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CLOSING THE NUTRIENT LOOP WITH ECOLOGICAL SANITATION IN NEPAL

Sabina Maharjan
Master of Science in Environment and Natural Resources –
Specialization Sustainable Water and Sanitation, Health and Development

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PREFACE

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science-Sustainable Water and Sanitation, Health and Development at the Fakultet for miljøvitenskap og naturforvaltning, (MINA) of Norges miljø- og biovitenskapelige universitet (NMBU). This thesis is based mostly on literature review of published literature as well as master's Thesis studying about ecological sanitation and its importance in developing countries like Nepal, as well as site visits. I hereby declare that this thesis is my original work. I sincerely hope it will contribute towards the implementation of holistic sanitation solutions which not only solve the prevailing sanitation problem but also help local population in their agriculture.

Lalitpur, June 2nd, 2020

Sabina Maharjan

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I would also like to thank Mr. Shushil Nhemhaphuki Assistant Technical Officer from the Environment and Public Health Organization (ENPHO) for his assistance on deciding on the location for the field visits in the limited time I had before the lock down started in Nepal due to COVID-19 pandemic.

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Thank you.

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LIST OF SYMBOLS

3R: Reduce, Reuse, Recycle

B: Boron

C/N: Carbon/Nitrogen

Ca: Calcium

Cl: Chlorine

Co: Cobalt

Cu: Copper

Fe: Iron

kW: Kilowatt

Mg: Magnesium

Mn: Manganese

Mo: Molybdenum

MT: Metric Ton

MW: Megawatt

S: Sulphur

Se: Selenium

Zn: Zinc

LIST OF ABBREVIATION

ADS: Agriculture Development Strategy

AEPC: Alternative Energy Promotion Centre

BSP: Biogas Support Program

CIUD: Centre for Integrated Urban Development

CNG: Compressed Natural Gas

DWSS: Department of Water Supply and Sewerage

ECOSAN: Ecological Sanitation

ENPHO: Environment and Public Health Organization

EU: European Union

GDP: Gross Domestic Product

GIZ: Gesellschaft für Internationale Zusammenarbeit

GoN: Government of Nepal

GTZ: German Technical Cooperation

MDG: Millennium Development Goals

NBPA: Nepal Improved Biogas Plant

NEA: Nepal Electricity Authority

NEAT: Nepal Economic, Agriculture and Trade Activity

NEWAH: Nepal Water for Health

NPK: Nitrogen, Phosphorus, Potassium

NRREP: National Rural Renewable Energy Programme

RWSS: Rural Water Supply and Sanitation

SDG: Sustainable Development Goals

SHMP: Sanitation and Hygiene Master Plan

UN: United Nation

UN-HABITAT: United Nation Human Settlement Program

UNICEF: United Nation Children's Fund

VDC: Village Development Committee

VIP: Ventilated Improved Pit

WAN: WaterAid Nepal

WASH: Water, Sanitation and Health

WHO: World Health Organization

YSD: Yashoda Sustainable Development

EXECUTIVE SUMMARY

Unsafe sanitation is one of the world's largest health and environmental problems. Many countries face great challenges to provide adequate sanitation while leaving their people at risk of water, sanitation, and health (WASH) related diseases as diarrhoea which is the second - most leading cause of death in many countries. Although over 2.2 billion people gained access to improved toilets since 1990, sanitation was one of the most off-track Millennium Development Goals (MDGs) globally. The world missed the MDG target for sanitation by 700 million people with 2.4 billion still lack improved sanitation facilities and 946 million practicing open defecation. Now, the United Nations' Sustainable Development Goals (SDG) states that everyone should have "adequate and equitable" sanitation by 2030. Nepal has been making considerable progress in expanding access to water and sanitation over the last few decades and despite the tremendous challenges such as poverty, difficult terrains, and conflicts, Nepal has formulated and enforced several WASH policies, guidelines, and acts. However, 10.8 million of about 29 million people in Nepal do not have access to improved sanitation. This study showed that ecological sanitation systems are promising for developing countries like Nepal because ecological sanitation is a circular economy, a "waste to resource" concept, and a closed nutrient loop sanitation system. In Nepal, the ecosan latrine concept was first introduced by ENPHO in 2002/2003 under the support of WaterAid Nepal with the implementation of Double Vault urine-diverting dry toilets. During the last few years, there has been rapid progress in the promotion of Ecosan toilets. By 2010, more than 770 Ecosan toilets had