ESTIMATION AND PREDICTION OF GREENHOUSE GAS EMISSIONS FROM INDIVIDUAL SEPTIC TANK AND IMHOFF TANK

FADZLIN MD SAIRAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy in (Civil Engineering)

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

AUGUST 2019

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to my main supervisor, Dr. Aznah Nor Anuar, for encouragement, guidance, and friendship. I am also very thankful to my co-supervisor Assoc. Prof. Dr. Roselina Salleh @ Sallehuddin and Associate Prof. Dr. Khalida Muda for their advice and motivation.

I would also like to thank my colleagues at Universiti Teknologi Malaysia for their support. I am also pleased to acknowledge lecturers at the Department of Environmental Engineering, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia for their valuable advice and support.

This work would not have been possible without the support of Indah Water Konsortium staff at Skudai Unit, Johor.

And last but not least, I am grateful to my family for their endless support to keep me motivated throughout my study.

ABSTRACT

Domestic wastewater treatment system is one of the sources that emit greenhouse gases (GHG) to the environment mostly due to the microbial breakdown of organics in human waste. This study aimed to estimate and predict GHG emissions for selected on-site domestic wastewater treatment systems in Malaysia, which are Individual Septic Tanks (ISTs) and Imhoff Tanks. In this study, the GHG inventory was developed for on-site septic systems, including 25 Imhoff Tanks and 2 ISTs situated at one of the earliest residential areas in southern part of Peninsular Malaysia. Direct GHG emissions include emissions of methane that can be biological produced, emitted in sewers and during wastewater treatment. Whilst indirect GHG emissions include emissions of carbon dioxide from the usage of electricity to operate the treatment facility and nitrous oxide emissions from wastewater treatment effluent that is discharged into river. Referring to the Intergovernmental Panel on Climate Change (IPCC) (2006) method and adaptation of several widely-used accounting procedures, the GHG emissions from Imhoff Tanks were estimated based on wastewater data provided by Imhoff Tanks operator, Indah Water Konsortium (IWK), Skudai Unit, Johor. However, for IST, the primary wastewater data was analyzed in-situ. In order to establish GHG emission inventory for certain period and to estimate per-capita basis, the procedures to estimate GHG emissions from the selected onsite septic systems, were developed, which can be a guideline for other case studies in Malaysia. The inventory of GHG emissions for one-year period shows that under different Population Equivalent (PE), wastewater with higher Biological Oxygen Demand (BOD) concentrations produced more methane compared to wastewater with lower BOD concentrations. Furthermore, the anaerobic treatment process in Imhoff Tank contribute to the highest direct GHGs emissions, compared with the indirect emissions from electricity consumption and wastewater treatment effluent that is discharged into river. Based on trendline and R-squared value analysis of six-year estimation, data showed that Imhoff Tanks (without pumping station) treating wastewater from the lowest PE (260) has GHG emissions of 471 tCO_2-eq/year and the highest PE (2,120) has GHG emissions of 50,838 tCO_2-eq/year. For the Imhoff Tanks (with pumping station) treating wastewater from the lowest PE (214) has GHG emissions of 421 tCO_2-eq/year and the highest PE (2,840) has GHG emissions of 86,264 tCO_2-eq/year. The six-year data of GHG emission for 25 Imhoff Tanks were then analyzed using MATLAB® version 2017 to identify the parameters that significantly influence the GHG emissions based on linear regression model. The analysis seemed that PE and BOD influent concentration significantly influenced GHG emission. By using two functions in Excel® version 2016, which are FORECAST and TREND, prediction of future GHG emission was then done for Imhoff Tank (without pumping station) that treats wastewater from 640 PE and Imhoff Tank (with pumping station) that treats wastewater from 520 PE. Hence, the estimation of GHG emission from Imhoff Tanks in other areas in Malaysia can be predicted based on wastewater from the same population. GHG emissions from the two ISTs were also successfully estimated for per-capita basis using IPCC (2006) method and adaptation of Sasse (1998) model. The overall GHG emission results show that anaerobic treatment process in the studied domestic wastewater treatment systems release methane which has greater Global Warming Potential (GWP) impact to environment.

