2019-03

Optimization of biogas production process in solid state digesters: option for minimizing deforestation in dry areas

Mahushi, Debora

NM-AIST

https://doi.org/10.58694/20.500.12479/269

OPTIMIZATION OF BIOGAS PRODUCTION PROCESS IN SOLID STATE DIGESTERS: OPTION FOR MINIMIZING DEFORESTATION IN DRY AREAS

Debora John Mahushi

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's of Environmental Science and Engineering of the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

March, 2019

ABSTRACT

Questionnaire survey, satellite images of 1987, 1997, 2002 and 2017 were used to assess energy sources, demand and the impact of fuel wood use to forest cover changes in Meru and Mwanga districts. The major energy sources identified in the study areas included cow dung cake, fire wood, charcoal, biogas and liquefied petroleum gas. The total energy demand consumed from these sources were 1400, 6289, 724 and 21 kg per day per total sampled households respectively. The area covered with forest in Meru district was found to be 1510, 1723, 1612 and 1327 ha for 1987, 1997, 2002 and 2017, respectively. Area covered with forest in Mwanga was 31 705, 31 988, 17 939 and 30 960 ha for 1987, 1997, 2002 and 2017 respectively. A batch study to verify the appropriate and optimal mixing ratio of feedstocks was also done. The mixing ratios of cow dung to water ranged from 2:1, 3:1 and 4:1. Total solids determined were 120, 150 and 170 mg/g of fresh sample for the ratios 2:1, 3:1 and 4:1, respectively. Biogas yield for 2:1, 3:1 and 4:1 were 21.4, 22.7 and 46.4 mL/gVS, respectively. These results showed a promising future of the technology which can be adopted by all solid state digester users living in dry areas. Lastly, fuel wood consumption is a real threat to forest, however, use of renewable energy such as biogas could save forest degradation.

DECLARATION

I, Debora John Mahushi do hereby declare to the senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

.... 12 March, 2019 ....

Debora John Mahushi **Date**

The above declaration is confirmed by

.... 19 March, 2019 ....

Dr. Revocatus L. Machunda **Date**

.... 19 MARCH 2019 ....

Prof. Alfred N. N. Muzuka **Date**

COPYRIGHT

CERTIFICATION

The undersigned certify that they have read the dissertation titled "Optimization of Biogas Production Process in Solid State Digesters: Option for minimizing Deforestation in Dry Areas" and recommended for examination in fulfillment of the requirement for the degree of Master's in Environmental Science and Engineering (EnSE) of the Nelson Mandela African Institution of Science and Technology (NM-AIST).

.... 19 March, 2019

Dr. Revocatus L. Machunda **Date**

.... 19 MARCH 2019

Prof. Alfred N. N. Muzuka **Date**

DEDICATION

This work is dedicated to my beloved parents; Rev. John Zephaniah Mahushi and Joyce Petro Matemani.

ACKNOWLEDGEMENTS

I would like to thank Dr. Revocatus L. Machunda and Prof. Alfred N. N. Muzuka my supervisors for their valuable advice, support, encouragement and guidance during the whole period of my studies. Special thanks goes to DAAD (Deutscher Akademischer Austauschdienst or German Academic Exchange Service) for sponsoring my studies through In-Country/In-Region Scholarship Programme Tanzania, 2015.

I am also grateful to Oikos East Africa for partial support during fieldwork through ECO-BOMA Project. I would like to acknowledge Mkwawa University College of Education and the Department of Physics in particular, for granting me the study leave that enable me achieve my dream.

My heartfelt gratitude goes to all staffs of the Department of Water Environmental Science and Engineering, the Nelson Mandela Institution of Science and Technology for being involved in one way or another to ensure a timely and successful completion of my studies.

It is also my pleasure to extend special thanks to Dr. Talam E. Kibona from Mkwawa University College of Education of the University of Dar es Salaam for encouragement and advice.

Last but not least, I would like to thank my parents, my brothers Dr. Daniel J. Mahushi, The late Malack J. Mahushi and Joshua J. Mahushi, my sisters; Naomi, Elizabeth, Naziel Eliakimu, Maria, Agnes, Mariam and Neema for their love, closeness, encouragement and moral support offered to me throughout my studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

CHNS/O	-	Carbon, Hydrogen, Nitrogen, Sulphur/ Oxygen
CN	-	Carbon/Nitrogen ratio
LPG	-	Liquefied Petroleum Gas
NM-AIST	-	Nelson Mandela African Institution of Science and Technology
SPSS	-	Statistical Package for Social Sciences
TDBP	-	Tanzania Domestic Biogas Program
TS	-	Total Solids
VFAs	-	Volatile Fatty Acids
VS	-	Volatile Solids
QGIS	-	Quantum Geographical Information System
SSD	-	Solid State Digester
FAO	-	Food and Agriculture Organization
NBS	-	National Bureau of Statistics
MNRT	-	Ministry of Natural Resources and Tourism
UTM	-	Universal Transverse Mercator
GCP	-	Ground Control Point

CHAPTER ONE

INTRODUCTION

1.1 Background

Forests are important sources of livelihoods to millions of people globally and contributes to national economic development of many countries (Sunderlin *et al.*, 2005). Forests provide fuel wood as the primary sources of energy, which occasionally meets as much as 90% of energy requirements in developing countries (Trossero, 2002). Forest and wood resources in Tanzania, which covers about 48 million hectors (MNRT, 2014) provide various goods and services including energy, construction materials and medicine.

The country is facing extraordinary loss of its forests up to present. Between 1990 and 2010, it lost an average of 403 350 ha per year which were estimated to be 19.4% (about 8 067 000 ha) of the forest cover within a period of twenty (20) years (Miya *et al.*, 2012). Through the periods of 1980-2010, the forest reserves in Tanzania have shown a substantial degradation mainly due to charcoal burning, logging, shifting agriculture, fire wood, pole cutting, expansion of commercial farms and climate change (Specht *et al.,* 2015). Forest degradation in Tanzania has been identified as a function of social, economic and governance factors such as human population growth, political instability of neighboring countries, poverty, urbanization, trade, expansion of agricultural lands, developing of new economic paths and infrastructure development (Miya *et al.,* 2012). Studies conducted in 1980s and 1990s report a strong relationship between population growth and deforestation in Central America, Africa, and South Asia (Rudel *et al.,* 2000). Deforestation is clearly linked with population growth if and only if the growing community depends much on forest products such as fuel wood, building materials, other goods and services (Miya *et al.,* 2012). Most studies rarely report that the greater part of consumption is by poor households. Sawe (2004) reported that, fuel wood are the most widely used sources of domestic energy in Tanzania and are among the most significant cause of forest degradation in many developing countries (Luoga *et al.,* 2000). The consumption of fuel wood in rural areas includes all dwellers, however limited studies have been carried out in pastoralist communities to find out the level of forests degradation and has remained the subject of significant discussion (Specht *et al.,* 2015). Statistically cleared forest in semi-arid areas are not well known (Specht *et al.,* 2015). Maasai communities residing in semi-arid areas previously were depending on milk and fresh meat as their main food but due to climate change, pastures for the cattle have been reduced allowing these communities to change their living style (Specht *et al.*, 2015). Changing of climatic conditions requires these communities to adopt new strategies including change of diet (from milk and fresh meat feeding to other types of food that entail more energy during preparation) (Specht *et al.*, 2015). Due to the dependence on fuel wood, forests goes on decreasing converting semi-arid areas into arid areas completely.

As the means of rescuing forest from further degradation, biogas technology which is a renewable and environmentally friendly source of energy has to be introduced. Since water is the great problem to semi-arid areas, solid state anaerobic digesters that require little amount of water during operation are of important.

This study was carried out to determine the operational performances of the Solid State Digester (SSD) installed in Mwanga cluster in northern Tanzania with the aim of improving their biogas production potentials. The prior purpose for establishment of SSD plants was to have a design with low water requirements and high biogas production per unit volume. The estimated biogas production was 1-1.5, 1.5-2.25 and 3 m^3/ day for digester with capacity of 4, 6 and 9 m^3 respectively (Kileo and Akyoo, 2014). However it has been reported that 34.1% of the installed digesters still produce insufficient biogas (Kileo and Akyoo, 2014), the main reason being poor feeding of the digesters using inappropriate mixing ratios of the feedstocks. The consequence is that even communities which could use biogas turn to non-environmental friendly sources of energy.

Findings from the field showed, the often use of mixing ratios such as 2:1 and 3:1 by the household might be affecting the availability of TS (Total Solids) and VS (Volatile Solids) in the substrate which consequently affect biogas production. This correspond with the study by Yi *et al.* (2014) which found out that when waste/cow dung is diluted, availability of TS and VS are affected. The more the waste is diluted, VS and TS do decrease. The decrease affects the amount of biogas to be generated since the production depends mostly on the availability of high amount of VS. Factors like: breed, growth stage of the animal and diet contributes much on the availability of VS, which vary significantly from area to area with time (Santana and Pound, 1980). Due to variations of VS from area to area, investigation of the right mixing ratio that gives the best and proper VS content for the selected study area (Mgagao) is of great importance. Additionally, this study provided basis for improving the biogas digesters planned for construction in similar dry areas such as Oldonyosambu and Ngarenanyuki in

Meru District. And lastly contributed on identifying the rate of forest degradation due to fuel wood use that was previously not known.

1.2 Problem statement

Forests in various places including the northern parts of Tanzania goes on being depleted due to high dependence on fuel wood as source of energy and other activities, consequently changing semi-arid areas into arid areas completely. However, the extent of forest cover depletion in the northern Tanzania remains poorly documented. In order to rescue forest deterioration, biogas technology which is a renewable and environmentally friendly source of energy has been seen and used as the alternative to fuel wood. Nevertheless, in semi-arid areas of the northern parts of Tanzania, biogas is produced in low amount (about 34.1%) of the installed wet and dry digesters (Kileo and Akyoo, 2014). Efforts have been made by Tanzania Domestic Biogas Program (TDBP) through modifying the wet reactor configuration to be used also for solid state digesters (Ng'wandu *et al.,* 2008). Despite the modifications, insufficient biogas production is still being reported. Factor like mixing ratio of feedstocks might be affecting the availability of TS and VS (which vary with time depending on breed, growth stage of the animal and diet) in the substrate. These factors need to be studied and improved. This study therefore, aims at documenting the extent of deforestation and optimizing biogas production process (through assessment of the mixing ratios and evaluate their contribution to ideal biogas production) in solid state digesters as the means for minimizing forest degradation in water scarce areas of Meru and Mwanga districts.

1.3 Justification of the problem

Lack of renewable sources of energy and insufficient production of biogas influences people to search for other energy sources like fuel wood which are detrimental to the environment (Panwar *et al.,* 2011; Renaud *et al.,* 2013). The dependence on fuel wood by the pastoralist communities living in arid and semi-arid areas contribute much to deforestation. Deforestation in semi-arid areas is poorly documented allowing the communities continue relying on the depleted resource, hence converting semi-arid to arid areas completely (Specht *et al.,* 2015). In order to save deforestation in arid and semi-arid areas, biogas technology which is a renewable and environmentally friendly source of energy has to be used. The available 27 digesters in Mgagao produce less amount of biogas that fails to suffice the need. Often use of mixing ratios such as 2:1 and 3:1 by the households in Mgagao affects the availability of TS and VS in the substrate which vary with time depending on breed, growth stage of the animal and diet, hence affecting biogas production. Therefore this reason called for assessing the effect of cow dung/water mixing ratios on biogas production in solid state digesters.

1.4 Objectives

1.4.1 General objective

To assess the energy demand and their impact on forest cover in water scarce areas of Mwanga and Meru district, and to undertake optimization of biogas production process in solid state digesters as possible option for minimizing deforestation.

1.4.2 Specific objectives

(i) To analyze existing energy sources, evaluate the energy demand and find out the impact of fuel wood use on forest cover within the pastoralists communities of Mwanga district (Mgagao) and Meru district (Ngarenanyuki and Oldonyosambu).

(ii) To optimize existing (in Mgagao) and new solid state digesters in (Meru) as alternative sources of energy.

1.5 Research questions

(i) What are existing energy sources, the current energy demand, and the impact of using the existing energy sources on forest cover in Maasai pastoralist communities of Mwanga and Meru district?

(ii) Can mixing ratios of the feedstock alone lead to improvement of biogas production in solid state digesters?

1.6 Significance of the study

The proposed study intended to provide solutions to problems of low biogas production in solid state digesters and forest cover deterioration to semi-arid areas. Similarly, adoption of the biogas technology by communities will reduce pressure on fuel wood use and thus reducing deforestation.

CHAPTER WO

LITERATURE REVIEW

2.1 Energy sources, demand and their impact on forest cover

The energy usage in most of developing countries constitutes of bio-energy, mainly in the form of fuel wood and cattle manure (Luoga *et al*., 2000). There are various existing energy sources such as fuel wood, cow dung, biogas, kerosene, coal, fossil fuels, electricity and solar energy which are used in cooking, lighting and other activities (Odhiambo, 2009). Due to inaccessibility of some of these sources of energy, people opt to rely on fuel wood.

Several studies report that, 89% of the total energy consumption in Tanzania is estimated to come from fuel wood while 9% and 2% comes from petroleum and electricity respectively, the remained percent is from biogas (Arvidson *et al.,* 2006; TDBP, 2012). As report earlier, reliance on certain type of energy depends on its availability, although this is indirectly connected with its demand (Arvidson *et al.,* 2006). Demand of a certain type of fuel depends on its calorific value, thermal efficiency and the useful heat it contains (Wargert, 2009). Energy demand in cooking from fire wood, charcoal and biogas can be estimated by measuring the amount (in kg or L) that is used in cooking per day by the respective number of people in the household. Fuels with higher useful heat are only required in less amount while those with lower useful heat they are required in large amount during cooking (Ng'wandu *et al.,* 2008). Energy fuel with high useful heat are more costly and less available to people with lower income, this influences most of the poor people to depend on the less costly fuel that is more available (Wargert, 2009). However to large extent the less costly and mostly used fuel such as fuel wood are not environmentally friendly since they result into clearance of forests (Saud *et al.,* 2012).

Biogas production is less costly and environmentally friendly, it is now becoming popular in many places and its demand can be calculated basing on the number of people and the type of food that is prepared per household per day. If 0.26 m^3 is the amount of biogas required to be consumed by one person per day in cooking (Deublein and Steinhauser, 2011), then total amount of biogas required to be spent by a certain number of people in a household can be determined. With a daily biogas production of about 3 m^3 per day for methane content of 55-70%, the probability of lighting even a lamp for about 20 hours per day is possible (Deublein and Steinhauser, 2011).

Forests provide fuel wood as the primary sources of energy which occasionally meets as much as 90% of energy requirements in developing countries (Trossero, 2002). Forests mostly provide fuel wood and other products however, the most unavoidable challenge associated with these consumptions is how to access them in terms that facilitate economic growth while respecting environment (Gorte and Sheikh, 2010). Consumption of fuel wood has been identified as one of the most significant cause of forest decline in most of developing countries which contributes to about 6% worldwide (Bhatt and Sachan, 2004; Miya *et al.,* 2012). About 58% of the energy supply in Africa comes from fuel wood. This cannot be neglected as a possible source of environmental distraction since its damage due to fuel wood harvesting can be significant if too many people depend on too few forested areas (Salim and Ullsten, 1999). Recently it has been reported that forest are being increasingly subjected to deforestation and degradation as demand for arable land, furniture, fuel wood and infrastructure (URT, 2012). The country is facing extraordinary loss of its forests where by between 1990 and 2010, the country has lost an average of 403 350 ha per year (Luoga *et al*., 2000; Miya *et al.,* 2012).

From 1980-2010, forest reserves in Tanzania have shown a substantial degradation chiefly due to charcoal burning and logging, encroachment for agriculture, fire wood, pole cutting, expansion of farms and climate change (URT, 2012).

Statistically the cleared forest areas due to fuel wood use in arid and semi-arid areas are not well known (Specht *et al.,* 2015). Since the impact of fuel wood use on forest cover is rarely reported in semi-arid areas, this study aimed at carrying out satellite image classification, determining energy sources that are used in cooking and calculating the energy demand from these energy sources. Due to the minimal production of biogas from the digester existing in semi-arid areas, this study also opted to find out the factors that affect biogas production and coming out with the solution that could optimize the production. Improvement of biogas production to these areas will allow the pastoralist communities to shift from fuel wood use to biogas which in no time could leave the environment safe.

2.2 Historical background of biogas and its production

Biogas is produced when organic matter undergo fermentation process in the closed system known as digester (Rasi *et al.,* 2007). Biogas is mainly composed of 50 to 70% methane, 30 to 40% carbon dioxide (CO_2) and low amount of other gases like hydrogen sulfide, water vapor, hydrogen sulfide and ammonia (Kavuma, 2013). In order to control biogas production process, some or all of the factors that affect the process need to be regulated through optimization process.

