of nitrogen in the wastewater effluent, kg N/yr
P = Human population
Protein = Annual per capita protein consumption, kg/person/yr
F_{npr} = Fraction of nitrogen in protein, default = 0.16, kg N/kg protein
$F_{non\text{-}con}$ = Factor for non-consumed protein added to the wastewater
$F_{ind\text{-}com}$ = Factor for industrial and commercial co-discharged protein into the sewer system
N_{sludge} = Nitrogen removed with sludge (default = zero), kg N/yr

2.3.7.3 Conversion of GHGs emission unit to CO_2 equivalent unit

According to UNSTAT, 2010, the conversion of ton CH_4/year and N_2O/year to ton CO_2 equivalent/year can be done by using GWP of CH_4 and N_2O of 56 and 280, respectively.

2.4 Quantitative Microbial Risk Assessment (QMRA) research works

2.4.1 QMRA research framework

Health risks were posed by pathogenic contamination of various environmental media, different FS management practices were assessed as the following basic procedures of QMRA which was comprised of four steps; 1) hazard identification, 2) exposure assessment, 3) dose-response assessment and 4) Risk characterization. Figure 2.5 shows overall QMRA research framework.

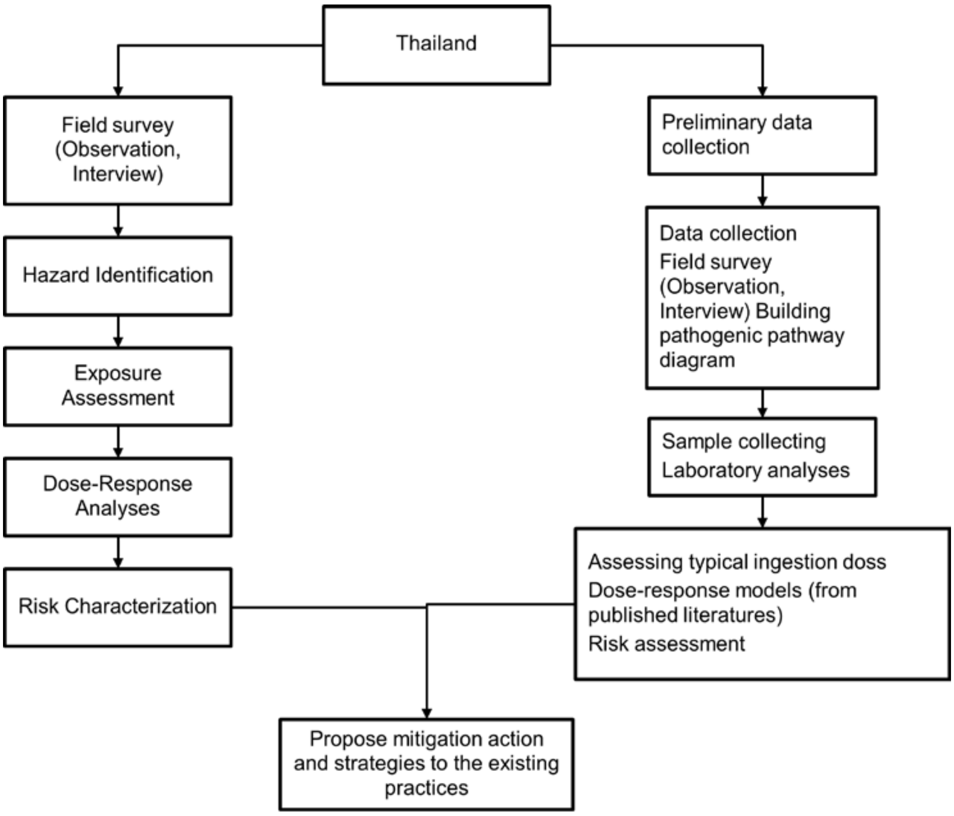


Figure 2.5 Overall QMRA research framework

2.4.2 Data collection

In order to study the relationship between environmental sanitation and excreta-related pathogen health risks due to selected activities in the study area, the primary data collection were obtained by field observations, questionnaires and interviews techniques. Secondary data were collected from various records, statistic reports, documents and journals which are available at the related organizations at provincial and national levels.

2.4.2.1 Reconnaissance survey

Reconnaissance survey on the physical features of environmental sanitation system and human activities related to exposures of excreta related-pathogens was undertaken by observations of local people and communities practices. This information was used to confirm the primary and secondary data in the study area. Detailed observations are as follows:

1. Land use identification e.g. agriculture, urban, marsh and water body
2. Flow directions of waste in the study area e.g. wastewater, faecal sludge, solid waste
3. Type of sanitations e.g. onsite, faecal sludge treatment, wastewater treatment

4. Activities related to contaminated sources e.g. activities in water bodies, activities in agricultural area, and activities in household

2.4.2.2 Questionnaires and sample size

Standardized questionnaires were used to acquire for quantitative and qualitative data from a chief of each village during the reconnaissance survey. In order to understand overviews of environmental sanitation and health risk in Thailand, the questionnaires were formulated according to:

1. Socio-economic background
2. Water uses and related activities
3. Sanitation system
4. Health status

2.4.2.3 Interviews

After the questionnaire process, in-depth interviews were undertaken on a person (2-3 persons) who answered that he or she might be exposed to excreta-related pathogen swimming in canal, vegetation or fishing in canal, irrigation on farmland, and eating raw vegetable. Questions for this in-depth interview were designed to specific water-borne diseases according to the aforementioned exposure pathways:

1. Practices for the exposures and health risks due to the contaminated sources
2. Number of exposures in year
3. Protections after exposures
4. Incidence of diarrhoea after exposed to the contaminated sources
5. Treatments and health services uses

2.4.3 QMRA steps

There are 4 procedures in QMRA; hazard identification, exposure assessment, dose-response assessment and risk characterization which will explain as follows;

2.4.3.1 Hazard Identification

The first step of QMRA was the identification of pathogenic organisms as agents of potential significance to cause acute or chronic effects to human health. As it had been discussed earlier, E. coli and Salmonella spp. were employed in this study. In this stage, general properties and associated clinical features of E. coli and Salmonella spp. as well as critical pathogenic pathways were identified.

Based on the schematic diagrams of pathways of pathogenic organisms, originating from the FS disposal site into the surrounding environment were constructed in order to identify the critical environmental media of pathogen transmission from its source to the public for each community as shown in Figure 2.6 and also to determine sampling locations for subsequent laboratory analysis of faecal contamination. As a result, canal water and tap water (groundwater abstracted) were identified as the critical transmission media.

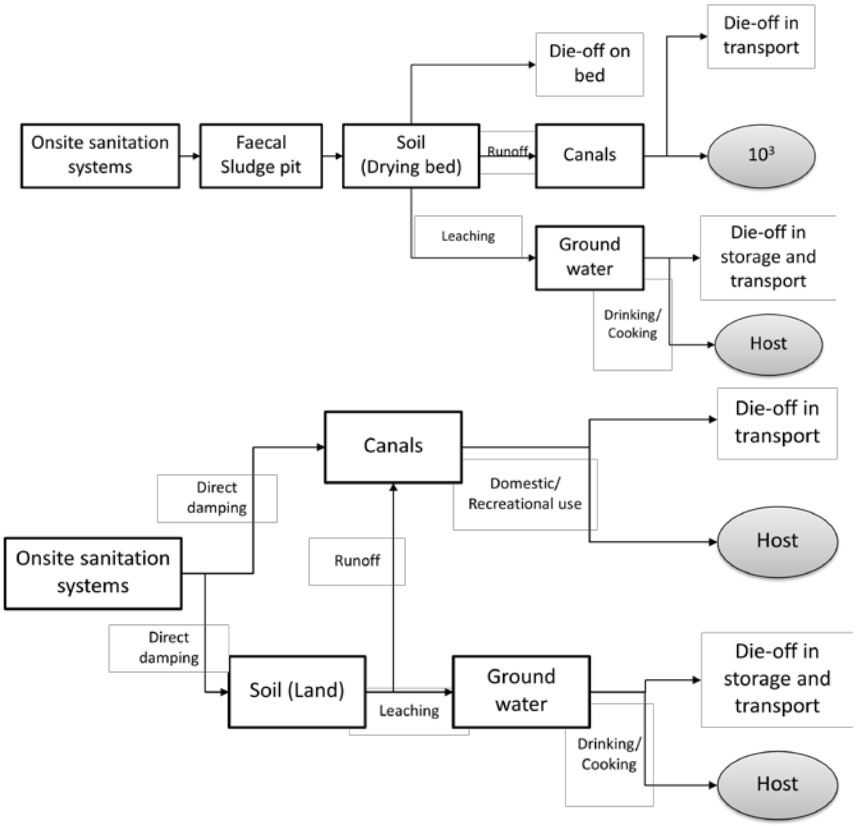


Figure 2.6 Event tree for transmission of fecal bacteria in community

2.4.3.2 Exposure assessment

The level estimations and the amounts of ingested/contacted materials per "exposure" of *E. coli* and *Salmonella spp.* in canal and tap water were determined to find the microbial doses. The concentrations of *E. coli* and *Salmonella spp.* in canal and tap water were collected from municipalily, local authorized offices, Department of Health and Local hospitals. In case of lacking of data, the water samples was took to the nearly laboratory for analysis. Moreover, FS samples were collected directly from FS collection truck and analyzed for *E. coli* and *Salmonella spp.*

Sampling points from canal and tap water were represented overall pathogenic contamination levels, the highest contact chances with the public were selected from the canal, river and households where the domestic wastewater were discharged. Moreover, sources of drinking water; river, well and tap water were collected as well as show in figure 2.7. Sampling procedures followed the standard sampling method for grab samples *(APHA, 1998)* which the sample was collected at the depth of 30 cm above canal surface. In the tap water sample collection, the mouth of tap was wiped with alcohol in order to reduce the potential of cross-contamination from the inner casing of the tap. The samples were putted into sterilized plastic bottles and immediately transported to the laboratory for analysis. Then, they where were kept at 5^{o}C for subsequent analysis. Maximum holding time of all samples for microbiological analysis was 8 hours.

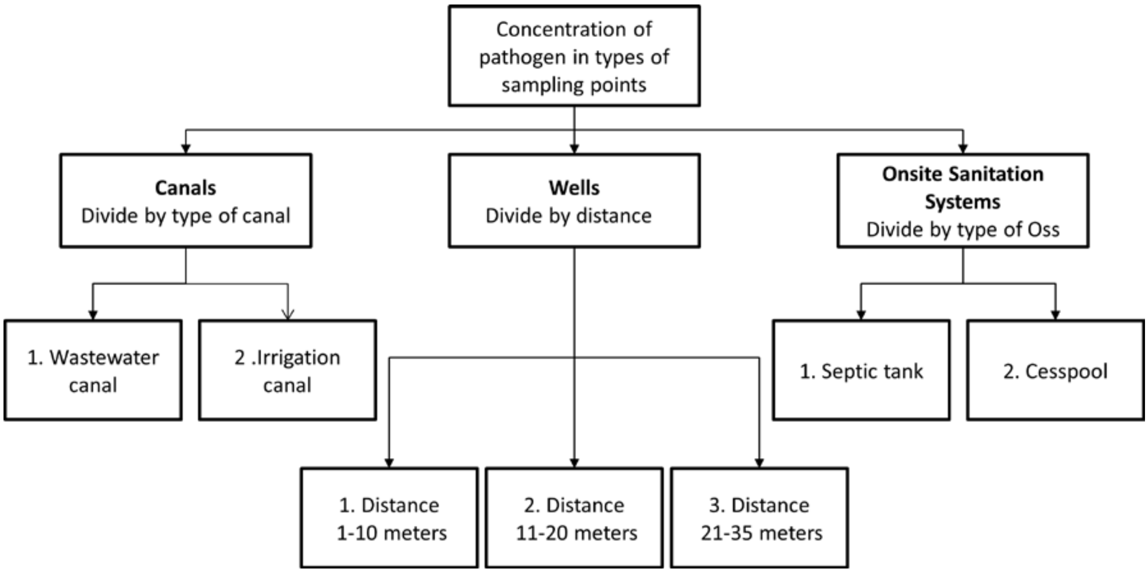


Figure 2.7 sampling points divided by sources of water

E. coli and *Salmonella spp.* concentrations were analyzed at laboratory by using a standard five tube most probable number (MPN) method. For *E. coli*, the standard method described by *APHA et al, 1998* while for *Salmonella spp.* the modified standard method of *Fukushi et al. 2003* was used. MPN analysis was always performed in duplicate and the arithmetic mean values were recorded as representative of each sample.

2.4.3.3 Dose-response assessment

The single exposure risks as well as yearly risks of *E. coli* / *Salmonella spp*. infections were calculated for each activity. The dose-response equation for *E. coli* and *Salmonella spp.* was adopted by Haas et al. (1999), the beta-Poisson dose-response models were employed to calculate the probability of infection after a single exposure (P1) to *E. coli* and *Salmonella spp.*, respectively (Haas et al, 1999) as shown in equation 2.8 and 2.9 respectively.

2.4.3.3.1 Escherichia coli (Multiple non-enterohaemorrhagic strains except for O111)

$$P_1 = 1 - \left[\frac{1+d}{N_{50}(2^{1/\propto})-1}\right]^{-\propto} \qquad \text{Equation 2.8}$$

Where:

d = dose or exposure (number of E. coli)
α = 0.1778 (parameter that characterize dose-response relationship)
N_{50} = 8.60 x 10^7(median infection dose

2.4.3.3.2 Salmonella spp. (Multiple non-typhoid pathogenic strains; S. pullorum excluded)

$$P_1 = 1 - \left[\frac{1+d}{N_{50}(2^{1/\propto})-1}\right]^{-\propto} \qquad \text{Equation 2.9}$$

Where:

d	= dose or exposure (number of *Salmonella spp*.)
α	= 0.3126
N_{50}	= 23,600

Risk was calculated at exposure to the mean as well as at the 9th percentile concentrations, considering worst cases since dose-response models tend to be conservative in nature. As mentioned earlier, the infection risks due to *E. coli* were assumed to indicate possible risk of infection, *E. coli* being fecal indicator organisms, whereas those calculations for *Salmonella spp.* were believed to indicate probable risk of infection, *Salmonella spp.* being the actual pathogenic organism.

Risk was calculated at exposure to the mean as well as the 95th percentile doses, and expressed in percentage (%) probability and a fraction of 10,000 of the population as well as the probability. According to USEPA (1994), maximum annual risk of enteric disease infection that can be considered as acceptable is 1 case in 10,000 persons per year.

2.4.3.3.3 Annual risk of infection

Annual risk of infection was calculated for each scenario by multiplying the obtained single exposure risks by the number of exposures per year, based on the assumption that the dose-response relationship is approximately linear at low doses (Haas et al., 1999), as can be described in the below equation:

$$P_n = 1 - (1 - P_1)^{n \approx} n \times P_1 \quad (P_1 \ll 1) \qquad \text{Equation 2.10}$$

Where P_1 and P_n are the probability of infection after a single (daily) exposure and after repeated exposures (n times a daily exposure) respectively.

Obtained data were expressed as a fraction of 10,000 of the population as well as percentage (%). It was also plotted in logarithmic graph for visual appraisal, in which acceptable risk defined by USEPA of 1 case/10,000 persons/year was marked for comparison.

2.4.3.4 Risk characterization

Risk characterization will be aimed at the integration of the outcomes obtained from the three steps in order to characterize the types and magnitudes of health risks pose on the public, comparing along with the guideline acceptable risk. Based on the results of the above four steps of QMRA, the following main objectives of the study were completed;

Health impacts posed by the microbial indicator organism and the entering pathogenic organisms; E. coli and Salmonella spp.: By using the results of *E. coli* and *Salmonella spp.* concentrations, the infections in the study area were estimated for the respective scenarios through different exposure volume and assumed injected dose on the households and service providers.

The applicability of the Quantitative Microbial Risk Assessment for conducting the health risk: Based on the results and integration of the hazard identification, exposure assessment and dose-response analysis, the possible risks pose from the set microorganisms in the defined study area were conducted by using QMRA.

Proposing mitigation strategies in order to reduce the resulted health risk from the existing practices and processes of the wastewater: Based on the outcome health risks and the existing practices and management of organic waste in the study area, the better management strategy and mitigation approach information to the service providers and public in order to fulfil the last objective

Chapter 3 Results and Discussions

3.1 Study Area

3.1.1 Thailand

3.1.1.1 General Information of Thailand

Thailand is located in Southeast Asia with 514,000 square kilometer (Km^2) area. It is connected to Myanmar in the west, Laos in the north, Cambodia in the east and Malaysia in the south as shows in figure 3.1. The gulf of Thailand and the Andaman Sea are the coasts in the eastern and western part which is approximately 2,420 kms length. Distance from north to north is about 1,650 kms while east to west is about 780 kms.

Figure 3.1 Map of Thailand

Central of Thailand, it is the most plenty area of country. In the north, it is higher mountain area and beforetime it is the most plenty forest area of country. One-third of country which consists Korat plateau (that have Mekong River bordered to north and east and the steep of Phanom Dong Rak) Mun river and Chee river is in the north-east of Thailand. This area quantity of rainfall is lower and soils are worse than other part of country. Southeast of Thailand is the coastal area where there is higher rainfall quantity and worse soils quality than the center region.

There are three main seasons as follows as cool season (November to February), hot season (March to May), and rainy seasons (June to October) in northern, northeastern and central Thailand. While in southern, there are two main seasons as follows as rainy seasons (April to November) and hot seasons (December to March).

The population in Thailand was approximately 64 million and in this number population about 9.3 million they lived in Bangkok and suburban and 94 percent of Buddhism population was speaking to Thai language. Thai language is official language of the country. There are 4 vernacular languages for use in the central, northern southern and northeastern. Most of population in four provinces in Southern as follow as Pattani Satun Yala and Narathiwat speaks Malay language. There are many regions as follow as Buddhists 94.2 percent Muslims 4.6 percent Christians 0.8 percent and others religions 0.4 percent respectively. Theravada Buddhism or Hinayana Buddhism is the national religion.

Thailand is today recognized as one of the most important countries in the world and has diverse food producers. It has a newly industrialized economy, which is highly export dependent, with exports accounting for more than two-third of Gross Domestic Product (GDP).

3.1.1.2 Sanitation systems in Thailand

Wastewater is one of the most serious environmental problems in Thailand. Domestic Wastewater in Thailand caused daily activities for living in community and occupation activities such as cooking toilet or clean in house etc. and then waste water will released to pipe or source water so contaminants from waste water were released to source water by direct or indirect. The contaminants will impact to source water too much including raw water source for make tap water, quality of human life, and quality environmental. Quantity of domestic waste water is about 80 percent of quantity from water used or estimated number of people or building area as shows in table 3.1.

Table 3.1 Rate of Waste Water generation per person per day

Rate of Waste Water generation (Liter/Person-Day)						
Regions	**1993**	**1997**	**2002**	**2007**	**2012**	**2017**
Central	160-214	165-242	170-288	176-342	183-406	189-482
Northern	183	200	225	252	282	316
North Eastern	200-253	216-263	239-277	264-291	291-306	318-322
Southern	171	195	204	226	249	275

3.1.1.2.1 Onsite sanitation system

Therefore, Thailand has coverage nearly 99 percent of basic sanitation facilities to all of areas, but pollution from wastewater and waste which are generated from human activity still present in most serious environmental and health problems to nationwide. It is importance to notice in Thailand of the sanitation crisis. As results of Ministry of Public Health *(MOPH, 2008),* more than 80 percent of domestic wastewater generated in Thailand are not treated this enters directly drains to environment in several ways by urban canals, and 80 percent of human waste or faecal sludge in Thailand, collected from onsite sanitation systems is disposed of in landfills, agricultural fields, and waterways. Untreated waste and wastewater causes contributing to the major source of pollution in Thailand.

NSO (2000) reported that 84 percent of onsite sanitation systems in Thailand was cesspool, 12 percent of septic tank and 0.4 percent of pit latrines as show in Figure 3.2. The popular type of onsite sanitation systems in rural areas is one cesspool system which made by low cost material and available in local place such as brick wall and concrete rings. Cesspools are simple designed to capture sanitary waste from household only, but do not treat those waste. Cesspools system is very low of efficiency for removal organic matter and nutrient in the wastewater and it can cause high-risk of groundwater pollution. Thus, during 1991-1996, Department of Health would like to promote the septic tank. Health Development Plan No. 7 by Department of Health promoted changing the type of onsite sanitation systems from cesspool to septic tank. The aim of this plan is to improve the sanitary and standard of onsite sanitation systems in Thailand. Recently, number of septic tank is increasing continuously.

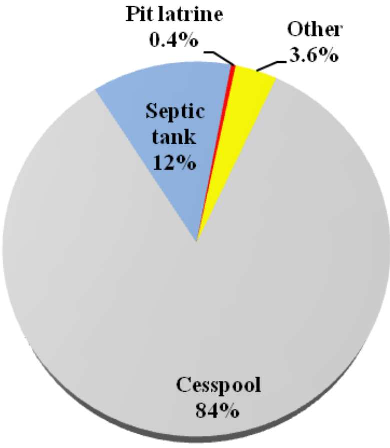


Figure 3.2 Percent of typical onsite sanitation in Thailand (Source: NSO, 2000)

3.1.1.2.2 Offsite sanitation system

There are 92 plants with total capacity 3,212,895 m^3/d treating domestic wastewater in Thailand *(PCD, 2012).* Only of 72 domestic wastewater treatment plants (DWTPs) are today in operation and the other DWTPs are: in construction period (6 plants), out of order during operation (8 plants), implementation period (4 plants), and not yet receive the project from contactor (2 plants) (PCD, 2011). The detail of 92 DWTPs were summarized and showed in table 3.2 and figure 3.3.

From Table 3.2 and Figure 3.3, there are 12 types of DWTP located in Thailand. First of all, the stabilization pond (SP) has the highest proportion (46%) and therefore follows by oxidation ditch (OD), aerated lagoon (AL), activated sludge (AS), SP+CW and constructed wetland with proportion of 19%, 17%, 7%, 3% and 2%, respectively. Apart from that, there were only 1% of each other types of DWTP which are sequencing batch reactors (SBR), rotating biological contactor (RBC), modified sequencing batch reactors (MSBR), SP+OD, trickling filter+OD and OD+AS. For the capacity and performance of DWTPs, the data vary substantially by type. The highest capacity is SP+OD which have capacity in the range from 16000-138000 m^3/d. Meanwhile, the lowest capacity is CW which has capacity only 200-400 m^3/d.

Table 3.2 The DWTP in Thailand type, capacity and performance

Type of domestic wastewater treatment plant in Thailand	Quantity	Capacity (m^3/d)
Stabilization Pond (SP)	42	500-78000
Oxidation Ditch (OD)	17	6000-36000
Aerated Lagoon (AL)	16	8200-78000
Activated Sludge (AS)	6	3000-41000
SP+CW	3	16000-138000
Constructed Wetland (CW)	2	200-400
Sequencing Batch Reactors (SBR)	1	1000
Rotating Biological Contactor (RBC)	1	8000
Modified Sequencing Batch Reactors (MSBR)	1	3600
SP+OD	1	70000
Trickling filter+OD	1	6000
OD+AS	1	22000
Total	92	

Note: The domestic wastewater treatment plant capacity was summarized from the data of PCD, 2011.

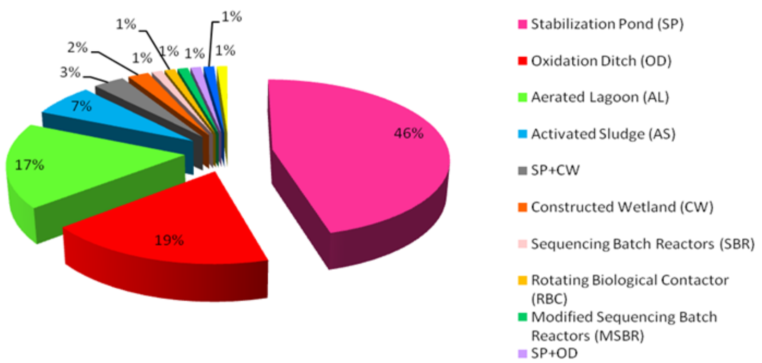


Figure 3.3 The proportion of DWTP type in Thailand

In terms of DWTPs' size, this is often used as a reference value for capacity of the plant, the medium-size DWTPs (40%) much better than other sizes. Despite this, 37% and 6% of DWTPs are small-size and large-size DWTPs, respectively. The numbers of DWTPs separated by size are shown in table 3.3.

Table 3.3 Size of DWTPs in Thailand

Size of domestic wastewater treatment plant in Thailand	Quantity
Large (> 50000 m^3/d)	6
Medium (10000-50000 m^3/d)	40
Small (< 10000 m^3/d)	37
No data *	9

*Note: * The data not yet available due to these domestic wastewater treatment plants are in the construction and improvement period.*

As mentioned there are 12 types of DWTPs used in Thailand, however difference DWTPs has different treatment efficiency, the table 3.4 shows the performance of DWTPs in Thailan

Table 3.4 Performance of DWTPs in Thailand

Parameters	BOD (mg/l)		COD (mg/l)		SS (mg/l)		TKN (mg/l)		Nitrite (mg/l)		Nitrate (mg/l)		Phosphorus		Oil and grease		Feacal Coliform		Total Coliform	
	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal	Effluent Conc (mg/l)	% Removal
SP	16	57	10	68	38	-15	4	53	0.02	76.32	0.40	22.22	0.99	43	130	-24	7.50E+06	88	3.10E+07	83
OD	11	78	30	71	22	68	7	53	0.13	44.21	3.76	-218.22	0.96	34	175	22	1.60E+03	99	1.60E+03	99
AL	14	46	17	36	24	23	5	60	8.67	-60.56	22.60	5.90	1.87	8	56	-209	1.30E+07	78	5.50E+07	81
AS	12	65	12	63	18	77	6	55	0.17	45.16	2.60	-550.00	1.16	35	56	-20	>16	-	>16	-
SP + CW	11	84	11	81	25	41	6	51	0.16	51.52	1.60	38.46	2.08	44	10	2	5.70E+05	100	4.00E+05	100
CW	23	94	No data		36	93	16	66	No data		No data		0.18	88	11	94	No data		No data	
SBR	8	71	No data		9	66	6	48	No data		No data		0.60	77	1	59	No data		No data	
RBC	11	80	4	85	18	52	9	39	0.16	51.52	1.60	38.46	0.28	65	430	-140	No data		No data	
MSBR	13	67	No data		15	66	-	-	No data		No data		0.60	25	7	39	No data		No data	
SP+OD	22	74	40	48	32	-19	10	84	30.76	-241.53	19.02	9.73	2.34	44	27	-4	1.50E+05	57	1.25E+05	100
Trickling filter + OD	5	98	5	98	8	93	2	50	13.00	35.00	71.00	-162.96	3.05	3	4	80	2.00E+00	50	2.00E+00	50

Note: The DWTP performance was summarized from the data of PCD, 1991and 2007-2010

3.1.2 Vietnam

3.1.2.1 General Information of Vietnam

Vietnam is located in the heart of South East Asia. The country is among the most populous nations in South East Asia. The population in 2011 was estimated to be 88 millions (World Bank, 2012). The Socialist Republic of Vietnam is located on the eastern coast of the Indochinese Peninsula. It is bordered on the north by China, on the west by Laos and Cambodia, and on the south and east by the South China Sea (Figure 3.4). Hanoi is the capital and Ho Chi Minh City (formerly Saigon) is the largest city and the commercial capital.

Figure 3.4 of Vietnam (source: www.vietnambudgettour.com, 2012).

Ho Chi Minh City located in Southern Vietnam is the largest city of Vietnam. It is located at $10^{0}10'$ - $10^{0}38'$ in North Vietnam, and $106^{0}2'$ - $106^{0}54'$ in East Vietnam. Ho Chi Minh City is 1,730 km (by land) from Hanoi capital of Vietnam. This city is far from the East Sea about 50 km. HCMC is in tropical zone and close to the sea so the weather is from warm to hot in a year. Dry season and rain season are two main seasons in HCMC. The dry season is from December to April. However, in December the weather is cooler. Rain fall begins in May and last until November. The rain becomes heavy from June to August. Dangerous typhoons often happen from July to November. Generally, average daily temperature of HCMC is 27^{0}C. Highest temperature is from 39^{0} – 40^{0}C (recorded in April) (Dan, 2008).

The land area of Ho Chi Minh is appropriate 2,095 km^2. Currently, its land use was divided into four categories such as agriculture, forest, residential areas, and nonresidential areas. HCMC population is 7,396,000 people in 2010 with the density of 3530 people/km^2 (General Statistic Office, 2012). GDP of whole Vietnam and HCMC is contributing 30% of budget of whole Vietnam. It has an important role in driving the developing Vietnam economy.

Currently, HCMC owns over 12 industrial zones. In 2004, HCMC attracted over 1621 projects from foreigner investment with 12.2 billion USD. At present, it owns over 300,000 businesses with different fields, and export processing zones. The investment into Ho Chi Minh City has the trend to high-tech, and high services. In 2011, the average income of per capita was 2800 USD/year (General Statistic Office, 2012).

3.1.2.2 Sanitation systems in Vietnam

Domestic wastewater consists of two types: wastewater from kitchen and bathroom areas; and wastewater from toilet. In Vietnam, wastewater from kitchen and bathrooms are discharged directly to the drain lines that were connected to drainage network. Wastewater from the toilet of each household is firstly collected to a septic tank usually placed under the house. Then, effluent from the last chamber of a septic tank is discharged into drain lines.

3.1.2.2.1 On-site sanitation system in HCMC

On-site sanitation consisting of water closet which is the most commonly used and septic tank is over 66% in comparison with off-site sanitation (18%) that includes water closet and sewer system. Latrine pit is not common in used.

According to the existing regulation of Vietnamese government, human toilet waste has to be treated by a septic tank before it will be discharged to sewer system and environment. About 55 - 65 % of household had septic tank laid under their houses (Thanh, 2011) while 4.8% of the population has not yet accessed to the toilet facilities. Approximately 9.0 % of population is used public toilets mainly constructed and managed by HCMC Urban Environmental Company. Public toilets are placed at public areas such as markets, parks, main streets and residential areas with high population density and low income. The sanitation systems of household in HCMC is presented in the figure 3.5

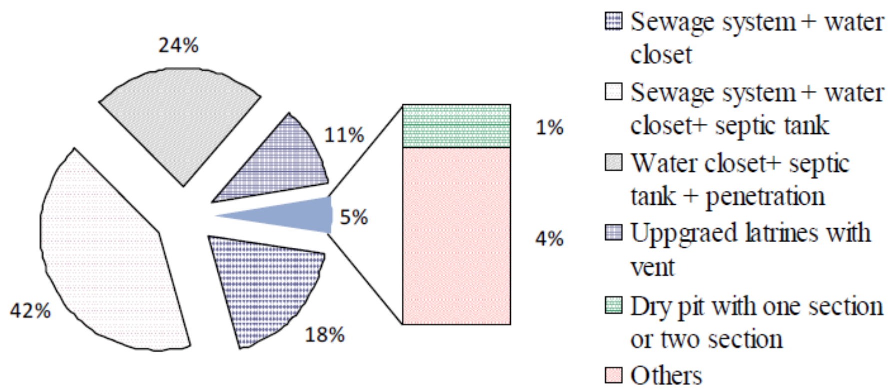


Figure 3.5 The sanitation systems in HCMC (Source: Thanh, 2011).

According to the actual survey data and theoretical calculations, the total volume of fecal sludge in HCMC is around 250 - 350 tonnes (wet weight)/day. The characteristics of faecal sludge are shown in table 3.5.

Table 3.5 Characteristics of faecal slude in Ho Chi Minh City

Parameters	Value
TSS (mg/L)	36,000- 131,00
VSS (mg/L)	27,000-49,000
TN (mg/L)	1,500-1,800

Source: Centema, 2008

In addition, Sludge also contain a lot of different types of waste is not biodegradable, such as nuts, seeds, paper, condoms, plastic bags, fabric, and etc.

3.1.2.2.2 Offsite sanitation systems

The drainage systems are combined with sewerage to be responsible in collecting both storm water and wastewater. Domestic wastewater, industrial wastewater and rain water are collected to sewage systems and directly discharged into the canal system of HCMC.

The drainage system of HCMC urban consists of approximately 780 km of sewer, 39,100 manholes and, 415 outfalls to canals that often receive the high capacity of daily discharge of wastewater from domestic and industry (Viet, 2008). Currently, there are five drainage canals connected with drainage systems of HCMC; Tan Hoa - Lo Gom canal, Tau Hu - Kenh Te-Ben Nghe canal, Nhieu Loc - Thi Nghe Canal, Tham Luong - Ben Cat - Vam Thuat river and Xuan Truong - Suoi Cai Canal.

HCMC can be divided into 3 areas; old urban area, new urban area and peri-urban area. The total daily domestic wastewater generated from different scale of population in HCMC is indicated in table 3.6

Table 3.6 Domestic Wastewater from Residential Areas

Area	Scale (people)	Criteria (L/person.day)	Wastewater flow rate (m^3/day)
Old urban area	4,500,000	315	1,418,000
New urban area	2,900,000	305	885,000
Peri-urban area	2,600,000	300	780,000
Average flow rate			3,082,000

Source: HCMC people's Committee, 2007

From table 3.6 shows that if wastewater will be reused with the ratio of 42% and 81%of total domestic wastewater in 2025, the water stress index will reduce from 22% to 15% and 10%. According to the master plan of HCMC, wastewater drainage system of HCMC will be divided into areas that will be applied centralized treatment system and decentralized treatment system. Centralized wastewater treatment system will divided into 9 drainage basins with total area of 18,978 ha, and capacity of treating wastewater is 1,780,000 m^3/day. For decentralized wastewater treatment system, the anaerobic baffled septic tanks will be used with wastewater capacity of 602,000 m^3/day for treatment *(Dan, 2008).*

From November 2008 up to now, HCMC only has one centralized wastewater treatment system plant located at Binh Chanh district with capacity of wastewater about 110,000 m^3/day. It is treating wastewater by using activated sludge, and the quality of treated water is showed in table 3.7.