ABSTRAK

Sistem rawatan air sisa domestik adalah salah satu sumber yang mengeluarkan gas rumah hijau kepada alam sekitar di mana kebanyakannya disebabkan peleraian mikrob daripada bahan organik dalam najis manusia. Kajian ini bertujuan untuk menganggar dan meramal pelepasan gas rumah hijau bagi loji rawatan air sisa domestik di tapak yang dipilih di Malaysia, iaitu tangki septik individu (IST) dan Tangki Imhoff. Inventori gas rumah hijau telah dibangunkan untuk sistem rawatan di tapak iaitu 25 Tangki Imhoff dan 2 IST yang terletak di salah satu kawasan perumahan terawal di selatan Semenanjung Malaysia. Pelepasan GHG secara langsung termasuk pelepasan metana yang boleh dihasilkan secara biologi, dilepaskan dalam saliran pembentungan dan semasa rawatan air sisa. Sementara pelepasan GHG secara tidak langsung termasuk pelepasan karbon dioksida yang terhasil daripada penggunaan elektrik untuk operasi fasiliti rawatan, dan pelepasan nitrous oksida daripada efluen rawatan air sisa yang dibuang ke sungai. Merujuk kepada Panel Antara Kerajaan mengenai Perubahan Iklim (IPCC) (2006) dan adaptasi beberapa prosidur penilaian yang digunakan secara meluas, pelepasan gas rumah hijau dari tangki Imhoff dianggar berdasarkan data air sisa kumbahan yang dikumpulkan daripada pengendali sistem iaitu Indah Water Konsortium (IWK), Unit Skudai, Johor. Namun, bagi IST, data primer air sisa diperolehi melalui analisis sampel di tapak. Bagi mewujudkan inventori pelepasan gas rumah hijau untuk tempoh tertentu dan untuk menganggar nilai per kapita, prosidur untuk mengukur pelepasan gas rumah hijau dari loji rawatan air sisa domestik yang dipilih, telah dibangunkan, yang boleh dijadikan panduan untuk kajian kes lain di Malaysia. Inventori pelepasan GHG untuk tempoh satu tahun menunjukkan bahawa untuk sistem dengan kapasiti Penduduk Setara (PE) yang berbeza, air sisa kumbahan dengan kepekatan Permintaan Oksigen Biokimia (BOD) yang lebih tinggi menghasilkan lebih banyak metana daripada air sisa dengan kepekatan BOD yang lebih rendah. Tambahan pula, proses rawatan anaerobik di Tangki Imhoff, menyumbang kepada kadar tertinggi GHG disebabkan dari pelepasan secara langsung, berbanding dengan pelepasan tidak langsung dari penggunaan elektrik dan efluen rawatan air sisa yang dialirkan ke sungai. Sementara itu berdasarkan analisis tren dan nilai R-kuadrat untuk enam tahun, data menunjukkan Tangki Imhoff (tanpa stesen pam) yang merawat air sisa kumbahan dari PE yang paling rendah (260) melepaskan GHG sebanyak 471 tCO_2-eq / tahun, dan PE tertinggi (2,120) melepaskan GHG sebanyak 50,838 tCO_2-eq / tahun. Bagi Tangki Imhoff (dengan stesen pam) yang merawat air sisa kumbahan dari PE yang paling rendah (214) melepaskan GHG sebanyak 421 tCO_2-eq / tahun dan PE tertinggi (2,840) melepaskan GHG sebanyak 86,264 tCO2-eq / tahun. Data enam tahun pelepasan gas rumah hijau untuk 25 Tangki Imhoff kemudiannya dianalisis menggunakan MATLAB® versi 2017 untuk mengenal pasti parameter yang secara ketara mempengaruhi kepada anggaran pelepasan gas rumah hijau berdasarkan model regresi linear. Keputusan analisis menunjukkan PE dan BOD mempengaruhi pengiraan pelepasan gas rumah hijau dari Tangki Imhoff. Melalui dua fungsi dalam Excel® versi 2016, FORECAST dan TREND, ramalan pelepasan gas rumah hijau untuk masa depan kemudiannya dilakukan untuk Tangki Imhoff (tanpa pam) yang merawat kumbahan dari 640 PE dan Tangki Imhoff (dengan pam) yang merawat kumbahan dari 520 PE. Oleh itu, anggaran pelepasan gas rumah hijau dari Tangki Imhoff kawasan lain di Malaysia boleh diramalkan dengan rawatan kumbahan dari populasi yang sama. Pelepasan gas rumah hijau dari dua IST yang dikaji juga berjaya dianggarkan untuk nilai per kapita dengan menggunakan kaedah IPCC (2006) dan adaptasi daripada model Sasse (1998). Secara keseluruhan, proses rawatan anaerobik dalam sistem rawatan air sisa domestik yang dikaji melepaskan metana yang mempunyai impak Potensi Pemanasan Global (GWP) yang tinggi terhadap alam sekitar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASP	-	Activated Sludge Process
BOD	-	Biological Oxygen Demand
COD	-	Chemical Oxygen Demand
DOE	-	Department of Environment
GHG	-	Greenhouse Gas
GWP	-	Global Warming Potential
HRT	-	Hydraulic Retention Time
IPCC	-	Intergovernmental Panel on Climate Change
IST	-	Individual Septic Tank
IWK	-	Indah Water Konsortium
KeTTHA	-	Ministry of Energy, Green Technology and Water
MCF	-	Methane Correction Factor
MNRE	-	Ministry of Natural Resources and Environment
MSTE	-	Ministry of Science, Technology and the Environment
NC	-	National Communication
PE	-	Population Equivalent
SPAN	-	Suruhanjaya Perkhidmatan Air Negara
SP	-	Stabilization Pond
STP	-	Sewage Treatment Plant
UNFCCC	-	United Nations Framework Convention on Climate Change
U.S. EPA	-	U.S. Environmental Protection Agency
VSS	-	Volatile Suspended Solids
WERF	-	Water Environment Research Foundation
WWTP	-	Wastewater Treatment Plant

LIST OF SYMBOLS

Σ	-	Cumulative
atm	-	atmosphere
bsCOD	-	Biological soluble COD
B_o	-	Maximum methane producing capacity
BOD_5	-	5-day test BOD
CH_4	-	Methane
CO_2	-	Carbon Dioxide
CO_2e	-	CO_2 equivalent
Ef_j	-	Emission Factor
$EF_{EFFLUENT}$	-	Emission Factor for N_2O emissions from discharged to wastewater

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

The first national inventory of GHG emissions was established as a part of Malaysia's commitment under Articles 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC), which Malaysia government has signed on 9 June 1993 and endorsed on 17 July 1994. Under the Convention, Malaysia is required to prepare a national inventory of GHG emissions; identify, examine and prioritise GHG mitigation options; review and update assessment of vulnerability and adaptation to climate change; and prepare a National Communication to the Conference of Parties (COP) of the UNFCCC. In the initial National Communication (NC) document, the inventory of GHG emission for Malaysia was reported by the Ministry of Science, Technology and the Environment using the reference year 1994 (MSTE, 2000). The inventory was recorded for sector of energy, industrial processes, agriculture, land use change and forestry, and waste (including domestic wastewater treatment) based on methodologies prepared by the Intergovernmental Panel on Climate Change (IPCC), 1995. However, for domestic wastewater sector, the estimation is only on methane gas that directly emit from treatment process. Then, in 2009, the second National Communication (NC2) came out with national GHG inventory using the year 2000 database (MNRE, 2009), however, the report for waste sector (domestic and commercial wastewater treatment) also focused on methane emission based on IPCC 1996 Guidelines.