Biogas technology has been used for many years in different places of the world and its impact to conservation of forest has been experienced (Chaudhary, 2000). The process of producing biogas is a technology which is acquiring attractiveness daily and is more broadly accepted for use (Okonkwo *et al.*, 2016). Biogas has been used in the world as a renewable and environmental friendly source of energy since 1895 (Tietjen, 1975). To many places of the world like China, India, Europe, South America and Africa especially in sub Saharan countries including Tanzania, biogas has been used (Surendra *et al.*, 2014). Biogas is rarely used in many places especially to Maasai pastoralist communities living in semi-arid areas of Africa (Chaudhary, 2000). These communities proceed depending on non-environmentally friendly sources of energy such as fuel wood where by the dependence from these sources of energy affect mostly the environment since their availability and usage are directly linked with forest dilapidation. In Tanzania biogas use gained its popularity since 1990s, however, it has been operated successfully in few places only (Rasi *et al.*, 2007). Biogas in most areas of Tanzania has been initiated although after sometimes the production process failed due to circumstances which are known and some which are not known (Surendra *et al*, 2014). Since biogas is the only renewable energy that is less costly and can be generated easily, there is a great need for Tanzania to advocate biogas production and use rather than other sources of energy which are more costly and environmentally non-friendly.

2.3 Optimization of biogas production

Optimization of biogas production can be done by varying some or all of the factors affecting biogas production from the digester (Vetter *et al.*, 1990; Adelekan and Bamgboye, 2009; Dobre *et al.*, 2014). Optimization of biogas production in digesters involves various optimization techniques depending on the factors, therefore before performing it there is a need for selecting the specific techniques to be used in the process (Dobre *et al.*, 2014). In determining the specific technique to be improved, characteristics of the feedstock such as Total Solids (TS), Volatile Solids (VS), CN (Carbon/Nitrogen) ratio and mixing ratio need to be known and their effect on biogas production need to be studied (Kavuma, 2013).

2.4 Effect of TS, VS, CN and mixing ratio of substrates on biogas production

The total solid content (TS), volatile solids (VS) and carbon/nitrogen (CN) ratio of organic wastes influences anaerobic digestion performance (Pavan *et al.,* 2000). These parameters affect the performances of anaerobic digestion and may lead to the change of microbial morphology in the system (Yi *et al.,* 2014). Abbassi-Guendouz *et al.* (2012) and Yi *et al.* (2014) report that, for anaerobic solid state digesters, as %TS increases from 10-25, methane production increases and when %TS is 30 methanogens activities are inhibited. At high %TS content greater than 25%, substrate degradation is reduced and contributes to reduction of methane and biogas production (Fernández *et al.,* 2008; Forster-Carneiro *et al.,* 2008; Motte *et al.,* 2013). In wet digesters, biogas production do increase with increase in %TS from 7-10% where by above and below this percentage biogas production decreases (Yavini *et al.,* 2014; Ranade *et al.,* 1990). The study on the effect of %TS in biogas production was again report by Maamri and Amrani (2014) where the results on their research findings show that, as % TS concentration increases the amount of biogas produced also increase.

Biogas production rate and the volatile solids concentration in the digestion process have a great relationship (Gelegenis *et al.,* 2007). Biogas production tend to increase when percentage of volatile solids increases (Gelegenis *et al.,* 2007; Ozturk, 2012). According to KeChrist *et al.* (2017), volatile solids are indicators of potential methane production. The specific methane yield with regards to the source of volatile solids has been found to be not constant (KeChrist *et al.,* 2017), although when % volatile solids fall into the range of 28-90% it result into more biogas production (Ozturk, 2012).

The quality and availability of nutrients in feed show how much is fed to meet nutritional requirements and how much will be excreted in the manure (Egilson and Grieger, 2014). The available nutrients excreted in animal manure include: macronutrients (N, C, P, K,), micronutrients (Cu, Mn, Zn, Co, Mo, B) and trace elements (Dick, 2003). Nutrients that are not kept back by the animal are excreted and end in the manure. Livestock generally excrete 50 to 90 % of the nutrients they are served, basing on the animal species, stage of growth and the portion provided (feed source and supplements) (Dick, 2003). Nitrogen is excreted in feces and the urine. Soluble N is excreted in the urine while, organic N is excreted in the feces. The excreted quantity of C and N make the so called CN ratio which has a greater influence on biogas production (Egilson and Grieger, 2014). CN is the ratio of elemental carbon to elemental nitrogen present in the material (Ozturk, 2012). Each material has its own

CN ratio, but mixing two or more different materials can alter the overall CN ratio of the total feedstock (Ghasimi *et al.*, 2009). CN ratio is of great importance in biogas production since the bacteria responsible for anaerobic process require both C and N, as all living organisms do, but they consume carbon roughly 30 times faster than nitrogen (Ozturk, 2012). For optimal biogas production, CN ratio should range from 25 to 30 (Maishanu and Hussani, 1991). Its variation affect the pH of the slurry. The increase in carbon content gives rise to more carbon dioxide formation and hence lowers the pH value while high nitrogen value enhances production of ammonia gas that upturns the pH to the detriment of the micro-organisms (Dioha *et al.*, 2013). The variation of CN ratio was report by Dick (2003), which ranged from 6-28 for cattle dung in Manitoba (Fig.1). This was report to be caused by factors like: livestock type, stage of growth and feeding practices (all of which determine nutrient excretion rates), amount of bedding or water added to the sample, type of sample storage, time that the samples spends in storage and weather conditions (Dick, 2003). Therefore, these mighty be the reasons also for the variations of CN ratios to various places.

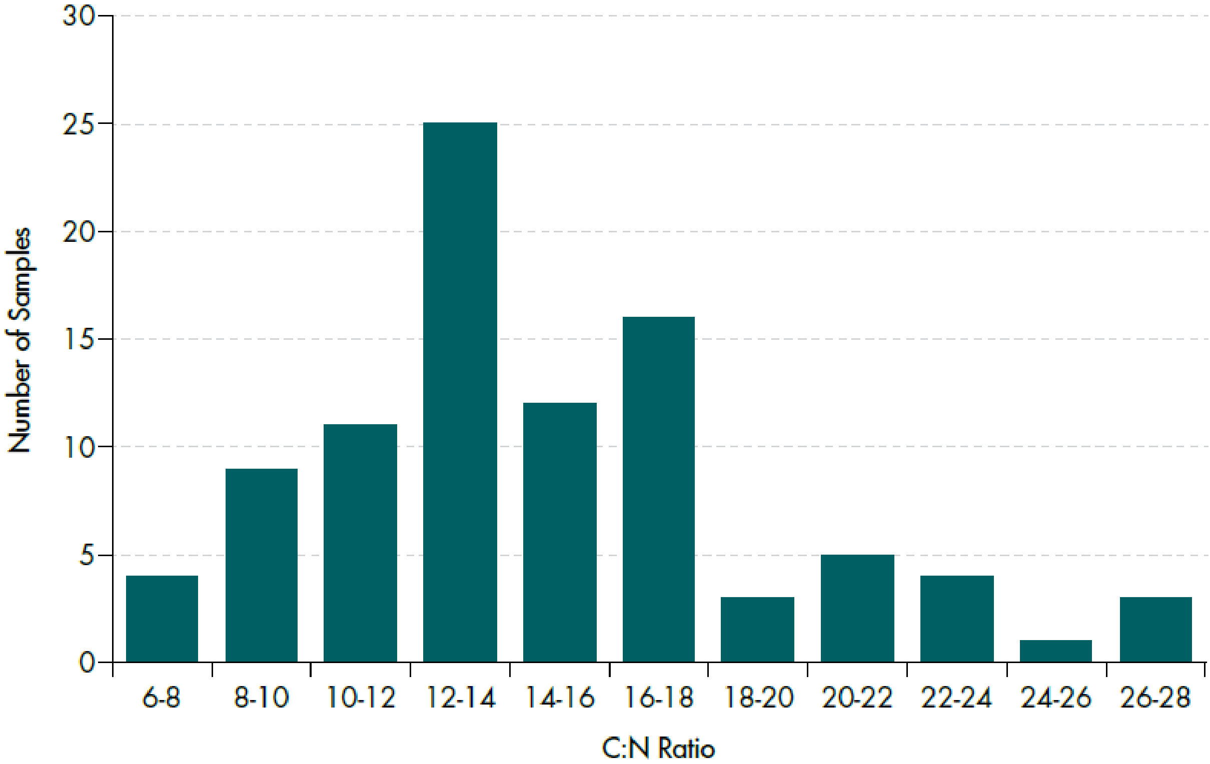

Figure 1**:** Distribution of C: N ratios for 93 dung samples collected from beef cattle farms in Manitoba (Dick, 2003)

Substrate/water mixing ratio have a very remarkable effect on %TS (Budiyono and Sumardion, 2014). %TS is affected when water is added to the substrate which leads to its decrease (Budiyono and Sumardion, 2014). Mixing ratio of substrates contributes much on the availability of microbial communities responsible for biogas production. Investigation on the effect of mixing ratio of wastes/water as presented by Adelekan and Bamgboye (2009) revealed that animal waste types and water mixing ratios jointly affect biogas yield. Therefore this study aimed also at evaluating the effect of fresh cow dung/water mixing ratio on biogas production in solid state anaerobic digester specifically in semi-arid areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area description

The study was conducted in Mwanga district (Lembeni and Njoro wards) Kilimanjaro region and Meru district (Oldonyosambu and Ngarenanyuki wards) Arusha region which are both semi-arid areas with approximately same climatic condition (Fig. 2).

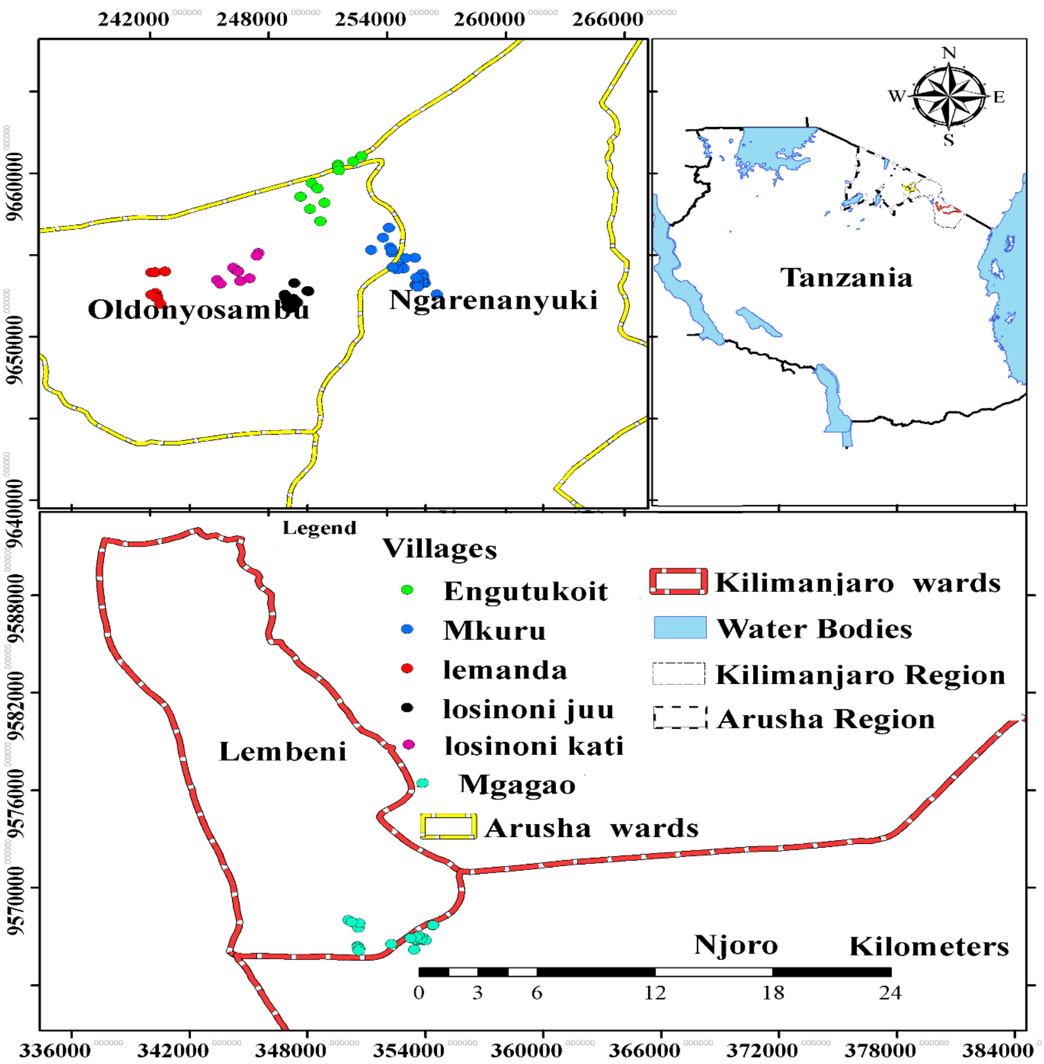

Figure 2: A map showing selected study areas surveyed in Meru and Mwanga districts

3.2 The impact of fuel wood use on forest cover: the case of semi-arid areas in northern Tanzania.

3.2.1 Analysis of existing energy sources and their demand

To understand the existing energy sources (fire wood, charcoal, biogas, cow dung cake and liquefied petroleum gas) and their demand a questionnaire survey was administered. The fuel wood demand quantification was done by weighing the amount of charcoal and fire wood used per day for each family surveyed. Before conduction of the questionnaire survey, sample size to be used was determined by using precision rate (*e*) of 7 and 93% confidence level for Meru and Mwanga (Dell *et al.*, 2002). The sample size obtained was 207 for the population with 5281 households in Meru. For Mwanga district, sample size was also calculated using equation 1 at the precision rate of 7% and 93% confidence level. The sample size obtained was 100 for the population with 1278 households. The type of interview conducted was both structured and unstructured. The interviewee who were not having the ability of reading and writing, oral interview was used where by the interviewer filled in all the answers given by the interviewee into the prepared questionnaires. The Statistical Package for the Social Sciences (SPSS) method was used in analyzing the data corrected from interview. Data were analyzed in frequencies and percentages after coding and presented by using charts. Unique identifier to each individual data were used and the text responses were coded in numerical form for easy analysis (example: 1 to reflect fire wood users, 2 to reflect charcoal users, 3 to reflect Liquefied Petroleum Gas users and 4 to reflect cow dung cake users). The data analyzed by the SPSS software were presented as shown in Figs. 5 and 6.

Through interview (Questionnaire survey,) energy sources existing in the study site were determined. The average domestic demand of charcoal, fire wood, dry cow dung cake and liquefied petroleum Gas used in cooking were identified.

$$n = \frac{N}{1+N(e)^2} \qquad 1$$

e = precision rate, n =Sample size, N = *Total population*

3.2.2 The effect of fuel wood use on forest cover

(i) Remote sensing data

Three-time series pairs of Landsat (TM and OLI) images for the year 1987, 1997, 2002 and 2017 covering the study area were utilized as the principal source of data. In order to avoid differences in vegetation phenology, the used images were captured on the same day or season (Dry periods of January-February and July-August), collected under relatively clear sky conditions.

(ii) Image pre-processing and processing

Images were radiometrically and geometrically calibrated and registered to the Universal Transverse Mercator (UTM) map coordinate system (i.e. UTM Zone 36 and 37 South, Spheroid Clarke 1880, Datum WGS 1984). Distinct features on the image (e.g. roads intersections, hills and other features) were used to establish Ground Control Points (GCP) for geometric calibration in order to match their corresponding coordinates on the ground. Atmospheric corrections were applied to correct the images for atmospheric scattering such as haze. Both radiometric and atmospheric correction were achieved through use of the Atmospheric Correction Tool in PCI (PCI, 2017). Imageries were then clipped to a boundary of study wards before classification, with a purpose of quick processing and better collection of sample points.

Stratified-random sampling technique following methods described in Foody (2002) was employed in acquiring training and validation samples for land use/cover classification in the study area. Fifty sample points per land use/cover class were randomly generated over the study area (Congalton, 1991; Lillesand *et al.*, 2014). The method was chosen because it reduces biases in collection of sample points, ensures that all classes are adequately represented, and an equal chance for samples (Foody, 2002). Samples were spaced 500 m interval to avoid auto-correlation (Rutherford *et al.*, 2007). The collected samples were initially assigned to 8-10 land use/cover classes using High resolution Google earth imageries, in case, for difficult and/or confusing classes to identify in Google image were assessed during the field work and based on expert knowledge of the study area. Image spectral signatures were visualized in scatter and/or signature plots to evaluate class signature separability using the Bhattacharyya Distance and or Transformed Divergence in PCI (PCI, 2017). Classes with an index (unit less) between 1.9 and 2.0 were considered separable.

Iterative process of merging and editing signature classes was performed until reasonably high-quality signature separability (For those classes of less than 1.9) achieved per class. The classification accuracy which is an indication of how well the image classified was calculated following procedures described by Zhan *et al.* (2002). The classification error and/or confusion matrix, per each land cover map was also calculated. Image classification was performed using the Maximum Likelihood Classification (MLC) in PCI Geomatica (PCI, 2017) using the approach in Fig. 3.