Table 3.7 Quality of Treated Wastewater

Parameters	Unit	Quality of effluent
SS	mg/L	5-50
Turbidity	NTU	1-30
BOD5	mg/L	10-30
COD	mg/L	50-150
Total coliform	MPN/100mL	< 10-107
Faecal coliform	MPN/100mL	< 10-106
Nitrogen	mg/L	10-30

Source: Dan, 2008

Most projects of construction of wastewater treatment plants have been placed in peri-urban area. Therefore the reuse of treated water for agricultural irrigation will be high potential, especially for coastal areas in dry season. However, there are few wastewater treatment plants which is constructing, and the capacity of centralized wastewater treatment plants from 2010 to 2020 are presented in table 3.8

Table 3.8 Capacity of Wastewater Treatment Plants from 2010 to 2020

Centralized wastewater treatment plant	Capacity (1000 m^3/day)	
	2015	**2025**
Nha Be	750	1000
Can Giuoc	500	700
Vinh Loc	650	800
Total	2400	3200

Source: Dan, 2008

3.1.3 Lao PDR

3.1.3.1 General Information of Lao PDR

People's Democratic Republic (Lao PDR) is located in South East Asia with a total population of around 6.2 million according to the 2008 Population Census and population density around 26 people per square kilometers. The total area of Lao PDR is 236,800 km^2 *(The Economic Research Department, 2010).* This country is shared its borders with Cambodia to the south, Thailand to the west, Vietnam to the east and China and Myanmar (Burma) in the north and north-west respectively. The map of Lao PDR is shows in figure 3.6.

Figure 3.6 Map of Lao PDR (Source: www.cia.gov, 2012)

Vientiane is a capital city of Lao PDR. The total population in Vientiane capital is estimated around 610,000. The administrative area of Vientiane capital is about 3,920 km^2. The ground elevation ranges from 160 -170 m above sea level *(Keosithamma, 2004).* Vientiane capital is administratively divided into 9 districts namely Meuang in Lao language; those are namely Chanthabuly, Sikhottabong, Xaysetha, Sisattanak, Naxaithong, Xaythany, Hadxayfong, Sangthong, Parkngum that is shown in the Figure 4.1.3-1 There are 3 season in the Vientiane capital included the cool season (November to February), the hot season (April to May) and the rainy season (June to October) due to the influence of southwest monsoons. The coolest average minimum temperature is 17 °C (63 °F) in January & December. The warmest average maximum temperature is 34 °C (93 °F) in April. The major drainage system of Vientiane capital is the Mekong River, one of the longest rivers in the world, flows along the borders with Thailand. The river flows through nearly 1,900 km of Lao territory and has always been a lifetime for the country in term of fish supplies, transportation routes and agriculture. Several hydro-electric facilities, situated on the tributaries of the Mekong, generate electricity for export to Thailand.

3.1.3.2 Sanitation systems in Lao PDR

3.1.3.2.1 Onsite sanitation systems

In 1996, the survey of Vientiane Integrated Urban Development Project (VIUDP) found 63% of the households have a sanitation system. In the same survey, 34% of the households used a septic tank for excreta disposal, 2% discharged human waste directly into the drainage system, while 1% used a dry pit latrine. Due to the low absorption capacity of the soil and the high ground water table in Vientiane, many soak ways fail to operate effectively, causing discharge of sewage from pits and tanks into roadside drains, drainage channels and low-lying areas *(UN, 2001).*

The onsite sanitation system takes care of the black water (water from the toilet) but the grey water (water used for cleaning, cooking, washing and bathing) is generally discharged without any treatment. There are no sewerage system or sewerage pipelines. For some houses, there are small open dug channels for the grey water along the side of the road, which reach the canal system, soaked up, or is dried in the sun. The black water treatment is questionable as the septic tank and the cesspools are made only due to government regulation but not considering the impact of poor sanitation to health or to the environment. The cesspool and the septic tanks leachate are not discarded to the dispersion area but the leachate is allowed to seep down to the ground in the premises of the house where a well is commonly located from which water is taken for household *(Longaphai, 2012).*

Keosithamma, 2004 also reported that the wastewater from individual households in Vientiane discharges into open drains along the roads and into natural wetlands in and around the city. Table 3.9 shows example of place wastewater discharge in some district in Vientiane. The high water table and low soil permeability in Vientiane creates further difficulties for drainage. The poor drainage of wastewater and seepage from septic tanks and poorly designed on-site sanitation creates a major concern for public health, causing widespread pollution of surface water and groundwater.

Table 3.9 An Example of wastewater disposal

Wastewater discharge to	**Urban districts in Vientiane**			
	Sihom	**Muang Va Thong**	**Nong Duang Thong**	**Si Mung**
Open drain	75 %	30 %	35 %	31 %
Road	6 %	5 %	29 %	44 %
No drainage	13 %	55 %	24 %	0 %
other	6 %	10 %	12 %	25 %

Source: Keosithamma, 2004

For Faecal sludge disposal, as Vientiane uses only on-site sanitation including cesspools and septic tanks. The faecal sludge is accumulated in the on-site sanitation systems, some of it is removed by faecal disposal companies (these are the private sectors) unused land without treatment and management, the rest infiltrates into the soil and ground water or flows in the drainage systems, then it flow to surface water. According to the village officials, the septage is not used in agricultural practices. The sludge accumulated in the septic tank is collected only when the septic tank is clogged in 5-10 years and is transported to the Vientiane municipality landfill. The landfill can be seen in Figure 3.7 with sludge from the septic tank.

Figure 3.7 Vientiane municipality landfill with faecal sludge disposal

3.1.3.2.2 Offsite sanitation systems

The majority of Vientiane City's untreated domestic wastewater is entering the "That Luang marsh", the largest remaining wetland in Vientiane Municipality and was built in 1993 with a 0.9 million US dollar grant from the European Union. This "That Luang Wastewater Management Project" (often referred to as "the EU-ponds") was planed and managed under the Department of Public Work and Transport (DPWT) of Vientiane. The marsh itself is roughly 20 km^2 and is part of the That Luang Basin *(Claridge, 1996)* collecting water that drains from Vientiane City and surrounding areas. Water draining into That Luang Marsh comes primarily from the Hong Ke stream which collects it's water from drainage canals running throughout Vientiane. Water running out of the marsh follows Houay Mak Hiao River dumping into the Mekong 64 km south east of Vientiane (Figure 3.8).

Figure 3.8 Vientiane capital treatment pond. Water intake is located in Nong Chan marsh, and pumped to the EU ponds near Hong Ke cannel. (Source: Longaphai, 2012)

3.2 GHGs emissions from sanitation systems

Methane (CH_4) has been identified as a potent greenhouse gas (GHG's); equivalent to 25 times of carbon dioxide. Similarly, nitrous oxide (N_2O) has a reported potency factor of 298 times of carbon dioxide *(IPCC, 2006).*Wastewaters; domestic, commercial and industrial wastewater can be a source of GHGs emission such as CH_4, and N_2O. Those can be emitted from sanitation systems when treated or disposed in anaerobic condition. The most common wastewater treatment methods in developed countries are centralized aerobic wastewater treatment plants and lagoons for both domestic and industrial wastewater. Domestic wastewater may also be treated in onsite sanitation systems and discharge to sewer system before entering to wastewater treatment plant. Moreover, the effluent from wastewater treatment plant and onsite sanitation systems may be disposed to environment as shows in figure 3.9 on wastewater treatment and discharge pathway.

The EPA (2009) has determined that a majority of the CH_4 emissions associated with wastewater originate from conventional septic tank systems, due to the large number of individual septic systems now in use. However, available actual data on the emission of CH_4 from septic systems are insufficient to produce an accurate GHG inventory for these systems.

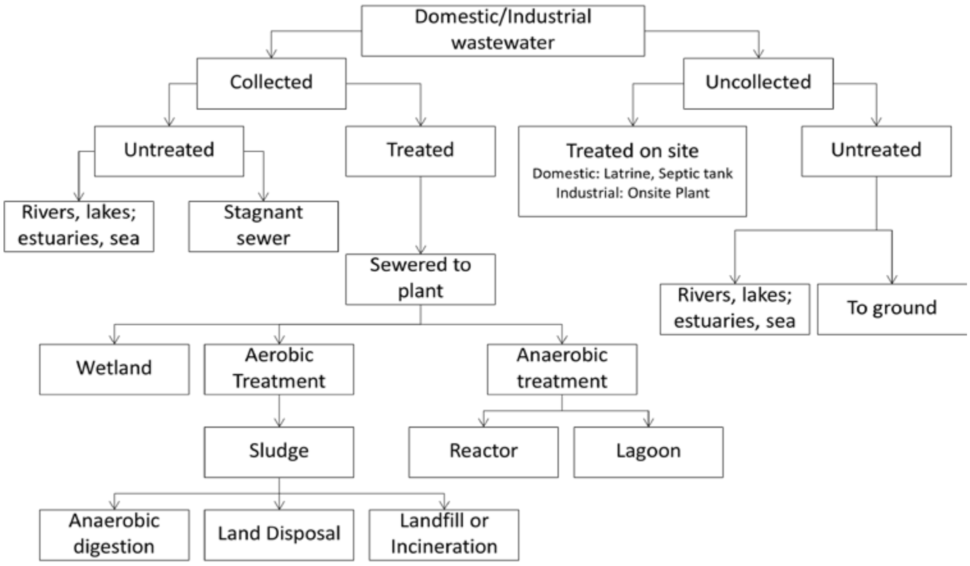


Figure 3.9 Wastewater treatment systems and discharge pathways

As mentioned, onsite sanitation systems are widely used and can generate the GHGs emission and release to atmosphere. Onsite sanitation systems have evolved from the pit privies. The ability of onsite sanitation system is to remove settle able solids, floatable grease and scum, nutrient, and pathogen before discharging effluent (EPA, 2002). It can also defined as a decentralized wastewater management installed with single household, condominium, or school to treat wastewater before discharging to environment (PCD, 1995).

3.2.1 On-site sanitation systems

There are several types of onsite sanitation systems such as pit latrine, composting latrine, pore flush latrine, cesspool and septic tank. However, recently cesspool and septic tank are commonly connected to the household toilets.

- **Cesspool:** A cesspool is a sealed underground tank where all the sewage from a property or properties is stored. There is no intent to treat or discharge the sewage and its function is simply to collect waste. When the cesspool is full, which is likely to be every four to six weeks, it needs to be emptied. Due to the fact that cesspools have to contain all the waste from the house, the frequency of emptying increases which will in turn increase the price of the total system. Consent will be required from the local authority before works instigate (Wealden, 2004). Kangwankraiphaisan, 2005 described the cesspools system was developed from the pit latrine. It consists of several (usually three or four) concrete rings, 80 cm in diameter and 40cm in height, which are placed on top of each other to form a tank. The bottom is preferably open and contains broken brick walls were perforated with several holes to allow the liquids to seep into the soil. The retaining solid excreta digested in anaerobic condition and become sludge. When this cesspool is full, septage is usually removed by a vacuum truck.

- **Septic tank**: A septic tank is a watertight tank, usually located just below ground, and receives both black water and portion of grey water. It can be used with pour flush toilets or cistern flush toilets. It functions as a storage tank for settled solids and floating materials (e.g. oils and grease). The storage time of the wastewater in the tank is usually between 2 and 4 days. About 50% removal of BOD and Suspended Solids (SS) is usually achieved in a properly operated septic tank due to the settling of the solids during wastewater storage as show in table 3.10 on effluent characteristic of septic tank. A septic tank can be constructed of bricks and mortar and rendered, or of concrete. Its shape can be rectangular or cylindrical. A septic tank can be partitioned into two chambers to reduce flow short-circuiting and improve solids removal which resulting in frequency of less emptying. The overflow from a septic tank is directed to a leach pit or trench. A leach pit is similar to the pit of a pit latrine or pour flush latrine. A leach pit or trench does not work when the soil permeability is too low (e.g. clayey soil or hard rock) (UNEP, 2002).

Table 3.10: Septic Tank Effluent Characteristics

Parameter	Crites and Tchobanoglous, 1998	US.EPA, 2002
pH	-	6.4 - 7.8
SS, mg/L	40 - 140	40 - 350
COD, mg/L	250 - 500	-
BOD, mg/L	150 - 250	46 - 156
NH_4-N, mg/L	30 - 50	-
NO_3-N, mg/L	-	0.01 - 0.16
TN, mg/L	50 - 90	19 - 53
TP, mg/L	12 - 20	7.2 - 17
FC, MPN/100 mL	-	106- 108

Source: Crites and Tchobanoglous, 1998 and US.EPA, 2002

Inside the onsite sanitation systems, there is an anaerobic process which the chemical and biological reactions occur inside a septic tank to decompose sludge and then generate the GHGs emission. As shows in figure 3.10, the anaerobic oxidation process can be described as a two-stage process the first stage is identified as waste conversion (acetogenesis, acidogenesis), in which complex organics are first hydrolyzed and then fermented into simple organic compounds (e.g., hydrogen (H) and CO_2) and VFAs (e.g., acetate) by facultative bacteria known as acetogens and acidogens (Bitton and Wiley, 1994; McCarty, 1964; Speece, 1983). After the organic matter has been converted to simpler compounds, waste stabilization (methanogenesis) takes place, where the acids are synthesized by methanogens into methane and carbon dioxide (Bitton and Wiley, 1994; McCarty, 1964). It should be noted that in some references anaerobic oxidation is considered to be a three-stage process in which the hydrolysis of the organic material to simple acids is considered to be a separate step.

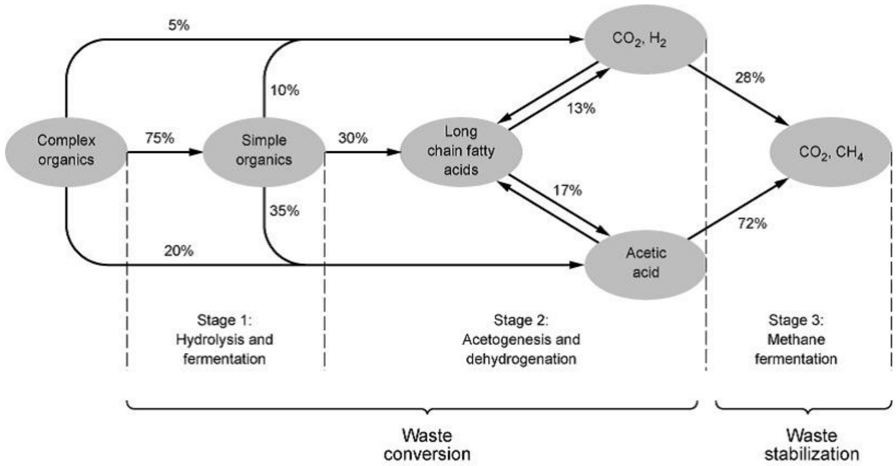


Figure 3.10 The intermediate steps of anaerobic reactions, with percentages based on COD conversion. (Source: Adapted from Speece, 1983, and Tchobanoglous et al.,2003)

The two major mechanisms of methane formation are the breakdown of acetic acid, which is the most prevalent volatile acid produced in the fermentation of carbohydrates, proteins, and fats, and the reduction of carbon dioxide (Bitton and Wiley, 1994; McCarty, 1964). The chemical reactions of methane formation are as follow:

1. Utilization of acetic acid: $CH_3COOH \rightarrow CH_4 + CO_2$

2. Reduction of carbon dioxide: $CO_2 + 8H \rightarrow CH_4 + 2H_2O$

Growth and acid utilization rates of methane formers are slow, and are usually limiting factors in anaerobic treatment (Mara and Horan, 2003, Speece, 1983). Methanogens are known to be different from the typical bacteria and are classified in a separate kingdom, the Archaea (Mara and Horan, 2003). The methane forming microorganisms are strict anaerobes and even small amounts of oxygen can be toxic. Methanogens are also sensitive to any environmental change including temperature, organic loading, waste composition, and other factors (McCarty, 1964). The microorganisms involved in the anaerobic process need sufficient concentrations of nutrients to operate properly. Nitrogen and phosphorus comprise about 11% and 2% of the dry weight of biological solids, respectively (McCarty, 1964).

In anaerobic digester’s, 70% of the methane gas is originated from acetate reduction and 30% is attributed to the substrates reduced by the hydrogen-utilizing methanogens

(Duncan and Horan, 2003). A COD balance can be used to estimate the theoretical methane production during anaerobic fermentation. The COD of the methane produced during anaerobic decomposition of organic matter is approximately equal to the COD of the converted organic matter (Tchobanoglous et al., 2003). The oxygen demand of methane is determined as follows (McCarty, 1964).

$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$$

3.2.1.1 Gas emissions from septic tanks

Anaerobic degradation, occurring within the sludge layer of the septic tank, results in the production of gases composed primarily of CH_4 and CO_2. When sulfate compounds are present in the influent wastewater, hydrogen sulfide and other sulfur containing gases may also be formed. Gases formed in the septic tank are evacuated typically from the system through the building drainage plumbing and vent system.

Building codes require that gases formed inside the septic tank be evacuated by means of a vent system. Household plumbing vents are used generally as vents for the septic tanks. Less commonly, gases may also be vented through the leach field or through screened atmospheric pipes located inside the tank (D'Amato et al., 2008). The two main purposes of tank vents are to avoid wastewater backflow due to a vacuum created inside the house plumbing fixtures and to let toxic, odorous (e.g., hydrogen sulfide, mercaptans), and explosive (e.g., methane) gases formed during the anaerobic degradation escape and be diluted in the atmosphere (Kaplan, 1991). Gases such as hydrogen sulfide often generate concern due to odor generation, potential human toxicity, and ignition properties (D'Amato et al., 2008). Nevertheless, based on measurements reported by Winneberger (1984), the hydrogen sulfide concentration from vented tanks are below detection limits and, therefore, gas evacuation throughout venting systems does not represent a fire risk for the household residents. It has been shown that gases in the headspace of the tank escape through the inlet and outlet tees and eventually to the house vents (Winneberger, 1984).

In a conventional septic system, clarified effluent is discharged typically to a soil dispersal system. The soil dispersal system receives the treated wastewater and distributes it into the soil through a perforated pipe system located in gravel filled excavated trenches (EPA, 2003). The soil operates as a biofilter, where biological, physical, and chemical processes take place. Inorganic and organic compounds may be transformed to various degrees in the soil while pathogens die off. Operationally, problems can occur in the soil dispersal system when the application of septic tank effluent exceeds the infiltration capacity of the soil. The infiltration capacity of the soil is a function of the soil properties and characteristics of the septic tank effluent. In general, loading of dissolved organic matter supports the growth of biomass that restricts soil pore space, while the loading of particulate matter fills and blocks soil pores (Leverenz et al., 2009). Thus, a high loading of both dissolved and particulate organic matter will result in a reduced infiltration rate. In the extreme case, effluent can surface above the soil dispersal field, which is an indication that the hydraulic loading rate has exceeded the soil infiltration rate for the given loading scenario (Crites and Tchobanoglous, 1998). Proper septic tank design, along with regular monitoring and maintenance, can be used to control the discharge of constituents that will reduce the infiltration capacity. The discharge of chemical and biological constituents to groundwater is also a concern associated with onsite wastewater systems.

3.2.1.2 Gas formation and temperature influence in septic tanks

The temperature inside a septic tank depends on the water use activities in the house and follows seasonal temperature changes according to geographic location. As shown on Figure 3.11 in tanks located in the San Francisco Bay area, which has a temperate climate and little seasonal variation, the temperature follows the ambient temperature patterns, varying about 6-8◦C throughout the year. However, as shown on Figure 3(b) and 3(c) for Quebec (Canada) and Kansas (U.S.), the temperature in septic tanks in more extreme climates is subject to higher seasonal variation than San Francisco. On Figure 2 has shown the intermediate steps of anaerobic reactions, with percentages based on COD conversion.

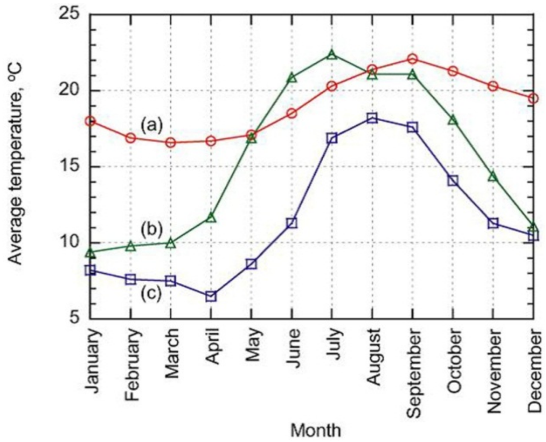


Figure 3.11 Average monthly temperature in septic tanks located in (a) San Francisco Bay Area, U.S. (Source: Winneberger, 1984); (b) Quebec, Canada (Roy and Dube, 1994) and (c) Kansas, U.S. (Murdock, 1920)

The gases formed during the anaerobic digestion process occurring within the sludge layer in the septic tank rise to the liquid surface or to the scum layer (if present). Settled solids accumulated on the bottom of the tank to which gas bubbles attach eventually become buoyant and rise to the surface to become part of the scum layer (Crites and Tchobanoglous, 1998; Murdock, 1920). The rate of gas formation inside the tank is related to temperature (D'Amato et al., 2008; Murdock, 1920; Winneberger, 1984) pointed out that septic tanks developed a temperature gradient from top to bottom. In the study, it was determined that warmer temperatures were located in the bottom and colder temperatures were found on the top. Based on the analysis and observations, temperature variation was correlated with hot water use in the house. In addition to the septic tank inner thermal stratification, seasonal temperature variation has also been reported (D'Amato et al., 2008; Murdock, 1920; Winneberger, 1984), as shown previously on figure 3. During cold months (winter), the rate of solids decomposition is reduced and the amounts of solids build up in the bottom of the tank increases. Conversely, in warmer months (spring) the degradation rate increases due to the elevated temperature in the accumulated solids. A sudden increase in the rate of anaerobic activity can result in a condition known as the spring turnover or spring boil (D'Amato et al., 2008; Winneberger, 1984). The increasing of gas production and the change in the solubility of the dissolved gases during the spring turnover results in a decrease in the solids removal efficiency due to the re-suspension and discharge of settled solids. The gases also disturb the incoming solids and therefore inhibit their ability to settle (D'Amato et al., 2008).

3.2.1.3 Estimates of methane production

To address the lack of studies on direct measurements of GHG emissions from septic tanks, it is necessary to calculate emission values that might represent a baseline for comparison when empirical values are obtained. Estimates of methane emissions can be developed based on an organic loading approach, where it is assumed that in the United States, one person discharges 200 g/d of COD (Crites and Tchobanoglous, 1998) and that 60% of the influent COD is reduced due to settling and anaerobic digestion inside the septic tank. Based on this calculation approach, the theoretical methane production is 11.0 g CH_4/capita/d. It should be noted that this calculation approach accounts for the COD that is eventually removed from the system as septage.

Studies from Kinnicutt et al. (1919) describe the significant relation that exists between the methane emissions from septic tanks and the temperature i.e. as in figure3.12 when the temperature is around 8-12˚C, methane emission rates in the range of 0.1 to 2 g CH_4/capita/d. Winneberger (1984) estimated 22-28 L/capita/d of gas from a single septic system. Assuming that, as reported, the gas was 70% methane and a methane density of 0.67 g/L CH_4 results in an emission rate range from 14-18 g CH_4/capita/d. Similarly, based on the method developed by the IPCC (1996, 2006), methane emissions from a domestic septic tank are approximately 25.5 g/capita/d. However, the IPCC method uses an assumed methane conversion factor (MCF) of 0.5 to represent the conversion of organic matter to methane. The estimation of methane emission rates from septic tank liquid surface has shown on Table 3.11.

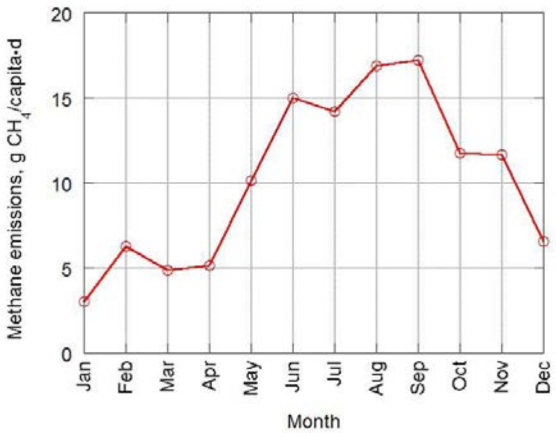


Figure 3.12 Monthly methane mission rate from liquid surface of community septic tank. (Source: Kinnicutt et al., 1919)

Table 3.11: Estimates of Methane Emission Rates from Septic Tank Liquid Surface

Method	Year	g CH4/Capita/day	Remarks
Winneberger	1984	14-18	Direct measured value from septic tank system
Sassc	1998	18	Calculated value assuming 25% CH4 dissolved
IPCC	2007	25.5	Calculated value assuming that half of the influent COD is converted anaerobically

3.2.2 Off-site sanitation systems

In developed countries, sewerage systems have been used successfully to provide adequate sanitation services, but they may not be appropriate in parts of developing countries. Sewerage systems can be more expensive to set-up and operate than on-site sanitation facilities. They also use large amounts of water, which may be a scarce resource in many Asian countries. Once disposed of, sewage can also have downstream health and environmental effects if inadequately treated. Onsite sanitation is the whole of actions related to the treatment and disposal of domestic waste water that cannot be carried away by an off-site sanitation system because of low density of population (technical guidelines on sanitation).

3.2.3 Treatment and Discharge Systems and CH_4 and N_2O Generation Potential

Treatment systems or discharge pathways that provide anaerobic environments will generally produce CH_4 whereas systems that provide aerobic environments will normally produce little or no CH_4. On the Table 3.12 has shown presents the main wastewater treatment and discharge systems in developed and developing countries, and their potentials to emit CH_4 and N_2O.

Table 3.12 The main wastewater treatment and discharge systems in developed and developing countries, and their potentials to emit CH_4 and N_2O.

<table>
<tr><th colspan="5">CH_4 and N_2O emission potentials for wastewater and sludge treatment and discharge systems</th></tr>
<tr><th colspan="4">Types of treatment and disposal</th><th>CH_4 and N_2O emission potentials</th></tr>
<tr><td rowspan="8">Collected (off-site)</td><td rowspan="3">Untreated</td><td colspan="2">River discharge</td><td>Stagnant, oxygen-deficient rivers and lakes may allow for anaerobic decomposition to produce CH_4.

Rivers, lakes and estuaries are likely sources of N_2O.</td></tr>
<tr><td colspan="2">Sewers (closed and under ground)</td><td>Not a source of CH_4/N_2O.</td></tr>
<tr><td colspan="2">Sewers (open)</td><td>Stagnant, overloaded open collection sewers or ditches/canals are likely significant sources of CH_4.</td></tr>
<tr><td rowspan="5">Treated</td><td rowspan="3">Aerobic treatment</td><td>Centralized aerobic wastewater treatment plants</td><td>May produce limited CH_4 from anaerobic pockets.

Poorly designed or managed aerobic treatment systems produce CH_4.

Advanced plants with nutrient removal (nitrification and denitrification) are small but distinct sources of N_2O.</td></tr>
<tr><td>Sludge anaerobic treatment in centralized aerobic wastewater treatment plant</td><td>Sludge may be a significant source of CH_4 if emitted CH_4 is not recovered and flared.</td></tr>
<tr><td>Aerobic shallow ponds</td><td>Unlikely source of CH_4/N_2O.

Poorly designed or managed aerobic systems produce CH_4.</td></tr>
<tr><td rowspan="2">Anaerobic treatment</td><td>Anaerobic lagoons</td><td>Likely source of CH_4.

Not a source of N_2O.</td></tr>
<tr><td>Anaerobic reactors</td><td>May be a significant source of CH_4 if emitted CH_4 is not recovered and flared.</td></tr>
<tr><td rowspan="3">Uncollected (on-site)</td><td colspan="3">Septic tanks</td><td>Frequent solids removal reduces CH_4 production.</td></tr>
<tr><td colspan="3">Open pits/Latrines</td><td>Pits/latrines are likely to produce CH_4 when temperature and retention time are favourable.</td></tr>
<tr><td colspan="3">River discharge</td><td>See above.</td></tr>
</table>

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 6: Wastewater Treatment and Discharge

3.3 Pathogen (E. coli and Salmonella) emission from treatment processes

Many cities in developing countries have sewage systems to carry wastewater from households and buildings to central treatment plants. The collected wastewater is a combination of excreta, flushing water, and grey water. It is much diluted depending on the per capita water uses *(Polprasert, 1996).* Moreover, it consists of pathogenic microorganisms which are the cause of waterborne diseases.

The main pathogenic microorganisms present in wastewater are bacteria, viruses and protozoan parasites. In contrast to chemical contaminants, the potential removal or destruction of pathogenic microorganisms during these unit processes may be overlooked when considering effluent microbiological quality *(Gray, 1999).* Generally, total coliforms; E. coli and Salmonella are used to assess the general bacteriological quality of treated wastewaters. Numbers of faecal coliforms provide a check for faecal pathogens *(Mara and Horan, 2003).*

E. coli bacteria are usually symbiotic as parts of the normal intestinal flora of animals and humans, some strains are capable of causing serious diarrhoea infections in human. Pathogenic *E. coli* are divided into six groups based on serological and virulence characteristics: Enterohemorrhagic (EHEC), Enterotoxigenic (ETEC), Enteropathogenic (EPEC), Enteroinvasive (EIEC), Enteroaggregative (EAggEC) and Diffuse adherence (DAEC). The most prominent representative of EHEC is *E. coli* O157:H7, first recognized as human pathogen in 1982 (Riley, 1983). *E. coli* O157:H7 is mainly transmitted by food. Transmission via drinking water and recreational water, person to person contact as well as direct animal to human contact has been documented (WHO, 2004).

Samonella spp. is considered one of the most important agents of food borne illness in worldwide. The genus Salmonella is comprised mostly of facultative anaerobic, oxidase-negative, catalase-positive, gram-negative, rod-shaped bacteria. *Salmonella* is transmitted by faecal-oral route. Infections with non-typhoid serovars are primarily associated with person to person contact, the consumption of variety of contaminated foods. Infection by typhoid serovars (*S typhi* and *S parathyphi*) is associated with ingestion of contaminated water and food, direct person to person transmission being uncommon (WHO, 2004).

The wastewater treatment plant generally consists of preliminary, primary, secondary and tertiary treatments. These are designed to remove contaminants in wastewater such as biodegradable organic compounds, toxic metals, suspended solids, nutrients (nitrogen and phosphorus) and microbial pathogens and parasites *(Bitton, 2011).* The primary and secondary wastewater treatments are effective in removing or destroying pathogen. On table 3.13 has shown the removal/inactivation efficiency of faecal coliform, Salmonella and enteric virusesby different unit operation and processes in a conventional wastewater treatment *(Godfree and Farrell, 2005).*

Table 3.13 Removal/inactivation efficiency of faecal coliform, Salmonella and enteric viruses by different unit operation and processes in a conventional wastewater treatment

Process	Removal (%)		
	Faecal Coliform	Salmonella	Enteric Viruses
Primary Sedimentation	50-90	50-90	0-30
Trickling Filter	90-95	90-95	90-95
Activated Sludge	90-99	90-99	90-99
Oxidation Ditch	90-99	90-99	90-99
Lagoon	2-6 log	99-100	99-100

Source: Godfree and Farrell, 2005

The wastewater treatment plants are intended to in reducing the microbial and pathogen load of human wastes before discharged to natural source of waters (final effluent) or land spread (biosolids). However, there is still the remaining pathogen in the effluent which discharge to water bodies and can cause diseases by transmitting to human.

3.3.1 Microbial Transmission Routes

Organic waste especially in sewage sludge and animal manure may contain a wide range of pathogenic microorganisms to man, including bacteria (e.g. Salmonella, Campylobacter, Listeria and various strains of E. coli), virus particles (e.g. Polio and Hepatitis), protozoa (e.g. Cryptosporidium and Giardia) and other intestinal parasites (e.g. Helminths). Many of these pathogens from animal manures may be zoonotic agents as well (Warnes et al., 2003). Without suitable treatment, there is potential for pathogens present to wash into adjacent surface waters, contaminate crops (fresh produce is of particular concern), or spread directly to man or farm and domestic animals using the land.

Many microorganisms are dead upon the excretion to the environment and only the microorganisms which are able to survive long in the environment are transmitted from one host to another. Routes of transmission can vary from simple transmission of Legionella-contaminated aerosols as direct inhalation to the complex one as the transfer of Salmonella from contaminated food products to a surface in a kitchen then to the finger of the food handler, to a salad, and finally to the mouth of the person consuming the salad respectively. The figure 3.13 shown the routes of enteric microorganisms transmission from human excreta to humans.