The first GHG inventory has provided a good foundation for the development of a more comprehensive national inventory in Malaysia. However, due to the lack of detailed database, inconsistencies in data sources, incomplete understanding on emissions method, and the emission factors and default values taken wholly from

IPCC guidelines, Malaysia can only produce imprecise estimation for domestic wastewater.

Therefore, the development of a proper database for estimation of GHG emissions from domestic wastewater treatment system in Malaysia is crucial. Furthermore, based on various actual system characteristics and operating conditions, the actual values of GHG emissions for domestic wastewater in Malaysia could be different from other countries.

In order to get better estimation of GHG emissions from domestic wastewater treatment system in Malaysia, this study is conducted to develop a new inventory for selected system based on IPCC and established methods. The GHG estimation comprises methane emission directly from liquid treatment processes as suggested by Monteith, Sahely, MacLean, & Bagley (2005); carbon dioxide emission from indirect activities including electricity consumption as suggested by Cakir & Stenstrom (2005), Bani Shahabadi, Yerushalmi, & Haghighat (2010) and Liu, Wei, Zhang, & Bi (2013); and nitrous oxide emission from wastewater treatment effluent (IPCC, 2006) that is discharged into river. Methane produced from sewage treatment (in this study refers to domestic treatment) was found to constitute about 5% of the global methane sources (El-Fadel & Massoud, 2001). Based on IPCC approach in 2006, wastewater as well as its sludge components can produce methane if it degrades anaerobically. The principal factor in determining the methane generation potential of wastewater is the amount of degradable organic material in the wastewater. Common parameters used to measure the organic component of the wastewater are Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Since BOD is more frequently reported for domestic wastewater, while COD is predominantly used for industrial wastewater, this study presents the inventory of methane emission using BOD concentration, where the standard measurement for BOD is a 5-day test (BOD5).

1.2 Problem Statement

GHG reduction is now becoming the most priority of countries in the world to protect our environment and minimize the impact of global warming and climate change. Many schemes have been launched by nations, which are very concern with the impact from any activities that can contribute to global warming. WWTPs are recognized as one of the larger minor sources of GHG emissions (i.e. carbon dioxide, methane, and nitrous oxide) into the atmosphere during the treatment processes and carbon dioxide from the energy demand of the plant (Sahely, MacLean, Monteith & Bagley, 2006). For domestic wastewater treatment, the current IPCC (IPCC, 2006) estimates methane and nitrous oxide emissions. Furthermore, for septic system, the IPCC approaches are based on steady state calculations (empirical approaches) without taking into account the wastewater treatment dynamics. In addition, some researchers estimated on particular wastewater treatment units only and do not consider the whole process e.g. Parravicini, Svardarl & Krampe (2016) studied on sludge treatment unit, Rodriguez-Caballero, Aymerich, Poch, & Pijuan (2014) investigated on plug-flow bioreactor, Foley, de Haas, Yuan, & Lant (2010) estimated nitrous oxide emission in biological nutrient removal units, Hiatt & Grady (2008) developed model to simulate emission of nitrous oxide from activated sludge unit, Cakir & Stenstrom (2005) analyzed GHG from aerobic and anaerobic treatment units, Monteith et al. (2005) estimated GHG from primary treatment units and activated sludge treatment units, Greenfield & Batstone (2005) estimated methane emission from anaerobic digestion units, Keller & Hartley (2003) studied on aerobic and anaerobic sludge treatment processes, and Batstone, Keller, Angelidaki, Kalyuzhnyi, Pavlostathis, Rozzi, Sanders, Siegrist & Vavilin (2002) developed model of anaerobic sludge treatment.

In order to estimate the GHG emissions from domestic wastewater treatment system in Malaysia especially for onsite wastewater treatment systems, which are commonly known as septic systems, this study is proposed as the first attempt to develop the inventory and prepare estimation based on the current IPCC and established methods. The inventory is developed using mostly from plant-specific data and general local data. Up to now, there is no particular institution in Malaysia especially Suruhanjaya Perkhidmatan Air Negara (SPAN) and Indah Water

Konsortium (IWK), the national sewerage company ever concerning to conduct comprehensive GHG emissions from onsite domestic wastewater treatment systems, which is an important step in reducing GHG emissions to the environment. Thus, the case studies are selected in Malaysia to estimate GHG emissions from septic systems, comprises directly from wastewater treatment processes and indirect activities including production of electricity. The expected results can give specific overview on how GHG emissions can be predicted from these septic systems when treating wastewater either for each Population Equivalent (PE), influent flowrate, or at specific organic loading rate (BOD or COD).