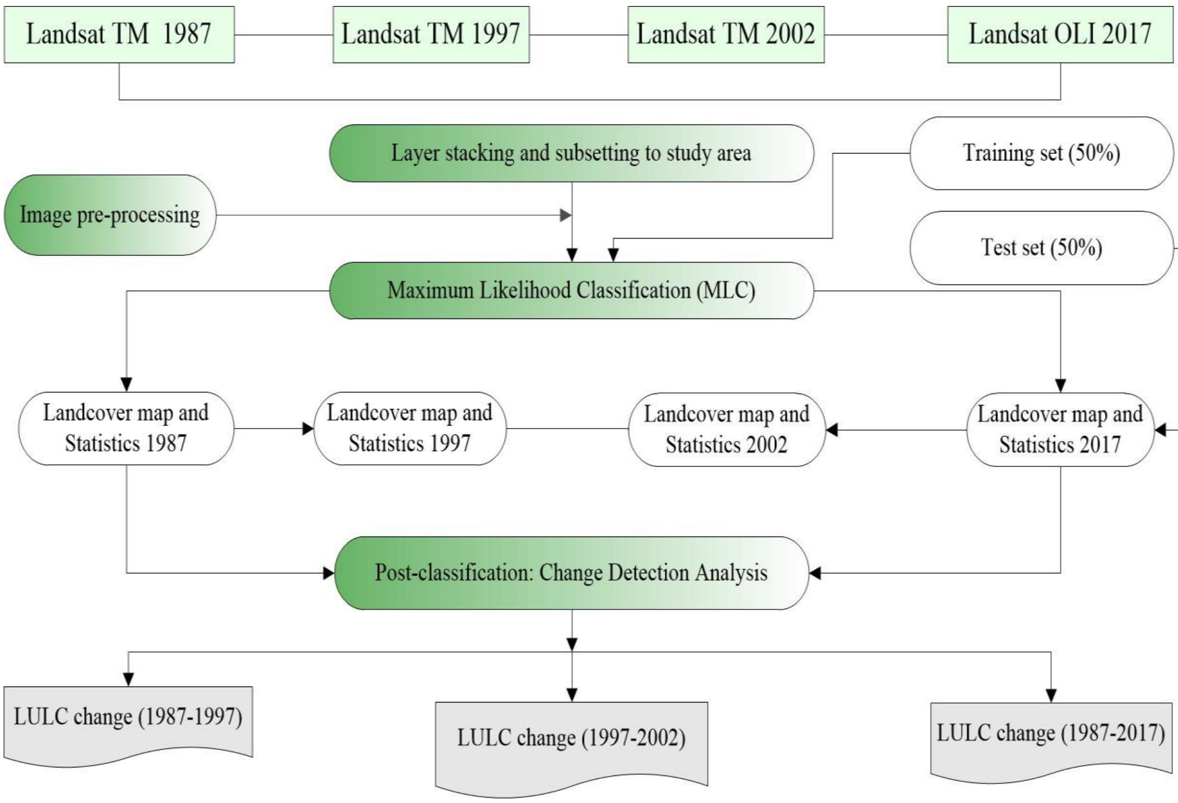

Figure 3**:** Approach for image classification using the Maximum Likelihood Classification (MLC*)*

(iii) Change detection/post classification analysis

Post-classification change detection method is the most widely used technique to ascertains the type, magnitude and spatial aspect of cover and use changes between two temporal images to detect the differences (Mengistu and Salami, 2007). In this study, a post-classification comparison between three time (1987-1997, 1997-2002 and 2002-2017) series images was performed using Semi-Automatic Classification Plugin in QGIS software (Congedo, 2013) to assess the land use changes that occurred between 1987-1997, 1997-2002 and 2002-2017.

3.3 Optimization of biogas production process in solid state digesters: the case of semi-arid areas in northern Tanzania.

3.3.1 Site selection and sample size

A survey was done at Mgagao using questionnaires to collect information from selected households. Information collected involved the management of the digesters from biogas users. About ten (10) questions were prepared where interviewee devoted fifteen minutes to answer the questions. Sample size was determined at precision rate (*e*) of 1% and 99% confidence level as recommended by Dobbin and Simon (2005). The sample size was calculated using equation 1 was 20.

$$n = \frac{N}{1+N(e)^2} \tag{2}$$

e = *Precision rate,* ***n*** =*Sample size,* **N** = *Total population*

3.3.2 Characterization of the feedstock

Fresh cow dung from the selected households of Mwanga (Kilimanjaro) and Meru (Arusha), were collected for analysis at the Nelson Mandela African Institution of Science and Technology (NM-AIST). In order to characterize the feedstock and provide more evidence of the best ratio to feed the digesters, experiments were carried out in the laboratory. The cow dung was characterized in terms of total carbon (C), total nitrogen (N), total Solids (TS) and volatile Solids (VS). Total Solids (TS) was determined at 105 ± 3°C, VS at 550°C in muffle furnace and carbon/nitrogen ratio by THERMO SCIENTIFIC™ FLASH™ 2000 ORGANIC ELEMENTAL ANALYZER operated at 950°C. Percentage total solid (TS) was determined by drying the fresh sample at 105°C for 12 hours and calculated (Equation 2) according to Singh *et al.* (2008).

$$\%\,TS = \frac{Weight\ of\ dry\ sample}{Weight\ of\ fresh\ sample} \times 100 \tag{3}$$

Volatile Solids were determined by drying the fresh samples at 105°C for 12 hours then heated at 550°C for three hours. The samples were left to cool for one hour, then weight of ash content and weight loss (VS) were calculated as per equation 3 (Singh *et al.*, 2008).

$$\%VS = \frac{Weight\ loss}{Weight\ of\ dry\ sample} \times 100 \tag{4}$$

3.3.3 The effect of mixing ratio on biogas production

The feedstock samples were obtained from cattle which are fed/pastured locally. A ratio of cow dung to water of 2:1, 3:1 and 4:1 were prepared in the laboratory. Anaerobic batch mode digesters were made from polyethylene bottles with a capacity of 10 L. The bottles were plugged with rubber plug fitted with delivery tube, the delivery tube were connected to measuring cylinder for biogas measurement. Due to solubility of biogas in water, measuring cylinders were filled with acidified saline water (prepared at pH of 0.5 and 95% NaCl).

During preparation of the feedstock, 2, 3 and 4 kg of cow dung were mixed with one kg of water per each to prepare 2:1, 3:1 and 4:1 mixing ratio respectively. Batch anaerobic digesters configuration and operation studies were performed to understand the best ratio of the feedstock mixture. Three experimental setup were set at the start of the experiment (Fig.4). The yielded biogas was measured per day by downward water displacement method using calibrated 2 litres cylindrical jar for each reactor. Average of the results obtained per each setup were calculated. The batch digesters were monitored for 60 days however daily production stopped on the 45th day in the 4:1 digester, 30th day in the 3:1 and 2:1 digesters.

Figure 4: Experimental laboratory set up for biogas production basing on different mixing ratios

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The impact of fuel wood use on forest cover: the case of semi-arid areas in northern Tanzania

4.1.1 Analysis of existing energy sources and their demand

The existing energy sources identified included liquefied petroleum gas, biogas, charcoal, fire wood and cow dung cake (Fig. 5). Fire wood was recognized to be the most preferred source of energy (by 63 and 78% of the users in Meru and Mwanga respectively) while LPG was used by 6% only of the user's surveyed (Fig. 6). For the 207 and 100 households assessed, 96.6 and 94.6% (N = 200 and 82) use fuel wood as the main source of energy for cooking respectively (Fig. 6). These included both households that depend on fire wood completely (N = 130 and 76), those that reported mixed use (fire wood, charcoal, dry cow dung, biogas and LPG) (N = 70 and 6). The remained number (7 and 18 households) for Meru and Mwanga reported to depend on Charcoal as the energy source in cooking.

The 2012 census conducted in Meru (Ngarenanyuki and Oldonyosambu wards), Lembeni and Njoro wards of Mwanga district reported a population of 31 623 people at the average family size of 4.8 which is approximately to 6588 households (NBS, 2012). With respect to the census total population, about 5102 household equivalent to 96.6% in Meru and 1048 households' equivalent to 94.6% in Mwanga depend on fire wood. 1400 kg of cow dung cake (in Meru), 2093 and 4196 kg of fire wood, 308 and 416 kg of charcoal for 100 and 207 households surveyed in Mwanga and Meru respectively were spent per day.

With 1278 and 5281 households in Mwanga and Meru respectively, 107 and 27 tons of fire wood, 4 and 11 tons of charcoal and 36 tons of cow dung cake (Meru) calculated to be used per day. Finding out the energy demand for Mwanga and Meru per year gives several tons of fire wood, charcoal and cow dung cake equivalent to 48 838, 5312 and 13 037 tons respectively. The calculated total amount of tons of trees cleared per year due to fuel wood usage was 101 953 tons. As reported by Kilahama (2008), in order to produce one tone of charcoal, about 10 tons of wood are required. Furthermore, 1 ha in Africa may contain up to 109 tons of wood (Engel and Frey, 1996). With this comparison, if more than 101 953 tons of wood are used annually then 935 ha/year of forest mighty be cleared for wood.

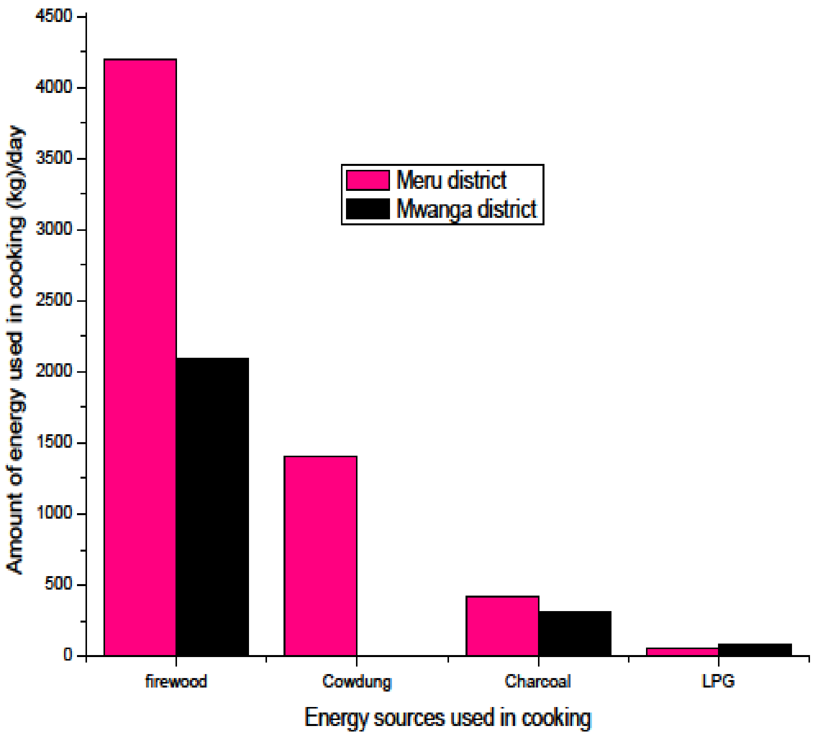

Figure 5**:** Type and amount of energy sources used for cooking

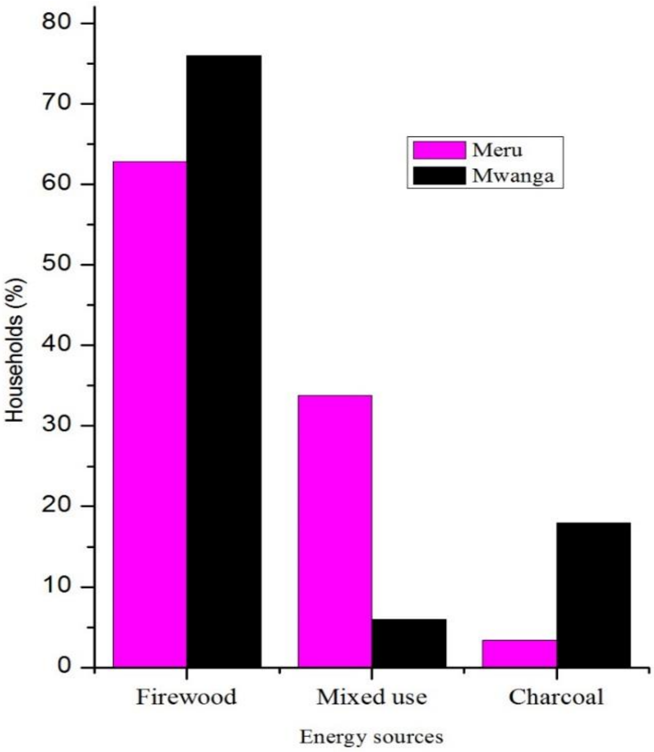

Figure 6: Energy sources that are used in cooking per respective number of households (Mixed use: Fire wood, charcoal, dry cow dung, biogas and LPG)

Fuel wood (Fire wood and charcoal) constitute the major cooking fuels (Trossero, 2002), this has also been reflected in the current study, however to some of the surveyed households, all fuels (Fire wood, charcoal, cow dung cake and LPG) were used in a mixed way. The dependency on fuel wood as a source of energy in the study area is increasing. Experimental evidence suggest that there are a number of factors which influence the increase (Luoga *et al*., 2000). The main factors being unavailability of alternative sources of energy and increasing prices of the available non-wood fuels. The findings from this study suggest that while efforts to adopt other sources of fuels alternative to fuel wood in the study area are highly recommended, renewable and less costly source of fuel such as biogas should be adopted and used.

4.1.2 The effect of fuel wood use on forest cover

Statistical data from the extracted and classified images indicated fluctuations in areas covered by forest. Key findings from the classified images (Fig. 7-14) and Table 1 presented total forested area for Meru in 1987, 1997, 2002 and 2017 to be 1510, 1723, 2061 and 1722 respectively. In Mwanga, the area covered with forest found to be 31 705, 31 988, 17 939 and 30960 for the year 1987, 1997, 2002 and 2017. An increase of 283 ha of the forested area was observed in 1987-1997. From 1997-2002 the loss of 14 049 ha was identified. In 2002-2017 the forest cover increased by 13 022 ha (Table 1) The regeneration in forest cover from 2002 to 2017 was due to the introduction of biogas technology that transformed the community from fuel wood dependence to biogas use. In Meru district, an increase of 213 ha was observed within a period of 10 years (1987-1997). This was followed by a decrease of 111 ha in a period of 5 years (1997-2002), a rapid change was once more recognized in 2002-2017 where by 285 ha were lost in this period of time. Forest degradation observed in Meru district was mainly contributed by fuel wood use and clearing of trees for fencing.

Table 1: Trends in total (net) forest cover in Meru and Mwanga from 1987 to 2017

Year	Forest cover (ha) Mwanga	Forest cover (ha) Meru	Change Rate (ha/year)					
			1987-1997		1997-2002		2002-2017	
			Mwanga	Meru	Mwanga	Meru	Mwanga	Meru
1987 1997 2002 2017	31 705 31 988 17 939 30 960	1510 1723 1612 1327	28.3	21.3	-2809.8	-22.2	868.1	-19

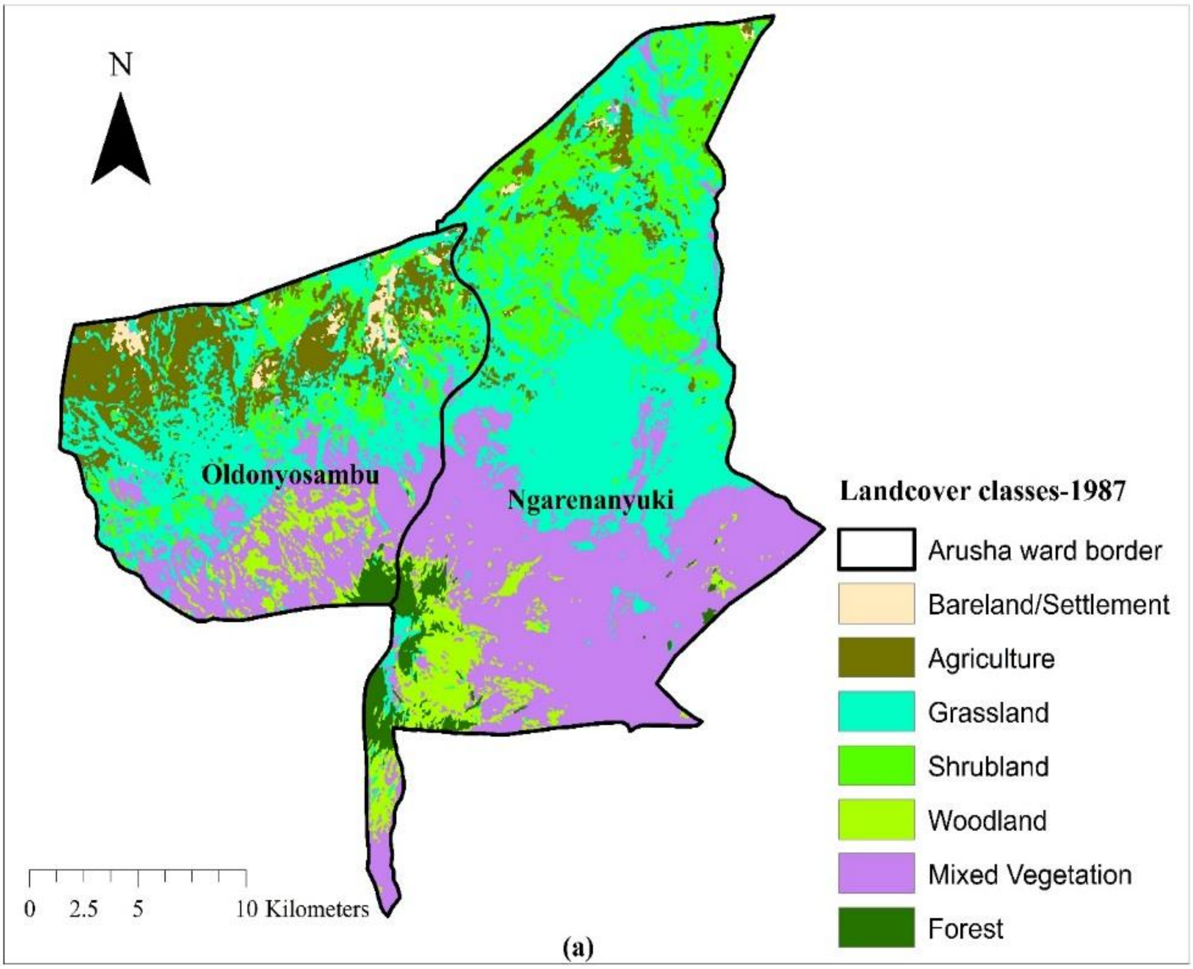

Figure 7: Image classification for 1987 land cover classes in Meru district (Arusha)