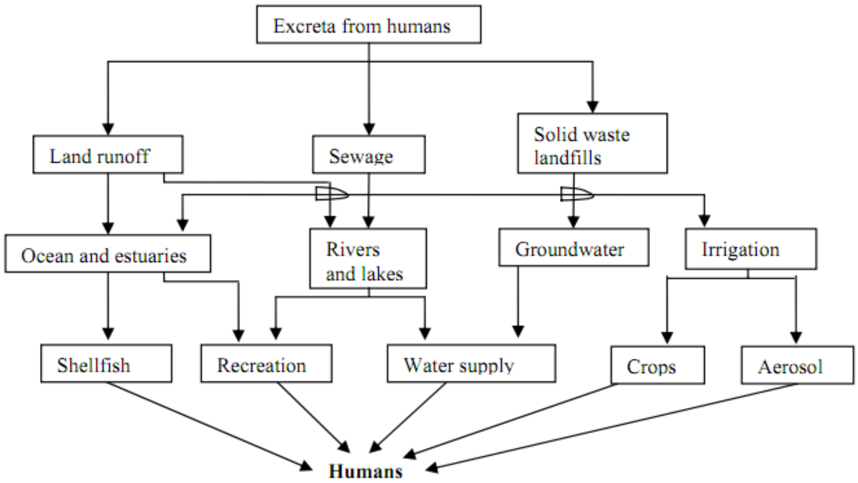


Figure 3.13 Routes of enteric microorganisms transmission (Haas et al, 1999)

Haas et al., 1999, reported that the major routes of microbial transmission are drinking water, inhalation, dermal exposure, oral ingestion, recreational activities and soil and fomites. Transmission of inhalation will be depending on the nature, size of the microorganisms and environmental condition as the organisms will release into the environment as the droplets. The droplet size, which will be releasing with the force of the air, the resistance to the temperature, moisture and ultraviolet light will play the important role in transmission by inhalation because many of the organisms die upon the exposure to the environmental conditions.

The most important determinant of the probability that a disease will be transmitted by aerosols is the ability of the microorganism to survive in aerosolized droplets or particulates. The potential exposures of workers by inhalation are those who live nearby the sites or those who work there; at the wastewater treatment plants, landfill sites and the composting sites. Histoplasmacapsulatum, Aspergillusfumigatus, Legionellapneumophila and Mycobacterium avium are of those examples. Besides, not only the respiratory and intestinal agents but also blood borne agents such as hepatitis B and Hantavirus and other area viruses may be spread by aerosols as well.

The transmission of microorganisms through the unbroken or cut skins is called dermal exposure. Infectious viral or bacterial are more likely transmit from skin vesicles, lesions, boils, pustules and so on. Staphylococcus acreus is responsible for the skin infections by fomites including clothing. Papovavirus can cause plantar warts which can be transmitted by walking barefoot in swimming areas, gymnasia, barracks or other public places.

Many of the transmission of the pathogenic microorganisms is responsible by means of the fecal-oral route as enteric pathogens to infect the gastrointestinal tract in the host then often excrete in large numbers in the feces to recycle the fecal-oral transmission route. Direct ingestion of contaminated drinking water and food is of the greatest impact on the human health worldwide. Besides recreational activities are of associating to the infectious diseases.

In brief, transmission of pathogenic organisms can be mentioned as; viruses and bacteria are immediately infective upon release into the environment. They can be predominantly transmitted through person to person contact and other faecal-oral transmission routes such as water or food (including fish). Though minimal infective dose is usually in viruses, infective dose can be medium to high in bacteria, which are in contrast to viruses they are able to multiply limitedly outside the host. Infection in protozoa is transmitted through environmentally-resistant cysts through hatching of the cysts in the new host's intestine either directly via faecally-contaminated hands or through ingestion via contaminated food or water. Due to the great resistance of helminthes eggs in the environment, any waste containing helminthes eggs continue to infect parts of the population (Koottatep, 2004). Although most of the facilities are properly designed, many are poorly constructed and/or managed, therefore poorly working. Cracks and permeable bottom of the failing septic tanks make groundwater contaminated by sewage leakage easy. Septic tanks blockage happens frequently. Somehow, although not conformed to regulations, part of the household sewage water is lead directly to open ditches .Situation goes worse during the rainy season, flooding raises the groundwater level and poorly constructed septic tanks become water storage tanks. With the growing of the water level, faeces are flushed out from the septic tanks to the lower area of the street.

3.3.2 Health impact of waterborne diseases due to climate change

It is already know that weather and climate are the impact factor on human health, both through direct effects of extreme events such as heat waves, floods and storms, and more indirect influences on the distribution and transmission intensity of infectious diseases, and on the availability of freshwater and food. It is therefore important to obtain the best possible assessment of the likely health impacts of climate change. The climate change, such as changing rainfall, temperature, droughts and floods are connected to the waterborne disease emission. Changing rainfall and temperature over the next decades are likely to make provision of clean water, good sanitation, and drainage even more complicated than it is now. Average annual rainfall is forecast to decrease in some regions and increase in others, and droughts and floods are likely to become more frequent and intense. The heavy rains can contaminate watersheds by transporting human and animal faecal products and other wastes in the groundwater.

Evidence of water contamination following heavy rains has been documented for cryptosporidium, giardia, and *E. coli (Parmenter et al, 1999,and Atherholt, et al.1999).* This type of event may be increased in conditions of high soil saturation due to more efficient microbial transport *(Rose et al, 1999).* At the other extreme, water shortages in developing countries have been associated with increases in diarrhoeal disease outbreaks that are likely attributed to improper hygiene *(WHO, 1999).*

Reduced river flows and increased water temperature will lead to declining water quality as the dilution of contaminants is reduced, less oxygen is dissolved in water, and microbiological activity increases *(Parry et al, 2007,and Bates et al, 2008).* These effects could lead to major health problems for vulnerable people, especially during drought, and might increase the risk of health impact of waterborne diseases emission as shows in figure 3.14 climate change affects human health pathways.

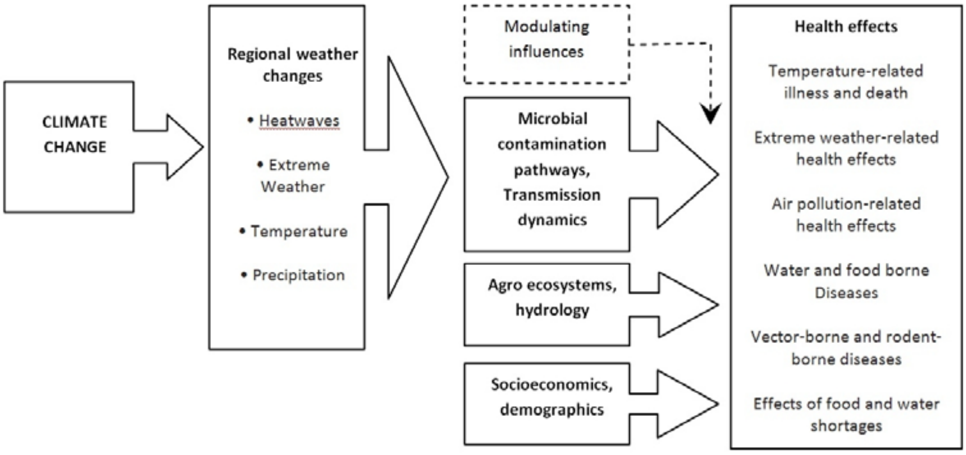


Figure 3.14 Climate change affects human health pathways (Source: adapted from Patz et al., 2000.)

3.3.2.1 Waterborne Diseases

The present potentially microbial pathogens in wastewater which cause health impact can be divided into three separate groups. These groups are the viruses, bacteria and the pathogenic protozoan/helminthes. The majority of these pathogens are enteric in origin, that is, they are excreted in faecal matter, contaminate the environment and then gain access to new hosts through ingestion. These microbial; protozoa, bacteria, and virus are the associated vector organism (mosquitoes, ticks, sand flies, etc.) The vector organism is typically very sensitive to changes in temperature, usually displaying an exponential relationship. Other climatic sensitivities for the agent, vector and host include level of precipitation, sea level elevation, wind and duration of sunlight. Human exposure to waterborne infections can occur as a result of contact with contaminated drinking water, recreational water, coastal water, or food. Exposure may be a consequence of human processes (improper disposal of sewage wastes) or weather events. Rainfall patterns can influence the transport and dissemination of infectious agents while temperature can affect their growth and survival *(Rose et al, 2001)*. Table 3.14 summarize the microbial pathogens which cause waterborne diseases and its transmission route.

Table 3.14 Microbial pathogens linked to drinking water or recreational water contact

Organism	Disease	Transmission	Clinical features
Helminths			
Schistosoma spp.	Schistosomaisi	Contact with surface water, infected with free swimming cercariae.	Urinary and intestinal damage. Bladder cancer
Dracunculusmedinensis	Dracunculiasis	Drinking water	Painful ulcers on lower limbs and feet
Protozoa			
Giardia duodenalis	Giardiasis	Faecal oral spread through drinking water or recreational water	Diarrhoea and abdominal pain, weight loss and failure to thrive
Cryptosporidium parvum	Cryptosporidiosis	Faecal oral spread through drinking water or recreational water	Diarrhoea often prolonged
Cyclospora cayetanensis	Cyclosporiasis	Faecal oral spread through drinking water	Diarrhoea and abdominal pain, weight loss and failure to thrive
Entamoebahistolytica	Amebiasis	Faecal oral spread through drinking water	Diarrhoea, may be severe dysentery
Toxoplasma gondii	Toxoplasmosis	Drinking water contaminated by feline animals	Glandular fever, foetal damage in pregnant women
Free-living amoebae	Amoebic meningoencephalitis	Aspiration of infected surface water into nose	Fatal encephalitis
Algae			
Cyanobacteria	Various	Toxins in drinking water or direct contact with surface water blooms	Dermatitis, hepatitis, respiratory symptoms, potentially fatal
Pfiesteriapiscicida	Estuary-associated syndrome	Toxins in water	Respiratory and eye irritation, deficiencies in learning and memory and acute confusional states.
Viruses			
Hepatitis A and Hepatitis E viruses	Viral hepatitis	Drinking and recreational water contact	Vomiting and diarrhoea
Various, esp. Norwalk-like viruses	Viral gastroenteritis	Drinking and recreational water contact	Vomiting and diarrhoea
Enteroviruses	Various, including poliomyelitis	Drinking and recreational water contact	Various

Table 3.14 Microbial pathogens linked to drinking water or recreational water contact (Cont.)

Organism	**Disease**	**Transmission**	**Clinical features**
Bacteria			
Vibrio cholerae	Cholera	Drinking water	Watery diarrhoea, may be severed
Salmonella spp.	Salmonellosis	Occasional outbreaks with drinking water	Diarrhoea, colicky abdominal pain and fever
Salmonella typhi	Typhoid	Drinking water	Fever, malaise and abdominal pain with high mortality
Shigella spp.	Shigellosis (bacillary dysentery)	Both drinking and recreational water	Diarrhoea frequently with blood loss
Campylobacter spp.	Campylobacteriosis	Both drinking and recreational water	Diarrhoea frequently with blood loss
Enterotoxigenic *E. coli*		Drinking water	Watery diarrhoea
Enterohaemorrhagic *E. coli*		Drinking water and recreational water contact	Bloody diarrhoea and haemolyicuraemic syndrome in children
Yersinia spp.	Yersiniosis	Drinking water	Fever, diarrhoea and abdominal pain
Helicobacter pylori		Drinking water	Gastritis that can progress to gastric cancer
Mycobacteria spp. not *M. tuberculosis*	Varies	Potable water systems in hospitals, somerecreation	Varies, includes respiratory disease, wound infections, skin disease

3.4 Material Flow Analysis (MFA)

3.4.1 MFA Model Development

An ideal MFA model of sanitation system in South East Asia is shows in Figure 3.15. However, from the preliminary data collection found that the actual MFA model was different as shows in Figure 3.1 due to the socio-cultural practice.

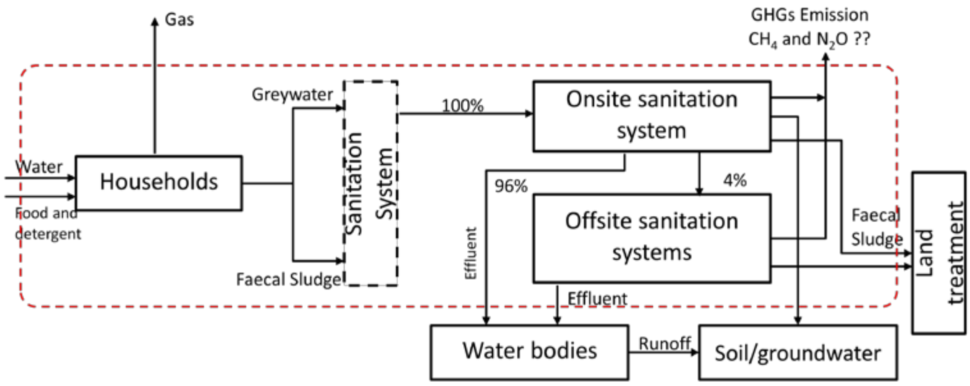


Figure 3.15 Actual MFA model in Thailand

From the preliminary observation, there are some activities which have to be removed from the MFA model because it is not practicable in the current situation in Thailand. For example, people in the community do not using the faecal sludge in agricultural practices hence the arrow was removed from the MFA system. Moreover, the onsite sanitation system also had no role in the agricultural practices, thus the arrow was also removed. Soil and groundwater were combined in process for two reasons. Firstly, soil and groundwater interacted with each other and it was complex to analyze. Chemical fertilizers interact with the soil surface and after long time get absorbed in the groundwater depending on the characteristics of the soil. Secondly, they are out of the MFA boundary. Furthermore, agricultural activities and discharging FS in land treatment is not being quantified in this MFA model.

From the study found that wastewater both greywater and black water is entering into onsite sanitation systems. Then, about 4% of onsite sanitation systems effluent goes to offsite sanitation system for further treatment while 96% is discharged to the water bodies, soil, and groundwater or land treatment. Moreover, the runoff effluent from offsite sanitation is also release to the water bodies and the runoff will pass through the soil and groundwater as shows in figure 3.15

3.4.2 Current Material Flow Analysis (MFA)

In the actual MFA model system boundary, there 3 units; households, onsite sanitation systems and offsite sanitation systems have to be considered. Each MFA process and sub-process is described in the below section in terms of Nitrogen (N) and Carbon (C).

3.4.2.1 Household

This process includes all the domestic related activities for nutrient flow such as eating, bathing, cleaning dish. The assessed nutrients are C and N. C and N mainly enter the house as food products, which are composed of carbohydrates, proteins and fats. After human consumption and nutrient absorption takes place, rest is wasted and leaves the house in the form on kitchen waste, greywater and excreta. There is a small loss as perspiration and flatus of C and N but the major sinks of nutrients are the three above-mentioned waste channels. N and C content in the detergent are not characterized in this flow as nitrogen content is negligible and carbon content is not organic. Specific to the study area, greywater is discharge into open unpaved drain and kitchen waste is dumped in remote location far from the home.

From the total population with 10% unregistered inhabitants' assumptions of 69,518,555 inhabitants in Thailand, the nutrient flow; N and C from the households are calculated and showing in Figure 3.16a and 3.16b respectively. The main entry for the nutrients in both N and C is food; 270,290.81 ton N/y and 16,346,754.71 ton C/y while N and C from drinking water were assumed negligible since it's packaged. The N and C from groundwater enter to the house 5,599.50 ton N/yr and 7.46 ton C/yr, respectively. Then perspiration and flatus occurs which 10,810.63 ton N/yr and 7,994.63 ton C/yr are released.

In our MFA system boundary, the nutrient flows out from the house through 2 channels. Firstly, N and C absent from the household with greywater such as bathing and washing activities about 89.06 ton N/yr and 587.16 ton C/yr. Secondary, the most of the waste is dispersed into the onsite sanitation system as excreta, urine; 179,913.49 ton N/yr and 2,201,847.43 ton C/yr. However, the nutrient also flows out as solid waste which will not be considered in this research approximately 20.30 ton N/yr and 4,086,688.68 ton C/yr.

The total stock can be calculated using equation 2.1 for N and C. It can be observed that nitrogen and carbon stock; 85,055.53 ton N/yr and 10,049,629.35 ton C/yr are significant while the study was done.

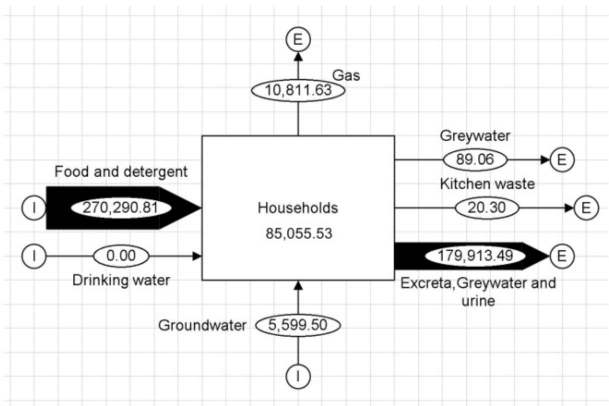


Figure 3.16 a : N flow in household proces

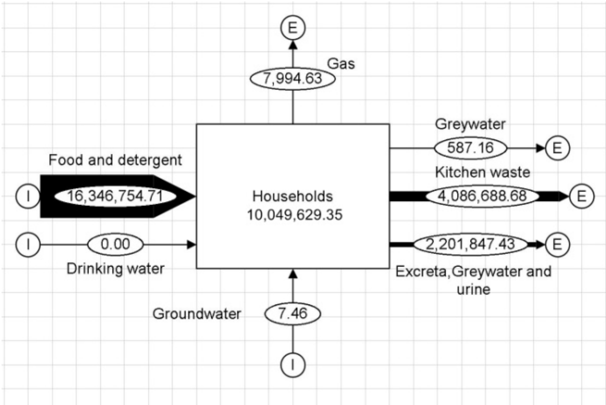


Figure 3.16 b: flow in household process

3.4.2.2 Onsite sanitation systems

From the data collection found that onsite sanitation systems are available in every house as either cesspool (84%) or septic tank (16%). There are 3 inputs to onsite sanitation systems which are; excreta, urine and greywater as shows in figure 3.1. These 3 inputs are considered as one in MFA model, thus there are only one input and four outputs in the onsite sanitation system.

In the current MFA, IPCC model calculation has been used to calculate GHG emissions from septic tank and cesspool which are commonly used in Thailand. They are defined as sub processes in the MFA of onsite sanitation systems. However, according to Montangero et al., 2006, nutrients removal mechanism in both cesspool and septic tank are same because C and N settle in particulate form and digested by the microorganism during anaerobic degradation of organic matters.

3.4.2.2.1 Cesspool

Cesspool is an antiquated solution to sanitation but still prevalent in Thailand as show that approximately 84% of households use this type of onsite sanitation system. It is not the best solution to sanitation system but it is better than open defecation. From the MFA of cesspool found that the amount of effluent received from the households in terms of C and N concentration are 1,849,551.84 ton C/yr and 139,078.98 ton N/yr correspondingly as shows in figure 3.17a and 3.17b.

Most of the C; 1,255,845.70 ton C/yr is leached into the ground water and 10,102.70 ton N/yr of the N is discharged. The major share of the N; 116,175.57 ton N/yr goes into the effluent and 521,507.40 ton C/yr of C flows to the effluent. Both nutrients flow into faecal sludge is limited to 12,795.27 ton N/yr and 55,486.56 ton C/yr. Moreover, GHGs emissions from cesspool are 16,712.19 ton CH_4/yr and 5.44 ton N_2O/yr.

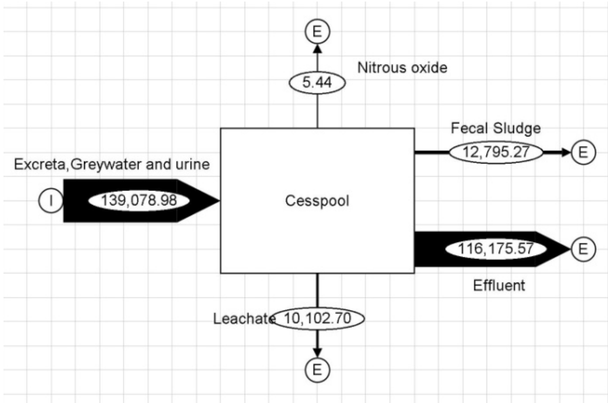


Figure 3.17 a : N flow in cesspool process

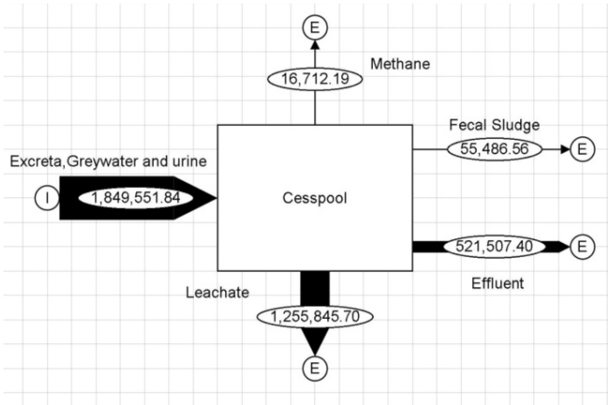


Figure 3.17 b : C flow in cesspool process

3.4.2.2.2 *Septic tank*

Septic tank has remained more or less the same since it was first reported in 1860 as a wastewater treatment system in France *(Dunbar, 1908).* In Thailand, the number of septic tank has been increased steadily, however from the survey found that there is only 16% of septic tank are used which is less than number of cesspool.

The MFA of septic tank in figure 3.18a and 3.18b shows the N and C flow in septic tank respectively. The N effluent from the household enters to the septic tank about 26,481.81 ton N/yr and then a major proportion is the effluent which goes to land treatment; 20,625.00 ton N/yr. Only 1,793.70 ton N/yr discharges with the leachate and faecal sludge; 4,060.54 ton N/yr. Furthermore, N_2O emission from septic tank is equals to 2.56 ton N_2O/yr. Similar to nitrogen flow, most of the C from the household; 352,295.59 ton C/yr is also going with the effluent approximately 307,397.02 ton C/yr and only small amount of C is retained in faecal sludge; 17,614.78 ton C/yr and the CH_4 emission 509.32 ton CH_4/yr.

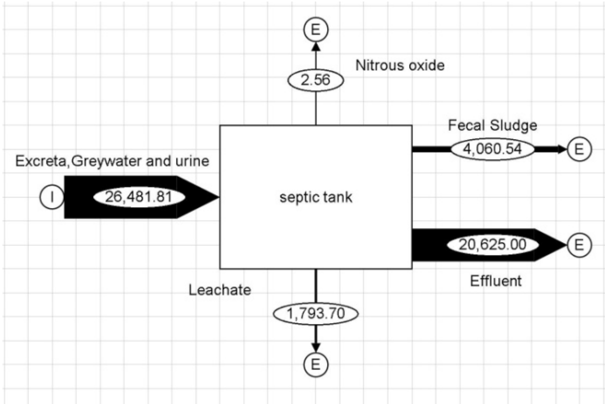


Figure 3.18 a : N flow in septic tank proc

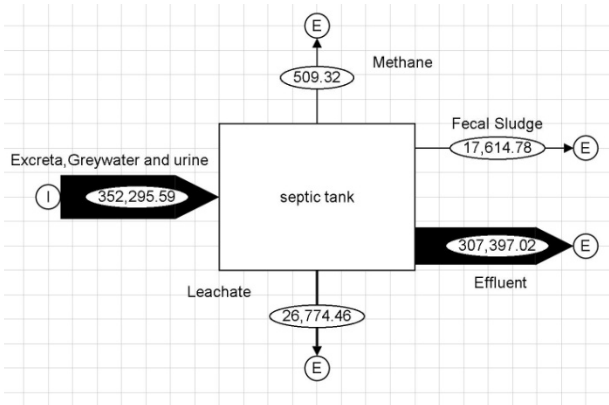


Figure 3.18 b : C flow in septic tank process

The total nutrient flow from the household enters to onsite sanitation systems is 165,560.78 ton N/yr and 2,201,847.43 ton C/yr. Total population in Thailand was defined as one household unit in the MFA model and when the nutrients enters sanitation system, it is divided into fraction of population using cesspool and fraction of population using septic tank.

The four outputs from onsite sanitation systems are effluent to ground, faecal sludge, effluent to offsite sanitation systems and gas emissions as shown in figure 3.19a and 3.19b. Leachate from the onsite sanitation system is quiet high for carbon 1,255,845.70 ton C/yr and less for nitrogen 10,102.70 ton N/yr as cesspool has an opened bottom to expel liquid influent. The current C and N moving with faecal sludge was 16,855.81 ton N/yr and 73,101.33 ton C/yr. The C and N of effluent from onsite sanitation systems which flow to offsite sanitation systems were 855,678.88 ton C/yr and 138,594.28 ton N/yr, respectively. GHGs emissions from onsite sanitation system in terms of nitrous oxide (N_2O) and methane (CH_4) were estimated.

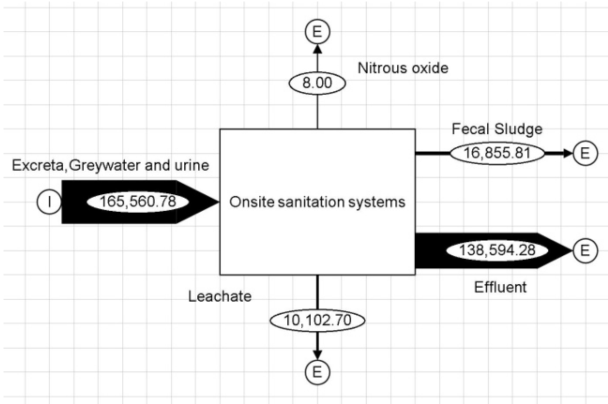


Figure 3.19 a : N flow in onsite sanitatio

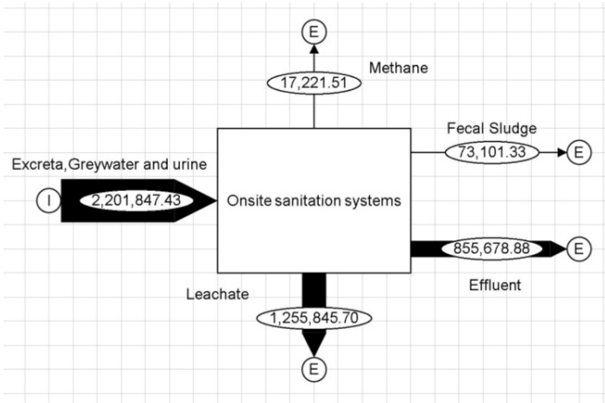


Figure 3.19 b : C flow in onsite sanitation process

The result of GHGs emissions are 8.00 ton N_2O/yr and 17,221.51 ton CH_4/y which equals to 2,240.08 ton CO_2 equivalent/yr for N_2O and 964,404.55 ton CO_2e/yr for CH_4. Thus, the total GHGs emission from onsite sanitation systems is 966,644.63 ton CO_2e/yr. The MFA of total emission from onsite sanitation systems including cesspool and septic tank are shown in figure 3.20a and 3.20b for N and C flow respectively.

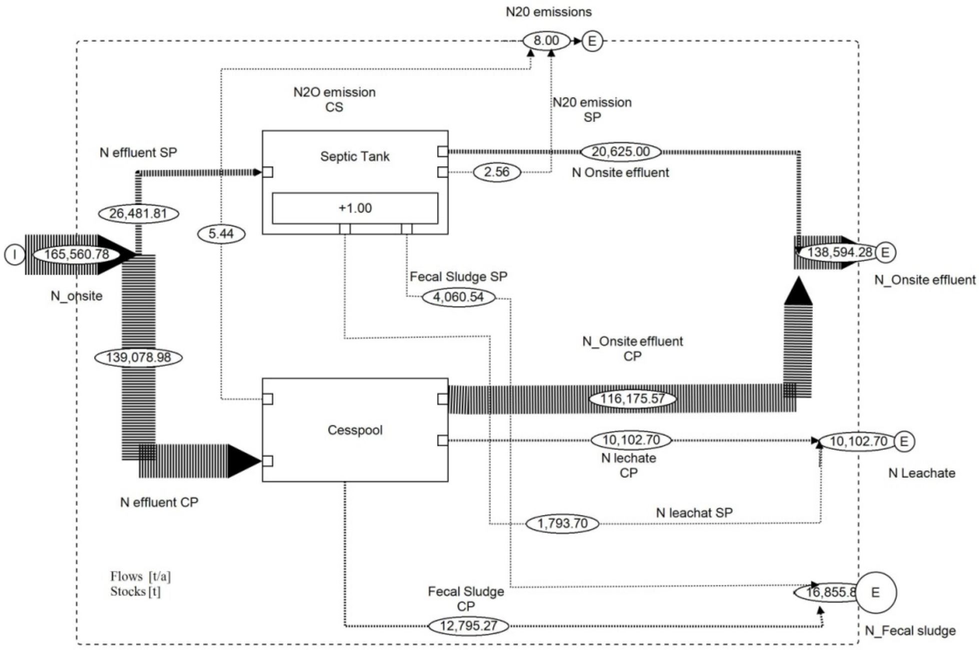


Figure 3.20 a : MFA of N flow from onsite

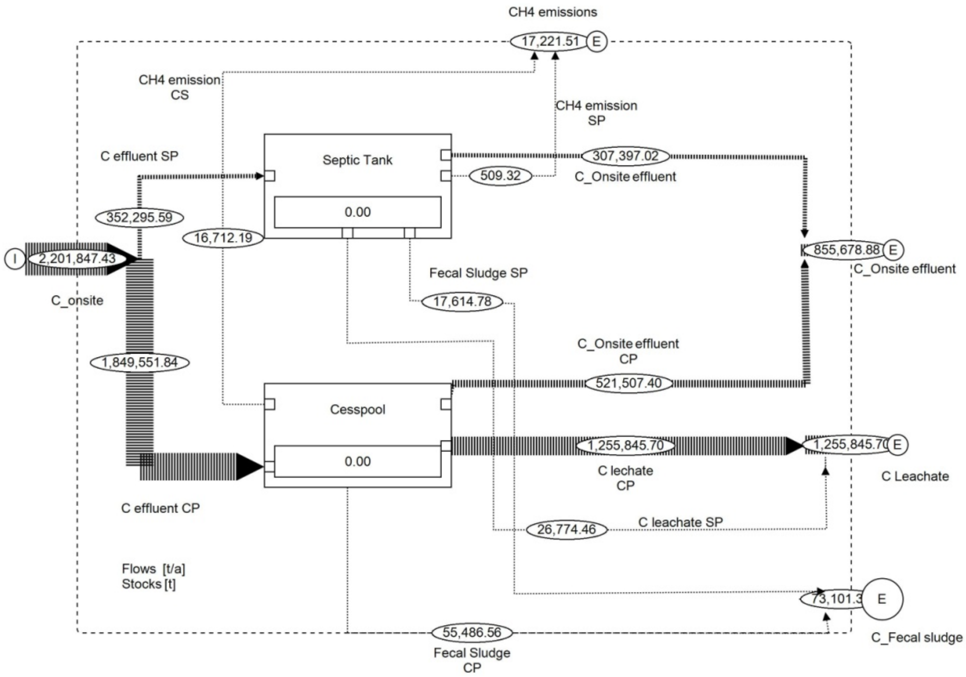


Figure 3.20 b : MFA of C flow from onsite sanitation systems

3.4.2.3 *Offsite sanitation systems*

MFA was conducted in Thailand with an average household population of 3.2 inhabitants. As mentioned above, there are approximately 12 types of offsite sanitation system used in Thailand; stabilization pond (SP), oxidation ditch (OD), aerated lagoon (AL), activated sludge (AS), constructed wetland (CW), SP with CW, SP with OD, trickling filter with OD, OD with AS, rotating biological contactor (RBC), sequencing batch reactors (SBR) and modified sequencing batch reactors (MSBR). The proportion of each type of offsite sanitation systems are used as considered parameter to calculate the N and C flow in the system. In the N and C flow, there is only one input which is from onsite sanitation systems effluent and 3 outflows; the effluent from onsite sanitation systems to water bodies, flow into sludge and GHGs emissions (N_2O and CH_4). The amount of N and C flows in each input and outputs are showing in table 3.15 and the MFA of offsite sanitation are shown in figure 3.21a and 3.21b as N and C flow respectively.