1.3 Research Objectives

IST and Imhoff Tank are two types of onsite domestic wastewater treatment system that easy to maintain and the construction cost is relatively cheap. However, there are some issues associated with these systems in Malaysia such as inadequacy to meet high effluent standard, poor operation and maintenance by entities and existence of too many systems to be properly supervised and controlled by the authorities. These septic systems are commonly treating raw wastewater of less than 5,000 PE. The most implemented technologies over 30 years ago in Malaysia, i.e. IST and Imhoff Tank are selected for this study, therefore this study is aimed to develop procedures to estimate GHG emissions through development of inventory for the ISTs and Imhoff Tanks based on actual wastewater plant data. The data will then be used to determine parameters that significantly influence GHG emissions from the Imhoff Tanks using MATLAB® (version 2017), which is a widely used high-performance language for technical computing. The historical time-based data will be also used to predict future trends of GHG emissions from Imhoff Tanks to the environment. In order to achieve the overall aim, the following specific objectives are defined:

(a) To develop procedures to estimate GHG emissions from the selected onsite domestic wastewater treatment systems (Individual Septic Tank and Imhoff Tank) in Malaysia.

(b) To estimate the GHG emissions through development of inventory for the selected onsite domestic wastewater treatment systems (Individual Septic Tank and Imhoff Tank) in Malaysia.

(c) To determine parameters that significantly influence the estimation of GHG emissions from the selected Imhoff Tanks using MATLAB® based on actual wastewater plant data.

(d) To predict future GHG emissions from the selected Imhoff Tanks based on historical time-based data.

The objectives of this study are targeted based on a hypothesis that GHG emissions from onsite septic systems, which treat domestic wastewater in tropical countries especially Malaysia are measurable and can contribute to global warming. The contribution of a GHG to global warming is commonly expressed by its Global Warming Potential (GWP), where carbon dioxide (CO_2) is used as a benchmark.

1.4 Scope of the Study

This study focuses on the development of inventory that can be used as a baseline data for estimating GHG emissions from the selected onsite domestic wastewater treatment systems in Malaysia, resulting from direct and indirect activities and also determination of parameters that significantly influence the estimation of GHG emissions from the studied systems using MATLAB® version 2017.

The case studies including two types of onsite domestic wastewater treatment system, i.e. IST, which is maintained by the premise owner and desludged by the national sewerage company, IWK based on request, and Imhoff Tank, which is operated by the same company.

IST was chosen because it is an existing technology, and can be found easily. Due to its simplicity, durability, little space required because of being underground, and its efficiency in comparison to price, this technology is implemented in many housing areas in Malaysia. Referring to Malaysian Sewerage Industry Guidelines (SPAN, 2011), there are two forms of septic tank widely used in Malaysia. The first type is a cast in-situ septic tank previously promoted by the Ministry of Health. It consists of a septic tank with a minimum of 24 hours hydraulic retention time followed by a dual size aggregate downflow filter media. The second type is the prefabricated septic tank manufactured locally using polyethylene, glass fibre reinforced plastic or reinforced precast concrete materials. The type of IST that was selected for this study is a cast in-situ septic tank that has been implemented more than 30 years ago. Imhoff tank is selected because it can be found easily along the road side of residential areas. Similar with IST, Imhoff Tanks that were selected for this study are cast in-situ septic tanks and have been used more than 30 years.

Nonetheless, this study did not cover most domestic wastewater treatment systems in Malaysia due to limited access to the plants for some security reasons and confidential issues. Therefore, the study is conducted based on research framework as summarized in Figure 1.1.