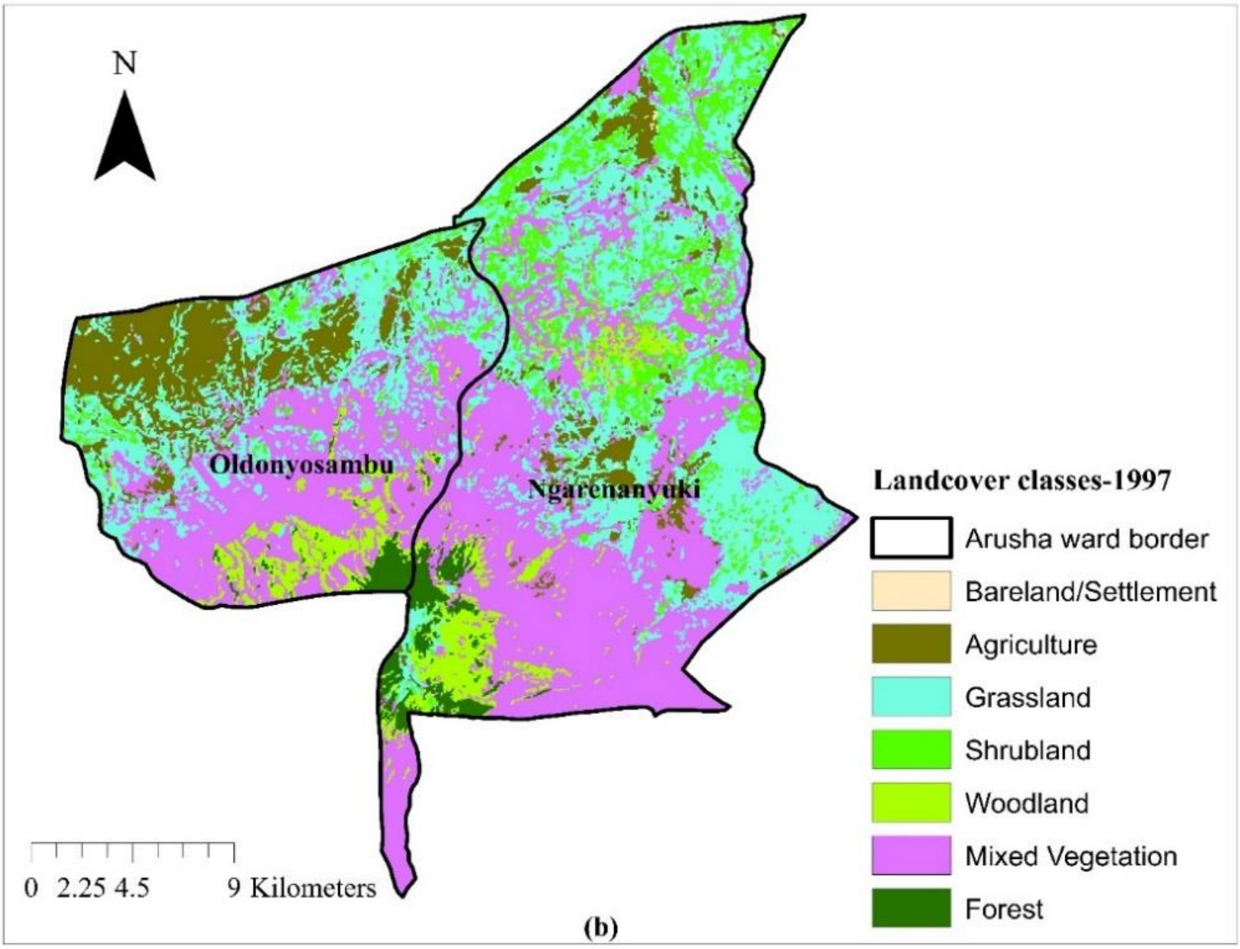

Figure 8: Image classification for 1997 land cover classes in Meru district (Arusha)

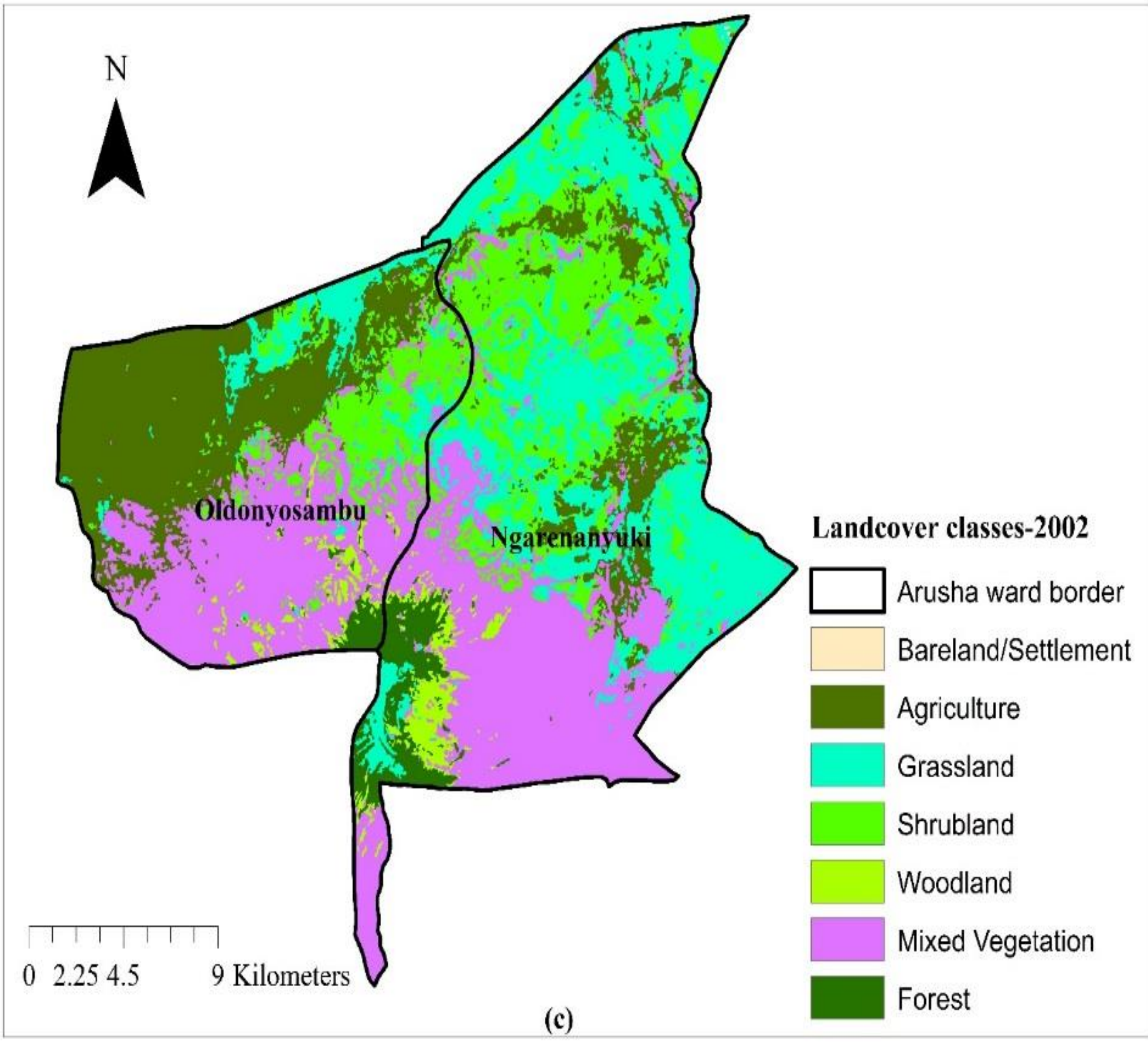

Figure 9: Image classification for 2002 land cover classes in Meru district (Arusha)

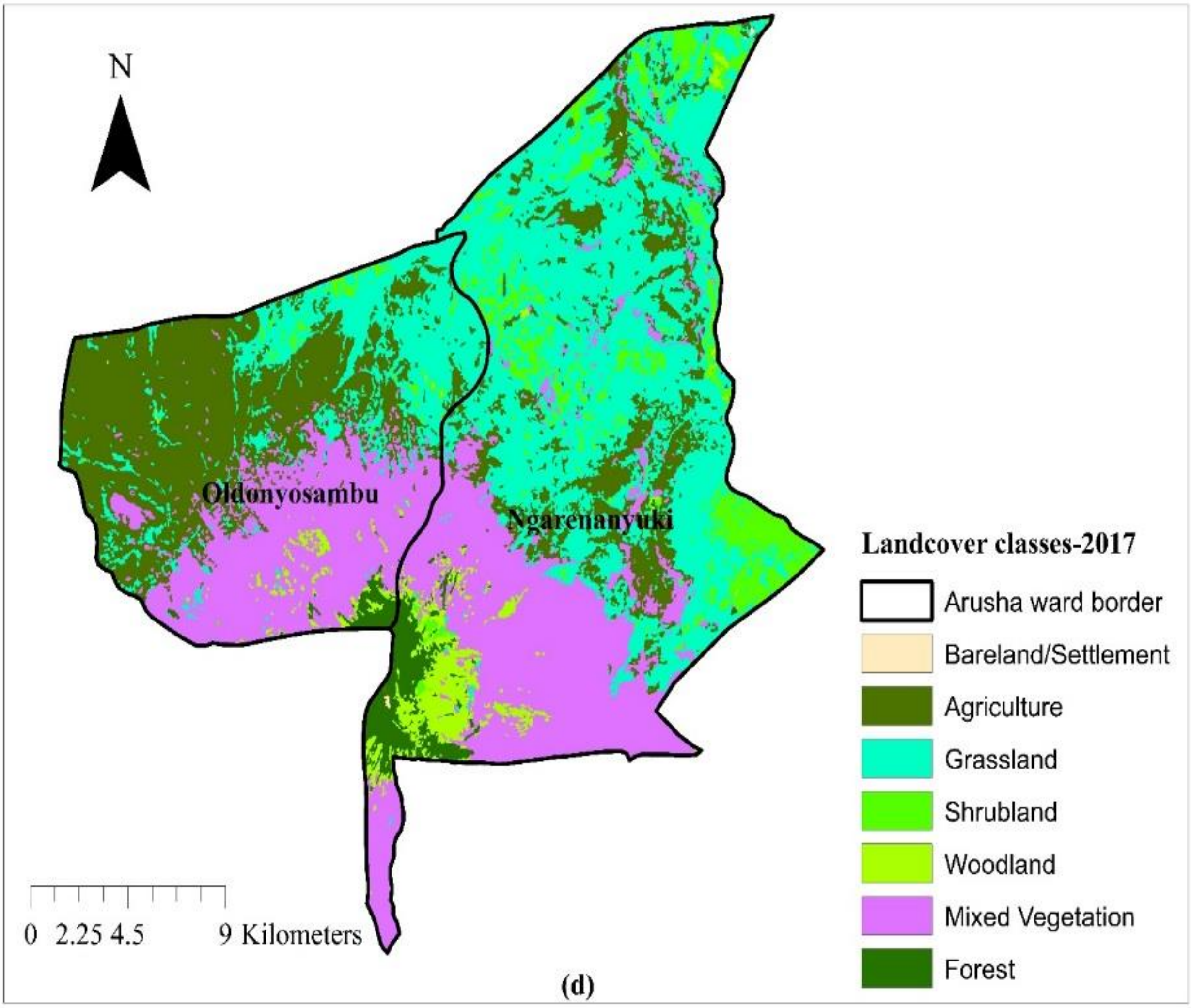

Figure 10: Image classification for 2017 land cover classes in Meru district (Arusha)

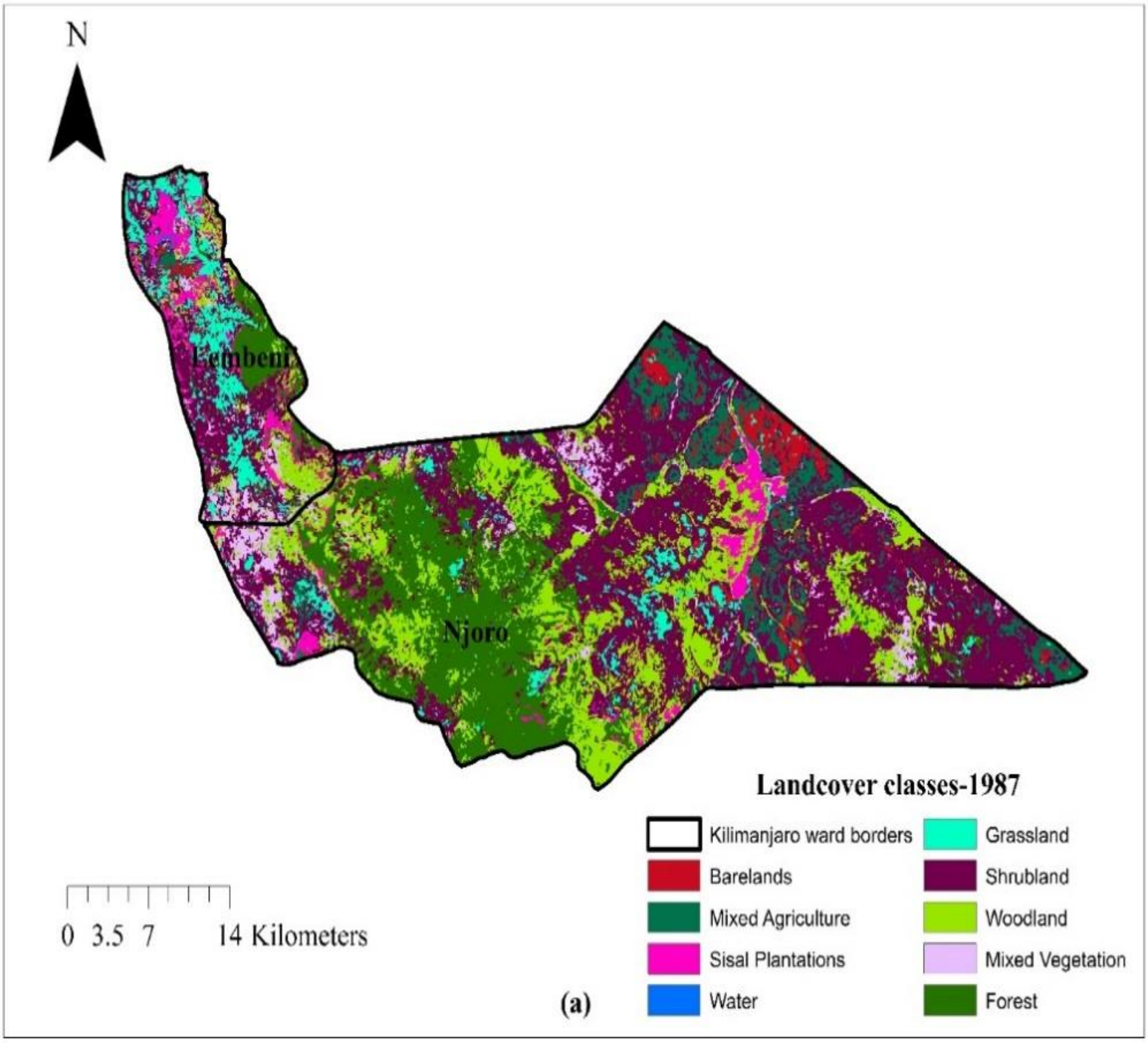

Figure 11: Image classification for 1987 land cover classes in Mwanga district (Kilimanjaro)