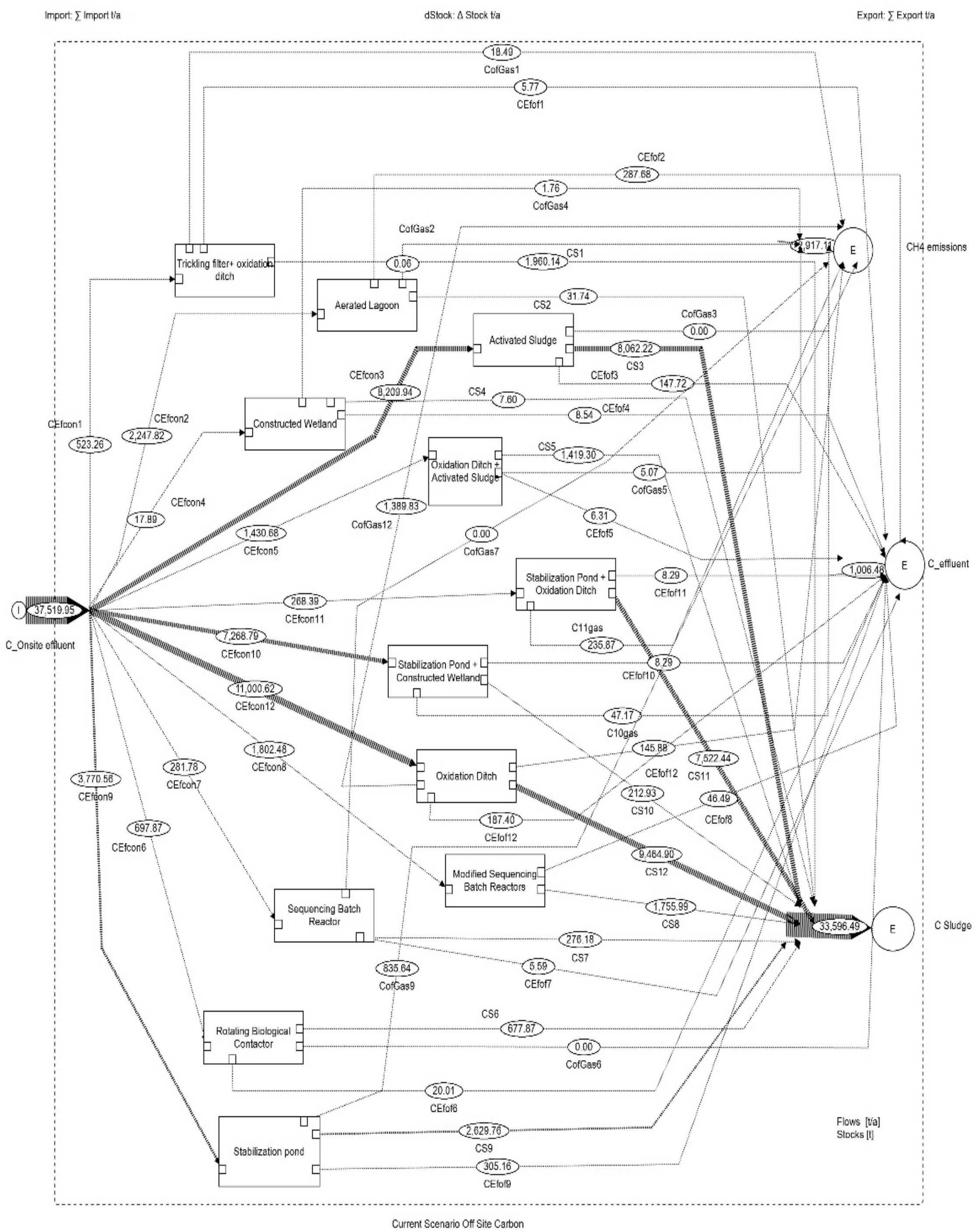


Figure 3.21 a : MFA of C flow from offsite

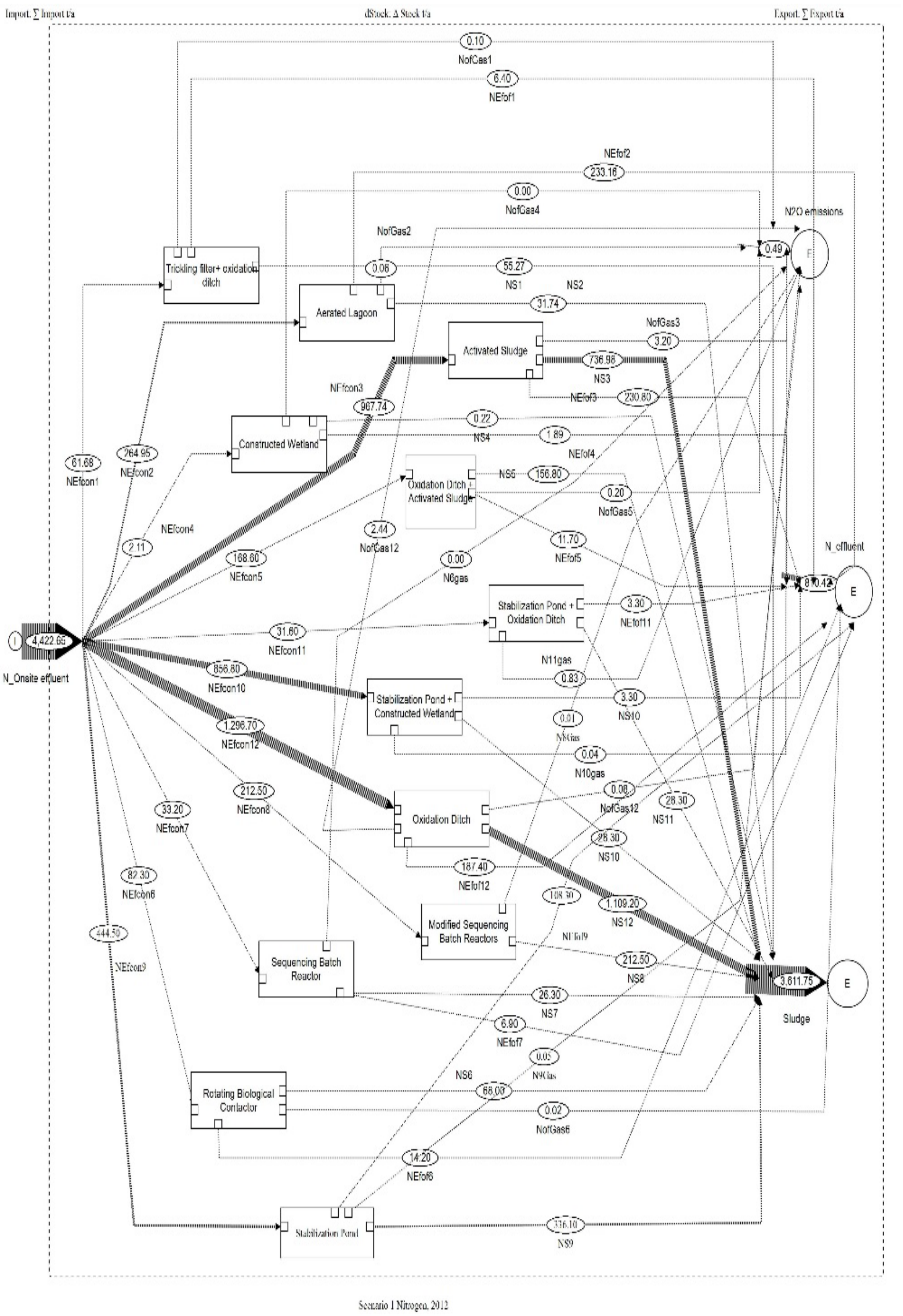


Figure 3.21 b : MFA of N flow from offsite sanitation systems

Table 3.15 N and C flows in each input and outputs

MFA of offsite sanitation systems	Unit	Offsite sanitation systems*											
		SP	OD	AL	AS	CW	SP + CW	SP + OD	TF + OD	OD + AS	RBC	SBR	MSBR
Nitrogen (N) flow													
N flow from effluent from onsite sanitation systems	ton N/year	402.85	1175.32	240.15	877.16	1.91	776.61	28.67	55.91	152.86	74.56	30.11	192.58
N flow in effluent to water bodies	ton N/year	108.28	187.43	233.16	230.76	1.89	6.41	3.29	6.40	11.67	14.24	6.90	0.00
N flow into sludge	ton N/year	294.52	987.81	6.94	646.39	0.03	770.16	25.36	49.50	140.98	60.31	23.20	192.57
Nitrous oxide (N_2O) emissions from plant	ton N_2O/year	0.05	0.08	0.06	0.00	0.00	0.04	0.03	0.00	0.20	0.02	0.00	0.01
Carbon (C) flow													
C flow from effluent from onsite sanitation systems	ton C/year	2487.19	7256.39	1482.74	5415.56	11.80	4794.75	177.04	345.16	943.73	460.34	185.87	1188.98
C flow in effluent to water bodies	ton C/year	305.16	145.88	287.68	147.72	8.54	19.04	8.29	5.77	6.31	20.01	5.59	46.49
C flow into sludge	ton C/year	1346.39	5720.68	1195.06	5267.85	1.51	4156.57	-302.99	320.90	898.56	440.33	180.28	1142.49
Methane emissions from plant	ton CH_4/year	835.64	1389.83	0.00	0.00	1.76	619.14	471.74	18.49	38.85	0.00	0.00	0.00

*Note: * = Stabilization pond (SP), Oxidation ditch (OD), Aerated lagoon (AL), Activated sludge (AS), Constructed wetland (CW), Trickling filter (TF), Rotating Biological Contactor (RBC), Sequencing Batch Reactors (SBR), Modified Sequencing Batch Reactors (MSBR)*

3.4.2.4 GHGs emissions from sanitation systems

In the previous section shows the MFA of N and C flow from sanitation systems which present in ton N_2O/yr and ton CH_4/yr. To calculate the GHGs emissions in term of ton CO_2 equivalent/yr, the GWP of each emission were applied. The summary of CH_4 and N_2O emissions from both onsite and offsite sanitation systems in Thailand are shown in table 3.16

3.4.2.4.1 GHGs emissions from onsite sanitation systems

The result of total GHGs emission from onsite sanitation systems for cesspool and septic tank are 937,406 ton CO_2 e/year and 29,239 ton CO_2 e/year, respectively. CH_4 is the main contribution of GHGs emission such as in cesspool; there is approximately 935,882 ton CO_2 e/year of CH_4 and 1,523 ton CO_2 e/year of N_2O. Similar to septic tank, there is approximately 28,522 ton CO_2 e/year of CH_4 and 717 ton CO_2 e/year of N_2O.

Moreover, cesspool gave higher GHGs emissions in both CH_4 and N_2O than septic tank; 97% of total GHGs emission generated from cesspool and 3% from septic tank as show in figure 3.22d. The first reason is there are more people using cesspool recently. Moreover, generally cesspool give higher GHGs emission than septic tank for example at the same proportion people onsite sanitation usage, the cesspool gave about 50% more GHGs emission than septic tank.

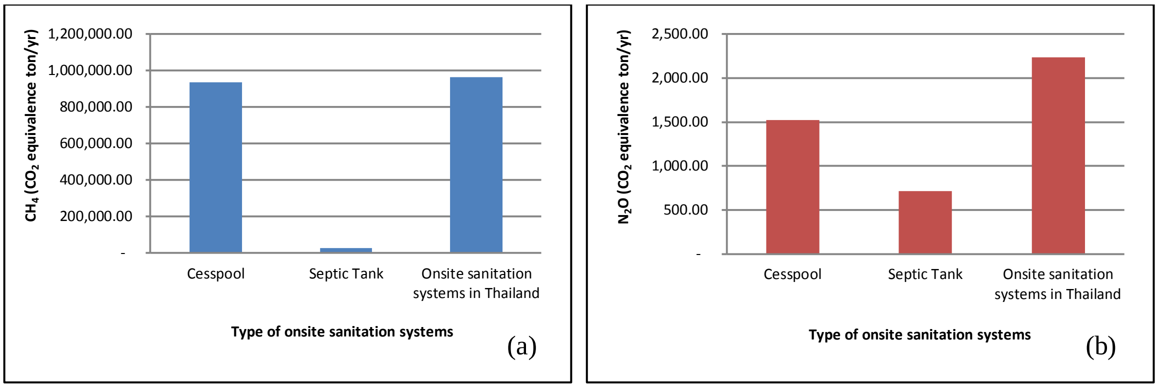


Figure 3.22 GHGs emissions from onsite sanitation systems in Thailand; (a) CH_4 emission, (b) N_2O emissiom, (c) Total GHGs emission and (d) Percentage of GHGs emission from onsite sanitation systems

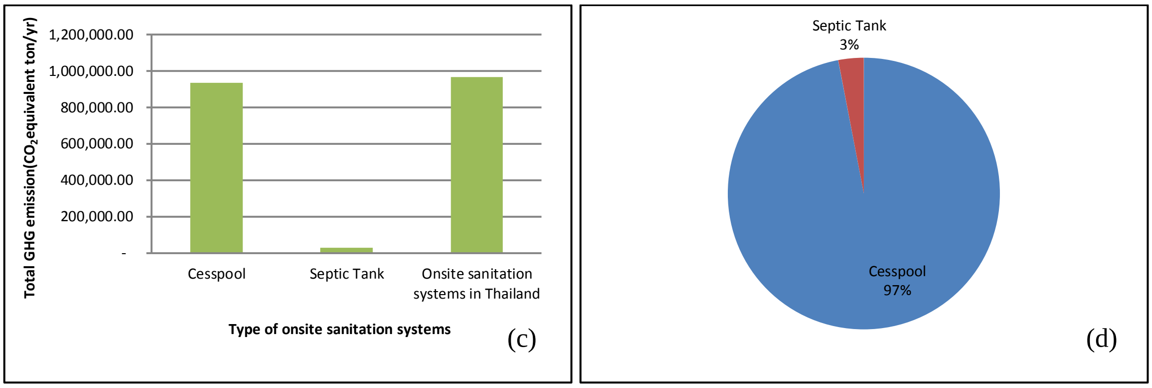
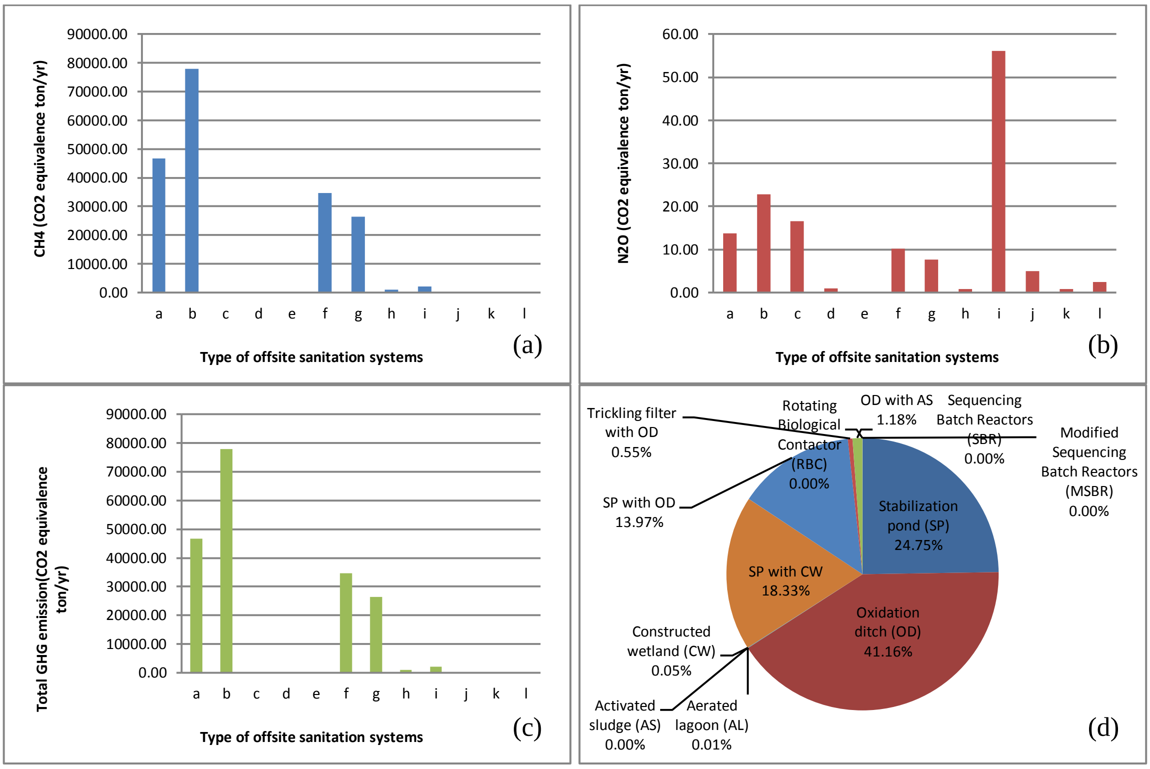


Figure 3.22(continue) GHGs emissions from onsite sanitation systems in Thailand; (a) CH_4 emission, (b) N_2O emissiom, (c) Total GHGs emission and (d) Percentage of GHGs emission from onsite sanitation systems

3.4.2.4.2 GHGs emissions from offisite sanitation systems

The offsite sanitation systems resulted in total CH_4 and N_2O of 189,026 ton CO_2 e/year and 137 ton CO_2 e/year, respectively. The GHGs emissions from each type of offsite sanitation systems can be seen in table 3.16. From figure 3.23a shows the CH_4 emission from offsite sanitation systems that oxidation ditch (OD), stabilization pond (SP) and stabilization pond with constructed wetland (SP+CW) gave the highest CH_4; 77,831, 46,796 and 34,672 ton CO_2 e/year, respectively as show in figure 3.23a. This may be because there is an anaerobic condition occurs during the process which produces CH_4. Moreover, these systems are mainly used in Thailand as show in figure 3.3. However there is no CH_4 emission from aerated lagoon (AL), activated sludge (AS), rotating biological contactor (RBC) sequencing batch reactors (SBR) and modified sequencing batch reactors (MSBR) because these systems are in aerobic condition therefore there is not CH_4 emit from the systems.



Note: (a) Stabilization pond (SP), (b) Oxidation ditch (OD), (c) Aerated lagoon (AL), (d) Activated sludge (AS), (e) Constructed wetland (CW), (f) SP with CW, (g) SP with OD, (h) Trickling filter with OD, (i) OD with AS, (j) Rotating Biological Contactor (RBC) (k) Sequencing Batch Reactors (SBR), (l) Modified Sequencing Batch Reactors (MSBR)

Figure 3.23 GHGs emissions from offsite sanitation systems in Thailand; (a) CH_4 emission, (b) N_2O emissiom, (c) Total GHGs emission and (d) Percentage of GHGs emission from offsite sanitation systems

For the N_2O found that in every systems the amount is much less than CH4 emission. However, oxidation ditch with activated sludge (OD+AS) gave highest N_2O emission; 56.13 ton CO_2 e/year. In contrast, constructed wetland (CW), the N2O emission is almost zero (0.08 ton CO_2 e/year), this because constructed wetland has ability to capture the N and used within the systems as shows in figure 3.23b.

From all offsite sanitation systems shows that the GHGs emissions are mainly from oxidation ditch (OD) (42%), stabilization pond (SP) (25%) and stabilization pond with constructed wetland (SP+CW) (18%) as presents in figure 3.23.

Table 3.16 The summary of current GHGs emissions from sanitation systems in Thailand

Sanitation Systems		GHGs emission (ton CO_2 equivalence/year)		
		Methane (CH_4)	Nirous oxide (N_2O)	Total GHGs emissions
Current situation				
Onsite sanitation systems	Cesspool	935,882.42	1,523.26	937,405.68
	Septic tank	28,522.13	716.83	29,238.96
Total GHGs emissions from onsite sanitation systems		**964,404.55**	**2,240.08**	**966,644.63**
Offsite sanitation systems	Stabilization pond (SP)	46,795.82	13.70	46,809.52
	Oxidation ditch (OD)	77,830.75	22.79	77,853.54
	Aerated lagoon (AL)	-	16.52	16.52
	Activated sludge (AS)	-	0.90	0.90
	Constructed wetland (CW)	98.48	0.08	98.56
	SP with CW	34,671.93	10.15	34,682.08
	SP with OD	26,417.38	7.73	26,425.11
	Trickling filter with OD	1,035.50	0.89	1,036.39
	OD with AS	2,175.71	56.13	2,231.84
	Rotating Biological Contactor (RBC)	-	5.06	5.06
	Sequencing Batch Reactors (SBR)	-	0.80	0.80
	Modified Sequencing Batch Reactors (MSBR)	-	2.51	2.51
Total GHGs emissions from offsite sanitation systems		189,025.57	137.27	189,162.83
Total GHGs emissions from sanitation systems in Thailand		**1,153,430.12**	**2,377.35**	**1,155,807.46**

3.4.2.4.3 GHGs emissions from sanitation systems in Thailand

The total GHGs emission from sanitation systems in Thailand in both onsite and offsite sanitation system is 1,155,807 ton CO_2e/year which consists of 1,153,430 ton CO_2e/year of CH_4 and 2377 ton CO_2e/year of N_2O. The main GHGs emissions is from onsite sanitation systems which is about 84% of total emission from sanitation systems as illustrates in figure 3.24d because as mentioned earlier, every households in Thailand connects with the onsite sanitation systems where both black and greywater are discharged and directly emit the GHGs to atmosphere.

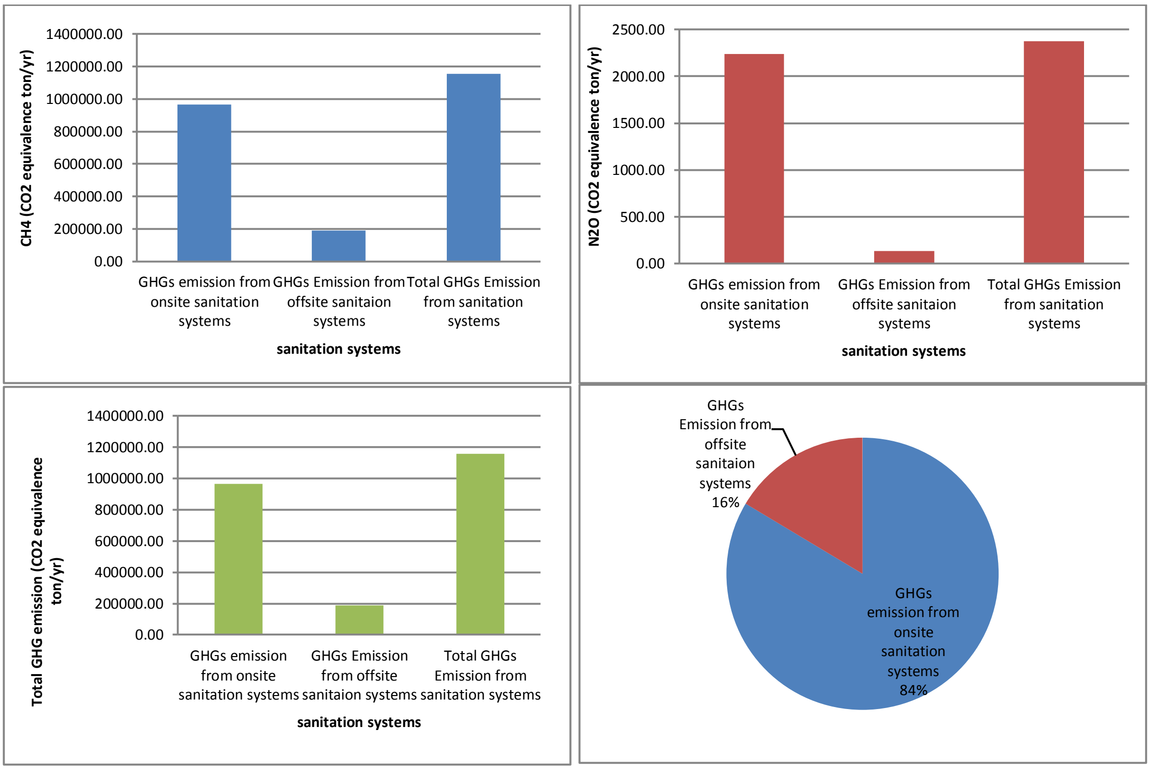


Figure 3.24 GHGs emissions from sanitation systems in Thailand; (a) CH_4 emission, (b) N_2O emission, (c) Total GHGs emission and (d) Percentage of GHGs emission from sanitation systems

Thus, to find the possible solution to reduce the GHGs emission from sanitation systems, two different scenarios have proposed;

Scenario 1: install biogas collection system at the existing offsite sanitation system

Scenario 2: The cesspools users change to use the septic tank while the septic tank users directly connected to offsite sanitation system and effluent from onsite sanitation system directly discharge to environment

3.4.3 Scenario Development

In order to reduce the GHGs emission from sanitation systems in Thailand, two scenarios are being proposed and assessed using MFA.

3.4.3.1 Scenario 1: install biogas collection system at the existing offsite sanitation system

In this scenario, all of domestic wastewater is still flow into the onsite sanitation system and then the effluents discharge into many places as same as the current situation but the biogas collection system is assumed to be installed at the offsite sanitation systems as shows in Figure 3.25. Then the biogas which is generated from offsite sanitation systems will be captured and can be further used in many applications.

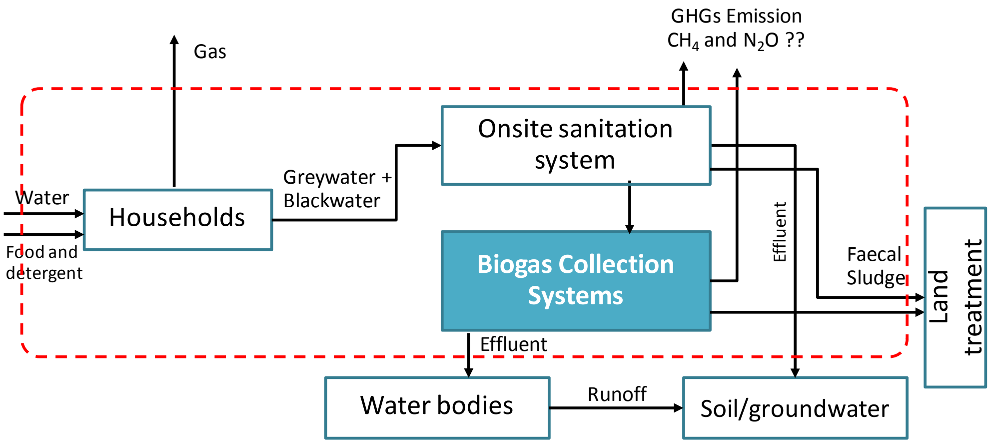


Figure 3.25 MFA model of Scenario 1

The total GHGs emission from this scenario is 966,645 ton CO_2e/year. It consists of CH_4 and N_2O which are 964,405 ton CO_2e/year of CH_4 and 2,240 ton CO_2e/year of N2O, respectively. Moreover, the CH_4 that could be captured from offsite sanitation is about 558,193 ton CO_2e/year.

3.4.3.2 Scenario 2: The cesspools users change to use the septic tank while the septic tank users directly connected to offsite sanitation system and effluent from onsite sanitation system directly discharge to environmen

In this scenario, it was assumed that the domestic wastewaters from households directly discharge to offsite sanitation system and effluents from onsite sanitation system directly discharge to environment as shows in figure 3.26.

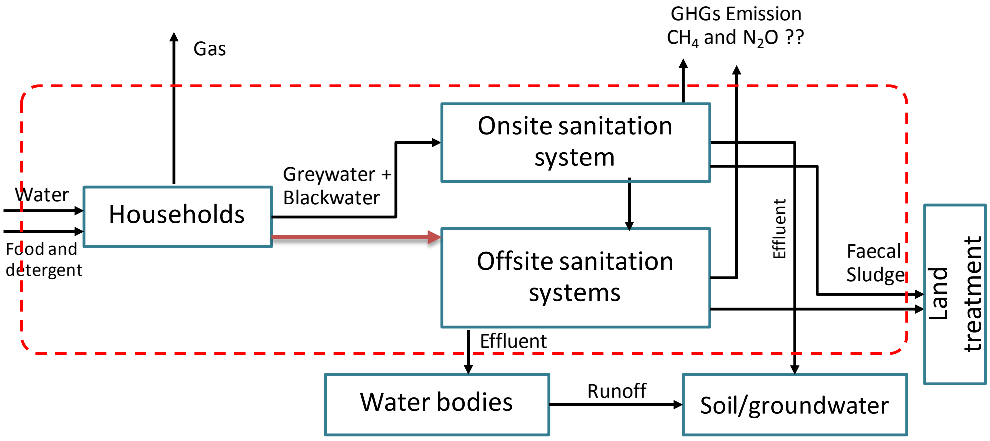


Figure 3.26 MFA model of Scenario 2

The total GHGs emission is approximately 976,020 ton CO_2e/year. As CH_4 and N_2O are considered as GHGs emission, there is about 975,167 ton CO_2e/year of CH_4 and 854 ton CO_2e/year of N_2O would release from this scenarios.

3.4.4 Comparison of current MFA and MFA scenarios

From the study found that both scenarios could reduce the GHGs emission in the Thailand approximately 15-16 % as presents in table 3.17. The GHGs emission reduces in scenario 1 because the biogas was captured and GHGs emission are mainly from onsite sanitation systems. The captured biogas may be used for domestic purposes or flared where CH_4 emission will be changed and release in term of CO_2 which there is less GWP comparing to CH_4. The scenario 2 can also decrease GHGs an emission due to septic tank is used instead of cesspool because at the same conditions, septic tank generates less GHGs emission compare to cesspool. Moreover, to reduce more GHGs emission, the biogas collection from the onsite sanitation systems may be developed in the future.

Thus, to install biogas collection system with the existing offsite sanitation systems or change the type of existing onsite sanitation systems can reduce GHGs emission.

Table 3.17 The summary of GHGs emission in Thailand from current situation, scenario 1 and scenario 2

GHGs Emissions	Unit	Current situation in Thailand			Scenario 1	Scenario 2
		GHGs emission from onsite sanitation systems	GHGs Emission from offsite sanitation systems	Total GHGs Emission from sanitation systems	Total GHGs Emission from Scenario 1	Total GHGs Emission from Scenario 2
Methane (CH_4)	CO_2e ton/yr	964,404.55	189,025.57	1,153,430.12	964,404.55	975,166.80
Nitrous oxide (N_2O)	CO_2e ton/yr	2,240.08	137.27	2,377.35	2,240.08	854.09
Total GHG emissions	CO_2e ton/yr	966,644.63	189,162.83	1,155,807.46	966,644.63	976,020.89
GHGs emission reduction from current situation	%				***16.37***	***15.56***

It is not only amount of GHGs emissions but also other parameters to be considered in order to choose a suitable sanitation system. The pathogen contaminations need to be taken into account as the effluent from sanitation systems discharged to environment; water bodies, soil and ground water because even though, both scenarios emit less GHGs, it may discharge high pathogen concentration.

3.5 Quantitative Microbial Risk Assessment (QMRA)

3.5.1 Hazard identification

This study was focusing on the risk of effluent sanitation discharge related to contaminated sources of receiving water. Number of diarrhoea cases is about approximately 1 million cases per years which are no trend to reduce although each household in Thailand has fully support of onsite sanitary. The diagnosis of diarrhoea revealed that *E. coli* and *Salmonella* are the major agents for this disease (MOPH, 2009). Thus *E. coli* and *Salmonella* were selected as target organism in order to estimate a probable risk of infection.

3.5.2 Exposure assessments

Exposure assessment aimed to estimate the microbial concentrations in source of water as canal, wells and OSS, which can be combined with the typical ingestion doses for various scenarios, to be applied to the subsequent dose response analysis. For this purpose, spatial trend of *E. coli* and *Salmonella* concentrations of each sanitation systems were explored.

As in the Table 3.18 concentration of *E. coli* and *Salmonella* were measured from effluence of onsite and offsite effluent sanitation system. According to mostly sanitation system in Southeast Asia region discharge the effluent to receiving environment such as i) underground soil which locate next to publish well, ii) publish cannel for swimming and agriculture, and iii) sea which

Table 3.18 Pathogenic contaminate in onsite and offsite effluent sanitation systems

Sampling site	At effluent point		Receiving canal	
	Pathogenic concentration (MPN/ 100 ml)			
	E. coli	***Salmonella***	***E. coli***	***Salmonella***
Onsite sanitation system (OSS)				
	4.42×10^6	1.60×10^6	2.5×10^2	2.4x10
Offsite sanitation system (OFS)				
SP	1.1×10^2	1.4x10	1.7	1.3x10
AL	9.3×10^3	3.5×10^2	8.8×10^2	3.3×10^2
AS	5.4×10^5	1.6×10^3	4.6×10^3	1.4×10^3
OD	6.8×10^4	2.4x10	6.2×10^2	2.2x10
Trickling Filter	2.1×10^5	8.5×10^2	4.8×10^2	1.9×10^2
RBC	8.8×10^5	1.2×10^4	2.5×10^3	3.4×10^3
SBR	6.6×10^5	2.4×10^3	2.2×10^3	8.0×10^2

* The reduction of concentration was 1-2 log for every activities. The reduction has many causes such as: pathogen reduction in term of volume and concentration die-off, reduction by range of ages, and actual risk from immune of residents.

3.5.3 Dose-response analysis

Dose-response assessment is to develop a relationship between the level of microbial exposure and the likelihood of occurrence of an adverse consequence. The activities that people may exposure to the risk show in Table 3.19. The probability risk of infection from *E. coli* and *Salmonella* were calculated from volume of ingestion by the exponential (Equation 2.8) and Beta-Poisson (Equation 2.9) dose response models (Teunis et al. 1996; Haas et al. 1999), as show in Table 3.20.