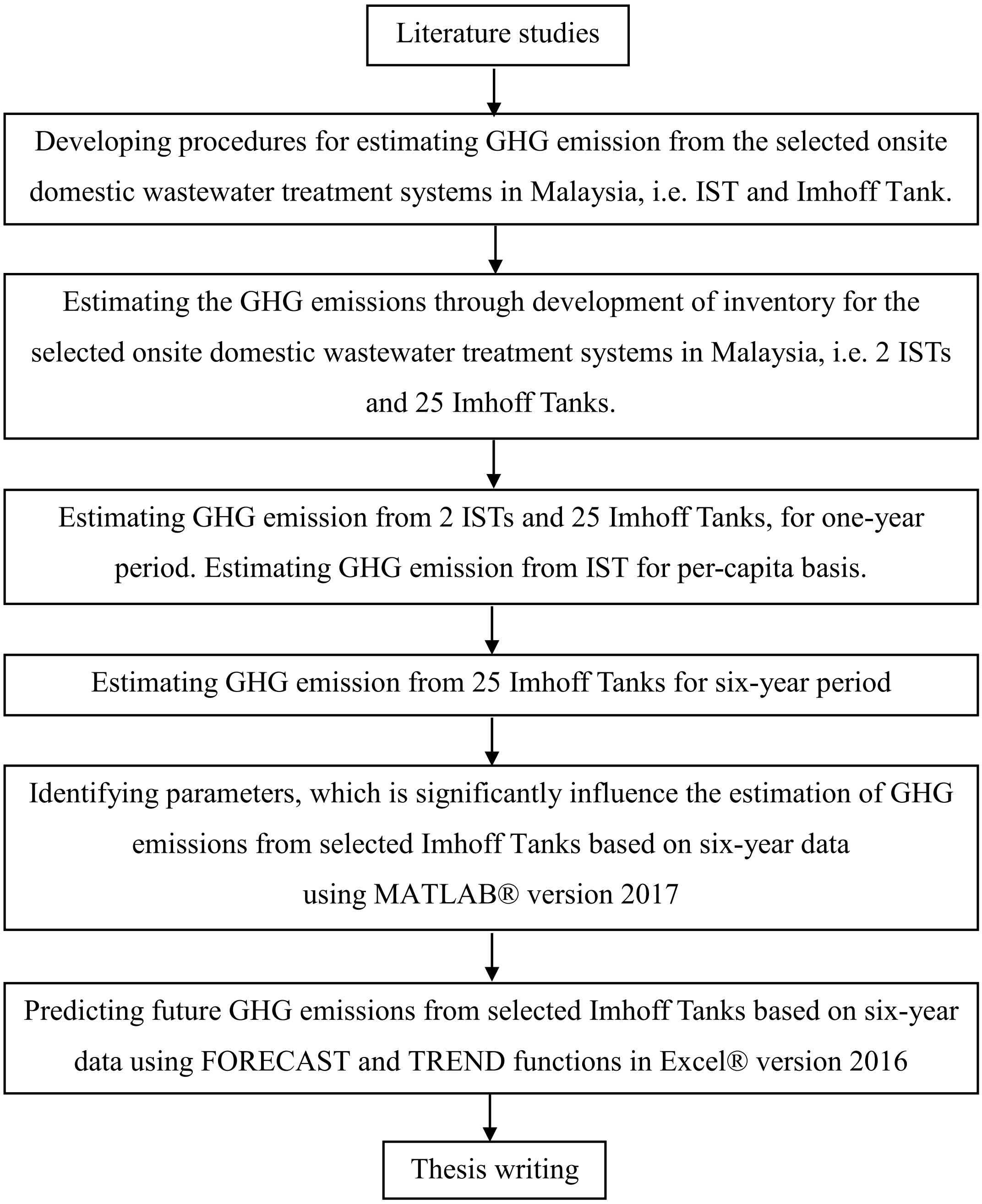

Figure 1.1 Flowchart of the research framework

1.5 Research Contribution

The impact of global warming and climate change around the globe is now clearly seen. In order to protect our environment, GHG reduction becoming the most priority of countries including Malaysia. Municipal or domestic wastewater treatment plants are one of the major contributors to the increase in the global GHG emissions and therefore it is necessary to carry out studies on estimation of GHG emissions in WWTPs (Zhan, Hu & Wu, 2018). However, the GHG emissions data from domestic wastewater treatment systems especially onsite septic systems are not properly compiled in Malaysia. Therefore, this study is conducted to contribute the following significant impact:

(a) To reduce the knowledge gap on GHG emissions from onsite septic systems, which treat domestic wastewater in Malaysia.

(b) To summarize the recent studies of GHG (mainly methane and nitrous oxide) generation and emission in domestic WWTPs.

(c) To highlight the concepts of direct emission and indirect emission, and describe the procedures to estimate GHG emissions from onsite domestic wastewater treatment systems.

(d) To contribute on the research and development of GHG emissions from onsite septic systems, as the outcomes of this research can give information to appropriate user either in the government or in the private sector and/or as a prediction system to assist in reducing GHG emission to the environment especially in Malaysia.

Even though the GHG inventory is developed by referring to the IPCC and referred methods, the wastewater data are ensured to be adopted from actual local plant. In addition, the outcomes of this study will enhance the understanding on the fundamentals of emissions of GHG from onsite domestic wastewater treatment processes; formulae and procedures. This study may also assist the wastewater operators' strategy to reduce energy consumption in conjunction with the aim of minimizing operation and maintenance cost of these onsite domestic wastewater treatment systems especially Imhoff Tank without forgetting any efforts to lessen the impact of global warming.

Based on review on similar studies globally especially in Malaysia, this study is very significant especially on the establishment of inventory that can be used as a baseline data for estimating GHG emissions from onsite domestic wastewater treatment system in Malaysia, resulting from direct and indirect activities. The determination of parameters that significantly influence estimation of GHG emissions from the selected systems using MATLAB® is also difference from other studies and is a new method for local case.

1.6 The Organization of the Thesis

The thesis consists of five chapters. Chapter I gives an introduction of this study including background of the study, statement of problem, objectives and scopes of study. The research contribution is also described and followed by the thesis structure. A literature review on domestic wastewater, wastewater treatment technologies including onsite septic system, i.e. IST and Imhoff Tanks, GHG emissions from domestic wastewater, and previous and present studies on GHG emissions, are described in Chapter II. Chapter III presents the overall research framework, procedures to estimate GHG emissions from the selected onsite septic systems, architecture of the GHG emissions inventory development for certain period and also estimation of GHG for per capita basis. Chapter IV presents the results and output of GHG emissions inventory for selected ISTs and Imhoff Tanks for one-year and six-year period, methane emissions per capita basis; identification of parameters that significantly influence the estimation of GHG emissions and prediction on future values, are also described in this chapter. The overall conclusions of the study and recommendations for future studies are explained in Chapter V.

REFERENCES

Abdel-Raouf, N., Al-Homaidan, A., & Ibraheem, I.B.M. (2012). Microalgae and wastewater treatment. Saudi Journal of Biological Sciences, 19, 257-275.

Academy of Sciences Malaysia (2015). Study on the current issues and needs for water Supply and wastewater management in Malaysia, Volume 2, Malaysia: ASM.

Akihisa, K. (2013, May 4). List of grid emission factor. Retrieved from the Institute for Global Environmental Strategies (IGES) website: http://pub.iges.or.jp/modules/envirolib/view.php?docid=2136

American Public Health Association (APHA) (1995). Standard Methods of American Public Health Association for the Examination of Water & Wastewater, 19th eds., ISBN: 978-0-87553-287-5.

Andrea Lenart Hicks (2010). Modeling greenhouse gas emissions from conventional wastewater treatment plants in South Carolina. Masters of Science, Clemson University, South Carolina.

Bani Shahabadi, M., Yerushalmi, L., & Haghighat F. (2010). Estimation of greenhouse gas generation in wastewater treatment plants - model development and application. Chemosphere, 78(9), 1085–1092.

Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T.M., Siegrist, H., & Vavilin, V.A. (2002). The IWA anaerobic digestion model No 1 (ADM1). Water Sci. Technol., 45(10), 65-73.