already been constructed (Messmer, 2011) and there is a demand for 3000 urine-diverting pans (Shakya, 2015). The nutrients contained in the excreta are recycled by using them in agriculture. Urine contains N, P, and K necessary for the plant growth in water-soluble ionic form and is therefore readily available for plant uptake. Human faeces also contain these elements though in lower concentrations along with organic matter essential for agricultural productivity. Not only nutrients but energy can also be recovered from human excreta by biogas production. Biogas is waste-to-energy technology that uses organic waste such as cattle manure, food waste, agricultural waste, and human excreta, separated or combined. The anaerobic digestion yielding biogas can also contribute to the necessary hygienization of the excreta. Source separated urine has been found to be a safe and efficient fertilizer for many crops and vegetables and has been studied in many different contexts since the late 1990s. However, human faeces are responsible for most diseases spread by human excreta as one gram of faeces contain about 100 million bacteria some of which are pathogenic. Therefore, faeces need to be hygienized either by dehydration or the composting process before its application. The slurry as a by-product of the anaerobic digestion process can be produced locally and used to increase soil fertility. However, findings showed that the biogas plant owners pay more attention to gas production and neglect the slurry application aspect. A developing country like Nepal needs a system that aims to treat the sludge generated from the septic tanks and reuse the end products such as biogas, treated sludge, compost manure, and water obtained after the treatment process. Despite the benefits, the application of human excreta in agriculture has been associated with health and environmental risks and socio-cultural issues. People need to transform the misconception of excreta as waste and dirt to view it as a resource and treat the excreta properly to produce a safe fertilizer product supplemented by biogas generation.

Keywords: WASH, ecological sanitation, closed nutrient loop, human excreta, fertiliser, biogas, slurry

1. BACKGROUND

1.1. SANITATION IN A GLOBAL CONTEXT

Unsafe sanitation is one of the world's largest health and environmental problems particularly for the poorest in the world (Ritchie and Roser, 2020). Many countries are challenged in providing adequate sanitation for their entire populations, leaving people at risk for water, sanitation, and hygiene WASH-related diseases (Ritchie and Roser, 2020). Diarrhoea is by far the single-most important WASH-related disease and still the second-leading cause of death in low-income economies (WHO, 2017). In 2012, 842,000 people are estimated to have died in low- and middle-income countries due to diarrheal diseases caused by inadequate sanitation (WHO, 2020).

In developing countries, 90% of the sewage is not treated before reaching water bodies (WAN, 2011), contributing to contamination of that 1.8 billion people's drinking water with faecal pathogens (UN, 2015). An estimated 2.6 billion people in the world lack access to improved sanitation, defined as the hygienic separation of human excreta from human contact (WHO/UNICEF, 2012). Improved sanitation facilities include flush or pour flush toilets to piped sewer systems or, septic tanks, ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilets (Ritchie and Roser, 2020). In 2010, 72% of sanitation facilities in Sub-Saharan Africa and 59% in Southern Asia were classified as "unimproved" (WHO/UNICEF, 2012).

Globally 2.3 billion people live without access to a basic sanitation service, 40% of them residing in Southern Asia (UN, 2015). Basic sanitation is described as having access to facilities for the safe disposal of human waste as well as having the ability to maintain hygienic conditions. Almost 15% of the world still practice open defecation. Though over 2.2 billion people gained access to improved toilets or latrines since 1990, sanitation was one of the most off-track Millennium Development Goals (MDGs) globally (Ritchie and Roser, 2020).

The world has missed the sanitation target by almost 700 million people, with 2.4 billion still lacking improved sanitation facilities and 946 million practicing open defecation (WHO & UNICEF, 2015). Now, the United Nations' Sustainable Development goal (SDG) is for everyone to have "adequate and equitable" sanitation by 2030 and end open defecation (WHO and UNICEF, 2015), where excreta is safely disposed of in situ or treated off-site (Ritchie et al., 2018).

Figure 1 shows the number of people without access to an improved sanitation in 2015 country wise in the world.