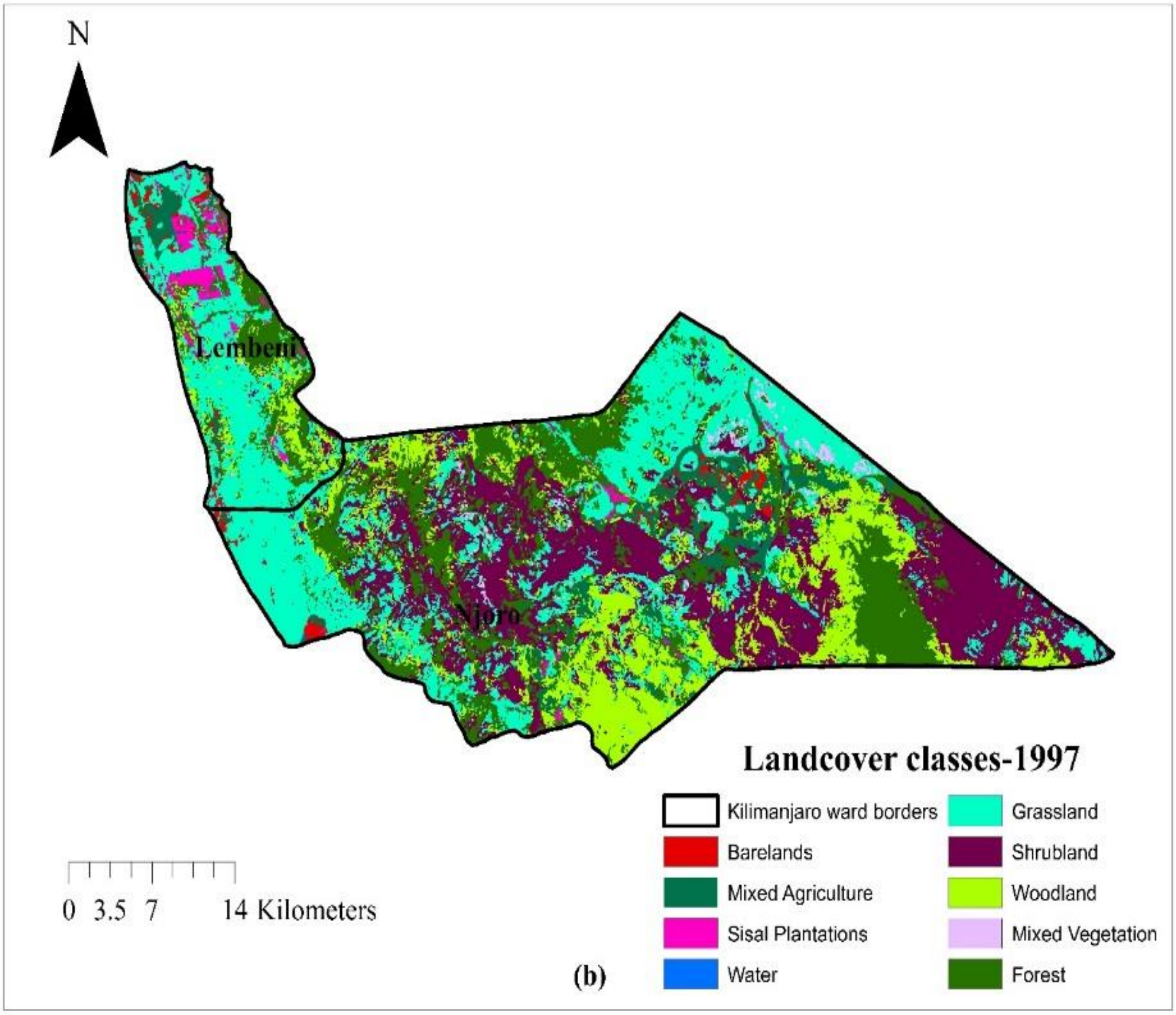

Figure 12: Image classification for 1997 land cover classes in Mwanga district (Kilimanjaro)

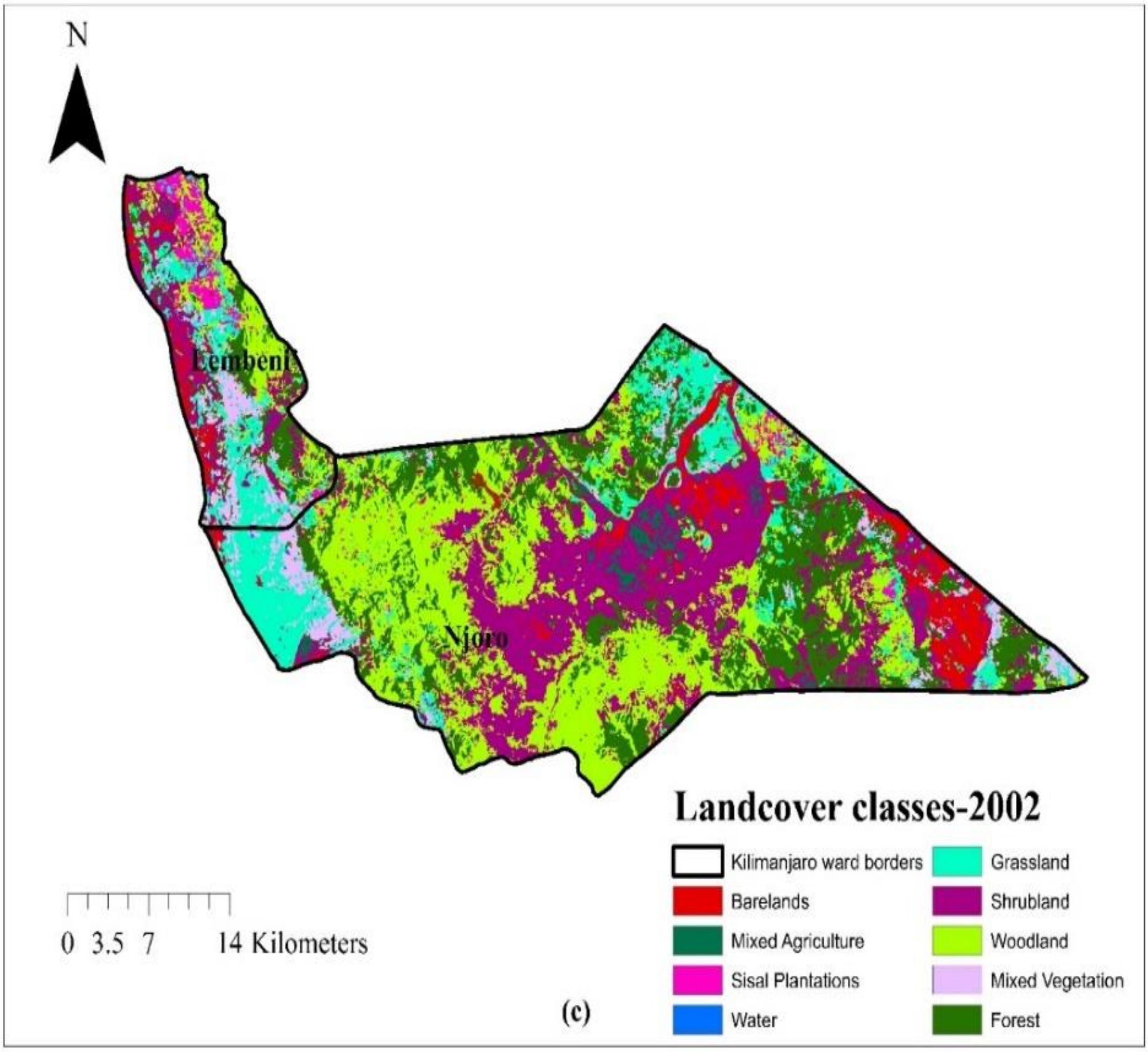

Figure 13: Image classification for 2002 land cover classes in Mwanga district (Kilimanjaro)

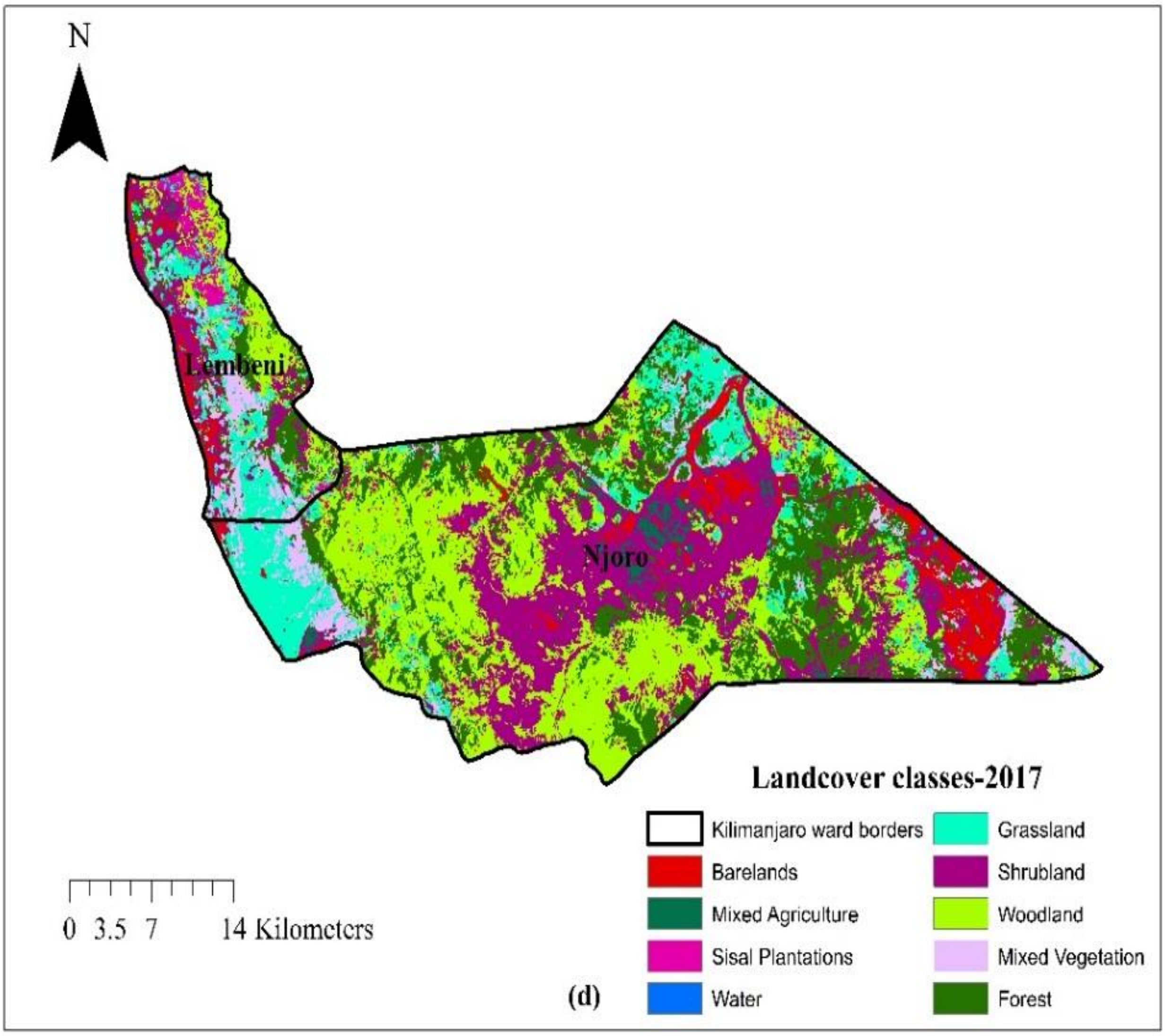

Figure 14: Image classification for 2017 land cover classes in Mwanga district (Kilimanjaro)

The dependence on fuel wood has a great meaning and implication to forest cover change over time (Arnold and Persson, 2003). Consumption of fuel wood per person per year is estimated to be very high and in satisfying this, great pressure on forest cover has to be generated (Miya *et al.*, 2012). In this study, a considerable number of the total population still rely on fuel wood as the basic energy source for cooking, consuming over 1.7 tons of fuel wood per capita per year. This general pattern of fuel wood consumption identified looks similar with results presented by D'Agostino *et al.* (2015).

Official data on fuel wood consumption and their impact on forest cover is often focused on industrial demands and neglects domestic use (Specht *et al*, 2015). In the current study, the amount of fuel wood needed to fuel the estimated levels of consumption requires that 101 953 tons of trees be harvested from forests per year. Due to this, it is estimated that 935 ha of forest are needed to meet the fuel wood demand of households in the surveyed area. The estimated level of fuel wood consumption reported in this study look also similar with what report by Hoffmann *et al.* (2015) where the increase in levels of consumption resulted into the increase of the deforested area.

A study by Boberg (2017) report fuel wood use by domestic and its effect on forest cover, the link obtained between the two seems to vary inversely proportional. Also a study conducted by Sassen *et al.* (2015) investigating the relationship between fuel wood use and forest cover change observed that, forest goes on decreasing due to fuel wood extraction. Results presented in this study suggest that fuel wood harvesting should not be ignored as an important source of forest degradation. Since they reveal the extent to which rural populations are depending on fuel wood and their impact on forest cover. Similar suggestions were also reported by Hojas-Gascón (2016) on the negligence of fuel wood use and their impact on forest degradation, however their study based mostly on industrial use leaving out the domestic use.

In this study, statistical data from the extracted and classified images showed the decrease in areas that are covered with forest. Forest degradation is contributed by factors such as: logging, shifting agriculture, pole cutting, expansion of commercial farms and fuel wood use (Arnold and Persson, 2003). Excluding fuel wood use, the previously mentioned factors are rarely/completely not practiced in the study area since the communities that live in these areas engage themselves on pastoralism and seldom in agricultural activities. Therefore these factors are less/not counted on deforestation process. Fuel wood (Fire wood and charcoal) observed to be the most frequently used source of energy in the study area. The sources are obtained from fresh trees and some from dead branches (as reported in the conducted survey), therefore it is likely that, deforestation process existing in Mwanga and Meru is due to the serious dependence on fuel wood use, clearing of trees for fencing and settlement expansion.

4.2 Optimization of biogas production process in solid state digesters: the case of semi-arid areas in northern Tanzania.

4.2.1 Characterization of the feedstock

TS (%), VS as %TS and CN ratio of fresh (undiluted) samples of cow dung collected from Mwanga and Meru district ranged from 16-23, 51-83 and 20-41 respectively (Tables 2 and 3).

Table 2: TS, VS and C/N ratio for samples from semi-arid areas of Meru

Sample name	TS (%)	VS (%)	C/N ratio
Losinoni Kati	20.0	67.3	25
Engutukoit	22.9	83.2	25
Lemanda	20.0	67.9	25
Losinoni Juu	21.2	76.4	28
Mkuru	20.2	69.5	25

When a sample with 20 % TS and 69% VS as % of TS was diluted at ratios of 2:1, 3:1 and 4:1, resulted into diluted samples with TS% and VS (as % of TS) of 12, 15 and 17; and 68.2, 68.5 and 68.7% correspondingly.

Table 3: VS, TS and C/N ratio for samples collected from biogas users in Mgagao (Mwanga)

Sample Name	TS%	VS%	C/N ratio
Household 1	20.4	69.5	20
Household 2	20.0	69.1	25
Household 3	16.2	51.4	20
Household 4	20.1	69.3	25
Household 5	20.0	69.0	25
Household 6	20.3	69.4	21
Household 7	20.0	68.9	25
Household 8	20.2	69.3	25
Household 9	21.2	73.0	20
Household 10	22.0	83.2	25
Household 11	19.8	68.4	25
Household 12	20.1	69.4	24
Household 13	21.3	73.2	41
Household 14	20.0	69.0	30
Household 15	22.2	79.2	25
Household 16	20.0	68.1	20
Household 17	20.3	69.0	25
Household 18	20.0	69.2	20
Household 19	22.8	83.0	25
Household 20	20.0	68.5	25
Household 21	22.7	68.0	25
Household 22	20.6	67.9	25
Household 23	23.7	69.0	24
Household 24	25.0	70.2	26
Household 25	21.2	83.0	25
Household 26	20.8	69.1	25
Household 27	23	69.0	25

The optimal %TS for solid state digesters is reported to range between 10 and 20 (Yi *et al.*, 2014). In this study, feedstock with TS of 17% produced biogas yield of up to 46.4 mL/g VS which was the highest production in all %TS tested. These results were in line with those reported by Widiasa and Seno (2010) when cattle manure were used as feedstock. Their results showed the increase in biogas production as %TS was changed from 7.4 to 9.2%. A similar relationship was established by KeChrist *et al.* (2017) using cattle manure as feedstock, where similar trend of results as of this study were obtained. Comparably Brown and Li (2013) reported an increase in biogas yield from 42 mL/gVS to 72 mL/gVS as %TS increase from 15 to 20 mL/gVS. However, study by Abbassi-Guendouz *et al.* (2012) reported contrary results for the effect of %TS on biogas production when similar feedstock as of this study were used.

CN ratio in this study ranged from 20 to 41 (Tables 2 and 3). Sample with optimal CN ratio (25) in the present study was selected for testing production of biogas in the laboratory. Feedstock with this CN ratio suggest a significant amount of biogas to be generated since the ratio is at its optimal point (Ghasimi *et al.,* 2009).

When %VS fall into the optimal range of 28-90% more biogas is produced (Ozturk, 2012). Concentration of VS in this study ranged from 54-83%, this is an indication that the feedstock is rich in organic solid content that can be converted into biogas during anaerobic digestion. Substrate with VS (69%) was sampled to be used in this study, however upon dilution VS slightly changed to 68.2, 68.5 and 68.8% for the 2:1, 3:1 and 4:1, respectively. Biogas production tend to increase when percentage of volatile solids increases (Gelegenis *et al.,* 2007; Ozturk, 2012). This have been confirmed in this study where feedstock with 68.8% generated high amount of biogas than others at 68.2 and 68.5%.

4.2.2 The effect of mixing ratio on biogas production

The laboratory experiment carried out revealed that, daily biogas production varied continuously for the 2:1, 3:1 and 4:1 mixing ratios. Fig. 15 shows the cumulative biogas production for the reactors operated at three different mixing ratio during the whole experiment. Each curve represents the average of three replicates. The best performance of biogas production was observed in the digester with mixing ratio of 4:1. This ratio provided cumulative biogas of 20.94 L equivalent to 46.4 mL/g VS biogas yield for 30 days while 3:1 and 2:1 gave 9.08 L (22.7 mL/g VS) and 7.39 L (21.4 mL/gVS), respectively as shown in Fig. 15.