Bryant, I.M. (2012). Maximum carbon recovery from source-separated domestic wastewater. Masters of Science, Wageningen University and Research Centre, The Netherlands.

Butler, D., & Payne, J. (1995). Septic tanks: problems and practice. Building and Environment, 30(3), 419-425.

Cakir F. Y., & Stenstrom M. K. (2005). Greenhouse gas production: a comparison between aerobic and anaerobic wastewater treatment technology. Water Res., 39(17), 4197–4203.

Chai, C. Y., Zhang, D. W., Yu, Y. L., & Feng, Y. J. (2015). Carbon footprint of municipal wastewater treatment plants. Environment, Energy and Applied Technology – Sung & Kao (Eds), 279-282.

Chang, J., Kyung, D., & Lee, W. (2014). Estimation of greenhouse gas (GHG) emission from wastewater treatment plants and effect of biogas reuse on GHG mitigation. Advances in Environmental Research, 3(2), 173-183.

Crites, R., & G. Tchobanoglous (1998). Small and decentralized wastewater management systems. New York: McGraw-Hill.

Czepiel, P., Crill, P., & Harriss, R. (1993). Methane emissions from municipal wastewater treatment processes. Environmental Science and Technology, 27(12), 2472 - 2477.

Czepiel, P., Crill, P., & Harriss, R. (1995) Nitrous oxide emissions from municipal wastewater treatment. Environmental Science and Technology, 29(9), 2352-2356.

Daelman, M. R. J. (2014). Emissions of methane and nitrous oxide from full-scale municipal wastewater treatment plants. Doctor Philosophy, Ghent University, Belgium and Delft University of Technology, Netherlands.

El-Fadel, M., & Massoud, M. (2011). Methane emissions from wastewater management. Environmental Pollution, 114(2), 177-185.

Fayez A. A., & Ziad D. A. (2000). Methane emissions from domestic waste management facilities in Jordan - applicability of IPCC methodology. Journal of the Air & Waste Management Association, 50(2), 234-239.

Fukushima Y., Liu, P. W. G., Tsai, J. H., Lee, C. F., & Tseng, T. K. (2008). Preliminary investigation of greenhouse gas emissions from the environmental sector in Taiwan, Journal of the Air & Waste Management Association, 58(1), 85-94.

Foley, J., de Haas, D., Yuan, Z.G., & Lant, P. (2010). Nitrous oxide generation in full-scale biological nutrient removal wastewater treatment plants. Water Res., 44, 831-844.

Greenfield, P. F., & Batstone, D. J. (2005). Anaerobic digestion: impact of future greenhouse gases mitigation policies on methane generation and usage. Water Science and Technology, 52(1-2), 39-47.

Gupta, D., & Singh, S. K. (2012). Greenhouse gas emissions from wastewater treatment plants: a case study of Noida. Journal of Water Sustainability. 2(2), 131-139.

Gunady, M., Shishkina, N., Tan, H., & Clemencia Rodriguez (2015). A review of on-site wastewater treatment systems in Western Australia from 1997 to 2011. Journal of Environmental and Public Health, Hindawi Publishing Corporation.

Hastuti, E., Darwati, S., Soewondo, P., & Ebie, Y. (2019, May 27). Regulation and standards of decentralized domestic wastewater treatment in Indonesia. Retrieved from the Japan Education Center of Environmental Sanitation website: https://www.jeces.or.jp/spread/pdf/05Indonesia5ws.pdf

Hiatt, W. C., & Grady, C. P. L. Jr. (2008). An updated process model for carbon oxidation, nitrification and denitrification. Water Environ. Res., 80(11), 2145-2156.

Henze, M., Harremoës, P., la Cour, J. J., & Arvin, E. (2001). Wastewater treatment: biological and chemical processes. (3rd ed.) Berlin: Springer.

Indah Water Konsortium Sdn. Bhd. (IWK). (2013, June 17). Challenges and solutions of technical aspects of household water security: Malaysian cost experience. Retrieved from the 2nd Asia-Pacific Water Summit website: http://apws2013.files.wordpress.com/2013/05/08-malaysian-cost.pdf

Indah Water Konsortium Sdn. Bhd. (IWK) (2018, August 2). Sustainability Report 2012-2013. Retrieved from Indah Water Konsortium Sdn. Bhd. (IWK) website: http://apws2013.files.wordpress.com/2013/05/08-malaysian-cost.pdf

Ireland Environmental Protection Agency (Ireland EPA). (2019, May 23). Regulation of septic tanks. Retrieved from Ireland EPA website: https://www.epa.ie/water/wastewater/legislation/

Intergovernmental Panel On Climate Change (IPCC). (2011, August 15). Revised 1996 IPCC guidelines for national greenhouse gas inventories - workbook (Volume 2). Retrieved from the IPCC website: https://www.ipcc-nggip.iges.or.jp/public/gl/invs5.html

Intergovernmental Panel On Climate Change (IPCC) (2011, June 15). IPCC second assessment climate change 1995. A report of the Intergovernmental Panel on Climate Change. Retrieved from IPCC website: http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf.

Intergovernmental Panel On Climate Change (IPCC) (2007). Climate change (2007) synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the IPCC core writing team, Pachauri, R.K. & Reisinger, A. (eds.). Switzerland: IPCC, Geneva.

Intergovernmental Panel On Climate Change (IPCC) (2006). 2006 IPCC guidelines for national greenhouse gas inventories. Prepared by the national greenhouse gas inventories programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Japan: Institute for Global Environmental Strategies (IGES).