Table 3.19 Summary of Activities for Estimate Health Risk by Volume Ingestion

No;	Activities	Sources	Frequency / year	Volume ingestion (ml/time)
1	Direct reuse at treatment plant (Plant vegetable)	OSS/OFS	300 – 365	1 – 5
2	Collecting vegetable from the canal	Canal	50 – 100	10 – 50
3	Fishing	Canal	300 – 365	1 – 10
4	Swimming	Canal	20 – 50	10 – 100
5	Irrigation of canal water on farmland	Canal	300 – 365	1 – 10

*Adapted from filed investigation and steyn et al. (2004)

Table 3.20 Probability of *E. coli* and *Salmonella* infection

Sampling site	Mean yearly risk of infection of each activities (P_{yearly})				
	1	2	3	4	5
E. coli					
Onsite sanitation system (OSS)	$1.2x10^{-1}$	$1.3x10^{-5}$	$7.5x10^{-6}$	$5.0x10^{-6}$	$7.4x10^{-6}$
Offsite sanitation system (OFS)					
SP	$3.3x10^{-6}$	$8.5x10^{-8}$	$5.1x10^{-8}$	$3.4x10^{-8}$	$5.1x10^{-8}$
AL	$2.8x10^{-4}$	$4.4x10^{-5}$	$2.6x10^{-5}$	$1.8x10^{-5}$	$2.6x10^{-5}$
AS	$1.6x10^{-2}$	$2.3x10^{-4}$	$1.4x10^{-4}$	$9.2x10^{-5}$	$1.4x10^{-4}$
OD	$2.0x10^{-3}$	$3.1x10^{-5}$	$1.9x10^{-5}$	$1.2x10^{-5}$	$1.9x10^{-5}$
TF	$6.3x10^{-3}$	$2.4x10^{-5}$	$1.4x10^{-5}$	$9.6x10^{-6}$	$1.4x10^{-5}$
RBC	$2.6x10^{-2}$	$1.3x10^{-4}$	$7.5x10^{-5}$	$5.0x10^{-5}$	$7.5x10^{-5}$
SBR	$2.5x10^{-2}$	$1.1x10^{-4}$	$6.6x10^{-5}$	$4.4x10^{-5}$	$6.6x10^{-5}$
Salmonella					
Onsite sanitation system (OSS)	1.0	$1.3x10^{-3}$	$7.8x10^{-4}$	$5.2x10^{-4}$	$7.7x10^{-4}$
Offsite sanitation system (OFS)					
SP	$4.5x10^{-2}$	$7.0x10^{-4}$	$4.2x10^{-4}$	$2.8x10^{-4}$	$4.2x10^{-4}$
AL	$6.8x10^{-1}$	$1.8x10^{-2}$	$1.1x10^{-2}$	$7.1x10^{-3}$	$1.1x10^{-2}$
AS	$9.9x10^{-1}$	$7.3x10^{-2}$	$4.5x10^{-2}$	$2.9x10^{-2}$	$4.5x10^{-2}$
OD	$7.5x10^{-2}$	$1.2x10^{-3}$	$7.2x10^{-4}$	$4.8x10^{-4}$	$7.2x10^{-4}$
Trickling Filter	$9.3x10^{-1}$	$1.0x10^{-2}$	$6.2x10^{-3}$	$4.1x10^{-3}$	$6.2x10^{-3}$
RBC	1.0	$1.7x10^{-1}$	$1.1x10^{-1}$	$7.1x10^{-2}$	$1.1x10^{-1}$
SBR	$9.9x10^{-1}$	$4.2x10^{-2}$	$2.6x10^{-2}$	$1.7x10^{-2}$	$2.6x10^{-2}$

3.5.3.1 *Direct reuse at treatment plant*

Health risks of infection from direct reuse at treatment plant were estimated from *E. coli* and *Salmonella* effluent concentration of each treatment systems. Figure 3.27 demonstrated that only effluent from SP is lower than the acceptable risk from *E. coli* concentration, while the direct reuse at treatment plant from the other sanitation systems are higher that the acceptable risk. Considering probability of *Salmonella* infection demonstrated that all sanitation systems are exceed the acceptable risk. Thus disinfection process or dilute of effluent water is recommended for the safe reuse of effluent from sanitation systems at the plant.

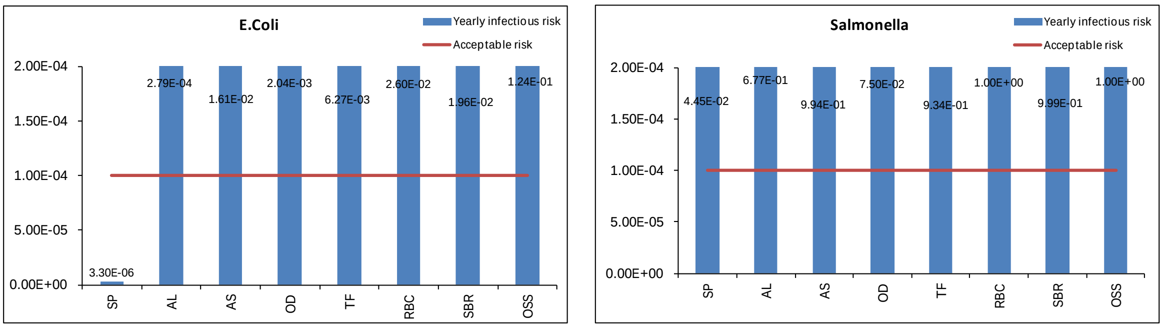


Figure 3.27 Yearly risks of *E. coli* and *Salmonella* infection of effluent direct reuse at treatment plant

3.5.3.2 *Collecting vegetable from the canal*

For second activity, the risk from the collecting vegetable from the canal was estimated from *E. coli* and *Salmonella* contaminated in the canal locate near by the treatment plant and the frequency that people may exposure. The result shown (Figure 3.28) that collecting vegetable from the canal located around SP, AL, OD and TF are under acceptable risk whereas canal around AS, RBC and SBR were higher the acceptable risk from E. coli infection. In the same trend as direct reuse at treatment plant, all sanitation treatment systems are over the acceptable risk from *Salmonella* infection.

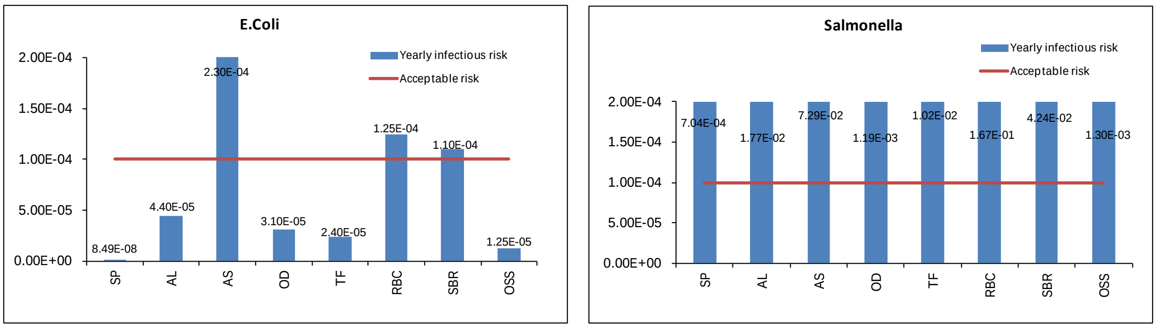


Figure 3.28 Yearly risks of *E. coli* and *Salmonella* infection of collecting vegetable from the canal

3.5.3.3 Fishing

Therefore the probability risk of infection from *E. coli* and *Salmonella* were calculated from accidental volume of ingestion during fishing (Figure 3.29), which not direct measure from the fish. The results demonstrated that fishing nearby treatment systems are mostly under the acceptable risk except AS treatment systems which slightly higher than the acceptable risk from E. coli infection. However the probabilities of Salmonella infection from all treatment systems of this activity were higher the acceptable risk.

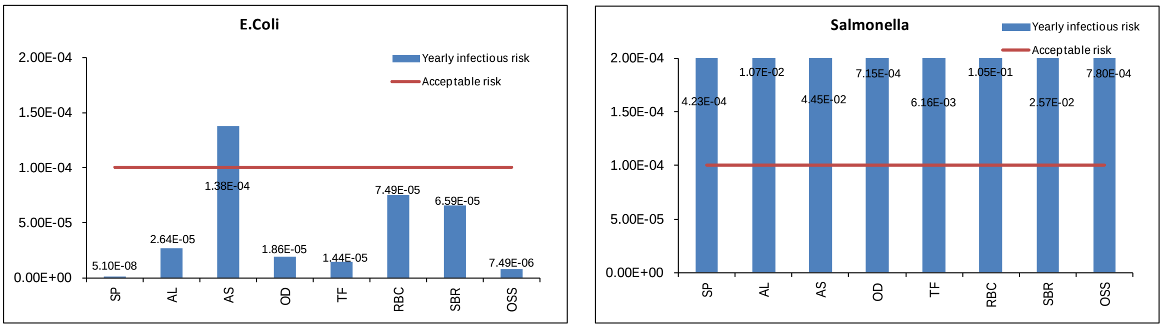


Figure 3.29 Yearly risks of *E. coli* and *Salmonella* infection of fishing from the canal

3.5.3.4 Swimming

The canal around all treatment systems were under acceptable risk for swimming from probability of E. coli infection (Figure 3.30). In the same trend as previous activities, all sanitation treatment systems are over the acceptable risk from *Salmonella* infection.

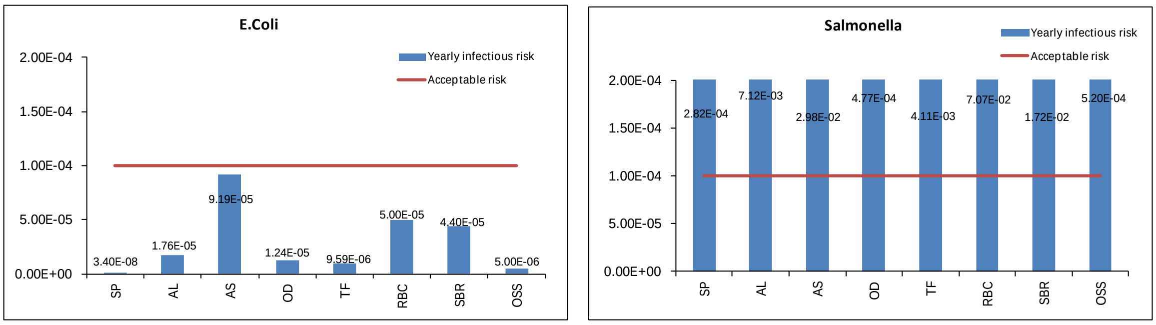


Figure 3.30 Yearly risks of *E. coli* and *Salmonella* infection of swimming in the canal

3.5.3.5 Irrigation of canal water on farmland

The results demonstrated that the use of canal water nearby treatment systems for irrigation are mostly under the acceptable risk except AS treatment systems which slightly higher than the acceptable risk from E. coli infection (Figure 3.31). However the probabilities of Salmonella infection from all treatment systems of this activity were higher the acceptable risk.

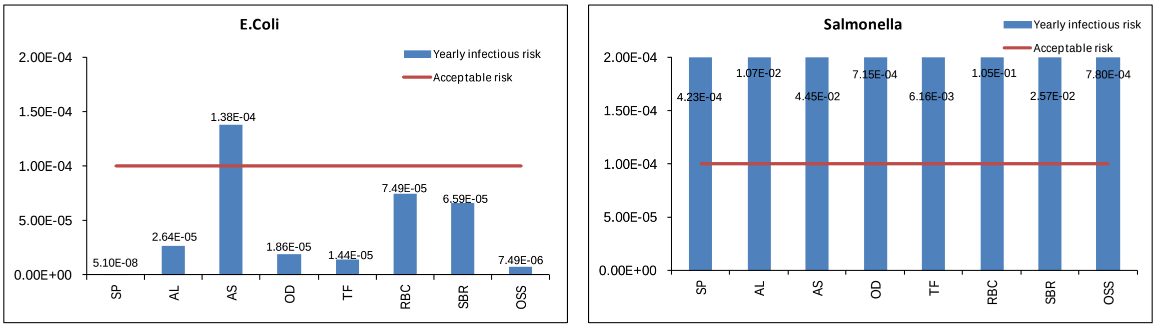


Figure 3.31 Yearly risks of *E. coli* and *Salmonella* infection of irrigation of canal water on farmland

3.5.3.6 Proposed new scenario for risk minimization

The results obtained from filed investigation demonstrated that SP and AL were under acceptable risk from E. coli infection for mostly activities. That probably due to the fact that SP and AL are mainly shallow man-made basins, intensity of the sunlight and temperature are key factors for the efficiency of the pathogen removal processes. However for risk minimization, disinfection process should be installed in order to eliminate pathogen from the effluent. Moreover as proposed in previous about the reduction of GHG emission section for 2 Scenarios, thus in this part probabilities of infection of each scenario were predict as follow.

Scenario 1: Install biogas collection system at the existing offsite sanitation system

In this scenario, all of domestic wastewater is still flow into the onsite sanitation system and then the effluents discharge into many places as same as the current situation but the biogas collection system is assumed to be installed at the offsite sanitation systems. Figure 3.32 shown probability of E. coli infection for Scenario 1, the result illustrated that only direct reuse at treatment will be over the acceptable risk for E. coli infection, whereas the other activities that expose to the canal are under acceptable risk.

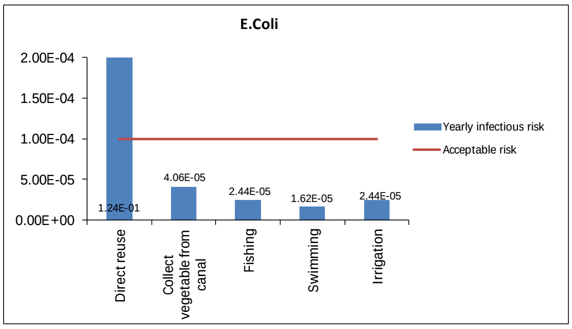


Figure 3.32 Probability of E. coli infection for Scenario 1

Scenario 2: The cesspools users change to use the septic tank while the septic tank users directly connected to offsite sanitation system and effluent from onsite sanitation system directly discharge to environment

In this scenario, it was assumed that the domestic wastewaters from households directly discharge to offsite sanitation system and effluents from onsite sanitation system directly discharge to environment. Therefore the probabilities of infection for Scenario 2 were presented separately of onsite and offsite area as shown in Figure 3.33. The result demonstrated that in the onsite system area; only direct reuse will be higher than the acceptable risk, while the other activities will be under the acceptable risk for E. coli infection. Considering area that directly connected to offsite sanitation system, the results demonstrated that all activities were over the acceptable risk. Probably due to the higher concentration of pathogen directly flow to the offsite treatment system then leaded to the reduction of removal efficiencies. However in order to minimize the risk at offsite treatment system, disinfection process should be installed by the probability of E. coli infection were presented in Figure 3.34. Therefore, about 99.99% of pathogenic removal then no activities in this research effected to people in their area.

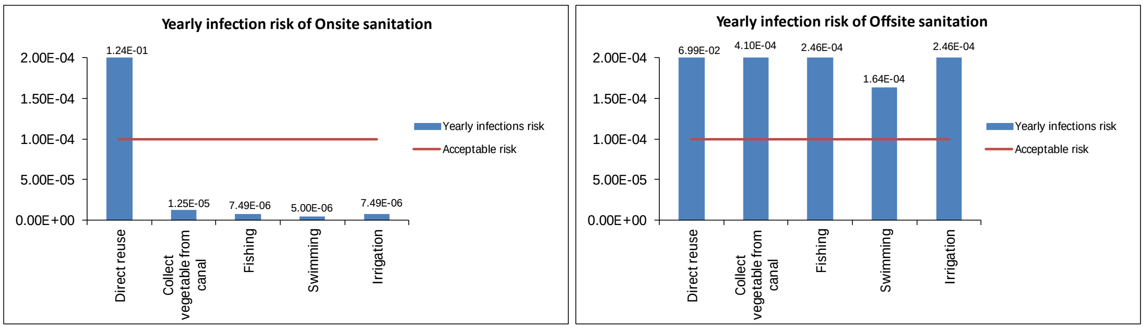


Figure 3.33 Probability of E. coli infection for Scenario 2

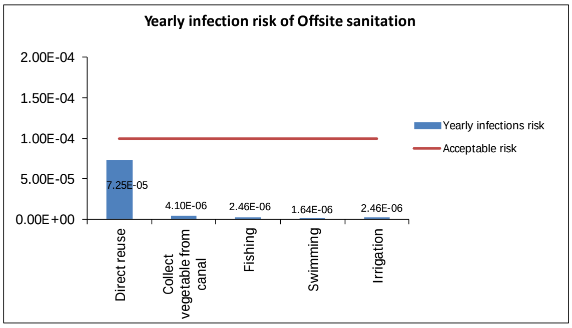


Figure 3.34 Probability of E. coli infection for Scenario 2 with the disinfection process

3.6 Scenario of sanitation management to emerge GHG emission and health risks for coping strategies

According to the emphases on reductions in climate change and health risks, in this part 2 scenarios of the integrated between MFA and QMRA were proposed. As presented in Figure 3.35, the installation biogas collection system at the existing offsite sanitation system (Scenario 1) could reduce the GHGs emission in the Thailand approximately 16 %, in the mean time all activities in the canal around offsite systems were not effect to people in that area. The 2nd scenario (Figure 3.36) demonstrated that 15% of GHGs emission will be decreased. However for health risk assessment of the 2nd scenario demonstrated that the probabilities of all activities will be higher than the acceptable risk, thus after disinfection process is installed will be leaded to reach the acceptable risk.

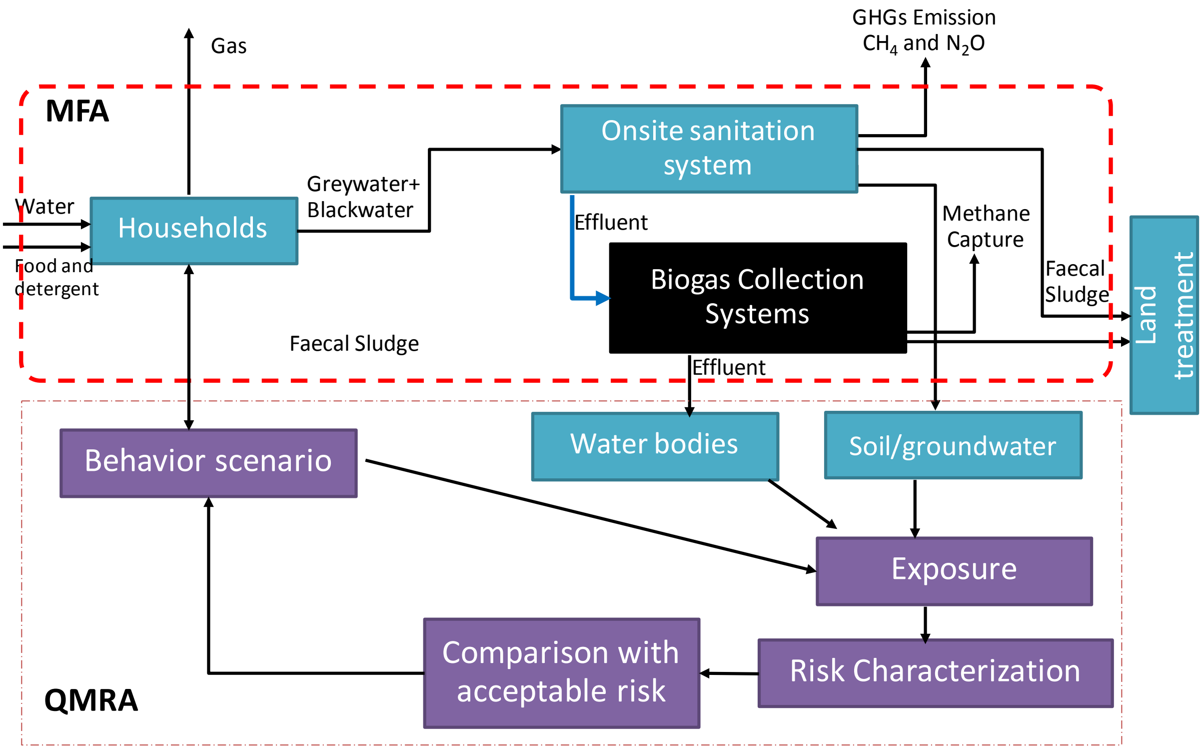


Figure 3.35 Scenario 1 of integrated between MFA and QMRA

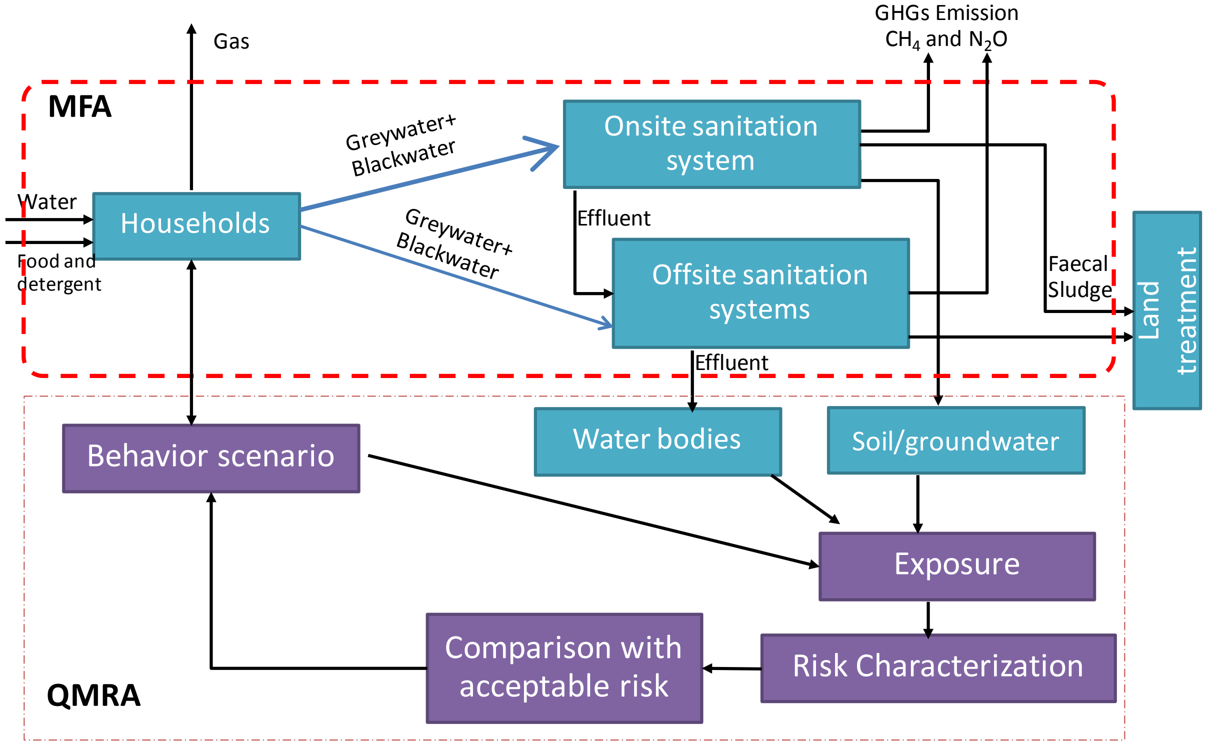


Figure 3.36 Scenario 2 of integrated between MFA and QMRA

Based on the proposed scenario, two coping strategies in for GHGs reduction and Health risk concern are proposed as follows;

Strategy I: GHGs reduction

In area served by offsite sanitation system, septic tank should be removed reducing total GHGs emission 15%. Anaerobic process with CH_4 capture should recommended for offsite sanitation system. In area served by onsite sanitation system, enhance the collection of CH_4 from septic tank in order to produce energy. Moreover the developing of novel onsite system should be concerned on organic degradation.

Strategy II: Health risk concern

Disinfection process should be installed in both of offsite and onsite sanitation systems with the properly operated, especially in offsite sanitation systems. The developing of novel onsite system should be concerned on reducing pathogen.

In order to meet two strategies, four Policies were proposed for Policy maker as following:

Policy 1: Building capacities of local authority

Policy 1.1: Develop administration system within authority

1.1.1 Put GHGs reduction and Health risk assessment strategies into local development plan

1.1.2 Establish a central unit for GHGs reduction and Health risk assessment database network among central government authorities, regional authorities, provincial authorities, local authorities, academic authorities and research institution

Policy 1.2: Develop personal capacity on GHGs reduction and Health risk assessment

1.2.1 Consist the Key Performance Indicators (KPIs) of GHGs reduction and Health risk assessment practice into Good Governance evaluation of local authorities to the Department of Local Administration (DLA)

1.2.2 Train related officer on key knowledge of GHGs reduction and Health risk assessment

Policy 1.3: Request the budget in GHGs reduction and Health risk assessment from Provincial Administrative Organization (PAO) or Provincial Natural Resources and Environment Office (PNREO)

1.3.1 Cooperate with neighboring local authorities to provide the effective action plan in GHGs reduction and Health risk assessment

1.3.2 Execution the public hearing to operate GHGs reduction and Health risk assessment

1.3.3 Request the budget

Policy 2: Providing suitable GHGs reduction and Health risk assessment practices

Policy 2.1: Decrease the volume of GHGs reduction at the original source

2.1.1 Set the standard design of novel onsite system which could reduce GHGs emission and improve pathogen treatment efficiency

2.1.2 Provide the action plan to install novel onsite system for individual household or cluster household

Policy 3: Enhance social learning process on GHGs reduction and Health risk assessment practices

Policy 3.1: Build the monitoring network for GHGs reduction and Health risk assessment

3.1.1 Establish the monitoring network including local people, academic authorities and research institutes

Policy 4: Provide the monitoring system on

Policy4.1: Develop monitoring system and evaluate GHGs reduction and Health risk assessment practice of local authorities

4.1.1 Establish the faculty team of local authority to monitor and evaluate the action plan

4.1.2 Establish the action plan to monitor and evaluate for GHGs reduction and Health risk assessment

Policy 4.2: Provide the system to access database of GHGs reduction and Health risk assessment practice for public people

4.2.1 Enhance the ways to access database of GHGs reduction and Health risk assessment such as website, monthly or annual report

3.7 The Seminar of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project

3.7.1 Stakeholder involvement

The seminar of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project was held at Miracle Grand Convention Hotel at 9.30 AM – 15.30 PM on Monday, January 14th, 2013 as shows in figure 3.37 The objective of the Seminar was to discuss the proposed coping strategies with key stakeholders including policy makers and disseminate the lessons-learnt and coping strategies to public. There are several representatives from organizations as shows in Appendix.

Firstly, Dr.Thammarat Koottatep who is project manager introduced the project included background, objectives, conceptual framework, concept of MFA and QMRA model development and expected outcomes involve scenario for sanitation management to emerge GHG emission and health risks to the participants.

After that, Dr. Atitaya Pauvatvanich gave presentation on Material flow analysis (MFA) of GHGs emission from onsite and offsite sanitation systems in Thailand. Moreover, two scenarios for reduce GHGs from sanitations systems had been proposed.

Then, Dr. Nawatch Surinkul presented on Quantitative Microbial Risk Assessment (QMRA). He briefly gave the concept of QMRA and then the current situation of QMRA from several activities relates sanitation systems in Thailand. Furthermore, the QMRA of two scenarios was also presented.

There were some questions and some suggestions from the stakeholders for the project which include;

Water Quality management Bureau, Pollution Control Department

1) Does the researcher study about energy consumption of CO_2 in the research too?
   Dr.Atitaya Pauvatvanich explained: In this research, researchers study the GHGs emission from sanitation systems by considering only CH_4 and N_2O, because according to IPCC 2006 guideline, the CO_2 is not considered as GHGs emission due they are of biogenic origin and should not be included in national total emissions.
2) Suggestion: The result of GHGs emission from onsite sanitation and offsite sanitation systems should be based on the same factors such as number of population etc, so the result will be more comparative.
   Dr.Atitaya Pauvatvanich explained: The researcher will check later.

Environmental Research and Training Centre (ERTC)

3) How to measure to the dose response; if you used indicator bacteria by E. coli for analyze QMRA?
   Dr. Nawatch Surinkul explained: In this research, the QMRA for risk assessment is study to quantity of E. coli in terms of policy or management. The researchers did not study the specific to the type of E. coli and quantity of pathogens yet.

Water Quality management Bureau, Pollution Control Department

4) Does researcher use number 1/10,000 is an acceptable risk estimate from single exposure? Should acceptable risk value be multi exposure value because some activities become cause of risk to get more diseases?
   Dr. Nawatch Surinkul explained: Acceptable Risk value consider from Single Exposure not Multi Exposure because of the limited data for QMRA.
5) How can the researchers be sure that the diseases/risks are come from onsite sanitation or offsite sanitation or from natural water bodies?
   Dr. Nawatch Surinkul explained: The cause of diseases can be E. coli from animals, and water sources, not only from human. That may need more study about risks with several factors.

6) From summary, a scenario for sanitation management to emerge GHG emissions and health risks and scenario 2 which the cesspool users change to use the septic tank and then households which recently use septic tank directly connect to offsite sanitation systems and effluent from onsite sanitation systems directly discharges to environment. However, the energy consumption of wastewater treatment should be concerned because approximately 80% of energy consumption is consumed by collecting system. The coliform bacteria should take into account in order to see if the disinfection is needed or not.

   Dr. Nawatch Surinkul explained: Every system had the disinfections, but the result is higher than reality because that makes the system got error.

   Dr.Thammarat Koottatep added: We are reviewing for more data however, the data of E. coli is not much available. Most of organizations use other pathogens for indicator. Moreover, this project studies only possible assessment. In Thailand, there should be a concept or planning method for each area. There should be a tool which will help the planers to make a decision about sanitation systems in the future such as the GHGs emission reduction measurement or estimation tool. However, it is also important to check that if the tool is applicable, accurate and reasonable to use.

7) Suggestion: it would be great if the researcher could consider Coliform Bacteria from sanitation systems in this project.

To register for the seminar

Dr.Thammarat Koottatep introduced the project.

Dr. Atitaya Pauvatvanich presented MFA of sanitation systems in Thailand

Dr. Nawatch Surinkul presented QMRA of sanitation systems in Thailand

Participants

Discussion

Dr.Thammarat Koottatep gave the conclusion and close the meeting

The researchers and participants

Figure 3.37 the photos from the seminar

3.7.2 Information Dissemination

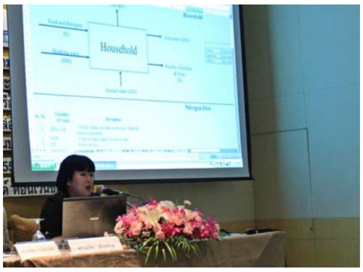
The dissemination of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project was held at Miracle Grand Convention Hotel at 9.30 AM – 12.00 AM on Friday, January 18th, 2013 as shows in figure 3.38 The objective of the dissemination was to propagate the lessons-learnt and coping strategies to public. There are several participants from organizations as shows in Appendix.

Miss Chuthathip Siripong who is a research associate, presented how to use Material flow analysis (MFA) model and Quantitative Microbial Risk Assessment (QMRA) model to the participants. After that there was open discussion and poster exhibition which the participants can test the model and discuss with the researchers. There were six posters in exhibition which includes; 1) Global Warming, 2) Effect of climate change, 3) Material flow analysis (MFA) of GHGs emission from onsite and offsite sanitation systems in Thailand, 4) Quantitative Microbial Risk Assessment (QMRA) from sanitation systems in Thailand, 5) Case study: Strategies for Sanitation Systems to Mitigate GHG Emission in Lao PDR, and 6) Case study: Wastewater Reuse and Quantitative Microbial Risk Assessment in Ban Soknoy, Vientiane capital, Lao. PDR.

From the open discussion exhibition, the opinions and questions from stakeholders can be listed as follow;

1) Regarding the scenario 2, directly discharge the wastewater from households to offsite sanitation directly. There will some problems about sewage pipeline and maintenance.
2) The wastewater management should start from household where onsite sanitation systems are located, thus would it be better to install aerobic system which there is not GHGs emission release?
3) Other uncertainties in the model should be checked.
4) This model is good to see overview of GHGs emission in Thailand, however, the model should be improved for using in smaller area such as municipality or communities.
5) The model is interesting and easy to use. However, the fill-in box should be in the different color from default value or calculated value boxes.
6) Even though the model can show how much GHGs emission release from sanitation systems, people may not pay attention because they are not affected directly. Thus, there should be study which shows the effects of GHGs emission in term of economic.
7) Moreover, if the new laws and regulation related to GHGs emission from sanitation system had proposed, it may take some time for people to accept the changes.
8) What method did the researcher use to measure pathogen? Because that value is not measured regularly such as how much human can get pathogen in to body by swimming in one time.

   Answer: We usually measure pathogen by indirect method. The related questions will be asked and then the data from field observation will be calculated to for the pathogen value. After that, we will compare that value with the references again to check if it is in the range or not. If it is in the range, that value can be used.



Miss Chuthathip Siripong presented how to use the models.

Test the models and discussion

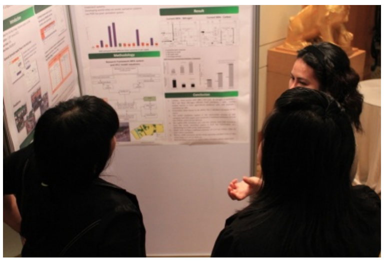
Test the models and discussion

Test the models and discussion

The exhibition

The exhibition

Stakeholders visited the exhibition and suggestion



Stakeholders visited the exhibition and suggestion

Figure 3.38 Poster present during the exhibition

Chapter 4 Conclusions

4.1 Conclusions

From the study found that the existing sanitation systems release GHGs emissions and also microbial health risks with people activities. Two scenarios have been proposed; 1) install biogas capture at offsite sanitation and 2) decrease number of cesspools by using septic tank to reduce GHGs emissions and risks. It can be concluded that biogas collection installation and reduction cesspools used could reduce GHGs emissions from existing sanitation system. In term of microbial health risk, the direct reuse at offsite sanitation systems is still higher than the acceptable risk in both scenarios while others activities; collecting vegetable from the canal, fishing , swimming, irrigation of canal water on farmland the exposure are under acceptable risks except the area that directly connected to offsite sanitation systems in scenario 2. Thus, disinfection process could help to remove pathogen and people are not affected from any activities. However, there is no relationship between GHG emission and probability of infection; thus it should be identified case by case**.**

In order to achieve, sustainable sanitation development, two strategies on GHGs emission and health risks reduction should be concerned. To reduce GHGs emission it should be separated depending on the area of sanitation systems available such as onsite sanitation should be removed in the area that offer offsite sanitation while in the area that there is no offsite sanitation system, the modified onsite sanitation systems should be installed. Moreover, disinfection process should be installed in both of offsite and onsite sanitation systems to reduce the pathogen.

Furthermore, to meet those two strategies, four policies were proposed for policy maker. Firstly, building capacities of local authority includes development of administration system personal capacity, and budget support on GHGs reduction and health risk assessment. Secondary, providing suitable GHGs reduction and Health risk assessment practices for example decrease GHGs emission at sources. Thirdly, the social learning process on GHGs reduction and health risk assessment practices should be enhanced. Fourthly, the monitoring system should be provided to evaluate GHGs reduction and Health risk assessment practice of local authorities.