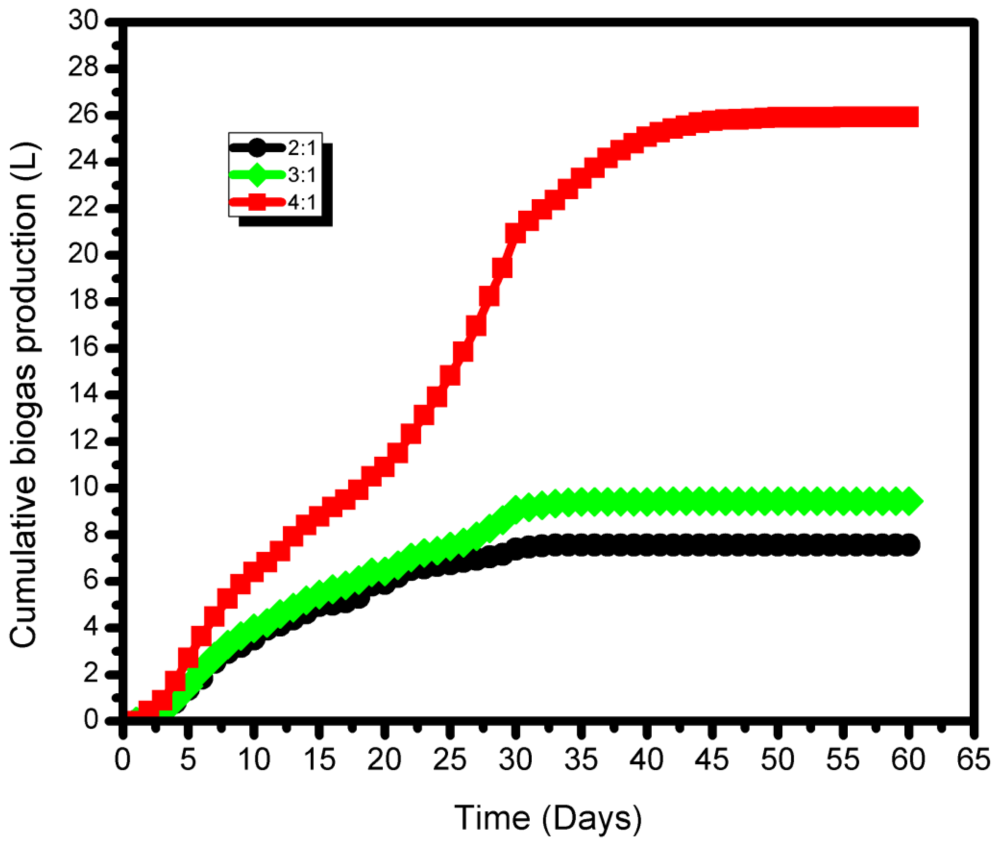

Figure 15: Effect of mixing ratios of cow dung to water on biogas production

The results obtained in this study clearly illustrate that, increase in substrate/water mixing ratio gives enhanced biogas production. This could be explained by the fact that, as substrate mixing ratios increase, volatile solids also increase resulting into higher production of biogas.

Working with cow dung/water feedstock, Adelekan and Bamgboye (2009) reported an increased biogas yield that was directly proportional to the increase in mixing ratio. Similarly, Haryanto *et al*. (2018) using comparable feedstock reported a potential increase in methane yield of up to 122 mL/gVS at 2:1 mixing ratio of waste/water as compared to 1:1 that produced only 78 mL/gVS. All of the finding obtained from the previous study were similar with those obtained in this study.

The impact of shifting from fuel wood use to biogas has been reflected to areas of Mwanga district. The classified images for Mwanga shows that since 2002 to 2017, forested area increased from 17 939 to 30 960 ha respectively. The rapidly use of biogas in Tanzania report to commence since 1990s (Rupf *et al.*, 2015), however biogas use to northern parts of

Tanzania gained its popularity in the year 2008 (Ng'wandu *et al.,* 2008). Though, biogas to these areas report to be produced in little amount (Kileo and Akyoo, 2014), its positive effect in forest cover change has been revealed. To semi-arid areas of Meru, the forest cover goes on decreasing (Table 1), biogas is completely not used to these areas and hence community goes on relying in fuel wood as their main energy sources.

Deublein and Steinhauser (2011) report that, 0.26 m^3 of biogas is estimated to be used up by one person per day in cooking. For the household owning a digester sized 9 m^3 which is fed with 80:20 kg of cow dung/water per day have an ability of producing 12 564 L of biogas per month that can save an average of 2.4 people within 30 days (Deublein and Steinhauser, 2011).

The conducted survey in Lembeni, Njoro, Mgagao, Ngarenanyuki and Oldonyosambu identified that 283 tons of wood are consumed by 31 623 people per day, equivalent to 9 kg per person. With this population of 31 623 people (equivalent to 4.8 people per household), if the surveyed community (with 6559 households) opt to shift from using wood fuel to biogas, about 15 812 people will be excluded from using wood fuel. Again, if 9 kg of wood are consumed by one person in cooking per day then the total number of 15 812 people will save about 142 tons per day equivalent to 51 003 tons per year. About 51 003 tons of wood would be saved per year if households in the surveyed areas were to shift from wood fuel use to biogas, 468 ha of forest that were to be cleared for fuel wood will be saved per year.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study focused on determining the energy sources that are regularly used, pinpointing the impact of wood fuel use, biogas use to forest cover change and reviewing on the effect of cow dung/water mixing ratios on biogas production in batch solid state anaerobic digester. The identified energy sources included cow dung cake, fire wood, charcoal, biogas, and LPG. The demand for the mentioned energy sources excluding biogas amounted to 1400, 6289, 724 and 21 kg per total number of household surveyed per day respectively. The decrease in forest cover for selected areas was 927 ha for the past 30 years from 1987-2017.

Cow dung/water ratio of 4:1 showed high production of biogas than that of 3:1 and 2:1. Improper mixing of the feedstock, feeding lower mixing ratios characterized with low amount of TS and VS resulted into low production of biogas.

Conclusively: This study contributed a scientific knowledge on right use of mixing ratios in solid state digesters for optimal production of biogas. It also presents data on forest degradation to semi-arid areas of Mwanga and Meru where previously were not known.

5.2 Recommendations

Sensitization of the pastoralist to shift from using fuel wood to biogas could save the ongoing degradation of forest.

Maintaining maximum production of biogas in SSD, proper mixing of the feedstock to obtain homogeneous mixture of the feedstock, use of appropriate mixing ratios should be taken into action.

Investigation of the feeding frequencies of the feedstock as among the factors that affect biogas production especially for SSD need further study.

REFERENCES

Abbassi-Guendouz, A., Brockmann, D., Trably, E., Dumas, C., Delgenès, J. P., Steyer, J. P. and Escudié, R. (2012). Total solids content drives high solid anaerobic digestion via mass Transfer limitation. *Bioresource Technology*. **111**: 55-61.

Adelekan, B. A. and Bamgboye, A. I. (2009). Effect of mixing ratio of slurry on biogas Productivity of major farm animal waste types. *Journal of Applied Biosciences*. **22**: 1333-1343.

Arnold, M. and Persson, R. (2003). Reassessing the fuel wood situation in developing countries. *Forestry*. **5**(4): 379-383.

Arvidson, A., Nordstrom, M., Forslund, H., Syngellakis, K., Marcel, J. C., Woodworth, G. and Ngoye, E. (2006). Scaling-up of energy services access in East Africa. *Forest Management*. **5**(2): 379-383

Bhatt, B. P. and Sachan, M. S. (2004). Fire wood consumption pattern of different tribal Communities in Northeast India. *Energy Policy*. **32**(1): 1-6.

Boberg, J. (2017). Wood fuel markets in developing countries: A case study of Tanzania. *Energy*. **31**(1): 1-10.

Brown, D. and Li, Y. (2013) Solid state anaerobic co-digestion of yard waste and food waste for biogas production. *Bioresource Technology.* **127**: 275-280.

Budiyono, B. and Sumardiono, S. (2014). Effect of total solid content to biogas production rate from vinasse. *International Journal of Engineering*. **27**(2): 177-184.

Chaudhary, R. P. (2000). Forest conservation and environmental management in Nepal: a review. *Biodiversity and Conservation*. **9**(9): 1235-1260.

Chakravarty, S., Ghosh, S. K., Suresh, C. P., Dey, A. N. and Shukla, G. (2012). Deforestation: causes, effects and control strategies. *Sustainable Forest Management*. **99**: 6075–6080.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment.* **37**(1): 35-46.

Congedo, L. (2013). Semi Automatic Classification Plugin for QGIS (Quantum Geographical Information System). Sapienza University., Rome. 27pp.

D'Agostino, A. L., Urpelainen, J. and Xu, A. (2015). Socio-economic determinants of charcoal expenditures in Tanzania: Evidence from panel data. *Energy Economics*. **49**: 472-481.

Dell, R. B., Holleran, S. and Ramakrishnan, R. (2002). Sample size determination. *ILAR (Institute for Laboratory Animal Research) Journal*. **43**(4): 207-213.

Deublein, D. and Steinhauser A. (2011). Biogas from waste and renewable resources. *Bioresource Technology*. **99** (14): 6075–6080.

Dick, S. (2003). Fluctuations in manure nutrient concentration during swine storage pump-outs. *Renewable Energy*. **19**(2): 973-986.

Dioha, I. J., Ikeme, C. H., Nafi'u, T., Soba, N. I. and Yusuf, M. B. S. (2013). Effect of Carbon to Nitrogen ratio on biogas production. *International Research Journal of Natural Sciences*. **1**(3): 1-10.

Dobre, P., Nicolae, F. and Matei, F. (2014). Main factors affecting biogas production-an overview. *Romanian Biotechnological Letters*. **19**(3): 9283-9296.

Egilson, K. and Grieger, L. (2014). Manure Treatment Technology Evaluation. The Manitoba livestock manure management initiative. *Energy*. **20**: 10-21.

Engel, T. and Frey, W. (1996). Fuel resources for copper smelting in antiquity in selected woodlands in the Edom highlands to the Wadi Arabah/Jordan. *Flora*. **191**(1): 29-39.

Fernández, J., Pérez, M. and Romero, L. I. (2008). Effect of substrate concentration on dry Mesophilic anaerobic digestion of organic fraction of municipal solid waste (OFMSW). *Bioresource Technology*. **99**(14): 6075–6080.

Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*. **80**(1): 185-201.

Forster-Carneiro, T., Pérez, M. and Romero, L. I. (2008). Influence of total solid and inoculum Contents on performance of anaerobic reactors treating food waste. *Bioresource Technology*. **99**(15): 6994-7002.

Gelegenis, J., Georgakakis, D., Angelidaki, I. and Mavris, V. (2007). Optimization of biogas production by co-digestion whey with diluted poultry manure. *Renewable Energy*. **32**: 2147-160.

Ghasimi, S. M. D., Idris, A., Chuah, T. G. and Tey, B. T. (2009). The effect of C:N:P ratio, volatile fatty acids and Na+ levels on the performance of an anaerobic treatment of fresh leachate from municipal solid waste transfer station. *African Journal of Biotechnology*. **8**: 4572-4581.

Gorte, R. W. and Sheikh, P. A. (2010). Deforestation and climate change. *Environmental Ecology*. **143**: 1-9

Haryanto, A., Hasanudin, U., Afrian, C. and Zulkarnaen, I. (2018). Biogas production from anaerobic co-digestion of cow dung and elephant grass (*Pennisetum Purpureum*) using batch digester. *Earth Environmental Science.* **141**: 1-10.

Hojas-Gascón, L., Eva, H. D., Ehrlich, D., Pesaresi, M., Achard, F. and Garcia, J. (2016). Urbanization and forest degradation in east Africa: A case study around Dar es Salaam. *Geoscience and Remote Sensing.* **141**: 1-18

Hoffmann, H., Uckert, G., Reif, C., Müller, K. and Sieber, S. (2015). Traditional biomass energy consumption and the potential introduction of fire wood efficient stoves: insights from western Tanzania. *Regional Environmental Change*. **15**(7): 1191-1201.

Kavuma, C. (2013). Variation of methane and carbon dioxide yield in a biogas plant. Unpublished Dissertation for Award of MSc Degree at Royal Institute of Technology. Sweden, pp. 240–326.

KeChrist, O., Sampson, M., Golden, M. and Nwabunwanne, N. (2017). Slurry Utilization and Impact of Mixing Ratio in Biogas Production. *Chemical Engineering and Technology*. **32**: 16-24

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A. and Lindquist, E. (2015). Dynamics of global forest area: Results from the FAO (Food and Agriculture Organization) global forest resources assessment. *Forest Ecology and Management*. **352**: 9-20.

Kilahama, F. (2008). Impact of increased charcoal consumption to forests and woodlands in Tanzania. *Forest Ecology and Management*. **308**: 45-55.

Kileo, J. O. and Akyoo, A. M. (2014). Technology transfer and farm-based renewable energy sources: The potential of biogas technology for rural development in Tanzania. *Regional Environmental Change.* **42**(19): 23-38

Lay, J. J., Li, Y.Y., Noike, T., Endo. J. and Ishimoto, S. (1997). Analysis of environmental factors affecting methane production from high-solids organic waste. *Water Science Technology*. **36**(7): 493-500.

Lillesand, T., Kiefer, R. W. and Chipman, J. (2014). Remote sensing and image interpretation. John Wiley and Sons. 315 pp.

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. (2000). Economics of charcoal production in Miombo woodlands of eastern Tanzania: some hidden costs associated with Commercialization of the resources. *Ecological Economics*. **35**(2): 243-257.

Maamri, S. and Amrani, M. (2014). Biogas production from waste activated sludge using cattle dung inoculums: Effect of total solid contents and kinetics study. *Energy Procedia*. **50**: 352-359.

Maishanu, S. M. and Hussaini, H. B. N. (1991). Studies on factors affecting biogas generation from Pista Stratiote. *Biotechnology for Biofuels*. **1**: 7-11.

Mengistu, D. A. and Salami, A. T. (2007). Application of remote sensing and GIS inland use/land cover mapping and change detection in a part of south western Nigeria. *African Journal of Environmental Science and Technology*. **1**(5): 99-109.

Ministry of Natural Resources and Tourism (2014). The forestry and beekeeping sub sector: Achievements, challenges and priorities. Dar es Salaam. 27pp

Miya, M., Ball, S. M. J. and Nelson, F. D. (2012). Drivers of deforestation and forest degradation in Kilwa district. *Forest Ecology and Management*. **322**: 1-34.

Motte, J. C., Trably, E., Escudié, R., Hamelin, J., Steyer, J. P., Bernet, N. and Dumas, C. (2013). Total solids content: a key parameter of metabolic pathways in dry anaerobic digestion. *Biotechnology for Biofuels*. **6**(1): 164.

Ng'wandu, E., Shila, L. C. and ter Heegde, F.E.W. (2008). Programme implementation Document: Tanzania Domestic Biogas Programme. *Energy Policy*. **23**: 16-32.

Odhiambo, N. M. (2009). Energy consumption and economic growth nexus in Tanzania: An ARDL bounds testing approach. *Energy Policy*. **37**(2): 617-622.

Okonkwo, U. C., Onokpite, E. and Onokwai, A. O. (2016). Comparative study of the optimal Ratio of biogas production from various organic wastes and weeds for digester/restarted digester. *Journal of King Saud University-Engineering Sciences*. **63**: 210-220.

Ozturk, B. (2012). Evaluation of biogas production yields of different waste materials. *Earth Science Research*. **2**(1): 165.

Panwar, N. L., Kaushik, S. C. and Kothari, S. (2011). Role of renewable energy sources in Environmental protection: a review. *Renewable and Sustainable Energy Reviews*. **15**(3): 1513-1524.

Pavan, P., Battistoni, P. and Mata-Alvarez, J. (2000) Performance of thermophilic semidry Anaerobic Digestion process changing the feed biodegradability. *Water Science Technology*. **41**: 75–81.

Rasi, S., Veijanen, A. and Rintala, J. (2007). Trace compounds of biogas from different biogas production plants. *Energy*. **32**: 1375-1380.

Ranade, D. R., Nagarwala, N. N., Dudhbhate, J. A., Gadre, R. V. and Godbole, S. H. (1990). Factors affecting biogas production process. *Indian Journal of Environment Health*. **32**: 63–65.

Renaud, A., Fournie, L., Girardeau, P., Chammas, M., Tarel, G., Chiche, A. and Riu, D. (2013). Study of the potential of energy storage-Investigation report-Synthesis. *Agence de l'Environnement et de la Maitrise de l'energie*. **12**: 35-42.

Rudel, T. K. (2007). Changing agents of deforestation: from state-initiated to enterprise driven Processes, 1970–2000. *Land Use Policy*. **24**(1): 35-41.

Rupf, G. V., Bahri, P. A., de Boer, K. and McHenry, M. P. (2015). Barriers and opportunities of Biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. *Renewable and Sustainable Energy Reviews*. **52**: 468-476.

Rutherford, G., Guisan, A. and Zimmermann, N. (2007). Evaluating sampling strategies and logistic regression methods for modelling complex land cover changes. *Journal of Applied Ecology*. **44**(2): 414-424.

Salim, E. and Ullsten, O. (1999). Our forest, our future. *PloS One*. **62**: 212-220.

Santana, A. and Pound, B. (1980). The production of biogas from cattle slurry: the effects of Concentration of total solids and animal diet. *Tropical Animal Production*. **5**(2): 130-135.

Saud, T., Gautam, R., Mandal, T. K., Gadi, R., Singh, D. P., Sharma, S. K. and Saxena, M. (2012). Emission estimates of organic and elemental carbon from household biomass fuel Used over the Indo-Gangetic Plain (IGP), India. *Atmospheric Environment*. **61**: 212-220.