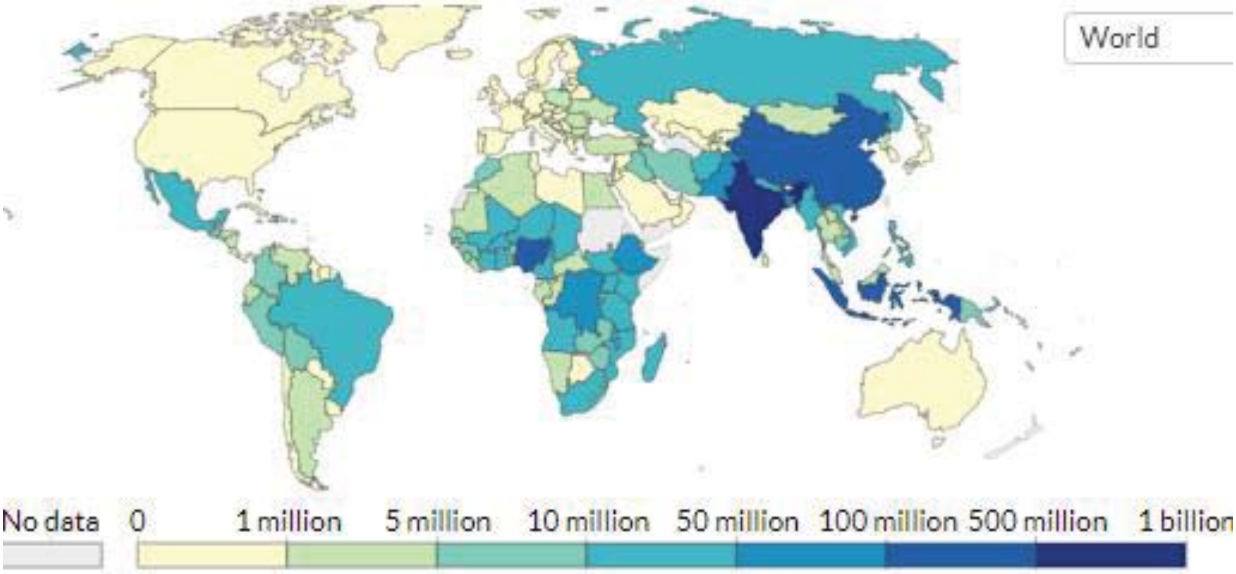

Figure 1 Number of People without access to improved sanitation in 2015

Source: Our World in Data based on the World Bank, World Development Indicators as cited in (Ritchie and Roser, 2020)

1.2. CONTEXTUAL BACKGROUND

1.2.1. NEPAL: GENERAL INFORMATION

Nepal is a landlocked country with the current population of over 28.4 million people. As reported by the World Bank, Nepal is one of the poorest nations in the world with an estimated GDP per capita of US$ 470 of which about 42 percent are living below the poverty line (Suwal, 2019).

Despite the tremendous challenges such as poverty, difficult terrains and conflicts, Nepal has been making significant progress in expanding access to water and sanitation over the last few decades by formulating and enforcing several WASH policies, guidelines and acts (UNICEF, 2020). In 1997, the government formulated a comprehensive 20 years' Water and Sanitation Strategies to achieve the target of 100% sanitation coverage (100 % of the total population which is 22.6 million according to the 2011 census) in the country by 2017 AD (UN/WHO, 2014) through the integrated National Rural Water Supply and Sanitation (RWSS) Policy and Strategy 2004 (Budhathoki, 2019). The Sanitation and Hygiene Master Plan (SHMP) was enforced by the government to gear up sanitation and hygiene programs ensuring access of all population to basic WASH facilities by the end 2017 (GoN, 2011).

Compared to 6 per cent in 1990, sixty-two per cent of households are now using improved sanitation facilities in Nepal. However, 10.8 million people still do not have access to improved sanitation (UNICEF, 2020). Nepal has already achieved the MDG targets of 53% in sanitation to be met by the end of 2015 but there are a lot of challenges for sustaining these achievements and making available sanitation facilities to the remaining portion of the population (Budhathoki, 2019).