Chapter 5 Future Directions

5.1 Future Directions

It has been concluded that there is no relationship between GHG emission and probability of infection. Thus, to determine the effects of GHGs emission and microbial health risk and find affordable sanitation systems, it should be identified case by case. However, appropriate concepts, planning method, and accurate tools should be set up as a guideline for policy makers.

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Appendix

Conferences/Symposia/Workshops

a) **Seminar of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project**

Agenda

Date: 14 January 2013

Venue: Executive Boardroom 4th floor in Miracle Grand Convention Hotel

Organized by: Environmental Engineering and Management, Asian Institute of Technology

Date: 14 January 2013		
9:00-9:30	Registration	
9:30-9:40	Welcome and Opening	Dr. Thammarat Koottatep/ AIT
9:40-9:55	Project overview introduction, Objectives, Key Milestones and Project vision	Dr. Thammarat Koottatep/ AIT
9:55-10:45	Material flow analysis (MFA) of GHGs emission from onsite and offsite sanitation systems in Thailand. The scenarios for reduce GHGs from sanitations systems	Dr. Atitaya Pauvatvanich/ AIT
10:45-11:15	Coffee break	
11:15-12.00	Quantitative Microbial Risk Assessment (QMRA); the concept, the current situation from several activities relates sanitation systems in Thailand, and the scenarios	Dr. Nawatch Surinkul/ AIT
12:00-13:30	Lunch	
13:30-14:30	Scenario for sanitation management to emerge GHG emission and health risks	Dr. Thammarat Koottatep/ AIT
14:30-15:30	Discussion	All participant

Participants List

The Seminar of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project

Date: 14 January 2013

Venue: Miracle Grand Convention Hotel, Room Executive Boardroom (4th floor)

Organized by: Environmental Engineering and Management, Asian Institute of Technology

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b) Information Dissemination of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project

Agenda

Date: 18 January 2013

Venue: Miracle Grand Convention Hotel, Room Executive Boardroom (4th floor)

Organized by: Environmental Engineering and Management, Asian Institute of Technology

Date: 18 January 2013		
9:00-9:30	Registration	
9:30-9:40	Welcome and Opening	Dr. Thammarat Koottatep/ AIT
9:40-10:10	Material flow analysis (MFA) of GHGs emission from onsite and offsite sanitation systems in Thailand. The scenarios for reduce GHGs from sanitations systems	Dr. Atitaya Pauvatvanich/ AIT
10.10-10:40	Quantitative Microbial Risk Assessment (QMRA); the concept, the current situation from several activities relates sanitation systems in Thailand, and the scenarios	Dr. Nawatch Surinkul/ AIT
10:40-10:55	Coffee break	
10.55-11.20	MFA and QMRA model presentation	Miss Chuthathip Siripong/ AIT
11.20-12.00	Test the models/exhibition and discussion	All participant
12.00-13.00	Lunch	

Participant list

The Information Dissemination of Affordable Sanitation as an Adaptive Strategy to Emerging Waterborne Diseases Due to Climate Change Project

Date: 18 January 2013

Venue: Miracle Grand Convention Hotel, Room Executive Boardroom (4th floor)

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MFA Model of Current situation
MFA of Households

Nitrogen (N) flow – Households

No.	Variables (tN/year)	Description
1	dMN(1)/dt	N Stock change (increase or decrease) within the process household
2	NGW	N flow in water supply of total of water
3	NF	N flow in food
4	NE	N flow to on-site sanitation (excreta, greywater)
5	NGrW	N flow to sewerage and drainage network (greywater)
6	NKW	N flow to "solid waste collection"
7	NBL	N flow to atmosphere wr.t. Body loss
8	DW	N flow from drinking water

Nitrogen (N) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants
2	aN,food	N load food	g/cap*day	Normal	10.65	FAO
3	aHH_W	Household water consumption	l/cap*day	Normal	35.03	Survey,2012
4	NW	N content water	mg/l	Lognormal	6.30	Khanh (2000)
5	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Montangero (2007)
6	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data
7	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.10	
8	aN,kitchenwaste	N load in Grey water from Kitchen	gN/cap*day	Lognormal	0.80	Diaz et al. (1996); Rytz (2001); Schouw et al. (2002b); Strauss et al. (2003); Sinsupan (2004)
9	rN_body_loss	N losses from the human body to the air	-	Lognormal	0.04	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data

Nitrogen (N) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMN(1)/dt	NF + NGW - NBL - NE - NGrW - NKW	tN/y	85,055.83
2	NF	n x aN,food x 365 x 10-6	tN/y	270,290.81
3	NGW	n x (aHH_GW x NW,GW) x 365 x 10-9	tN/y	5,599.50
4	NE	n×(aN excreta×10−6 +aN grey×rgrey ST×10−9)×365	tN/y	179,913.49
5	NGrW	n x aN_grey x (1- rgrey_ST) x 365 x 10-9	tN/y	89.06
6	NKW	n x aN,kitchenwaste x 365 x 10-9	tN/y	20.30
7	NBL	rN_body_loss x NF	tN/y	10,811.63

Carbon (C) flow - Households

No.	Variables (tN/year)	Description
1	dMC(1)/dt	C Stock change (increase or decrease) within the process household
2	CGW	C flow in water supply of total of water
3	CF	C flow in food
4	CE	C flow to on-site sanitation (excreta, greywater)
5	CGrW	C flow to sewerage and drainage network (greywater)
6	CKW	C flow to "solid waste collection"
7	CBL	C flow to atmosphere wr.t. Body loss

Carbon (C) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
2	aC,food	C load food	g/cap*day	Normal	644.23	composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
3	aHH_GW	Household water consumption	l/cap*day	Normal	147.00	Survey,2012
4	CC,GW	C content water	mg/l	Lognormal	0.00	Development of site-specific impact to ground water soil remediation standards using the soil-water partition equation
5	aC_excreta	C load excreta	gC/cap*day	Normal	132.00	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007).
6	aC_grey	C load grey water	gC/cap*day	Normal	26.00	E. Friedler (2004) Quality of individual domestic greywater Streams and its implication for on-site Treatment and reuse possibilities
7	rgrey_ST	Ratio greywater to sanitation system	%	Lognormal	0.11	Assumption
8	aC,kitchenwaste	C load in kitchen waste	gC/cap*day	Normal	161.06	http://www.epa.gov/reg3wcmd/pdf/foodwasterecovery.pdf C/N=15
9	rC_body_loss	C losses from the human body to the air	gC/cap*day	normal	0.32	West, Tristram O (2009) The human carbon budget: an estimate of the spatial distribution of metabolic carbon consumption and release

Carbon (C) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMC(1)/dt	CF +CGW - CBL - CE - CGrW - CKW	tC/y	10,049,629.35
2	CF	n x aC,food x 365 x 10-6	tC/y	16,346,754.71
3	CGW	n x (aHH_GW x CC,GW) x 365 x 10-9	tC/y	7.46
4	CE	n×(aC excreta×10−6 +aC grey×rgrey ST×10−9)×365	tC/y	2,201,847.43
5	CGrW	n x aC_grey x (1- rgrey_ST) x 365 x 10-9)	tC/y	587.16

6	CKW	n x aC,kitchenwaste x 365 x 10^{-6}	tC/y	4,086,688.68
7	CBL	rC_body_loss x population x 365/10-6	tC/y	7,994.63

MFA of onsite sanitation systems – Cesspools

Nitrogen (N) flow - Cesspools

No.	Variables (tN/year)	Description
1	dMN(2a)/dt	N Stock change (increase or decrease) within the process cesspools
2	E1	N flow from household to cesspool (N in grey water, Excreta, Flushwater)
3	Ef1	N flow in effluent to sewerage and drainage
4	L1	N flow in effluent to soil
5	FS1	N flow in faecal sludge (see process on-site sanitation)
6	N1	N emissions as N_20
7	GrW1	N flow from household to cesspool (N in greywater)

Nitrogen (N) flow parameters - Cesspools

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kN(ST),fs	N transfer coefficient in faecal sludge from Cesspool	-	lognormal	0.06	Assumption
2	rCSeffluent_ground	Ratio of Cesspool effluent discharged into ground	-	normal	0.92	Assumption
3	Ffr	Faecal sludge emptying frequency factor	-	lognormal	10.00	Montangero and Belevi (2007)
4	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value
5	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
6	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.25	IPCC (2006), default value
7	Fpop_cs	Fraction of population using Cesspool		normal	0.84	Survey

8	rgrey_CS	Ratio greywater to Cesspool	%	Lognormal	0.50	Assumption
9	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Sybill report in Lai Xa

Nitrogen (N) flow calculation - Cesspools

No.	Symbol	Equation	Unit	Mean
1	dMN(2a)/dt	NE2-NL2-NFS2-NEf2-N2 (assuming = 0)	tN/y	0.0
2	NE1	aN,excreta x rCS x n x F_{pop_cs} x 365 x 10-6 + n x aN_grey x rgrey_CS x 365 x 10-9 (greywater10% to Cesspool)	tN/y	139,078.98
3	NEf1	((NE1-NFS1) x rCSeffluent_ground)-N1gas	tN/y	116,175.57
4	NL1	(NE1-NFS1) x (1-rCSeffluent_drain)	tN/y	10,102.70
5	NFS1	NE1 x (kN(ST),fs) / Ffr	tN/y	12,795.27
6	N1gas	$N_{Effluent}$ • $Ef_{effluent}$ • 44 / 28	tN/y	5.44
7	Neffluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	692,388.79

Carbon (C) flow - Cesspools

No.	Variables (tN/year)	Description
1	dMC(2a)/dt	C Stock change (increase or decrease) within the process cesspools
2	CE1	C flow from household to septic tank (C in grey water, Excreta, Flushwater)
3	CEf1	C flow in effluent to sewerage and drainage
4	CL1	C flow in effluent to soil
5	CFS1	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters - Cesspools

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(ST),fs	C transfer coefficient in faecal sludge from cesspool	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income group i in		lognormal	0.30	Govt stats

		inventory year,				
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	Assumption
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	-	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	644.23	composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.03	Survey,2012

Carbon (C) flow calculation - Cesspools

No.	Symbol	Equation	Unit	Mean
1	dMC(2a)/dt	CE1-CL1-CFS1-CEf1-M1 (assuming = 0)	tC/y	0.00
2	CE1	aC,excreta x rST x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-6 (greywater(10% to septic tank)	tC/y	1,849,551.84
3	CEf1	((CE1-CFS1) x rSTeffluent_drain)-M1 gas	tC/y	521,507.40
4	CL1	(CE1-CFS1) x (1-rSTeffluent_drain)	tC/y	1,255,845.70
5	CFS1	CE1 x (kC(ST),fs) / Ffr	tC/y	55,486.56
6	M1gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	16,712.19
7	Efj	Bo x MCFj	tC/y	0.30
8	TOW	n x BOD x 0.001 x I x 365	tC/y	1,031,616,425.81

MFA of onsite sanitation systems – Septic Tank

Nitrogen (N) flow - Septic Tank

No.	Variables (tN/year)	Description
1	dMN(2b)/dt	N Stock change (increase or decrease) within the process septic tank
2	E2	N flow from household to cesspool (N in grey water, Excreta, Flushwater)
3	Ef2	N flow in effluent to sewerage and drainage
4	L2	N flow in effluent to soil
5	FS2	N flow in faecal sludge (see process on-site sanitation)
6	N2	N emissions as N_20
7	GrW2	N flow from household to cesspool (N in greywater

Nitrogen (N) flow parameters - Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kN(ST),fs	N transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.09	Montangero and Belevi (2007)
2	rSTeffluent_drain	Ratio of septic tank effluent discharged into drainage	-	normal	0.92	Assumption
3	Ffr	Faecal sludge emptying frequency factor	-	lognormal	6.00	Montangero and Belevi (2007)
4	FNPR	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value
5	F NON-COM	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
6	FIND-COM	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.25	IPCC (2006), default value
7	Protien	Annual per capita protein consumption, kg/person/yr.		normal	66.58	FAO,2010
8	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Sybill report in Lai Xa
9	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Sybill report in Lai Xa
10	Fpop_cs	Fraction of population using Septic tank		normal	0.16	Survey

11	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.01	Assumption
12	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants

Nitrogen (N) flow calculation - Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMN(2b)/dt	NE2-NL2-NFS2-NEf2-N2 (assuming = 0)	tN/y	0.00
2	NE2	aN,excreta x rST x n x 365 x 10-6 + n x aN_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tN/y	26,481.81
3	NEf2	((NE2-NFS2) x rCSeffluent_ground)-N2gas	tN/y	20,625.00
4	NL2	Assumed to be zero	tN/y	1,793.70
5	NFS2	NE2 x (kN(ST),fs) / Ffr	tN/y	4,060.54
6	N2gas	NEffluent • Efeffluent • 44 / 28	tN/y	2.56
7	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	325,830.02

Carbon (C) flow - Septic Tank

No.	Variables (tN/year)	Description
1	dMC(2b)/dt	C Stock change (increase or decrease) within the process septic tank
2	CA1-2a	C flow from household to septic tank (P in grey water, Excreta, Flushwater)
3	CA2a-3	C flow in effluent to sewerage and drainage
4	CA2a-16	C flow in effluent to soil
5	CA2a-FS	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters - Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(ST),fs	C transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income		lognormal	0.30	Govt stats

		group i in inventory year,				
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	From Survey
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	-	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	644.23	Composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.03	Survey,2012
10	CN,GW	C content groundwater	mg/l	Lognormal	0.00	DEVELOPMENT OF SITE-SPECIFIC IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS USING THE SOIL-WATER PARTITION EQUATION
11	aC_excreta	C load excreta	gC/cap*day	Normal	80.19	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007). C/N ratio =10 (6-10) (http://large.stanford.edu/courses/2010/ph240/cook2/)
12	aC_grey	C load grey water	gC/cap*day	Normal	26.00	
13	BOD		g/per/day		48.40	Survey data
14	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.50	Assumption

Carbon (C) flow calculation - Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMC(2b)/dt	CE2-CL2-CFS2-CEf2-M2 (assuming = 0)	tC/y	0.00
2	CE2	aC,excreta x rST x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tC/y	352,295.59
3	CEf2	((CE2-CFS2) x rSTeffluent_drain)-M2 gas	tC/y	307,397.02
4	CL2	(E2-FS2) x (1-rSTeffluent_drain)	tC/y	26,774.46

5	CFS2	E2 x (kN(ST),fs) / Ffr	tC/y	17,614.78
6	M2gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	509.32
7	Efj	Bo x MCFj	tC/y	0.30
8	TOW	n x BOD x 0.001 x I x 365	tC/y	196,498,366.82

MFA of onsite sanitation systems

Nitrogen (N) flow - onsite sanitation systems

No.	Variables (tN/year)	Description
1	dMN(2)/dt	N Stock change (increase or decrease) within the process on-site sanitation
2	NE	N flow from the household (excreta, greywater)
3	NEf	N flow in effluent to drainage system
4	NL	N flow in effluent to soil/groundwater
5	N	N flow in biogas to atmosphere

Nitrogen (N) flow parameters - onsite sanitation systems

No.	Symbol	Description	Unit	Distribution	Mean (Min)	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rCS	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

Nitrogen (N) flow calculations - onsite sanitation systems

No.	Symbol	Equation	Unit	Mean
1	dMN(2)/dt	NE-NEf-NNgas-NFS (assuming this to be 0)	tN/y	0.00
2	NE	NE1+NE2	tN/y	165,560.78
3	NEf	NEf1 + NEf2	tN/y	138,594.28
4	NFS	NFS1 + NFS2	tN/y	16,855.81
5	NNgas	NNgas1 + NNgas2	tN/y	8.00
6	NL	NL1+NL2	tN/y	10,102.70

Carbon (C) flow - onsite sanitation systems

No.	Variables (tN/year)	Description
1	dMC(2)/dt	C Stock change (increase or decrease) within the process on-site sanitation
2	CE	C flow from the household (excreta, greywater)
3	CEf	C flow in effluent to drainage and sewerage system
4	CF	C flow in faecal sludge to landfill
5	CL	C flow in effluent to soil

Carbon (C) flow parameters- onsite sanitation systems

No.	Symbol	Description	Unit	Distribution	Mean (Min)	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rPF	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

Carbon (C) flow calculations - onsite sanitation systems

No.	Symbol	Equation	Unit	Mean
1	dMC(2)/dt	CE-CEf-CMgas-FS-CL (assuming this to be 0)	tC/y	0.00
2	CE	CE1+CE2	tC/y	2,201,847.43
3	CEf	CEf1 + CEf2	tC/y	855,678.88
4	CFS	CFS1 + CFS2	tC/y	73,101.33
5	CM_{gas}	$CM_{gas}1 + CM_{gas}2$	tC/y	17,221.51
6	CL	CL1+CL2	tC/y	1,255,845.70

MFA of trickling filter (TF)

Nitrogen (N) flow - trickling filter (TF)

No.	Variables (tN/year)	Description
1	dMN(3a)/dt	N Stock change (increase or decrease) within the process trickling filter
2	NEfcon1	N flow from effluent from onsite sanitation systems
3	NEfof1	N flow in effluent to water bodies
4	NOt1	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS	N flow into sludge
6	NofGas1	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - trickling filter (TF)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		6.40	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (6477HH * 3.2 (average no. of people in HH))	inhabitants	Normal	20,726.40	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Trickling filter + oxidation ditch	%	Lognormal	0.01	Assumption
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person /year		0.00	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Equation	Unit	Mean
1	dMN(3a)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon1	rOn_TO*Nefcon	tN/y	55.91
3	NEfof1	TKN * effluent *0.000365	tN/y	6.40
4	NS1	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	49.50
5	NofGas1	NEffluent • Efeffluent • 44 / 28	tN/y	0.00
6	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	4,042.15

Carbon (C) flow - trickling filter (TF) + oxidation ditch (OD)

No.	Variables (tN/year)	Description
1	dMC(3a)/dt	C Stock change (increase or decrease) within the process trickling filter+ oxidation ditch (OD)
2	CEfcon1	C flow from effluent from onsite sanitation systems
3	CEfof1	C flow in effluent to water bodies
4	CS1	C flow into sludge
5	CNofGas1	Methane emissions from plant

Carbon (C) flow parameters - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	5.77	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Trickling filter + oxidation ditch	%	Lognormal	0.01	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC

7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	20,726.40	Survey,2012

Carbon (C) flow calculation - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Equation	Unit	Mean
1	dMC(3a)/dt		tC/y	0.00
2	CEfcon1	Cefcon*rOn_TO	tC/y	345.16
3	CEfof1	By Calcualtion of p'Dear using TOC	tC/y	5.77
4	CS1	CEfcon1-(CEfof1+CofGas1)	tC/y	320.90
5	CofGas1	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	18.49
6	Efj	Bo x MCFj	tC/y	0.18
7	TOW	n x BOD x 0.001 x I x 365	tC/y	366,152.58

MFA of Aerated Lagoon (AL)

Nitrogen (N) flow - Aerated Lagoon (AL)

No.	Variables (tN/year)	Description
1	dMN(3b)/dt	N Stock change (increase or decrease) within the process Aerated Lagoon (AL)
2	NEfcon2	N flow from effluent from onsite sanitation systems
3	NEfof2	N flow in effluent to water bodies
4	NOt2	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS	N flow into sludge
6	NofGas2	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Aerated Lagoon (AL)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		233.16	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (132391HH * 3.2 (average no. of people in HH))	inhabitants	Normal	423,651.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Aerated Lagoon	%	Lognormal	0.06	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Effluent	Emission factor	gN_20/person/year		0.00	
8	Protein	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Aerated Lagoon (AL)

No.	Symbol	Equation	Unit	Mean
1	dMN(3c)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon2	rOn_TO*Nefcon	tN/y	240.15
3	NEfof2	TKN * effluent *0.000365	tN/y	233.16
4	NS2	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	6.94
5	NofGas2	NEffluent • Efeffluent • 44 / 28	tN/y	0.06
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	75,111.05

Carbon (C) flow - Aerated Lagoon (AL)

No.	Variables (tN/year)	Description
1	dMC(3b)/dt	C Stock change (increase or decrease) within the process Aerated Lagoon (AL)
2	CEfcon2	C flow from effluent from onsite sanitation systems
3	CEfof2	C flow in effluent to water bodies
4	CS2	C flow into sludge
5	CNofGas2	Methane emissions from plant

Carbon (C) flow parameters - Aerated Lagoon (AL)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	287.68	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Aerated Lagoon (AL)	%	Lognormal	0.06	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	-	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	423,651.20	Survey,2012

Carbon (C) flow calculation - Aerated Lagoon (AL)

No.	Symbol	Equation	Unit	Mean
1	dMC(3b)/dt		tC/y	0.00
2	CEfcon3	Cefcon*rOn_TO	tC/y	1,482.74
3	CEfof3	By Calculations of p'Dear using TOC	tC/y	287.68
4	CS3	CEfcon1-(CEfof1+CofGas1)	tC/y	1,195.06
5	CofGas3	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.00
6	Efj	Bo x MCFj	tC/y	0.00
7	TOW	n x BOD x 0.001 x I x 365	tC/y	7,484,222.10

MFA of Activated Sludge (AS)

Nitrogen (N) flow - Activated Sludge (AS)

No.	Variables (tN/year)	Description
1	dMN(3c)/dt	N Stock change (increase or decrease) within the process Activated Sludge (AS)
2	NEfcon3	N flow from effluent from onsite sanitation systems
3	NEfof3	N flow in effluent to water bodies
4	NOt3	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS3	N flow into sludge
6	NofGas3	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Activated Sludge (AS)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	230.76	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (240284HH * 3.2 (average no. of people in HH))	inhabitants	Normal	768,908.80	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Activated Sludge (AS)	%	Lognormal	0.22	

4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.00	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Activated Sludge (AS)

No.	Symbol	Equation	Unit	Mean
1	dMN(3c)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon3	rOn_TO*Nefcon	tN/y	877.16
3	NEfof3	TKN * effluent *0.000365	tN/y	230.76
4	NS3	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	646.39
5	NofGas3	NEffluent • Efeffluent • 44 / 28	tN/y	0.00322
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	4,095.27

Carbon (C) flow - Activated Sludge (AS)

No.	Variables (tN/year)	Description
1	dMC(3c)/dt	C Stock change (increase or decrease) within the process Activated Sludge (AS)
2	CEfcon3	C flow from effluent from onsite sanitation systems
3	CEfof3	C flow in effluent to water bodies
4	CS3	C flow into sludge
5	CofGas3	Methane emissions from plant

Carbon (C) flow parameters - Activated Sludge (AS)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	147.72	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Activated Sludge (AS)	%	Lognormal	0.22	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	-	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	768,908.80	Survey,2012

Carbon (C) flow calculation - Activated Sludge (AS)

No.	Symbol	Equation	Unit	Mean
1	dMC(3c)/dt		tC/y	-
2	CEfcon3	Cefcon*rOn_TO	tC/y	5,415.56
3	CEfof3	By Calcualtion of p'Dear using TOC	tC/y	147.72
4	CS3	CEfcon1-(CEfof1+CofGas1)	tC/y	5,267.85
5	CofGas3	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	-
6	Efj	Bo x MCFj	tC/y	-
7	TOW	n x BOD x 0.001 x I x 365	tC/y	13,583,542.86

MFA of Constructed Wetland (CW)

Nitrogen (N) flow - Constructed Wetland (CW)

No.	Variables (tN/year)	Description
1	dMN(3d)/dt	N Stock change (increase or decrease) within the process Constructed Wetland (CW)
2	NEfcon4	N flow from effluent from onsite sanitation systems
3	NEfof4	N flow in effluent to water bodies
4	NOt24	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS4	N flow into sludge
6	NNofGas4	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Constructed Wetland (CW)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	1.89	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (616HH * 3.2 (average no. of people in HH))	inhabitants	Normal	1,971.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.00048	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Constructed Wetland (CW)

No.	Symbol	Equation	Unit	Mean
1	dMN(3d)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon4	rOn_TO*Nefcon	tN/y	1.91
3	NEfof4	TKN * effluent *0.000365	tN/y	1.89
4	NS4	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	0.03
5	NofGas4	NEffluent • Efeffluent • 44 / 28	tN/y	0.00
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	349.48

Carbon (C) flow - Constructed Wetland (CW)

No.	Variables (tN/year)	Description
1	dMC(3d)/dt	C Stock change (increase or decrease) within the process Constructed Wetland (CW)
2	CEfcon4	C flow from effluent from onsite sanitation systems
3	CEfof4	C flow in effluent to water bodies
4	CS4	C flow into sludge
5	CofGas4	Methane emissions from plant

Carbon (C) flow parameters - Constructed Wetland (CW)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	8.54	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.00	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC

7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	1,971.20	Survey,2012

Carbon (C) flow calculation - Constructed Wetland (CW)

No.	Symbol	Equation	Unit	Mean
1	dMC(3d)/dt		tC/y	-
2	CEfcon4	Cefcon*rOn_TO	tC/y	11.80
3	CEfof4	By Calcualtion of p'Dear using TOC	tC/y	8.54
4	CS4	CEfcon1-(CEfof1+CofGas1)	tC/y	1.51
5	CofGas4	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	1.76
6	Efj	Bo x MCFj	tC/y	0.18
7	TOW	n x BOD x 0.001 x I x 365	tC/y	34,823.22

MFA of Oxidation Ditch + Activated Sludge (OD+AS)

Nitrogen (N) flow - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tN/year)	Description
1	dMN(3e)/dt	N Stock change (increase or decrease) within the process Oxidation Ditch + Activated Sludge (OD+AS)
2	NEfcon5	N flow from effluent from onsite sanitation systems
3	NEfof5	N flow in effluent to water bodies
4	NOt5	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS5	N flow into sludge
6	NNofGas5	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		11.67	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (13609HH * 3.2 (average no. of people in HH))	inhabitants	Normal	43,548.80	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch + Activated Sludge	%	Lognormal	0.04	Assumption
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Equations	Unit	Value
1	dMN(3e)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon5	rOn_TO*Nefcon	tN/y	152.9
3	NEfof5	TKN * effluent *0.000365	tN/y	11.7
4	NS5	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	141.0
5	NofGas5	NEffluent • Efeffluent • 44 / 28		0.200
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		255138.8

Carbon (C) flow - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tC/year)	Description
1	dMC(3e)/dt	C Stock change (increase or decrease) within the process Oxidation Ditch + Activated Sludge (OD+AS)
2	CEfcon5	C flow from effluent from onsite sanitation systems
3	CEfof5	C flow in effluent to water bodies
4	CS5	C flow into sludge
5	CNofGas5	Methane emissions from plant

Carbon (C) flow parameters - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	6.31	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to OD+WL	%	Lognormal	0.04	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	43,548.80	Survey,2012

Carbon (C) flow calculation - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tC/year)	Equations	Unit	Value
1	dMC(3e)/dt			0.000
2	CEfcon5	Cefcon*rOn_TO		943.725

3	CEfof5	By Calcualtion of p'Dear using TOC		6.310
4	CS5	CEfcon1-(CEfof1+CofGas1)		898.563
5	CofGas5	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗		38.852
6	Efj	Bo x MCFj		0.18
7	TOW	n x BOD x 0.001 x I x 365		769333.1008

MFA of Rotating Biological Contactor (RBC)

Nitrogen (N) flow - Rotating Biological Contactor (RBC)

Sr. No	Variables (tN/year)	Description
1	dMN(3f)/dt	N Stock change (increase or decrease) within the process Rotating Biological Contactor (RBC)
2	NEfcon6	N flow from effluent from onsite sanitation systems
3	NEfof6	N flow in effluent to water bodies
4	NOt6	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS6	N flow into sludge
6	NNofGas6	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	14.24	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (40513HH * 3.2 (average no. of people in HH))	inhabitants	Normal	129,641.60	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to RBC	%	Lognormal	0.0186	

4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3f)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon6	rOn_TO*Nefcon	tN/y	74.6
3	NEfof6	TKN * effluent *0.000365	tN/y	14.2
4	NS6	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	60.3
	NofGas6	NEffluent • Efeffluent • 44 / 28		0.0181
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		22984.7

Carbon (C) flow - Rotating Biological Contactor (RBC)

Sr. No	Variables (tC/year)	Description
1	dMC(3f)/dt	C Stock change (increase or decrease) within the process Rotating Biological Contactor (RBC)
2	CEfcon6	C flow from effluent from onsite sanitation systems
3	CEfof6	C flow in effluent to water bodies
4	CS6	C flow into sludge
5	CNofGas6	Methane emissions from plant

Carbon (C) flow parameters - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	20.01	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.0186	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	129,641.60	Survey,2012

Carbon (C) flow calculation - Rotating Biological Contactor (RBC)

Sr. No	Variables (tC/year)	Equations	Unit	Value
1	dMC(3f)/dt		tC/y	0.000
2	CEfcon6	Cefcon*rOn_TO	tC/y	460.340
3	CEfof6	By Calcualtion of p'Dear using TOC	tC/y	20.006
4	CS6	CEfcon1-(CEfof1+CofGas1)	tC/y	440.334
5	CofGas6	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		2290248.506

MFA of Sequencing Batch Reactors (SBR)

Nitrogen (N) flow - Sequencing Batch Reactors (SBR)

Sr. No	Variables (tN/year)	Description
1	dMN(3g)/dt	N Stock change (increase or decrease) within the process Sequencing Batch Reactors (SBR)
2	NEfcon7	N flow from effluent from onsite sanitation systems
3	NEfof7	N flow in effluent to water bodies
4	NOt7	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS7	N flow into sludge
6	NNofGas7	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	6.90	Montangero and Belevi (2007)
12	n	Number of inhabitants using the treatment system (6414HH * 3.2 (average no. of people in HH))	inhabitants	Normal	20,524.80	Assuming 10% unregistered inhabitants
10	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.007510	
7	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
6	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
5	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
	Efeffluent	Emission factor	g N20/person/year		0.0005	
	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	

4	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3g)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon7	rOn_TO*Nefcon	tN/y	30.1
3	NEfof7	TKN * effluent *0.000365	tN/y	6.9
4	NS7	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	23.2
	N6gas	NEffluent • Efeffluent • 44 / 28		0.0029
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		3638.9

Carbon (C) flow - Sequencing Batch Reactors (SBR)

Sr. No	Variables (tC/year)	Description
1	dMC(3g)/dt	C Stock change (increase or decrease) within the process Sequencing Batch Reactors (SBR)
2	CEfcon7	C flow from effluent from onsite sanitation systems
3	CEfof7	C flow in effluent to water bodies
4	CS7	C flow into sludge
5	CNofGas7	Methane emissions from plant

Carbon (C) flow parameters - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	5.59	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.0075	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey

5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	20,524.80	Survey,2012

Carbon (C) flow calculation - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Equations	Unit	Value
1	dMC(2g)/dt		tC/y	0.000
2	CEfcon7	Cefcon*rOn_TO	tC/y	185.869
3	CEfof7	By Calcualtion of p'Dear using TOC	tC/y	5.593
4	CS7	CEfcon1-(CEfof1+CofGas1)	tC/y	180.275
5	CofGas7	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.0000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		362591.1168

MFA of Modified Sequencing Batch Reactors (MSBR)

Nitrogen (N) flow - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Variables (tN/year)	Description
1	dMN(3h)/dt	N Stock change (increase or decrease) within the process MSBR
2	NEfcon8	N flow from effluent from onsite sanitation systems
3	NEfof8	N flow in effluent to water bodies
4	NOt8	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS8	N flow into sludge
6	NNofGas8	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	0.00	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (6414HH * 3.2 (average no. of people in HH))	inhabitants	Normal	64,473.60	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to MSBR	%	Lognormal	0.0480	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3h)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon8	rOn_TO*Nefcon	tN/y	192.6
3	NEfof8	TKN * effluent *0.000365	tN/y	0.0
4	NS8	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	192.6
	N8gas	NEffluent • Efeffluent • 44 / 28		0.0090
5	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge		11430.8

Carbon (C) flow - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Variables (tC/year)	Description
1	dMC(3h)/dt	C Stock change (increase or decrease) within the process MSBR
2	CEfcon8	C flow from effluent from onsite sanitation systems
3	CEfof8	C flow in effluent to water bodies
4	CS8	C flow into sludge
5	CNofGas8	Methane emissions from plant

Carbon (C) flow parameters - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	46.49	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to MSBR	%	Lognormal	0.0480	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	64,473.60	Survey,2012

Carbon (C) flow calculation - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3g)/dt	Equations	tC/y	0.000
2	CEfcon8	Cefcon*rOn_TO	tC/y	1,188.981
3	CEfof8	By Calcualtion of p'Dear using TOC	tC/y	46.493
4	CS8	CEfcon1-(CEfof1+CofGas1)	tC/y	1,142.487

5	CofGas8	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.0000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		1138990.618

MFA of Stabilization Pond (SP)

Nitrogen (N) flow - Stabilization Pond (SP)

Sr. No	Variables (tN/year)	Description
1	dMN(3i)/dt	N Stock change (increase or decrease) within the process Stabilization Pond (SP)
2	NEfcon9	N flow from effluent from onsite sanitation systems
3	NEfof9	N flow in effluent to water bodies
4	NOt9	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS9	N flow into sludge
6	NNofGas9	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond (SP)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	108.28	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (109765HH * 3.2 (average no. of people in HH))	inhabitants	Normal	351,248.00	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.1005	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	

9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond (SP)

Sr. No	Symbol	Equations	tN/y	Mean
1	dMN(3i)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon9	rOn_TO*Nefcon	tN/y	402.9
3	NEfof9	TKN * effluent *0.000365	tN/y	108.3
4	NS9	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	294.5
	N9gas	NEffluent • Efeffluent • 44 / 28		0.0489
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		62274.4

Carbon (C) flow - Stabilization Pond (SP)