Sassen, M., Sheil, D. and Giller, K. E. (2015). Fuel wood collection and its impacts on a protected tropical mountain forest in Uganda. *Forest Ecology and Management*. **354**: 56-67.

Sawe, E. (2004). An overview of charcoal industry in Tanzania-issues and challenges. *Global Ecology and Conservation.* **23**(17): 234-260.

Scheba, A. and Mustalahti, I. (2015). Rethinking expert knowledge in community forest Management in Tanzania. *Forest Policy and Economics*. **60**: 7-18.

Singh, P., Suman. A., Tiwari, P., Arya, N., Gaur, A. and Shrivastava, A. K. (2008). Biological pretreatment of sugarcane trash for its conversion to fermentable sugars. *World Journal of Microbiology and Biotechnology*. **24**(5): 667-673.

Specht, M. J., Pinto, S. R. R., Albuquerque, U. P., Tabarelli, M. and Melo, F. P. (2015). Burning biodiversity: Fuel wood harvesting. *Global Ecology and Conservation*. **3**: 200-209.

Surendra, K. C., Takara, D., Hashimoto, A. G. and Khanal, S. K. (2014). Biogas as a sustainable Energy source for developing countries: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*. **31**: 846-859.

Tanzania Domestic Biogas Programme. (2012). TDBP (Tanzania Domestic Biogas Programme) Plant Model: research on the Operation and performance of the 9 m^3 solid state plant. *Unasylva*. **65**(4): 1-16.

Tanzania, N. B. S. (National Bureau of Statistics) (2012). Population and housing census: population distribution by Administrative areas. Ministry of Finance, Dar es Salaam.

Tietjen, C. (1975). From biodung to biogas—historical review of European experience: *Energy*. **5**(6): 247-259.

Trossero, M. A. (2002). Wood energy: the way ahead. *Unasylva*. **53**(4): 3-12.

URT (United Republic of Tanzania) (2012). Tanzania country study on biological diversity report. Government of United Republic of Tanzania. 163pp.

Vetter, R. L., Friederick, D. J. and Huntington, P. (1990). Full scale anaerobic digester and waste management system for a 300 cow dairy. *Agricultural and food processing waste*. **12**: 16-28

Wargert, D. (2009). Biogas in developing rural areas. *PloS one.* **16**: 34-45.

Yavini, T. D., Chia, A. I. and John, A. (2014). Evaluation of the effect of total solids concentration on biogas yields of agricultural wastes. *International Research Journal of Environmental Science*. **3**(2): 70-75.

Yi, J., Dong, B., Jin, J. and Dai, X. (2014). Effect of increasing total solids contents on anaerobic digestion of food waste under mesophilic conditions: performance and microbial characteristics analysis. *PloS One*. **9**(7): 1025.

Zhan, X., Sohlberg, R. A., Townshend, J. R. G., DiMiceli, C., Carroll, M. L., Eastman, J. C., Hansen, M. C. and DeFries, R. S. (2002). Detection of land cover changes using modis 250 m data. *Remote Sensing of Environment.* **83**(1): 336-350.

RESEARCH OUTPUT

Journal paper

OPTIMIZATION OF BIOGAS PRODUCTION PROCESS IN SOLID STATE DIGESTERS IN SEMIARID AREAS OF NORTHERN TANZANIA

Debora J Mahushi[ab], Alfred NN Muzuka[a] and Revocatus L Machunda[a*]

[a]Department of Water, Environmental Science and Engineering, The Nelson Mandela African Institution of Science and Technology, P.O.Box 447, Arusha, Tanzania.
[b]Department of Physics, Mkwawa University College of Education, University of Dar es Salaam P.O Box 2513, Iringa, Tanzania.

**corresponding author: revocatus@gmail.com*

ABSTRACT

Solid state digestion process has received much attention due to its low water requirements, making it preferred in semi-arid areas as well. In this study, the performance of the household solid state digesters was evaluated through monitoring of the feedstock mixing ratios and using the digester gas pressure as a measure of performance. Additionally, a batch study to verify the appropriate and optimal mixing ratio of feedstocks was also done. The mixing ratios of cow dung to water ranged from 2:1, 3:1 and 4:1. Total solids determined were 120, 150 and 170 mg/g for the ratios 2:1, 3:1 and 4:1, respectively. Biogas yield for 2:1, 3:1 and 4:1 mixing ratios in laboratory batch mode were 21.4, 22.7 and 46.4 mL/gVS, respectively. These results from a practical scenario show a promising future of the technology which can be adopted by all solid state digester users living in dry areas.

Key words*:* Cowdung, Biogas, Mixing ratio, Batch solid state anaerobic digester.

INTRODUCTION

Biogas production and utilization has gained much interest in recent years due to its importance as an alternative and environmentally friendly energy source (Panwar et al. 2011). Biogas technology can be deployed at small and large scale in urban and very remote locations. Varieties of feedstock and reactor configurations have been tested and proved to be effective in the production of biogas (Brown and Li 2013). Depending on the availability of total solids content in organic wastes, digesters are categorized into two group namely (i) liquid state and (ii) solid-state anaerobic digesters (Brown and Li 2013). The solid-state anaerobic digester is one in which total solid content range between 10-20% while liquid state anaerobic digester is one in which total solid content is less than 10% (Yi et al. 2014). Solid state digestion process has received much attention due to its low water requirement and improved biogas production efficiencies than the liquid state digestion process (Gelegenis et al. 2007).

This study was carried out to determine the operational performances of the Solid State Digester (SSD) installed digesters in Mwanga cluster in northern Tanzania with the aim of improving their biogas production potentials. The prior purpose for establishment of SSD plants was to have a design with low water requirements and high biogas production per unit volume. The estimated biogas production was 1-1.5, 1.5-2.25 and 3 m^3 for digester with capacity of 4, 6 and 9 m^3 respectively (Kileo and Akyoo 2014). It has been reported that 34.1% of the installed digesters still produce insufficient biogas, the main reason being poor feeding of the digesters using inappropriate mixing ratios of the feedstocks (Kileo and Akyoo 2014). The consequence is that even communities which could use biogas turn to non-environmental friendly sources of energy.

Technically, insufficient production of biogas in SSD may be caused by factors such as solid retention time, feedstock quality, feeding frequency, mixing ratios of feedstock, reactor configuration, organic loading rate, inoculation, co-digestion, pretreatment, purification, addition of additives and environmental conditions within the digester (i.e. temperature, pH, buffering capacity and volatile fatty acids concentration) (Lay et al. 1997). Monitoring of the digesters could therefore be done by measuring the daily digester gas pressure, measurements of the total volatile solids degraded and measurements of the amount of biogas being produced. Findings from the field showed, the often use of mixing ratios such as 2:1 and 3:1 by the household might be affecting the availability of TS and VS in the substrate which consequently affect the biogas production. This correspond with the study by Yi et al. (2014) that found out that when waste/cowdung is diluted, availability of TS and VS are affected. The more the waste is diluted, VS and TS do decrease. The decrease affects the amount of biogas to be generated since the production depends mostly on the availability of high amount of VS. Factors like: breed, growth stage of the animal and diet contributes much on the availability of VS, which vary significantly from area to area (Santana and Pound 1980). Due to variations of VS from area to area, investigation of the right mixing ratio that gives the best and proper VS content for the selected study area (Mgagao) is of great importance. Additionally, this study also provide a basis for improving the biogas digesters planned for construction in similar dry areas such as Oldonyosambu and Ngarenanyuki in Arusha District Councils.

MATERIALS AND METHODS

Study site description

The study was conducted in selected households at Mgagao in Mwanga district (Kilimanjaro region). Additionally, results of the survey in Mgagao are planned to be applied in Oldonyosambu and Ngarenanyuki in Meru district since they have nearly similar climatic conditions as Mgagao. The study areas are as shown in Figure 1.

Site selection and sample size

A survey was done at Mgagao using questionnaires to collect information from selected households. Information collected involved the management of the digesters from biogas users. About ten (10) questions were prepared where interviewee devoted fifteen minutes to answer the questions. Sample size was determined at precision rate (e) of 1% and 99% confidence level as recommended by Dobbin and Simon (2005). The sample size was calculated using equation 1 was 20.

$$n = \frac{N}{1 + N(e)^2} \qquad (1)$$

e = *Precision rate,* n=*Sample size,*
N= *Total population*

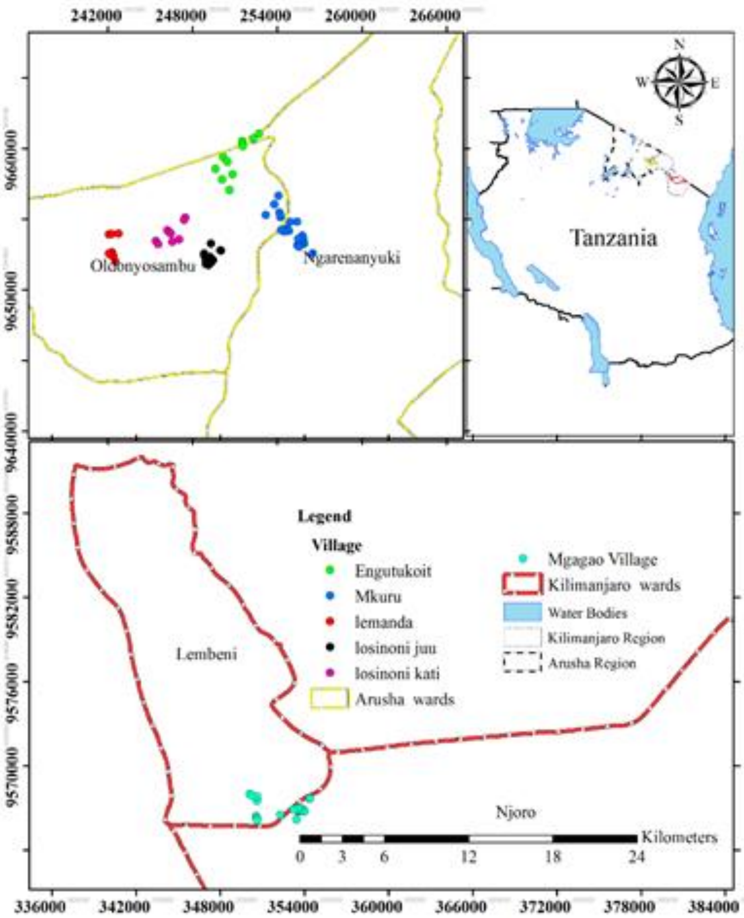

Figure 1: A map showing selected study sites surveyed in Meru and Mwanga districts (Mahushi 2018)

Characterization of the Feedstock

Fresh cow dung from the selected households of Mwanga (Kilimanjaro) and Meru (Arusha), were collected for analysis at the Nelson Mandela African Institution of Science and Technology (NM-AIST). In order to characterize the feedstock and provide more evidence of the best ratio to feed the digesters, experiments were carried out in the laboratory. The cowdung was characterized in terms of total carbon (C), total nitrogen (N), total Solids (TS) and volatile Solids (VS). Dry weight (TS) was determined at 105 ± 3°C, VS at 550°C in muffle furnace and carbon/nitrogen ratio by THERMO SCIENTIFIC™ FLASH™ 2000 ORGANIC ELEMENTAL ANALYZER operated at 950°C. Percentage total solid (TS) was determined by drying the fresh sample at 105°C for 12 hours and calculated (Equation 2) according to Singh et al. (2008).

$$\% TS = \frac{Weight\ of\ dry\ sample}{Weight\ of\ fresh\ sample} \times 100 \qquad (2)$$

Volatile Solids were determined by drying the fresh samples at 105°C for 12 hours then heated at 550°C for three hours. The samples were left to cool for one hour, then weight of ash content and weight loss (VS) were calculated as per equation 3 (Singh et al. 2008).

$$\%VS = \frac{Weight\ loss}{Weight\ of\ dry\ sample} \times 100$$

For the Households in Mgagao, measurements of the performance of the digesters were done by measuring the digester gas pressure using a data logger for a month.

For the batch experiment in the laboratory, the feedstock samples were obtained from cattle which are fed/pastured locally. A ratio of cowdung to water of 2:1, 3:1 and 4:1 were prepared in the laboratory. Anaerobic batch mode digesters were made from polyethylene bottles with a capacity of 10 L. The bottles were plugged with rubber plug fitted with delivery tube, the delivery tube were connected to measuring cylinder for biogas measurement. Due to solubility of biogas in water, measuring cylinders were filled with acidified saline water (prepared at pH of 0.5 and 95% NaCl).

During preparation of the feedstock, 2, 3 and 4 kg of cowdung were mixed with one kg of water per each to prepare 2:1, 3:1 and 4:1 mixing ratio respectively. Batch anaerobic digesters configuration and operation studies were performed to understand the best ratio of the feedstock mixture. Three experimental setup were set at the start of the experiment. The yielded biogas was measured per day by downward water displacement method using calibrated 2 litres cylindrical jar for each reactor. Average of the results obtained per each setup were calculated. The batch digesters were monitored for 60 days however daily production stopped on the 45^{th} day in the 4:1 digester, 30^{th} day in the 3:1 and 2:1 digesters.

RESULTS AND DISCUSSION

Feedstock characteristics (TS, VS and C/N ratio)

TS (%), VS as %TS and CN ratio of fresh (undiluted) samples of cow dung collected from Mwanga and Meru district ranged from 16-23, 51-83 and 20-41 respectively (Tables 1 and 2). When a sample with 20 % TS and 69% VS as % of TS was diluted at ratios of 2:1, 3:1 and 4:1, resulted into diluted samples with TS% and VS (as % of TS) of 12, 15 and 17; and 68.2, 68.5 and 68.7% correspondingly.

Table 1: TS, VS and C/N ratio for samples from semi-arid areas of Meru

Sample name	TS (%)	VS%	C/N ratio
Losinoni Kati	20.0	67.3	25
Engutukoit	22.9	83.2	25
Lemanda	20.0	67.9	25
Losinoni Juu	21.2	76.4	28
Mkuru	20.2	69.5	25

Table 2: VS, TS and C/N ratio for samples collected from biogas users in Mgagao (Mwanga)

Sample Name	TS%	VS%	C/N ratio
Household 1	20.4	69.5	20
Household 2	20.0	69.1	25
Household 3	16.2	51.4	20
Household 4	20.1	69.3	25
Household 5	20.0	69.0	25
Household 6	20.3	69.4	21
Household 7	20.0	68.9	25
Household 8	20.2	69.3	25
Household 9	21.2	73.0	20
Household 10	22.0	83.2	25
Household 11	19.8	68.4	25
Household 12	20.1	69.4	24
Household 13	21.3	73.2	41
Household 14	20.0	69.0	30
Household 15	22.2	79.2	25
Household 16	20.0	68.1	20
Household 17	20.3	69.0	25
Household 18	20.0	69.2	20
Household 19	22.8	83.0	25
Household 20	20.0	68.5	25

The optimal %TS for solid state digesters is reported to range between 10 and 20 (Yi et al. 2014). In this study, feedstock with TS of 17% produced biogas yield of up to 46.4 mL/g VS which was the highest production in all %TS tested. These results were in line with those reported by Widiasa and Seno (2010) when cattle manure were used as feedstock. Their results showed the increase in biogas production as %TS was changed from 7.4 to 9.2%. A similar relationship was established by KeChrist et al. (2017) using cattle manure as feedstock, where similar trend of results as of this study were obtained. Comparably Brown and Li (2013) reported an increase in biogas yield from 42 mL/gVS to 72 mL/gVS as %TS increase from 15 to 20 mL/gVS. However, study by Abbassi-Guendouz et al. (2012) reported contrary results for the effect of %TS on biogas production when similar feedstock as of this study were used.

CN ratio in this study ranged from 20 to 41 (Tables 1 and 2). Sample with optimal CN ratio (25) in the present study was selected for testing production of biogas in the laboratory. Feedstock with this CN ratio suggest a significant amount of biogas to be generated since the ratio is at its optimal point (Ghasimi et al. 2009).

When %VS fall into the optimal range of 28-90% more biogas is produced (Ozturk

2012). Concentration of VS in this study ranged from 54-83%, this is an indication that the feedstock is rich in organic solid content that can be converted into biogas during anaerobic digestion. Substrate with VS (69%) was sampled to be used in this study, however upon dilution VS slightly changed to 68.2, 68.5 and 68.8% for the 2:1, 3:1 and 4:1, respectively. Biogas production tend to increase when percentage of volatile solids increases (Gelegenis et al. 2007, Ozturk 2012). This have been confirmed in this study where feedstock with 68.8% generated high amount of biogas than others at 68.2 and 68.5%.

The digester gas pressure

From the household survey it was noted that, at Mgagao, digester users fed their biogas plants using mixing ratio ranging from 1:1, 2:1 and 3:1. The evaluation of the feeding practices in terms of the ratios for the household survey at Mgagao were checked against the digester pressure. Generally, when the digester is fed properly, digester gas pressure correspond with specific theoretical pressure. The digester of 9 m^3 that was being fed at the ratio of 4:1 was sampled for investigations. Data for digester gas pressures were recorded by the data loggers except where the gas meter was installed in the kitchen. Data were recorded daily for a month. Figure 2 shows the pressure recorded during the respective month. In the month, the digesters were fed with the right proportions of 4:1. The results of the analysis were summarized and presented in weekly basis as per Figure 2. The pressure started increasing at the beginning of week two. This is because during week one, such digesters had not picked up for producing the biogas.