Intergovernmental Panel On Climate Change (IPCC) (1996). Climate Change 1995: The science of climate change. Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., & Maskell, K. (eds.), United Kingdom: Cambridge University Press, Cambridge.

Keller, J., & Hartley, K. (2003). Greenhouse gas production in wastewater treatment: process selection is the major factor. Water Sci. Technol., 47(12), 43-48.

Kim, D. (2014). Model development and system optimization to minimize greenhouse gas emissions from wastewater treatment plants. Doctor Philosophy, University of North Carolina, U.S.

Kinnicutt, L.P., Winslow, C. E. A., & Pratt, R.W. (1910). Sewage disposal, New York: John Wiley & Sons.

Lavigne, R., & Gloger, K. (2008). The carbon footprint of wastewater treatment. Boating on the Hudson and Beyond, 16, 45 - 48.

Liu, B., Wei, Q., Zhang, B., & Bi, J. (2013). Life cycle GHG emissions of sewage sludge treatment and disposal options in Tai Lake Watershed, China. Science of the Total Environment, 447, 361 – 369.

Marko, M.M., Nebojsa M.J., Goran B. B., Vanja M.S., & Milun J.B. (2015). Overview of the methane emissions from domestic wastewater in the Republic of Serbia, Desalination and Water Treatment, 1-10.

Mc Carty, P.L., Bae, J., & Kim, J. (2011). Domestic wastewater as a net energy producer-can this be achieved. Environmental Science and Technology, 45, 7100-7106.

Metcalf & Eddy, Inc. (1991). Wastewater Engineering: Treatment, Disposal, and Reuse. (3rd ed.), Singapore: McGraw-Hill.

Metcalf & Eddy, Inc. (2004). Wastewater Engineering: Treatment and Reuse. (4th ed.) Revised by George Tchobanoglous, Franklin L. Burton, and H. David Stensel, New York: McGraw Hill.

Milasinovic, M.M., Jovicic, N.M., Boskovic, G.B., Sustersic, V.M., & Babic, M.J. (2016). Overview of the methane emissions from domestic wastewater in the Republic of Serbia. Desalination and Water Treatment, 57, 16353–16362.

Ministry of Energy, Green Technology and Water Malaysia (KeTTHA) (2011, September 22). An overview of Malaysia's sewerage management. Retrieved from Water Environment Partnership in Asia (WEPA) website: http://www.wepa-db.net/pdf/1203forum/20.pdf

Ministry of Energy, Green Technology and Water Malaysia (KeTTHA) (2017). Green Technology Master Plan Malaysia 2017 – 2030. Malaysia: KeTTHA.

Ministry of Natural Resources and Environment (MNRE) (2009). Malaysia's Second National Communication (NC2). Submitted to the United Nations Framework Convention on Climate Change (UNFCCC), ISBN 978-983-44294-9-2.

Ministry of Science, Technology and the Environment Malaysia (MSTE) (2000). Malaysia Initial National Communication. Submitted to the United Nations Framework Convention on Climate Change (UNFCCC), July 2000.

Monteith, H.D., Sahely, H.R., MacLean, H.L., & Bagley, D.M. (2005). A rational procedure for estimation of greenhouse-gas emissions from municipal wastewater treatment plants. Water Environ. Res., 77, 390 - 403.

Moore, D. S., Notz, W. I, & Flinger, M. A. (2013). The basic practice of statistics. (6th ed.). New York: W. H. Freeman and Company.

Muna A. (2014). Streamlining the greenhouse gases reporting using Matlab for aluminium smelter. Masters of Science, Hamdan Bin Muhammed e-University (HBMeU), Dubai.

Nam, B.H. (2019, May 22). Current situation and policies on wastewater management in Vietnam. Retrieved from the Current situation and policies on wastewater management in Vietnam website: http://wepa-db.net/activities/2016/20160728/PDF/S1_Vietnam_MONRE.pdf

Nabavi-Pelesaraei, A., Abdi, R., & Rafiee, S. (2016). Neural network modeling of energy use and greenhouse gas emissions of watermelon production systems. Journal of the Saudi Society of Agricultural Sciences, 15, 38 - 47.

Oladoja, N.A. (2017). Appropriate technology for domestic wastewater management in under-resourced regions of the world. Appl. Water Sci., 7, 3391–3406.

Omid, A. (2012). Estimation of greenhouse gas emissions in wastewater treatment plant of pulp & paper industry. Doctor Philosophy, Concordia University, Canada.

Par, S. (2005). Control of nitrogen removal in activated sludge processes. Doctor Philosophy, Uppsala University, Sweden.

Paredes, M.G., Güereca, L.P., Molina, L.T., & Noyola, A. (2015). Methane emissions from stabilization ponds for municipal wastewater treatment in Mexico. Journal of Integrative Environmental Sciences, 12(sup1), 139-153.

Parr, J., Smith, M., & Shaw, R. (2007). Technical brief on wastewater treatment options. Unpublished note, Water and Environmental Health at London and Loughborough (WELL).

Parravicini, V., Svardarl, K., & Krampe, J. (2016). Greenhouse gas emissions from wastewater treatment plants. Energy Procedia, 97, 246 – 253.

Prühlinger, T., Shmandiy, O., & Putala, P. (2006). Comparison of different methods of sludge management in Austria, Ukraine and Poland. A report for the intensive international course in solid waste management, 4C1352 - Spring 2006, Austria, Ukraine and Poland.

RM Consulting Group Pty Ltd (RMCG) (2018). Domestic wastewater management plan 2018. Reported to the rural city of Wangaratta (Council), August 2018.

Roda, I. R., Pocha, M., & Ban˜ares-Alca´ntarab, R. (2000). Conceptual design of wastewater treatment plants using a design support system. Journal of Chemical Technology and Biotechnology, 75, 73 - 81.