Sr. No	Variables (tC/year)	Description
1	dMC(3i)/dt	C Stock change (increase or decrease) within the process Stabilization Pond (SP)
2	CEfcon9	C flow from effluent from onsite sanitation systems
3	CEfof9	C flow in effluent to water bodies
4	CS9	C flow into sludge
5	CNofGas9	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond (SP)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	305.16	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.1005	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC

6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	351,248.00	Survey,2012

Carbon (C) flow calculation - Stabilization Pond (SP)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3i)/dt		tC/y	0.000
2	CEfcon9	Cefcon*rOn_TO	tC/y	2,487.193
3	CEfof9	By Calcualtion of p'Dear using TOC	tC/y	305.160
4	CS9	CEfcon1-(CEfof1+CofGas1)	tC/y	1,346.393
5	CofGas9	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	835.64
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		6205147.168

MFA of Stabilization Pond + Constructed Wetland (SP+CW)

Nitrogen (N) flow - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Variables (tN/year)	Description
1	dMN(3j)/dt	N Stock change (increase or decrease) within the process Stabilization Pond + Constructed Wetland
2	NEfcon10	N flow from effluent from onsite sanitation systems
3	NEfof10	N flow in effluent to water bodies
4	NOt10	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS10	N flow into sludge
6	NNofGas10	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	6.41	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (81327HH * 3.2 (average no. of people in HH))	inhabitants	Normal	260,246.40	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Constructed Wetland	%	Lognormal	0.1937	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3j)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon10	rOn_TO*Nefcon	tN/y	776.6
3	NEfof10	TKN * effluent *0.000365	tN/y	6.4
4	NS10	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	770.2
	N10gas	NEffluent • Efeffluent • 44 / 28		0.0363
5	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge		46140.3

Carbon (C) flow - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Variables (tC/year)	Description
1	dMC(3j)/dt	C Stock change (increase or decrease) within the process Stabilization Pond + Constructed Wetland
2	CEfcon10	C flow from effluent from onsite sanitation systems
3	CEfof10	C flow in effluent to water bodies
4	CS10	C flow into sludge
5	CNofGas10	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	19.04	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Constructed Wetland	%	Lognormal	0.1937	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	260,246.40	Survey,2012

Carbon (C) flow calculation - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3j)/dt		tC/y	0.000
2	CEfcon10	Cefcon*rOn_TO	tC/y	4,794.752

3	CEfof10	By Calcualtion of p'Dear using TOC	tC/y	19.044
4	CS10	CEfcon1-(CEfof1+CofGas1)	tC/y	4,156.567
5	CofGas10	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	619.1415
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		4597512.902

MFA of Stabilization Pond + Oxidation Ditch (SP+OD)

Nitrogen (N) flow - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Variables (tN/year)	Description
1	dMN(3k)/dt	N Stock change (increase or decrease) within the process Stabilization Pond + Oxidation Ditch
2	NEfcon11	N flow from effluent from onsite sanitation systems
3	NEfof11	N flow in effluent to water bodies
4	NOt11	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS11	N flow into sludge
6	NNofGas11	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	3.29	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (61965HH * 3.2 (average no. of people in HH))	inhabitants	Normal	198,288.00	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Oxidation Ditch	%	Lognormal	0.0072	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010

5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Equations	Unit	Value
1	dMN(3k)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon11	rOn_TO*Nefcon	tN/y	28.7
3	NEfof11	TKN * effluent *0.000365	tN/y	3.3
4	NS11	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	25.4
	N11gas	NEffluent • Efeffluent • 44 / 28		0.0276
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		35155.4

Carbon (C) flow - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Variables (tC/year)	Description
1	dMC(3k)/dt	C Stock change (increase or decrease) within the process Stabilization Pond + Oxidation Ditch
2	CEfcon11	C flow from effluent from onsite sanitation systems
3	CEfof11	C flow in effluent to water bodies
4	CS11	C flow into sludge
5	CNofGas11	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	8.29	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Oxidation Ditch	%	Lognormal	0.0072	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	198,288.00	Survey,2012

Carbon (C) flow calculation - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3k)/dt		tC/y	0.00
2	CEfcon11	Cefcon*rOn_TO	tC/y	177.04
3	CEfof11	By Calcualtion of p'Dear using TOC	tC/y	8.29
4	CS11	CEfcon1-(CEfof1+CofGas1)	tC/y	-302.99
5	CofGas11	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	471.74
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		3,502,955.81

MFA of Oxidation Ditch (OD)

Nitrogen (N) flow - Oxidation Ditch (OD)

Sr. No	Variables (tN/year)	Description
1	dMN(3k)/dt	N Stock change (increase or decrease) within the process Oxidation Ditch
2	NEfcon11	N flow from effluent from onsite sanitation systems
3	NEfof11	N flow in effluent to water bodies
4	NOt11	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS11	N flow into sludge
6	NNofGas11	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Oxidation Ditch (OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	187.43	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (182561HH * 3.2 (average no. of people in HH))	inhabitants	Normal	584,195.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch	%	Lognormal	0.2932	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Oxidation Ditch (OD)

Sr. No	Symbol	Equations	tN/y	Mean
1	dMN(3k)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon12	rOn_TO*Nefcon	tN/y	1175.3
3	NEfof12	TKN * effluent *0.000365	tN/y	187.4
4	NS12	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	987.8
	NofGas12	NEffluent • Efeffluent • 44 / 28		0.0814
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		103574.6

Carbon (C) flow - Oxidation Ditch (OD)

Sr. No	Variables (tC/year)	Description
1	dMC(3k)/dt	C Stock change (increase or decrease) within the process Oxidation Ditch
2	CEfcon12	C flow from effluent from onsite sanitation systems
3	CEfof12	C flow in effluent to water bodies
4	CS12	C flow into sludge
5	CofGas12	Methane emissions from plant

Carbon (C) flow parameters - Oxidation Ditch (OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	145.88	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch	%	Lognormal	0.2932	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC

8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	584,195.20	Survey,2012

Carbon (C) flow calculation - Oxidation Ditch (OD)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3k)/dt		tC/y	0.000
2	CEfcon11	Cefcon*rOn_TO	tC/y	7,256.393
3	CEfof11	By Calcualtion of p'Dear using TOC	tC/y	145.881
4	CS11	CEfcon1-(CEfof1+CofGas1)	tC/y	5,720.677
5	CofGas11	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	1,389.8349
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		10320392.4

MFA of Scenario 1: Install biogas collection system at the existing offsite sanitation system

MFA of Households

Nitrogen (N) flow – Households

No.	Variables (tN/year)	Description
1	dMN(1)/dt	N Stock change (increase or decrease) within the process household
2	NGW	N flow in water supply of total of water
3	NF	N flow in food
4	NE	N flow to on-site sanitation (excreta, greywater)
5	NGrW	N flow to sewerage and drainage network (greywater)
6	NKW	N flow to "solid waste collection"
7	NBL	N flow to atmosphere wr.t. Body loss
8	DW	N flow from drinking water

Nitrogen (N) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants
2	aN,food	N load food	g/cap*day	Normal	10.65	FAO
3	aHH_W	Household water consumption	l/cap*day	Normal	35.03	Survey,2012
4	NW	N content water	mg/l	Lognormal	6.30	Khanh (2000)
5	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Montangero (2007)
6	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data
7	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.10	
8	aN,kitchenwaste	N load in Grey water from Kitchen	gN/cap*day	Lognormal	0.80	Diaz et al. (1996); Rytz (2001); Schouw et al. (2002b); Strauss et al. (2003); Sinsupan (2004)
9	rN_body_loss	N losses from the human body to the air	-	Lognormal	0.04	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data

Nitrogen (N) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMN(1)/dt	NF + NGW - NBL - NE - NGrW - NKW	tN/y	85,055.83
2	NF	n x aN,food x 365 x 10-6	tN/y	270,290.81
3	NGW	n x (aHH_GW x NW,GW) x 365 x 10-9	tN/y	5,599.50
4	NE	n×(aN excreta×10−6 +aN grey×rgrey ST×10−9)×365 and See On-site sanitation	tN/y	179,913.49
5	NGrW	n x aN_grey x (1- rgrey_ST) x 365 x 10-9	tN/y	89.06
6	NKW	n x aN,kitchenwaste x 365 x 10-9	tN/y	20.30
7	NBL	rN_body_loss x NF	tN/y	10,811.63

Carbon (C) flow - Households

No.	Variables (tN/year)	Description
1	dMC(1)/dt	C Stock change (increase or decrease) within the process household
2	CGW	C flow in water supply of total of ground water
3	CF	C flow in food
4	CE	C flow to on-site sanitation (excreta, greywater)
5	CGrW	C flow to sewerage and drainage network (greywater)
6	CKW	C flow to "solid waste collection"
7	CBL	C flow to atmosphere wr.t. Body loss

Carbon (C) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
2	aC,food	C load food	g/cap*day	Normal	644.23	composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
3	aHH_GW	Household water consumption	l/cap*day	Normal	147.00	Survey,2012
4	CC,GW	C content water	mg/l	Lognormal	0.00	"DEVELOPMENT OF SITE-SPECIFIC
5	aC_excreta	C load excreta	gC/cap*day	Normal	132.00	IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS
6	aC_grey	C load grey water	gC/cap*day	Normal	26.00	USING THE SOIL-WATER PARTITION EQUATION"
7	rgrey_ST	Ratio greywater to sanitation system	%	Lognormal	0.11	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007). C/N ratio =10 (6-10)(http://large.stanford.edu/courses/2010/ph240/cook2/)
8	aC,kitchenwaste	C load in kitchen waste	gC/cap*day	Normal	161.06	E. Friedler (2004) Quality of individual domestic greywater Streams and its implication for on-site Treatment and reuse possibilities
9	rC_body_loss	C losses from the human body to	gC/cap*day	normal	0.32	Assumption

		the air				

Carbon (C) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMC(1)/dt	CF +CGW - CBL - CE - CGrW - CKW	tC/y	10,049,629.35
2	CF	n x aC,food x 365 x 10-6	tC/y	16,346,754.71
3	CGW	n x (aHH_GW x CC,GW) x 365 x 10-9	tC/y	7.46
4	CE	n×(aC excreta×10−6 +aC grey×rgrey ST×10−9)×365 and See On-site sanitation	tC/y	2,201,847.43
5	CGrW	n x aC_grey x (1- rgrey_ST) x 365 x 10-9)	tC/y	587.16
6	CKW	n x aC,kitchenwaste x 365 x 10-6	tC/y	4,086,688.68
7	CBL	rC_body_loss x population x 365/10-6	tC/y	7,994.63

MFA of onsite sanitation systems

Nitrogen (N) flow - Onsite sanitation systems

No.	Variables (tN/year)	Description
1	dMN(2)/dt	N Stock change (increase or decrease) within the process on-site sanitation
2	NE	N flow from the household (excreta, greywater)
3	NEf	N flow in effluent to drainage system
4	NL	N flow in effluent to soil/groundwater
5	N	N flow in biogas to atmosphere

Nitrogen (N) flow parameters - Onsite sanitation systems

No.	Symbol	Description	Unit	Distribution	Mean (Min)	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rCS	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

Nitrogen (N) flow calculations - Onsite sanitation systems

No.	Symbol	Equation	Unit	Mean
1	dMN(2)/dt	NE-NEf-NNgas-NFS (assumming this to be 0)	tN/y	-
2	NE	NE1+NE2	tN/y	165,560.78
3	NEf	NEf1 + NEf2	tN/y	138,594.28
4	NFS	NFS1 + NFS2	tN/y	16,855.81
5	NNgas	NNgas1 + NNgas2	tN/y	8.00
6	NL	NL1+NL2	tN/y	10,102.70

Carbon (C) flow - Onsite sanitation systems

No.	Variables (tN/year)	Description
1	dMC(2)/dt	C Stock change (increase or decrease) within the process on-site sanitation
2	CE	C flow from the household (excreta, greywater)
3	CEf	C flow in effluent to drainage and sewerage system
4	CF	C flow in faecal sludge to landfill
5	CL	C flow in effluent to soil

Carbon (C) flow parameters - Onsite sanitation systems

No.	Symbol	Description	Unit	Distribution	Mean (Min)	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rPF	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

arbon (C) flow calculations - Onsite sanitation systems

No.	Symbol	Equation	Unit	Mean
1	dMC(2)/dt	CE-CEf-CMgas-FS-CL (assumming this to be 0)	tC/y	-
2	CE	CE1+CE2	tC/y	2,201,847.43
3	CEf	CEf1 + CEf2	tC/y	855,678.88
4	CFS	CFS1 + CFS2	tC/y	73,101.33
5	CMgas	CMgas1 + CMgas2	tC/y	17,221.51
6	CL	CL1+CL2	tC/y	1,255,845.70

MFA of onsite sanitation systems – Cesspools

Nitrogen (N) flow - Cesspools

No.	Variables (tN/year)	Description
1	dMN(2a)/dt	N Stock change (increase or decrease) within the process septic tank
2	E1	N flow from household to septic tank (N in grey water, Excreta, Flushwater)
3	Ef1	N flow in effluent to sewerage and drainage
4	L1	N flow in effluent to soil
5	FS1	N flow in faecal sludge (see process on-site sanitation)
6	N1	N emissions as N20
7	GrW1	N flow from household to septic tank (N in greywater

Nitrogen (N) flow parameters - Cesspools

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kN(ST),fs	N transfer coefficient in faecal sludge from Cesspool	-	lognormal	0.06	Assumption
2	rCSeffluent_ground	Ratio of Cesspool effluent discharged into ground	-	normal	0.92	Assumption
3	Ffr	Faecal sludge emptying frequency factor	-	lognormal	10.00	Montangero and Belevi (2007)
4	FNPR	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value
5	F NON-COM	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
6	FIND-COM	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.25	IPCC (2006), default value
7	Fpop_cs	Fraction of population using Cesspool		normal	0.84	Survey
8	rgrey_CS	Ratio greywater to Cesspool	%	Lognormal	0.50	Assumption
9	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Sybill report in Lai Xa

Nitrogen (N) flow calculation - Cesspools

No.	Symbol	Equation	Unit	Mean
1	dMN(2a)/dt	NE2-NL2-NFS2-NEf2-N2 (assuming = 0)	tC/y	0.0
2	NE1	aN,excreta x rCS x n x Fpop_cs x 365 x 10-6 + n x aN_grey x rgrey_CS x 365 x 10-9(greywater10% to Cesspool)	tC/y	139,079.0
3	NEf1	((NE1-NFS1) x rCSeffluent_ground)-N1gas	tC/y	116,175.6
4	NL1	(NE1-NFS1) x (1-rCSeffluent_drain)	tC/y	10,102.7
5	NFS1	NE1 x (kN(ST),fs) / Ffr	tC/y	12,795.3
6	N1gas	NEffluent • Efeffluent • 44 / 28	tC/y	5.4
7	Neffluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tC/y	692,388.8

Carbon (C) flow - Cesspools

No.	Variables (tN/year)	Description
1	dMC(2a)/dt	C Stock change (increase or decrease) within the process septic tank
2	CE1	C flow from household to septic tank (C in grey water, Excreta, Flushwater)
3	CEf1	C flow in effluent to sewerage and drainage
4	CL1	C flow in effluent to soil
5	CFS1	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters - Cesspools

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(ST),fs	C transfer coefficient in faecal sludge from cesspool	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income group i in inventory year,		lognormal	0.30	Govt stats
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	Assumption
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	-	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	644.23	composition of urine, faeces,

						greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.03	Survey,2012

Carbon (C) flow calculation - Cesspools

No.	Symbol	Equation	Unit	Mean
1	dMC(2a)/dt	CE1-CL1-CFS1-CEf1-M1 (assuming = 0)	tC/y	0.00
2	CE1	aC,excreta x rST x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-6 (greywater(10% to septic tank)	tC/y	1,849,551.84
3	CEf1	((CE1-CFS1) x rSTeffluent_drain)-M1 gas	tC/y	521,507.40
4	CL1	(CE1-CFS1) x (1-rSTeffluent_drain)	tC/y	1,255,845.70
5	CFS1	CE1 x (kC(ST),fs) / Ffr	tC/y	55,486.56
6	M1gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	16,712.19
7	Efj	Bo x MCFj	tC/y	0.30
8	TOW	n x BOD x 0.001 x I x 365	tC/y	1,031,616,425.81

MFA of onsite sanitation systems – Septic Tank

Nitrogen (N) flow – Septic Tank

No.	Variables (tN/year)	Description
1	dMN(2b)/dt	N Stock change (increase or decrease) within the process septic tank
2	E2	N flow from household to septic tank (N in grey water, Excreta, Flushwater)
3	Ef2	N flow in effluent to sewerage and drainage
4	L2	N flow in effluent to soil
5	FS2	N flow in faecal sludge (see process on-site sanitation)
6	N2	N emissions as N20
7	GrW2	N flow from household to septic tank (N in greywater

Nitrogen (N) flow parameters – Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kN(ST),fs	N transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.09	Montangero and Belevi (2007)
2	rSTeffluent_drain	Ratio of septic tank effluent discharged into drainage	-	normal	0.92	Assumption
3	Ffr	Faecal sludge emptying frequency factor	-	lognormal	6.00	Montangero and Belevi (2007)
4	FNPR	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value
5	F NON-COM	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
6	FIND-COM	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.25	IPCC (2006), default value
7	Protien	Annual per capita protein consumption, kg/person/yr.		normal	66.58	FAO,2010
8	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Sybill report in Lai Xa
9	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Sybill report in Lai Xa
7	Fpop_cs	Fraction of population using Septic tank		normal	0.16	Survey
10	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.50	Assumption
12	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants

Nitrogen (N) flow calculations – Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMN(2b)/dt	NE2-NL2-NFS2-NEf2-N2 (assuming = 0)	tN/y	0.00
2	NE2	aN,excreta x rST x n x 365 x 10-6 + n x aN_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tN/y	26,481.81
3	NEf2	((NE2-NFS2) x rCSeffluent_ground)-N2gas	tN/y	20,625.00
4	NL2	(NE2-NFS2) x (1-rSTeffluent_drain)	tN/y	1,793.70
5	NFS2	NE2 x (kN(ST),fs) / Ffr	tN/y	4,060.54
6	N2gas	NEffluent • Efeffluent • 44 / 28	tN/y	2.56
7	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	325,830.02

Carbon (C) flow – Septic Tank

No.	Variables (tN/year)	Description
1	dMC(2b)/dt	C Stock change (increase or decrease) within the process septic tank
2	CA1-2a	C flow from household to septic tank (P in grey water, Excreta, Flushwater)
3	CA2a-3	C flow in effluent to sewerage and drainage
4	CA2a-16	C flow in effluent to soil
5	CA2a-FS	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters – Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(ST),fs	C transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income group i in inventory year,		lognormal	0.30	Govt stats
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	From Survey
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	-	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	644.23	Composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.03	Survey,2012
10	CN,GW	C content groundwater	mg/l	Lognormal	0.00	" DEVELOPMENT OF SITE-SPECIFIC
11	aC_excreta	C load excreta	gC/cap*day	Normal	80.19	IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS
12	aC_grey	C load grey water	gC/cap*day	Normal	26.00	USING THE SOIL-WATER PARTITION EQUATION "
13	BOD		g/per/day		48.40	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007).

14	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.50	

Carbon (C) flow calculations – Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMC(2b)/dt	CE2-CL2-CFS2-CEf2-M2 (assuming = 0)	tC/y	-0.00
2	CE2	aC,excreta x rST x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tC/y	352,295.59
3	CEf2	((CE2-CFS2) x rSTeffluent_drain)-M2 gas	tC/y	307,397.02
4	CL2	(E2-FS2) x (1-rSTeffluent_drain)	tC/y	26,774.46
5	CFS2	E2 x (kN(ST),fs) / Ffr	tC/y	17,614.78
6	M2gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	509.32
7	Efj	Bo x MCFj	tC/y	0.30
8	TOW	n x BOD x 0.001 x I x 365	tC/y	196,498,366.82

MFA of Biogas plant

Nitrogen (N) flow - Biogas plant

No.	Variables (tN/year)	Description
1	dMN(6)/dt	N Stock change within the process biogas latrine
2	E5	N flow from household to biogas latrine
3	Str	N flow in pig slurry
4	Ef5	N flow in effluent to sewerage and drainage
5	FS5	N flow in faecal sludge (see process on-site sanitation)
6	N5	N flow in gas used as energy for cooking

Nitrogen (N) flow parameters - Biogas plant

No.	Symbol	Description	Unit	Distribution	Mean (Min)	Reference/Remark
1	kN(BG),fs	N transfer coefficient in faecal sludge from biogas latrines	-	lognormal	0.09	Assumption (see septic tanks)
2	Ffr	Faecal sludge emptying frequency factor	year	lognormal	10.00	Montangero (2006), local farmers
3	Fstraw	N content in straw		Normal	0.16	Montangero (2007)
4	rBG	Ratio of Biogas Latrine effluent discharged into drainage			0.90	
5	Straw used					

Nitrogen (N) flow calculations - Biogas plant

No.	Symbol	Equation	Unit	Mean
1	dMN(6)/dt	NE5-Nstraw-NFS5-NEf5-N5gas	tN/y	0
2	NE5	aN,excreta x rBG x n x 365 x 10-6 + n x aN_grey x rgrey x 365 x 10-9	tN/y	138594.28
3	Nstraw	Kg straw used x Fstrawx 365 x 10-6	tN/y	0.00
4	NFS5	(Es) x (KN (BG),fs/Ffr	tN/y	1243.35
5	NEf 5(100% effluent from biogas to drainage sys)	(Es) x (1 - KN (BG),fs/Ffr	tN/y	137346.93
6	N5gas	NEffluent • Efeffluent • 44 / 28	tN/y	4.0001
7	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	509109.4

Carbon (C) flow - Biogas plant

No.	Variables (tN/year)	Description
1	dMC(5)/dt	C Stock change (increase or decrease) within the process septic tank
2	CA1-2a	C flow from household to septic tank (P in grey water, Excreta, Flushwater)
3	CA2a-3	C flow in effluent to sewerage and drainage
4	CA2a-16	C flow in effluent to soil
5	CA2a-FS	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters - Biogas plant

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(BG),fs	C transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income group i in inventory year,		lognormal	0.3	Govt stats
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	From Survey
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	0.00	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69518555	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	820.5897	composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.028	Survey,2012
10	CN,GW	C content groundwater	mg/l	Lognormal	0.002	"DEVELOPMENT OF SITE-SPECIFIC
11	aC_excreta	C load excreta	gC/cap*day	Normal	80.19	IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS
12	aC_grey	C load grey water	gC/cap*day	Normal	0.5	USING THE SOIL-WATER PARTITION EQUATION"
13	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.1	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007). C/N ratio =10 (6-10)(http://large.stanford.edu/courses/2010/ph240/cook2/)
14	rBG_effluent_drain	Ratio of septic tank effluent discharged into drainage	-	normal	0.90	

Carbon (C) flow calculations - Biogas plant

No.	Symbol	Equation	Unit	Mean
1	dMC(6)/dt	CE2-CL2-CFS2-CEf2-M2 (assuming = 0)	tC/y	0.000
2	CE5	aC,excreta x rBG_effluent_drain x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tC/y	855,678.88
3	CEf5	(CE2-CFS2) x rBG_effluent_drain	tC/y	747,007.666
4	CL5	(CE2-CFS2) x (1-rBG_effluent_drain)	tC/y	83,000.852
5	CFS5	CE2 x (kC(BG),fs) / Ffr	tC/y	25,670.367
6	M5gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	9,947.730
7	Efj	Bo x MCFj	tC/y	0.3
8	TOW	n x BOD x 0.001 x I x 365	tC/y	614057396.32

MFA of Scenario 2: The cesspools users change to use the septic tank while the septic tank users directly connected to offsite sanitation system and effluent from onsite sanitation system directly discharge to environment

MFA of Households

Nitrogen (N) flow – Households

No.	Variables (tN/year)	Description
1	dMN(1)/dt	N Stock change (increase or decrease) within the process household
2	NGW	N flow in water supply of total of water
3	NF	N flow in food
4	NE	N flow to on-site sanitation (excreta, greywater)
5	NGrW	N flow to sewerage and drainage network (greywater)
6	NKW	N flow to "solid waste collection"
7	NBL	N flow to atmosphere wr.t. Body loss
8	DW	N flow from drinking water

Nitrogen (N) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants
2	aN,food	N load food	g/cap*day	Normal	10.65	FAO
3	aHH_W	Household water consumption	l/cap*day	Normal	35.03	Survey,2012
4	NW	N content water	mg/l	Lognormal	6.30	Khanh (2000)
5	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Montangero (2007)
6	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data
7	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.10	
8	aN,kitchenwaste	N load in Grey water from Kitchen	gN/cap*day	Lognormal	0.80	Diaz et al. (1996); Rytz (2001); Schouw et al. (2002b); Strauss et al. (2003); Sinsupan (2004)
9	rN_body_loss	N losses from the human body to the air	-	Lognormal	0.04	Assessing nutrient fluxes in a Vietnamese rural area despite limited and highly uncertain data

Nitrogen (N) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMN(1)/dt	NF + NGW - NBL - NE - NGrW - NKW	tN/y	125,890.34
2	NF	n x aN,food x 365 x 10-6	tN/y	270,290.81
3	NGW	n x (aHH_GW x NW,GW) x 365 x 10-9	tN/y	5,599.50
4	NE	n×(aN excreta×10−6 +aN grey×rgrey ST×10−9)×365 and See On-site sanitation	tN/y	139,078.98
5	NGrW	n x aN_grey x (1- rgrey_ST) x 365 x 10-9	tN/y	89.06
6	NKW	n x aN,kitchenwaste x 365 x 10-9	tN/y	20.30
7	NBL	rN_body_loss x NF	tN/y	10,811.63

Carbon (C) flow - Households

No.	Variables (tN/year)	Description
1	dMC(1)/dt	C Stock change (increase or decrease) within the process household
2	CGW	C flow in water supply of total of ground water
3	CF	C flow in food
4	CE	C flow to on-site sanitation (excreta, greywater)
5	CGrW	C flow to sewerage and drainage network (greywater)
6	CKW	C flow to "solid waste collection"
7	CBL	C flow to atmosphere wr.t. Body loss

Carbon (C) flow parameters - Households

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
2	aC,food	C load food	g/cap*day	Normal	644.23	composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
3	aHH_GW	Household water consumption	l/cap*day	Normal	147.00	Survey,2012
4	CC,GW	C content water	mg/l	Lognormal	0.00	"DEVELOPMENT OF SITE-SPECIFIC
5	aC_excreta	C load excreta	gC/cap*day	Normal	132.00	IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS
6	aC_grey	C load grey water	gC/cap*day	Normal	26.00	USING THE SOIL-WATER PARTITION EQUATION"
7	rgrey_ST	Ratio greywater to sanitation system	%	Lognormal	0.11	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007). C/N ratio =10 (6-10)(http://large.stanford.edu/courses/2010/ph240/cook2/)
8	aC,kitchenwaste	C load in kitchen waste	gC/cap*day	Normal	161.06	E. Friedler (2004) Quality of individual domestic greywater Streams and its implication for on-site Treatment and reuse possibilities
9	rC_body_loss	C losses from the human body to the air	gC/cap*day	normal	0.32	Assumption

Carbon (C) flow calculations - Households

No.	Symbol	Equation	Unit	Mean
1	dMC(1)/dt	CF +CGW - CBL - CE - CGrW - CKW	tC/y	10,401,924.94
2	CF	n x aC,food x 365 x 10-6	tC/y	16,346,754.71
3	CGW	n x (aHH_GW x CC,GW) x 365 x 10-9	tC/y	7.46
4	CE	n×(aC excreta×10−6 +aC grey×rgrey ST×10−9)×365 and See On-site sanitation	tC/y	1,849,551.84
5	CGrW	n x aC_grey x (1- rgrey_ST) x 365 x 10-9)	tC/y	587.16
6	CKW	n x aC,kitchenwaste x 365 x 10-6	tC/y	4,086,688.68
7	CBL	rC_body_loss x population x 365/10-6	tC/y	7,994.63

MFA of onsite sanitation systems

Nitrogen (N) flow - Onsite sanitation system

No.	Variables (tN/year)	Description
1	dMN(2)/dt	N Stock change (increase or decrease) within the process on-site sanitation
2	NE	N flow from the household (excreta, greywater)
3	NEf	N flow in effluent to drainage system
4	NL	N flow in effluent to soil/groundwater
5	N	N flow in biogas to atmosphere

Nitrogen (N) flow parameters - Onsite sanitation system

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rCS	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

Nitrogen (N) flow calculations - Onsite sanitation system

No.	Symbol	Equation	Unit	Mean
1	dMN(2)/dt	NE-NEf-NNgas-NFS (assumming this to be 0)	tN/y	0.00
2	NE	NE1+NE2	tN/y	139,078.98
3	NEf	NEf1 + NEf2	tN/y	113,483.00
4	NFS	NFS1 + NFS2	tN/y	25,590.53
5	NNgas	NNgas1 + NNgas2	tN/y	5.44
6	NL	NL1+NL2	tN/y	0.00

Carbon (C) flow - Onsite sanitation system

No.	Variables (tN/year)	Description
1	dMC(2)/dt	C Stock change (increase or decrease) within the process on-site sanitation
2	CE	C flow from the household (excreta, greywater)
3	CEf	C flow in effluent to drainage and sewerage system
4	CF	C flow in faecal sludge to landfill
5	CL	C flow in effluent to soil

Carbon (C) flow parameters - Onsite sanitation system

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	rST	Ratio of households equipped with septic tank	%	normal	0.16	Survey(2012)
2	rPF	Ratio of households equipped with Cesspool	%	normal	0.84	Survey(2012)

Carbon (C) flow calculations - Onsite sanitation system

No.	Symbol	Equation	Unit	Mean
1	dMC(2)/dt	CE-CEf-CMgas-FS-CL (assumming this to be 0)	tC/y	0.00
2	CE	CE1+CE2	tC/y	1,849,551.84
3	CEf	CEf1 + CEf2	tC/y	1,721,866.54
4	CFS	CFS1 + CFS2	tC/y	110,973.11
5	CMgas	CMgas1 + CMgas2	tC/y	16,712.19
6	CL	CL1+CL2	tC/y	0.00

MFA of onsite sanitation systems – Septic Tank

Nitrogen (N) flow - Septic Tank

No.	Variables (tN/year)	Description
1	dMN(2b)/dt	N Stock change (increase or decrease) within the process septic tank
2	E2	N flow from household to septic tank (N in grey water, Excreta, Flushwater)
3	Ef2	N flow in effluent to sewerage and drainage
4	L2	N flow in effluent to soil
5	FS2	N flow in faecal sludge (see process on-site sanitation)
6	N2	N emissions as N20
7	GrW2	N flow from household to septic tank (N in greywater

Nitrogen (N) flow parameters - Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kN(ST),fs	N transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.09	Montangero and Belevi (2007)
2	rSTeffluent_drain	Ratio of septic tank effluent discharged into drainage	-	normal	0.92	Assumption
3	Ffr	Faecal sludge emptying frequency factor	-	lognormal	6.00	Montangero and Belevi (2007)
4	FNPR	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value
5	F NON-COM	Factor for non-consumed protein added to the		normal	1.10	IPCC (2006), default value

		wastewater				
6	FIND-COM	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.25	IPCC (2006), default value
7	Protien	Annual per capita protein consumption, kg/person/yr.		normal	66.58	FAO,2010
8	aN_excreta	N load excreta	gN/cap*day	Normal	7.09	Sybill report in Lai Xa
9	aN_grey	N load grey water	gN/cap*day	Normal	3.90	Sybill report in Lai Xa
10	Fpop_cs	Fraction of population using Septic tank (use% cesspool which convert to septic tank)		normal	0.84	Survey
11	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.01	Assumption
12	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Assuming 10% unregistered inhabitants

Nitrogen (N) flow calculations - Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMN(2b)/dt	NE2-NL2-NFS2-NEf2-N2 (assuming = 0)	tN/y	0.00
2	NE2	aN,excreta x rST x n x 365 x 10-6 + n x aN_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tN/y	139,029.50
3	NEf2	((NE2-NFS2) x rCSeffluent_ground)-N2gas	tN/y	108,292.15
4	NL2	Assumed to be zero	tN/y	9,416.93
5	NFS2	NE2 x (kN(ST),fs) / Ffr	tN/y	21,317.86
6	N2gas	NEffluent • Efeffluent • 44 / 28	tN/y	2.56
7	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	325,830.02

Carbon (C) flow - Septic Tank

No.	Variables (tN/year)	Description
1	dMC(2b)/dt	C Stock change (increase or decrease) within the process septic tank
2	CA1-2a	C flow from household to septic tank (P in grey water, Excreta, Flushwater)
3	CA2a-3	C flow in effluent to sewerage and drainage
4	CA2a-16	C flow in effluent to soil
5	CA2a-FS	C flow in faecal sludge (see process on-site sanitation)

Carbon (C) flow parameters - Septic Tank

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	kC(ST),fs	C transfer coefficient in faecal sludge from septic tanks	-	lognormal	0.30	Kristina Dahlman (2009)
2	Ui	Fraction of population in income group i in inventory year,		lognormal	0.30	Govt stats
3	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.18	From Survey
4	B0	Maximum CH4 producing capacity,	CH4/Kg BOD	normal	0.60	Default value IPCC
5	MCFj	Methane correction factor (fraction)		normal	0.50	Default value IPCC
6	R	Amount of CH4 recovered in inventory year,	kg CH4/yr	normal	-	Default value IPCC
7	n	Number of inhabitants	inhabitants	Normal	69,518,555.00	Survey,2012
8	aC,food	C load food	g/cap*day	Normal	644.23	Composition of urine, faeces, greywater and biowaste for utilisation in the URWARE model (2005)
9	aHH_GW	Household groundwater consumption	l/cap*day	Normal	35.03	Survey,2012
10	CN,GW	C content groundwater	mg/l	Lognormal	0.00	" DEVELOPMENT OF SITE-SPECIFIC
11	aC_excreta	C load excreta	gC/cap*day	Normal	80.19	IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS
12	aC_grey	C load grey water	gC/cap*day	Normal	26.00	USING THE SOIL-WATER PARTITION EQUATION "
13	BOD		g/per/day		48.40	C. Polprasert, Organic Waste Recycling (IWA Publishing, 2007). C/N ratio =10 (6-10) (http://large.stanford.edu/courses/2010/ph240/cook2/)
14	rgrey_ST	Ratio greywater to septic tank	%	Lognormal	0.50	