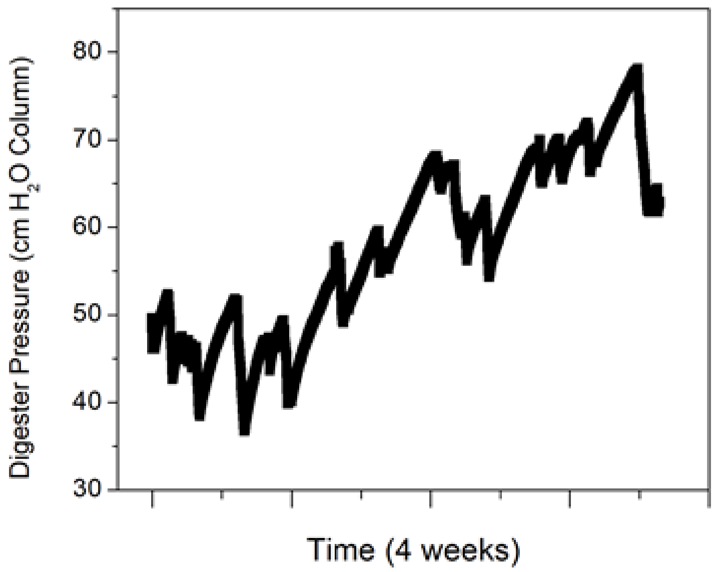

Figure 2: The variation of gas pressure in the digester with time

Digester pressure is one of the best indicators of digester performance and could also measure the level of digester services provided by the households. The theoretical pressures for 9 m^3 digesters is 80-100 cm H_20 column if all conditions are ideal (Zalm

2017). Performance of the digester pressure tested in Mgagao indicated that, higher ratio of cowdung to water lead into more pressure. But, lower ratio of cowdung to water result into low pressure. The digester pressure (Figure. 2) did vary much from the start until the end of the exercise, with more stable pressure being observed after the first two weeks. The observed pressure for the first week were below the theoretical value since such digesters had not improved much for producing biogas.

Pressure on the fourth week increased nearly to the theoretical pressure since such digesters had picked up for much production of biogas. Therefore, digester gas pressure observed in a month confirmed that the best mixing ratio for optimal biogas production in solid state digesters is 4:1.

The effect of mixing ratio on biogas production

The laboratory experiment carried out revealed that, daily biogas production varied continuously for the 2:1, 3:1 and 4:1 mixing ratios. Figure 3 shows the cumulative biogas production for the reactors operated at three different mixing ratio during the whole experiment. Each curve represents the average of three replicates. The best performance of biogas production was observed in the digester with mixing ratio of 4:1. This ratio provided cumulative biogas of 20.94 L equivalent to 46.4 mL/g VS biogas yield on the 30th day while 3:1 and 2:1 gave 9.08 L (22.7 mL/g VS) and 7.39 L (21.4 mL/gVS), respectively as shown in Figure. 3.

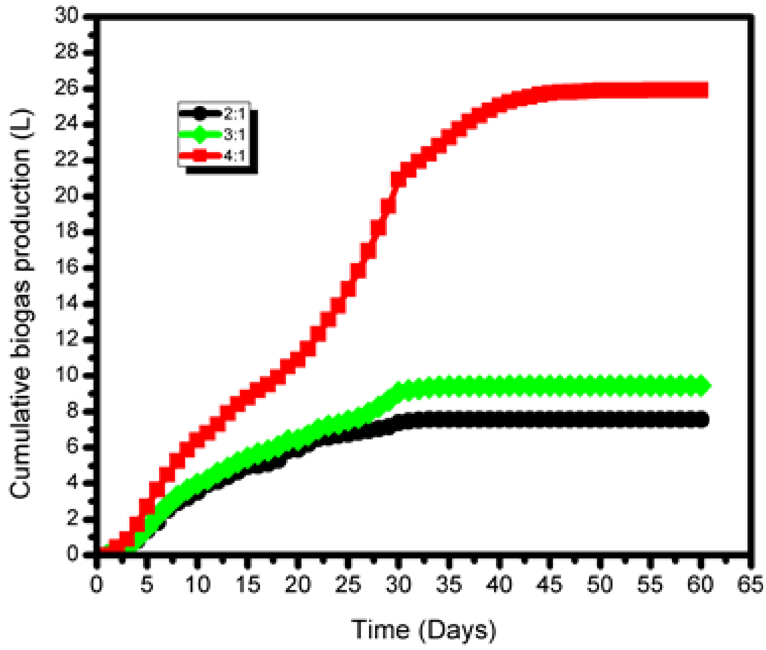

Figure 3: Effect of mixing ratios of cowdung to water on biogas production

Working with cowdung/water feedstock, Adelekan and Bamgboye (2009) reported an increased biogas yield that was directly proportional to the increase in mixing ratio. Similarly, Haryanto et al (2018) using comparable feedstock reported a potential increase in methane yield of up to 122 mL/gVS at 2:1 mixing ratio of waste/water as compared to 1:1 that produced only 78 mL/gVS. The results obtained in this study clearly illustrate that, increase in substrate/water mixing ratio gives enhanced biogas production. This could be explained by the fact that, as substrate mixing ratios increase, volatile solids also increase resulting into higher production of biogas.

Statistical analysis

In order to describe the relationship between 2:1-3:1, between 2:1-4:1 and 3:1-4:1 on biogas production in SSD, Pearson correlation was used. The variables were classified as per Guildford's rule of thumb for interpreting correlation coefficient (Guilford and Fruchter 1965). The interpretation was based on correlation coefficient value (r), where 0.0 to 0.29 negligible or little correlation, 0.3 to 0.49 low correlation, 0.5 to 0.69 moderate or marked correlation, 0.7 to 0.89 high correlations and 0.9 to 1.00 very high correlations. The significance level (or p-value) is the probability of obtaining results as extreme as the one observed. If the significance level is very small (less than 0.05) then the correlation is significant and the two variables are linearly related. If the significance level is relatively large (for example, 0.50) then the correlation is not significant and the two variables are not linearly related (Guilford and Fruchter 1965).

Very high positive correlation existed between 2:1 and 3:1 ($r = 0.96034$, $p=0.0$). Very high positive correlation also existed between 2:1 and 4:1($r = 0.99225$, $p = 0.0$). A very high positive correlation ($r = 0.92128$, $p = 0.0$) occurred between 3:1 and 4:1. All mixing ratios displayed a linear relationship ($p = 0.0$) meaning that results were linearly related.

CONCLUSION AND RECOMMENDATION

Cowdung/water ratio of 4:1 showed high production of biogas than that of 3:1 and 2:1. Feeding lower ratios would result into low production of biogas as reported elsewhere. Solid state digesters are best fit for areas where there are insufficient water supply. Digester pressure best provides for the health of the digester as a performance evaluation parameter. Sensitization of the communities to use appropriate and recommended ratios is important and calls for implementation if we are to make the communities use efficiently the biogases. Investigation of the frequencies of feeding especially for SSD need further investigation.

ACKNOWLEDGEMENT

The authors would like to thank ECOBOMA project funded under the EU and DAAD for providing financial support toward accomplishment of this work.

REFERENCES

Abbassi-Guendouz A, Brockmann D, Trably E, Dumas C, Delgenès JP, Steyer JP and Escudié R 2012 Total solids content drives high solid anaerobic digestion via mass transfer limitation. *Bioresour. Tech.* **111**:55-61.

Adelekan BA and Bamgboye AI 2009 Effect of mixing ratio of slurry on biogas productivity of major farm animal waste types. *J. App. Biosci.* **22**:1333-1343.

Brown D and Li Y 2013 Solid state anaerobic co-digestion of yard waste and food waste for biogas production. *Bioresour. Tech.* **127**: 275-280.

Dobbin K and Simon R 2005 Sample size determination in microarray experiments for class comparison and prognostic classification. *Biostat.* **6**(1): 27-38.

Gelegenis J, Georgakakis D, Angelidaki I and Mavris V 2007 Optimization of biogas production by co-digestion whey with diluted poultry manure. *Renew. Energy* **32**:2147-2160.

Ghasimi SMD, Idris A, Chuah TG and Tey BT 2009 The effect of C:N:P ratio, volatile fatty acids and Na^+ levels on the performance of an anaerobic treatment of fresh leachate from municipal solid waste transfer station. *African J. Biotech.* **8**: 4572-4581.

Guilford JP and Fruchter B 1965 Fundamental statistics in psychology and education. McGraw-Hill, New York.

Haryanto A, Hasanudin U, Afrian C and Zulkarnaen I 2018 Biogas production from anaerobic co-digestion of cowdung and elephant grass (*Pennisetum Purpureum*) using batch digester. *Earth. Environ. Sci.* 141: 1-10.

KeChrist O, Sampson M, Golden M and Nwabunwanne N 2017 Slurry utilization and impact of mixing ratio in biogas production. *Chem. Eng. Tech.* **1**(2): 12-23.

Kileo JO and Akyoo AM 2014 Technology transfer and farm-based renewable energy sources: the potential of biogas technology for rural development in Tanzania. *African J. Biotech.* **2**:436-441.

Lay JJ, Li YY, Noike T, Endo J and Ishimoto S 1997 Analysis of environmental factors affecting methane production from high-solids organic waste. *Water Sci. Tech.* **36**(6-7): 493-500.

Mahushi DJ 2018 *Optimization of biogas production process in solid state digesters: Option for minimizing deforestation in dry areas*. MSc. thesis, Department of Water Environmental Science and Engineering, The Nelson Mandela African Institution of Science and Technology, Tanzania.

Ozturk B 2012 Evaluation of biogas production yields of different waste materials. *Earth Sci. Res.* **2**(1):165-174.

Panwar NL, Kaushik SC and Kothari S 2011 Role of renewable energy sources in environmental protection: a review. *Renew. Sust. Energy Rev.* **15**(3):1513-1524.

Santana A and Pound B 1980 The production of biogas from cattle slurry: the effects of concentration of total solids and animal diet. *Trop. Anim. Prod.* **5**(2):130-135.

Singh P, Suman A, Tiwari P, Arya N, Gaur A and Shrivastava AK 2008 Biological pretreatment of sugarcane trash for its conversion to fermentable sugars. *World J. Microbiol. Biotech.* **24**(5): 667-673.

Widiasa IN and Seno J 2010 The influence of total solid contents on biogas yield from cattle manure using fluid rumen inoculum. *Energy Res. J.* **1**(1): 6-11.

Yi J, Dong B, Jin J and Dai X 2014 Effect of increasing total solids contents on anaerobic digestion of food waste under mesophilic conditions: performance and microbial characteristics analysis. *PloS one* **9**(7):1025.

Zalm JE 2017 *Performance of domestic biodigesters in Kenya towards the development of a comparative method for measuring the performance of different biodigester types in Sub-Saharan Africa.* MSc. thesis, Department of Energy Science, University of Utrecht.

Poster presentation

OPTIMIZATION OF BIOGAS PRODUCTION PROCESS IN SOLID STATE DIGESTERS: OPTION FOR MINIMIZING DEFORESTATION IN DRY AREAS

Debora J Mahushi, Revocatus L. Machunda, Alfred N.N Muzuka
Department of Water Environmental Science and Engineering, NM-AIST, Tanzania

INTRODUCTION

- Fuel wood from forest as the primary source of energy meets as much as 99% of energy requirement (**Trossero, 2002**).
- Valuation of the actual amount and their influences on forest has remained the subject of significant discussion (**Mwampamba *et al.*, 2013**).
- Due to dependence on fuelwood, forests in Tanzania goes on decreasing, converting semi-arid areas into arid areas (**Trossero, 2002**).
- Saving forest from degradation, biogas technology use has to be introduced.
- Biogas: CH_4 (60%), CO_2 (30-40%), traces (NH_3 , H_2O , H_2S)(**Rasi *et al.*, 2007**).
- It is produced when organic matter undergo fermentation in closed system (digester) (**Rasi *et al.*, 2007**).
- Optimized solid state anaerobic digester is of great important to semi arid areas.
- Up to 27 digesters were installed in the northern part of Tanzania (Mgagao, Mwanga).
- Despite the adjustments made by TDBP, a study by Kileo and Akyoo (2014) revealed that, 34.1% of the installed digesters had insufficient biogas production.
- It was found that feeding practices in terms of mixing ratios of feedstocks was the major causing factor.
- Therefore, assessment of the right mixing ratio and evaluation of its contribution to optimal biogas production was carried out.

OBJECTIVES

Main Objective:
Assessment of the energy demand, the impact on forest cover and undertaking optimization of biogas production process in solid state digesters as possible option for minimizing deforestation in water scarce areas.

Specific Objectives:
1. To analyze existing energy sources, evaluate the energy demand and find out the impact of fuelwood use on forest cover within the pastoralists communities of Mwanga and Meru district
2. To optimize existing and new solid state digesters as alternative sources of energy.

SIGNIFICANCE OF THE RESEARCH

The proposed study intended to provide solutions to problems of low biogas production in solid state digesters and forest cover deterioration to semi-arid areas.
Similarly, adoption of the biogas technology by communities will reduce pressure on fuel wood use and thus reducing deforestation.

METHODOLOGY

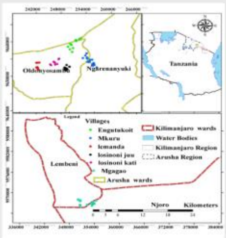

Figure 1: A map showing selected study sites surveyed in Meru and Mwanga districts

- ✓ Energy sources and forest cover
- Questionnaire survey
- Landsat (TM and OLI)
- Images radiometrically and geometrically calibrated
- Semi-Automatic Classification Plugin in QGIS software.
- ✓ Biogas production in SSD
- TS, VS and CN ratio
- Anaerobic batch mode digesters (Fig. 2)

Fig. 2: Experimental set up for biogas production basing on different mixing ratios

RESULTS

Energy sources and forest cover

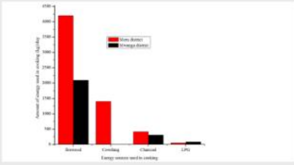

Fig. 3: Type and amount of energy sources used for cooking

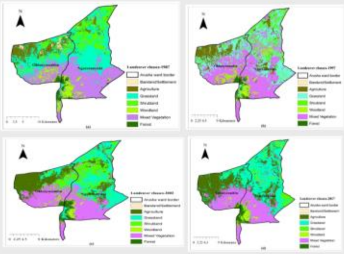

Fig. 4: Image classification for land cover classes in Meru district (Arusha)

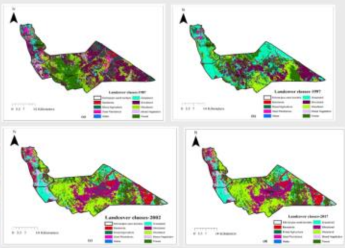

Fig 5. Image classification for land cover classes in Mwanga district (Kilimanjaro)

✓Biogas production in SSD

Table 1: TS, VS and C/N ratio for samples from semi-arid areas of Meru

Sample name	TS (%)	VS (%)	C/N ratio
Losinoni Kati	20.0	67.3	25
Engutukoit	22.9	83.2	25
Lemanda	20.0	67.9	25
Losinoni Juu	21.2	76.4	28
Mkuru	20.2	69.5	25

Table 3: VS, TS and C/N ratio for samples collected from biogas users in Mgagao (Mwanga)

Sample Name	TS%	VS%	C/N ratio
Household 1	20.4	69.5	20
Household 2	20.0	69.1	25
Household 3	16.2	51.4	20
Household 4	20.1	69.3	25
Household 5	20.0	69.0	25
Household 6	20.3	69.4	21
Household 7	20.0	68.9	25
Household 8	20.2	69.3	25
Household 9	21.2	73.0	20
Household 10	22.0	83.2	25
Household 11	19.8	68.4	25
Household 12	20.1	69.4	24
Household 13	21.3	73.2	41
Household 14	20.0	69.0	30
Household 15	22.2	79.2	25
Household 16	20.0	68.1	20
Household 17	20.3	69.0	25
Household 18	20.0	69.2	20
Household 19	22.8	83.0	25
Household 20	20.0	68.5	25
Household 21	22.7	68.0	25
Household 22	20.6	67.9	25
Household 23	23.7	69.0	24
Household 24	25.0	70.2	26
Household 25	21.2	83.0	25
Household 26	20.8	69.1	25
Household 27	23.0	69.0	25

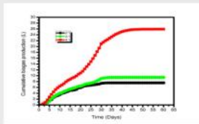

Figure 6: Effect of mixing ratios of cowdung to water on biogas production

CONCLUSIONS

The identified energy sources included cowdung cake, firewood, charcoal, biogas, and LPG. The demand amounted to 1400, 6289, 724 and 21 kg per day. The decrease in forest cover for selected areas was 927 ha for the past 30 from 1987-2017 years. Pastoralist are sensitized to shift from using fuelwood to biogas.
Cowdung/water ratio of 4:1 showed high production of biogas. Sensitization of the communities to use appropriate and recommended ratios is important and calls for implementation.

References

1. Kileo, J. O. and Akyoo, A. M. (2014). Technology transfer and farm-based Renewable energy sources.
The Potential of biogas technology for rural Development in Tanzania.
2. Mwampamba, T. H., Ghilardi, A., Sander, K. and Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy Sustainable Development*. **17**:75–85.
3. Rasi, S., Veijanen, A. and Rintala, J. (2007). Trace compounds of biogas from different biogas production plants. *Energy*. **32**: 1375-1380.