Rodriguez-Caballero, A., Aymerich, I., Poch, M., & Pijuan, M. (2014). Evaluation of process conditions triggering emissions of green-house gases from a biological wastewater treatment system. Science of the Total Environment, 493, 384 – 391.

Sahely, H.R., MacLean, H.L., Monteith, H.D., & Bagley, D.M. (2006). Comparison of onsite and upstream greenhouse gas emissions from Canadian municipal wastewater treatment facilities. J. Environ. Eng. Sci., 5(5), 405 – 415.

Sasse, L. (1998). DEWATS - Decentralized wastewater treatment in developing countries. Delhi, India: Bremen Overseas Research and Development Association (BORDA).

Scott, H.B. (2009). Multiple linear regression analysis: a matrix approach with MATLAB. Alabama Journal of Mathematics.

Seema, R.D. (2011). Estimation of greenhouse gases emissions from biological wastewater treatment plants at Windsor. Master of Applied Science, University of Windsor, Canada.

Sewerage Services Department (SSD), Ministry of Housing and Local Government (1998). Guidelines for Developers, Volume IV - Sewage Treatment Plants. (2nd ed.) Malaysia.

Sewerage Services Department (SSD), Ministry of Energy, Water and Communications (2006). Malaysian sewerage industry guidelines: Volume II - sewerage works procedures. (2nd ed.) Malaysia.

Suruhanjaya Perkhidmatan Air Negara (SPAN). (2011, May 20). Malaysian sewerage industry guidelines, volume V – septic tanks. Retrieved from the SPAN website: https://www.span.gov.my/document/upload/SJbdHsvUewq2bp3oFKYXfLXhv4S6gxKz.pdf

Suruhanjaya Perkhidmatan Air Negara (SPAN). (2019, May 22). Malaysian sewerage industry guidelines Jilid IV Sec. 3 - Sewage characteristics and effluent discharge requirements. Retrieved from the SPAN website: https://www.span.gov.my/article/view/malaysian-sewerage-industry-guidelines-msig

Sonune, A., & Ghate, R. (2004). Developments in wastewater treatment methods. Desalination. 167. 55-63.

Subbiah, R.M., Hamid, H. Sasidharan, V., & Tan, K.Y. (2007). Treatment of raw sewage using anaerobic process. Proceedings of the International Conference on Water Management and Technology Applications in Developing Countries. 14 – 16 May 2007. Kuala Lumpur Convention Centre, Malaysia.

Tasik Maju Realty Sdn. Bhd. (2010, Feb 1). Layout drawing of Individual Septic Tank (IST) and Imhoff Tank in Taman Ungku Tun Aminah. Available from: Tasik Maju Realty Sdn. Bhd.

Tchobanoglous, G, Burton, F.L., & Stensel, H.D. (2003). Wastewater Engineering: Treatment and Reuse, McGraw-Hill, New York, USA.

The MathWorks (2018, August 8). Computing GHG emissions (Input-Output). Retrieved from The MathWorks website: https://ww2.mathworks.cn/matlabcentral/fileexchange/63015-computing-ghg-emissions-input-output

Ujang, Z., & Henze, M. (2006). Municipal Wastewater Management for Developing Countries. London, IWA Publishing.

United States Environmental Protection Agency (US EPA) (2008). Inventory of U.S. greenhouse gas emissions and sinks: 1990-2006, Washington, D.C., USA.

U.S. EPA (2019, May 23). Effluent guidelines. Retrieved from the US EPA website: https://www.epa.gov/eg

U.S. EPA (2009). Inventory of U.S. greenhouse gas emissions and sinks: 1990-2007, EPA 430-R-09-004, Washington, D.C., USA.

U.S. EPA (1994). Guide to septage treatment and disposal, EPA/625/R-94/002. Washingtion, D.C., USA.

Yeruva, D.K., Jukuri, S., Velvizhi, G., Kumar, A.N., Swamy, Y.V., & Mohan, S.V. (2015). Integrating sequencing batch reactor with bio-electrochemical treatment for augmenting remediation efficiency of complex petrochemical wastewater. Bioresource Technology, 188, 33-42.

Victorian Auditor-General's Office (VAGO) (2018). Managing the environmental impacts of domestic wastewater. Independent assurance report to Parliament, September 2018.

Viessman W., & Hammer, M. J. (2005). Water Supply and Pollution Control, 7th ed., University of Michigan: Pearson Prentice Hall.

Water Environment Research Foundation (WERF) (2010). Final report: Evaluation of greenhouse gas emissions from Septic Systems. United Kingdom: IWA Publishing.

Wijaya, I.M.W., & Soedjono, E.S. (2018). Domestic wastewater in Indonesia: Challenge in the future related to nitrogen content. International Journal of GEOMATE, 15(47), 32-41.

Winneberger, J.H.T. (1984). Septic-tank systems a consultant's toolkit. Volume II-The septic tank. MI: The Butterworth Group, Ann Arbor.

World Business Council for Sustainable Development (WBCSD) & the World Resources Institute (WRI) (2001). GHG Protocol Corporate Reporting and Accounting Standard. USA: WBCSD & WRI.

Zhan, X., Hu, Z., & Wu, G. (2018). Greenhouse Gas Emission and Mitigation in Municipal Wastewater Treatment Plants. London, UK: IWA Publishing.

Zhou, X., Zheng, Y.F., Kang, N., Zhou, W., & Yin, J.F. (2012). Greenhouse gas emissions from sewage treatment in China during 2000-2009. Advances in Climate Change Research, 3(4), 205-211.