Carbon (C) flow calculations - Septic Tank

No.	Symbol	Equation	Unit	Mean
1	dMC(2b)/dt	CE2-CL2-CFS2-CEf2-M2 (assuming = 0)	tC/y	0.00
2	CE2	aC,excreta x rST x n x 365 x 10-6 + n x aC_grey x rgrey_ST x 365 x 10-9 (greywater(10% to septic tank))	tC/y	1,849,551.84
3	CEf2	((CE2-CFS2) x rSTeffluent_drain)-M2 gas	tC/y	1,602,470.07
4	CL2	(E2-FS2) x (1-rSTeffluent_drain)	tC/y	140,565.94
5	CFS2	E2 x (kN(ST),fs) / Ffr	tC/y	92,477.59
6	M2gas	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	14,038.24
7	Efj	Bo x MCFj	tC/y	0.30
8	TOW	n x BOD x 0.001 x I x 365	tC/y	1,031,616,425.81

MFA of offsite sanitation

Nitrogen (N) flow - offsite sanitation

No.	Variables (tN/year)	Description
1	dMN(3)/dt	N Stock change (increase or decrease) within the process on-site sanitation
2	Nefon	Portion of N flow from effluent of onsite sanitation system
3	Nefof	N flow in effluent to drainage system
4	NS	N flow in effluent to sludge/landfill
5	NofGas	N flow in biogas to atmosphere
5	dMN(3)/dt	N Stock change (increase or decrease) within the process on-site sanitation

Nitrogen (N) flow parameters - offsite sanitation

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	rTO	Ratio of wastewater from onsite effluent treated by Trickling filter+ oxidation ditch	%	Normal	0.01	Survey(2012)
2	rAL	Ratio of wastewater from onsite effluent treated by Aerated Lagoon	%	Normal	0.06	
3	rAS	Ratio of wastewater from onsite effluent treated by Activated Sludge	%	Normal	0.22	
4	rCW	Ratio of wastewater from onsite effluent treated by Constructed Wetland	%	Normal	0.00	
5	rOA	Ratio of wastewater from onsite effluent treated by Oxidation Ditch + Activated Sludge	%	Normal	0.04	
6	rSO	Ratio of wastewater from onsite effluent treated by Stabilization Pond + Oxidation Ditch	%	Normal	0.01	
7	rSC	Ratio of wastewater from onsite effluent treated by Stabilization Pond + Constructed Wetland	%	Normal	0.19	
8	rSP	Ratio of wastewater from onsite effluent treated by Stabilization Pond	%	Normal	0.10	
9	rOD	Ratio of wastewater from onsite effluent treated by Oxidation Ditch	%	Normal	0.29	
10	rRBC	Ratio of wastewater from onsite effluent treated by Rotating Biological Contactor	%	Normal	0.02	
11	rSBR	Ratio of wastewater from onsite effluent treated by Sequencing Batch Reactors	%	Normal	0.01	
12	rMSBR	Ratio of wastewater from onsite effluent treated by Modified Sequencing Batch Reactors	%	Normal	0.05	Survey(2012)

Nitrogen (N) flow calculations - offsite sanitation

No.	Symbol	Equation	Unit	Mean
1	dMN(3)/dt	NEfon -NEfof-NS-Nngas (assuming to be zero)	tN/y	-0.03
2	NEfon	Nef (Septic tank inflow from current situation)	tN/y	26,481.81
3	Nefof	NEfof (1+2+3+4+5+6+7+8+9+10+11+12)	tN/y	9,115.03
4	NS	NS (1+2+3+4+5+6+7+8+9+10+11+12)	tN/y	17,366.32
5	NNgas	NofGas (1+2+3+4+5+6+7+8+9+10+11+12)	tN/y	0.49

Carbon (C) flow - offsite sanitation

No.	Variables (tN/year)	Description
1	dMC(3)/dt	C Stock change (increase or decrease) within the process on-site sanitation
2	CefOn	Portion of C flow from effluent of onsite sanitation system
3	CEfof	C flow in effluent to drainage system
4	CS	C flow in effluent to sludge/landfill
5	CofGas	C flow in biogas to atmosphere

Carbon (C) flow parameters - offsite sanitation

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	rTO	Ratio of wastewater from onsite effluent treated by Trickling filter+ oxidation ditch	%	Normal	0.01	Survey(2012)
2	rAL	Ratio of wastewater from onsite effluent treated by Aerated Lagoon	%	Normal	0.06	
3	rAS	Ratio of wastewater from onsite effluent treated by Activated Sludge	%	Normal	0.22	
4	rCW	Ratio of wastewater from onsite effluent treated by Constructed Wetland	%	Normal	0.00	
5	rOA	Ratio of wastewater from onsite effluent treated by Oxidation Ditch + Activated Sludge	%	Normal	0.04	
6	rSO	Ratio of wastewater from onsite effluent treated by Stabilization Pond + Oxidation Ditch	%	Normal	0.01	
7	rSC	Ratio of wastewater from onsite effluent treated by Stabilization Pond + Constructed Wetland	%	Normal	0.19	
8	rSP	Ratio of wastewater from onsite effluent treated by Stabilization Pond	%	Normal	0.10	

9	rOD	Ratio of wastewater from onsite effluent treated by Oxidation Ditch	%	Normal	0.29	
10	rRBC	Ratio of wastewater from onsite effluent treated by Rotating Biological Contactor	%	Normal	0.02	
11	rSBR	Ratio of wastewater from onsite effluent treated by Sequencing Batch Reactors	%	Normal	0.01	
1	rMSBR	Ratio of wastewater from onsite effluent treated by Modified Sequencing Batch Reactors	%	Normal	0.05	Survey(2012)
13	BOD		g/per/day	Normal	48.40	Survey(2012)

Carbon (C) flow calculations - offsite sanitation

No.	Symbol	Equation	Unit	Mean
1	dMC(3)/dt	CEfon -CEfof-CS-Cngas (assuming to be zero)	tC/y	0.00
2	CEfon	CEfon	tC/y	1,721,866.54
3	CEfof	CEfof (1+2+3+4+5+6+7+8+9+10+11)	tC/y	5,832.94
4	CS	CS (1+2+3+4+5+6+7+8+9+10+11)	tC/y	1,712,663.72
5	CofGas	CofGas (1+2+3+4+5+6+7+8+9+10+11)	tC/y	3,375.46

MFA of trickling filter (TF)

Nitrogen (N) flow - trickling filter (TF)

No.	Variables (tN/year)	Description
1	dMN(3a)/dt	N Stock change (increase or decrease) within the process trickling filter
2	NEfcon1	N flow from effluent from onsite sanitation systems
3	NEfof1	N flow in effluent to water bodies
4	NOt1	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS	N flow into sludge
6	NofGas1	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - trickling filter (TF)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		6.40	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (6477HH * 3.2 (average no. of people in HH))	inhabitants	Normal	20,726.40	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Trickling filter + oxidation ditch	%	Lognormal	0.01	Assumption
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person /year		0.00	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Equation	Unit	Mean
1	dMN(3a)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon1	rOn_TO*Nefcon	tN/y	55.91
3	NEfof1	TKN * effluent *0.000365	tN/y	6.40
4	NS1	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	49.50
5	NofGas1	NEffluent • Efeffluent • 44 / 28	tN/y	0.00
6	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	4,042.15

Carbon (C) flow - trickling filter (TF) + oxidation ditch (OD)

No.	Variables (tN/year)	Description
1	dMC(3a)/dt	C Stock change (increase or decrease) within the process trickling filter+ oxidation ditch (OD)
2	CEfcon1	C flow from effluent from onsite sanitation systems
3	CEfof1	C flow in effluent to water bodies
4	CS1	C flow into sludge
5	CNofGas1	Methane emissions from plant

Carbon (C) flow parameters - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	5.77	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Trickling filter + oxidation ditch	%	Lognormal	0.01	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	20,726.40	Survey,2012

Carbon (C) flow calculation - trickling filter (TF) + oxidation ditch (OD)

No.	Symbol	Equation	Unit	Mean
1	dMC(3a)/dt		tC/y	0.00
2	CEfcon1	Cefcon*rOn_TO	tC/y	345.16
3	CEfof1	By Calcualtion of p'Dear using TOC	tC/y	5.77
4	CS1	CEfcon1-(CEfof1+CofGas1)	tC/y	320.90
5	CofGas1	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	18.49
6	Efj	Bo x MCFj	tC/y	0.18
7	TOW	n x BOD x 0.001 x I x 365	tC/y	366,152.58

MFA of Aerated Lagoon (AL)

Nitrogen (N) flow - Aerated Lagoon (AL)

No.	Variables (tN/year)	Description
1	dMN(3b)/dt	N Stock change (increase or decrease) within the process Aerated Lagoon (AL)
2	NEfcon2	N flow from effluent from onsite sanitation systems
3	NEfof2	N flow in effluent to water bodies
4	NOt2	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS	N flow into sludge
6	NofGas2	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Aerated Lagoon (AL)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		233.16	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (132391HH * 3.2 (average no. of people in HH))	inhabitants	Normal	423,651.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Aerated Lagoon	%	Lognormal	0.06	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010

5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Effluent	Emission factor	gN_20/person/year		0.00	
8	Protein	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Aerated Lagoon (AL)

No.	Symbol	Equation	Unit	Mean
1	dMN(3c)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon2	rOn_TO*Nefcon	tN/y	240.15
3	NEfof2	TKN * effluent *0.000365	tN/y	233.16
4	NS2	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	6.94
5	NofGas2	NEffluent • Efeffluent • 44 / 28	tN/y	0.06
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	75,111.05

Carbon (C) flow - Aerated Lagoon (AL)

No.	Variables (tN/year)	Description
1	dMC(3b)/dt	C Stock change (increase or decrease) within the process Aerated Lagoon (AL)
2	CEfcon2	C flow from effluent from onsite sanitation systems
3	CEfof2	C flow in effluent to water bodies
4	CS2	C flow into sludge
5	CNofGas2	Methane emissions from plant

Carbon (C) flow parameters - Aerated Lagoon (AL)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	287.68	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Aerated Lagoon (AL)	%	Lognormal	0.06	Assumption

3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	-	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	423,651.20	Survey,2012

Carbon (C) flow calculation - Aerated Lagoon (AL)

No.	Symbol	Equation	Unit	Mean
1	dMC(3b)/dt		tC/y	0.00
2	CEfcon3	Cefcon*rOn_TO	tC/y	1,482.74
3	CEfof3	By Calculations of p'Dear using TOC	tC/y	287.68
4	CS3	CEfcon1-(CEfof1+CofGas1)	tC/y	1,195.06
5	CofGas3	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.00
6	Efj	Bo x MCFj	tC/y	0.00
7	TOW	n x BOD x 0.001 x I x 365	tC/y	7,484,222.10

MFA of Activated Sludge (AS)

Nitrogen (N) flow - Activated Sludge (AS)

No.	Variables (tN/year)	Description
1	dMN(3c)/dt	N Stock change (increase or decrease) within the process Activated Sludge (AS)
2	NEfcon3	N flow from effluent from onsite sanitation systems
3	NEfof3	N flow in effluent to water bodies
4	NOt3	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS3	N flow into sludge
6	NofGas3	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Activated Sludge (AS)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	230.76	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (240284HH * 3.2 (average no. of people in HH))	inhabitants	Normal	768,908.80	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Activated Sludge (AS)	%	Lognormal	0.22	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.00	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Activated Sludge (AS)

No.	Symbol	Equation	Unit	Mean
1	dMN(3c)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon3	rOn_TO*Nefcon	tN/y	877.16
3	NEfof3	TKN * effluent *0.000365	tN/y	230.76
4	NS3	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	646.39
5	NofGas3	NEffluent • Efeffluent • 44 / 28	tN/y	0.00322
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge	tN/y	4,095.27

Carbon (C) flow - Activated Sludge (AS)

No.	Variables (tN/year)	Description
1	dMC(3c)/dt	C Stock change (increase or decrease) within the process Activated Sludge (AS)
2	CEfcon3	C flow from effluent from onsite sanitation systems
3	CEfof3	C flow in effluent to water bodies
4	CS3	C flow into sludge
5	CofGas3	Methane emissions from plant

Carbon (C) flow parameters - Activated Sludge (AS)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	147.72	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Activated Sludge (AS)	%	Lognormal	0.22	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	-	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	768,908.80	Survey,2012

Carbon (C) flow calculation - Activated Sludge (AS)

No.	Symbol	Equation	Unit	Mean
1	dMC(3c)/dt		tC/y	-
2	CEfcon3	Cefcon*rOn_TO	tC/y	5,415.56
3	CEfof3	By Calcualtion of p'Dear using TOC	tC/y	147.72
4	CS3	CEfcon1-(CEfof1+CofGas1)	tC/y	5,267.85
5	CofGas3	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	-

6	Efj	Bo x MCFj	tC/y	-
7	TOW	n x BOD x 0.001 x I x 365	tC/y	13,583,542.86

MFA of Constructed Wetland (CW)

Nitrogen (N) flow - Constructed Wetland (CW)

No.	Variables (tN/year)	Description
1	dMN(3d)/dt	N Stock change (increase or decrease) within the process Constructed Wetland (CW)
2	NEfcon4	N flow from effluent from onsite sanitation systems
3	NEfof4	N flow in effluent to water bodies
4	NOt24	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS4	N flow into sludge
6	NNofGas4	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Constructed Wetland (CW)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	1.89	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (616HH * 3.2 (average no. of people in HH))	inhabitants	Normal	1,971.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.00048	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Constructed Wetland (CW)

No.	Symbol	Equation	Unit	Mean
1	dMN(3d)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.00
2	NEfcon4	rOn_TO*Nefcon	tN/y	1.91
3	NEfof4	TKN * effluent *0.000365	tN/y	1.89
4	NS4	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	0.03
5	NofGas4	NEffluent • Efeffluent • 44 / 28	tN/y	0.00
6	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge	tN/y	349.48

Carbon (C) flow - Constructed Wetland (CW)

No.	Variables (tN/year)	Description
1	dMC(3d)/dt	C Stock change (increase or decrease) within the process Constructed Wetland (CW)
2	CEfcon4	C flow from effluent from onsite sanitation systems
3	CEfof4	C flow in effluent to water bodies
4	CS4	C flow into sludge
5	CofGas4	Methane emissions from plant

Carbon (C) flow parameters - Constructed Wetland (CW)

No.	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	8.54	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.00	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.67	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	-	Default value IPCC
8	I	Correction factor for additional industrial BOD			1.00	

		discharged into sewers				
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	1,971.20	Survey,2012

Carbon (C) flow calculation - Constructed Wetland (CW)

No.	Symbol	Equation	Unit	Mean
1	dMC(3d)/dt		tC/y	-
2	CEfcon4	Cefcon*rOn_TO	tC/y	11.80
3	CEfof4	By Calcualtion of p'Dear using TOC	tC/y	8.54
4	CS4	CEfcon1-(CEfof1+CofGas1)	tC/y	1.51
5	CofGas4	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	1.76
6	Efj	Bo x MCFj	tC/y	0.18
7	TOW	n x BOD x 0.001 x I x 365	tC/y	34,823.22

MFA of Oxidation Ditch + Activated Sludge (OD+AS)

Nitrogen (N) flow - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tN/year)	Description
1	dMN(3e)/dt	N Stock change (increase or decrease) within the process Oxidation Ditch + Activated Sludge (OD+AS)
2	NEfcon5	N flow from effluent from onsite sanitation systems
3	NEfof5	N flow in effluent to water bodies
4	NOt5	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS5	N flow into sludge
6	NNofGas5	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	tN/y		11.67	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (13609HH * 3.2 (average no. of people in HH))	inhabitants	Normal	43,548.80	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch + Activated Sludge	%	Lognormal	0.04	Assumption
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.10	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Equations	Unit	Value
1	dMN(3e)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon5	rOn_TO*Nefcon	tN/y	152.9
3	NEfof5	TKN * effluent *0.000365	tN/y	11.7
4	NS5	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	141.0
5	NofGas5	NEffluent • Efeffluent • 44 / 28		0.200
6	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		255138.8

Carbon (C) flow - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tC/year)	Description
1	dMC(3e)/dt	C Stock change (increase or decrease) within the process Oxidation Ditch + Activated Sludge (OD+AS)
2	CEfcon5	C flow from effluent from onsite sanitation systems
3	CEfof5	C flow in effluent to water bodies
4	CS5	C flow into sludge
5	CNofGas5	Methane emissions from plant

Carbon (C) flow parameters - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	6.31	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to OD+WL	%	Lognormal	0.04	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.30	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	43,548.80	Survey,2012

Carbon (C) flow calculation - Oxidation Ditch + Activated Sludge (OD+AS)

Sr. No	Variables (tC/year)	Equations	Unit	Value
1	dMC(3e)/dt			0.000
2	CEfcon5	Cefcon*rOn_TO		943.725

3	CEfof5	By Calcualtion of p'Dear using TOC		6.310
4	CS5	CEfcon1-(CEfof1+CofGas1)		898.563
5	CofGas5	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗		38.852
6	Efj	Bo x MCFj		0.18
7	TOW	n x BOD x 0.001 x I x 365		769333.1008

MFA of Rotating Biological Contactor (RBC)

Nitrogen (N) flow - Rotating Biological Contactor (RBC)

Sr. No	Variables (tN/year)	Description
1	dMN(3f)/dt	N Stock change (increase or decrease) within the process Rotating Biological Contactor (RBC)
2	NEfcon6	N flow from effluent from onsite sanitation systems
3	NEfof6	N flow in effluent to water bodies
4	NOt6	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS6	N flow into sludge
6	NNofGas6	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	14.24	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (40513HH * 3.2 (average no. of people in HH))	inhabitants	Normal	129,641.60	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to RBC	%	Lognormal	0.0186	

4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3f)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon6	rOn_TO*Nefcon	tN/y	74.6
3	NEfof6	TKN * effluent *0.000365	tN/y	14.2
4	NS6	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	60.3
	NofGas6	NEffluent • Efeffluent • 44 / 28		0.0181
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		22984.7

Carbon (C) flow - Rotating Biological Contactor (RBC)

Sr. No	Variables (tC/year)	Description
1	dMC(3f)/dt	C Stock change (increase or decrease) within the process Rotating Biological Contactor (RBC)
2	CEfcon6	C flow from effluent from onsite sanitation systems
3	CEfof6	C flow in effluent to water bodies
4	CS6	C flow into sludge
5	CNofGas6	Methane emissions from plant

Carbon (C) flow parameters - Rotating Biological Contactor (RBC)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	20.01	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to constructed wetland	%	Lognormal	0.0186	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	129,641.60	Survey,2012

Carbon (C) flow calculation - Rotating Biological Contactor (RBC)

Sr. No	Variables (tC/year)	Equations	Unit	Value
1	dMC(3f)/dt		tC/y	0.000
2	CEfcon6	Cefcon*rOn_TO	tC/y	460.340
3	CEfof6	By Calcualtion of p'Dear using TOC	tC/y	20.006
4	CS6	CEfcon1-(CEfof1+CofGas1)	tC/y	440.334
5	CofGas6	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		2290248.506

MFA of Sequencing Batch Reactors (SBR)

Nitrogen (N) flow - Sequencing Batch Reactors (SBR)

Sr. No	Variables (tN/year)	Description
1	dMN(3g)/dt	N Stock change (increase or decrease) within the process Sequencing Batch Reactors (SBR)
2	NEfcon7	N flow from effluent from onsite sanitation systems
3	NEfof7	N flow in effluent to water bodies
4	NOt7	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS7	N flow into sludge
6	NNofGas7	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	6.90	Montangero and Belevi (2007)
12	n	Number of inhabitants using the treatment system (6414HH * 3.2 (average no. of people in HH))	inhabitants	Normal	20,524.80	Assuming 10% unregistered inhabitants
10	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.007510	
7	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
6	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
5	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
	Efeffluent	Emission factor	g N20/person/year		0.0005	
	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	

4	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3g)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon7	rOn_TO*Nefcon	tN/y	30.1
3	NEfof7	TKN * effluent *0.000365	tN/y	6.9
4	NS7	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	23.2
	N6gas	NEffluent • Efeffluent • 44 / 28		0.0029
5	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge		3638.9

Carbon (C) flow - Sequencing Batch Reactors (SBR)

Sr. No	Variables (tC/year)	Description
1	dMC(3g)/dt	C Stock change (increase or decrease) within the process Sequencing Batch Reactors (SBR)
2	CEfcon7	C flow from effluent from onsite sanitation systems
3	CEfof7	C flow in effluent to water bodies
4	CS7	C flow into sludge
5	CNofGas7	Methane emissions from plant

Carbon (C) flow parameters - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	5.59	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.0075	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey

5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	20,524.80	Survey,2012

Carbon (C) flow calculation - Sequencing Batch Reactors (SBR)

Sr. No	Symbol	Equations	Unit	Value
1	dMC(2g)/dt		tC/y	0.000
2	CEfcon7	Cefcon*rOn_TO	tC/y	185.869
3	CEfof7	By Calcualtion of p'Dear using TOC	tC/y	5.593
4	CS7	CEfcon1-(CEfof1+CofGas1)	tC/y	180.275
5	CofGas7	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.0000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		362591.1168

MFA of Modified Sequencing Batch Reactors (MSBR)

Nitrogen (N) flow - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Variables (tN/year)	Description
1	dMN(3h)/dt	N Stock change (increase or decrease) within the process MSBR
2	NEfcon8	N flow from effluent from onsite sanitation systems
3	NEfof8	N flow in effluent to water bodies
4	NOt8	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS8	N flow into sludge
6	NNofGas8	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	0.00	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (6414HH * 3.2 (average no. of people in HH))	inhabitants	Normal	64,473.60	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to MSBR	%	Lognormal	0.0480	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND\text{-}COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON\text{-}COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3h)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon8	rOn_TO*Nefcon	tN/y	192.6
3	NEfof8	TKN * effluent *0.000365	tN/y	0.0
4	NS8	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	192.6
	N8gas	NEffluent • Efeffluent • 44 / 28		0.0090
5	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge		11430.8

Carbon (C) flow - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Variables (tC/year)	Description
1	dMC(3h)/dt	C Stock change (increase or decrease) within the process MSBR
2	CEfcon8	C flow from effluent from onsite sanitation systems
3	CEfof8	C flow in effluent to water bodies
4	CS8	C flow into sludge
5	CNofGas8	Methane emissions from plant

Carbon (C) flow parameters - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	46.49	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to MSBR	%	Lognormal	0.0480	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.00	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	64,473.60	Survey,2012

Carbon (C) flow calculation - Modified Sequencing Batch Reactors (MSBR)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3g)/dt	Equations	tC/y	0.000
2	CEfcon8	Cefcon*rOn_TO	tC/y	1,188.981
3	CEfof8	By Calcualtion of p'Dear using TOC	tC/y	46.493
4	CS8	CEfcon1-(CEfof1+CofGas1)	tC/y	1,142.487

5	CofGas8	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	0.0000
6	Efj	Bo x MCFj		0
7	TOW	n x BOD x 0.001 x I x 365		1138990.618

MFA of Stabilization Pond (SP)

Nitrogen (N) flow - Stabilization Pond (SP)

Sr. No	Variables (tN/year)	Description
1	dMN(3i)/dt	N Stock change (increase or decrease) within the process Stabilization Pond (SP)
2	NEfcon9	N flow from effluent from onsite sanitation systems
3	NEfof9	N flow in effluent to water bodies
4	NOt9	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS9	N flow into sludge
6	NNofGas9	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond (SP)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	108.28	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (109765HH * 3.2 (average no. of people in HH))	inhabitants	Normal	351,248.00	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.1005	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	

9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond (SP)

Sr. No	Symbol	Equations	tN/y	Mean
1	dMN(3i)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon9	rOn_TO*Nefcon	tN/y	402.9
3	NEfof9	TKN * effluent *0.000365	tN/y	108.3
4	NS9	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	294.5
	N9gas	NEffluent • Efeffluent • 44 / 28		0.0489
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		62274.4

Carbon (C) flow - Stabilization Pond (SP)

Sr. No	Variables (tC/year)	Description
1	dMC(3i)/dt	C Stock change (increase or decrease) within the process Stabilization Pond (SP)
2	CEfcon9	C flow from effluent from onsite sanitation systems
3	CEfof9	C flow in effluent to water bodies
4	CS9	C flow into sludge
5	CNofGas9	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond (SP)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	305.16	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to SBR	%	Lognormal	0.1005	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC

6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	351,248.00	Survey,2012

Carbon (C) flow calculation - Stabilization Pond (SP)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3i)/dt		tC/y	0.000
2	CEfcon9	Cefcon*rOn_TO	tC/y	2,487.193
3	CEfof9	By Calcualtion of p'Dear using TOC	tC/y	305.160
4	CS9	CEfcon1-(CEfof1+CofGas1)	tC/y	1,346.393
5	CofGas9	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	835.64
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		6205147.168

MFA of Stabilization Pond + Constructed Wetland (SP+CW)

Nitrogen (N) flow - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Variables (tN/year)	Description
1	dMN(3j)/dt	N Stock change (increase or decrease) within the process Stabilization Pond + Constructed Wetland
2	NEfcon10	N flow from effluent from onsite sanitation systems
3	NEfof10	N flow in effluent to water bodies
4	NOt10	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS10	N flow into sludge
6	NNofGas10	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	6.41	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (81327HH * 3.2 (average no. of people in HH))	inhabitants	Normal	260,246.40	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Constructed Wetland	%	Lognormal	0.1937	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Equations	Unit	Mean
1	dMN(3j)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon10	rOn_TO*Nefcon	tN/y	776.6
3	NEfof10	TKN * effluent *0.000365	tN/y	6.4
4	NS10	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	770.2
	N10gas	NEffluent • Efeffluent • 44 / 28		0.0363
5	N effluent	(n • protein • Fnpr • Fnon − con • Find −com) − N sludge		46140.3

Carbon (C) flow - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Variables (tC/year)	Description
1	dMC(3j)/dt	C Stock change (increase or decrease) within the process Stabilization Pond + Constructed Wetland
2	CEfcon10	C flow from effluent from onsite sanitation systems
3	CEfof10	C flow in effluent to water bodies
4	CS10	C flow into sludge
5	CNofGas10	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	19.04	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Constructed Wetland	%	Lognormal	0.1937	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	260,246.40	Survey,2012

Carbon (C) flow calculation - Stabilization Pond + Constructed Wetland (SP+CW)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3j)/dt		tC/y	0.000
2	CEfcon10	Cefcon*rOn_TO	tC/y	4,794.752

3	CEfof10	By Calcualtion of p'Dear using TOC	tC/y	19.044
4	CS10	CEfcon1-(CEfof1+CofGas1)	tC/y	4,156.567
5	CofGas10	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	619.1415
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		4597512.902

MFA of Stabilization Pond + Oxidation Ditch (SP+OD)

Nitrogen (N) flow - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Variables (tN/year)	Description
1	dMN(3k)/dt	N Stock change (increase or decrease) within the process Stabilization Pond + Oxidation Ditch
2	NEfcon11	N flow from effluent from onsite sanitation systems
3	NEfof11	N flow in effluent to water bodies
4	NOt11	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS11	N flow into sludge
6	NNofGas11	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	3.29	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (61965HH * 3.2 (average no. of people in HH))	inhabitants	Normal	198,288.00	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Oxidation Ditch	%	Lognormal	0.0072	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010

5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Equations	Unit	Value
1	dMN(3k)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon11	rOn_TO*Nefcon	tN/y	28.7
3	NEfof11	TKN * effluent *0.000365	tN/y	3.3
4	NS11	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	25.4
	N11gas	NEffluent • Efeffluent • 44 / 28		0.0276
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		35155.4

Carbon (C) flow - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Variables (tC/year)	Description
1	dMC(3k)/dt	C Stock change (increase or decrease) within the process Stabilization Pond + Oxidation Ditch
2	CEfcon11	C flow from effluent from onsite sanitation systems
3	CEfof11	C flow in effluent to water bodies
4	CS11	C flow into sludge
5	CNofGas11	Methane emissions from plant

Carbon (C) flow parameters - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	8.29	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Stabilization Pond + Oxidation Ditch	%	Lognormal	0.0072	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC
8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	198,288.00	Survey,2012

Carbon (C) flow calculation - Stabilization Pond + Oxidation Ditch (SP+OD)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3k)/dt		tC/y	0.00
2	CEfcon11	Cefcon*rOn_TO	tC/y	177.04
3	CEfof11	By Calcualtion of p'Dear using TOC	tC/y	8.29
4	CS11	CEfcon1-(CEfof1+CofGas1)	tC/y	-302.99
5	CofGas11	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	471.74
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		3,502,955.81

MFA of Oxidation Ditch (OD)

Nitrogen (N) flow - Oxidation Ditch (OD)

Sr. No	Variables (tN/year)	Description
1	dMN(3k)/dt	N Stock change (increase or decrease) within the process Oxidation Ditch
2	NEfcon11	N flow from effluent from onsite sanitation systems
3	NEfof11	N flow in effluent to water bodies
4	NOt11	N flow from other sources which contribute to total nitrogen in treatment plant
5	NS11	N flow into sludge
6	NNofGas11	Nitrous oxide emissions from plant

Nitrogen (N) flow parameters - Oxidation Ditch (OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TKN	Total Kjeldhal nitrogen in the effluent	-	lognormal	187.43	Montangero and Belevi (2007)
2	n	Number of inhabitants using the treatment system (182561HH * 3.2 (average no. of people in HH))	inhabitants	Normal	584,195.20	Assuming 10% unregistered inhabitants
3	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch	%	Lognormal	0.2932	
4	Protien	Annual per capita protein consumption	kg/person/yr.	normal	33.29	FAO,2010
5	$F_{IND-COM}$	Factor for industrial and commercial co-discharged protein into the sewer system		normal	1.00	IPCC (2006), default value
6	$F_{NON-COM}$	Factor for non-consumed protein added to the wastewater		normal	1.00	IPCC (2006), default value
7	Efeffluent	Emission factor	g N20/person/year		0.0005	
8	Protien	Annual per capita protein consumption, kg/person/yr.		normal	33.29	
9	F_{NPR}	Fraction of nitrogen in protein		normal	0.16	IPCC (2006), default value

Nitrogen (N) flow calculation - Oxidation Ditch (OD)

Sr. No	Symbol	Equations	tN/y	Mean
1	dMN(3k)/dt	(NEfcon1+N Ot1)-(NEfof1+NS+NNofGas1) (assuming it to be zero)	tN/y	0.0
2	NEfcon12	rOn_TO*Nefcon	tN/y	1175.3
3	NEfof12	TKN * effluent *0.000365	tN/y	187.4
4	NS12	NEfcon1 - (NEfof1 + NNofGas1)	tN/y	987.8
	NofGas12	NEffluent • Efeffluent • 44 / 28		0.0814
5	N effluent	(n • protein • Fnpr • Fnon – con • Find –com) – N sludge		103574.6

Carbon (C) flow - Oxidation Ditch (OD)

Sr. No	Variables (tC/year)	Description
1	dMC(3k)/dt	C Stock change (increase or decrease) within the process Oxidation Ditch
2	CEfcon12	C flow from effluent from onsite sanitation systems
3	CEfof12	C flow in effluent to water bodies
4	CS12	C flow into sludge
5	CofGas12	Methane emissions from plant

Carbon (C) flow parameters - Oxidation Ditch (OD)

Sr. No	Symbol	Description	Unit	Distribution	Value	Reference/Remark
1	TOCef	C in effluent	tC/y	normal	145.88	Kristina Dahlman (2009)
2	rOn_TO	Ratio of wastewater directed from onsite sanitation to Oxidation Ditch	%	Lognormal	0.2932	Assumption
3	Ui	Fraction of population in income group i in inventory year,		lognormal	0.668	Govt stats
4	Ti,j	fraction i in inventory year Income group: rural, urban high income and urban low income		lognormal	0.42	From Survey
5	B0	Maximum CH4 producing capacity,	CH_4/Kg BOD	normal	0.60	Default value IPCC
6	MCFj	Methane correction factor (fraction)		normal	0.80	Default value IPCC
7	R	Amount of CH4 recovered in inventory year,	kg CH_4/yr	normal	0.00	Default value IPCC

8	I	Correction factor for additional industrial BOD discharged into sewers			1.00	
9	n	Number of inhabitants using the treatment system	inhabitants	Normal	584,195.20	Survey,2012

Carbon (C) flow calculation - Oxidation Ditch (OD)

Sr. No	Symbol	Equations	Unit	Mean
1	dMC(3k)/dt		tC/y	0.000
2	CEfcon11	Cefcon*rOn_TO	tC/y	7,256.393
3	CEfof11	By Calcualtion of p'Dear using TOC	tC/y	145.881
4	CS11	CEfcon1-(CEfof1+CofGas1)	tC/y	5,720.677
5	CofGas11	[∑_(i,j) 〖(Ui·Ti.j·EF)] (TOW-S)-R〗	tC/y	1,389.8349
6	Efj	Bo x MCFj		0.48
7	TOW	n x BOD x 0.001 x I x 365		10320392.4