1.2.2. PRESENT SITUATION OF HUMAN WASTE MANAGEMENT IN NEPAL

The Kathmandu Valley has a total population of over 2.4 million spread in a total area of 716 km^2 in three districts: Kathmandu, Lalitpur and Bhaktapur (Uprety, 2017). It is estimated that the Kathmandu Valley only generates around 122,000 tons of fecal sludge every year, and almost 95 percent of this waste ends up in rivers without any treatment (The Kathmandu Post, 2016) as common waste management practice in Nepal involves discharging of untreated sewage, domestic waste, industrial waste and municipal waste into aquatic environments without proper treatment. There are few wastewater-treatment plants, mainly located in Kathmandu valley, but most of the plants based on centralized wastewater treatment strategy, are not operating well causing harmful materials including biodegradable organic matter, toxic substances, pathogens and chemicals to end up in water streams and rivers. The concept of treatment or recycling of wastewater before discharging into water bodies is normally considered as unaffordable and consequently adopting rate of treatment technology is very slow (Jha and Bajracharya, 2014). As a result, Nepal faces a high number of WASH-related diseases such as diarrhea, dysentery, typhoid, gastroenteritis and cholera. Children under the age of five are the most affected with an estimated 44,000 children dying every year in Nepal from waterborne diseases (Suwal, 2019).

The Water, Sanitation and Hygiene Sector Development Plan (2016) realizes, inter alia, the importance of strengthening facilities for water security, sanitation, solid waste collection, sanitary landfill sites, adoption of 3R (reduce, reuse and recycle) and establishment of a dedicated solid waste management unit in municipalities. The framework and guidelines equally focus on sustained management and reuse of wastes, fecal sludge and groundwater (Uprety, 2017).

The challenge at present is to increase the toilet coverage and its accessibility by making sure toilets are hygienic, safe and environmentally friendly and affordable (WAN, 2011).

By 2030, Nepal has planned to achieve the following targets under SDG 6:

a. 95 % households using unshared improved sanitation facilities;
b. 98 % population using latrines; and
c. All urban households that have toilets are connected to a sewerage system.

Nepal, however, has not set any targets for untreated wastewater both domestic and industrial (Uprety, 2017).

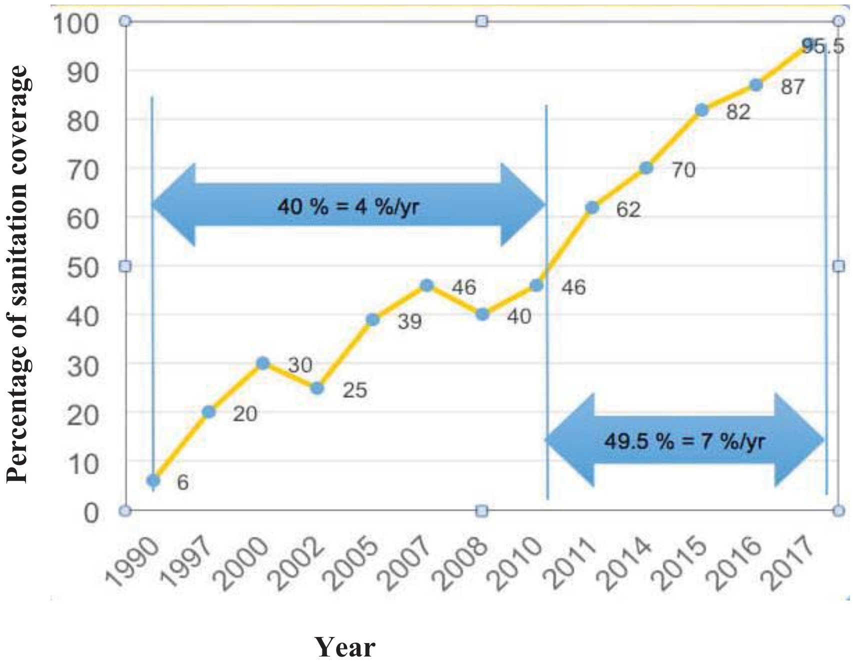

Figure 2 Sanitation Coverage in Nepal till 2017

Source: (DWSS, 2018) as cited in (Tuladhar, 2018)

Figure 2 shows the sanitation coverage of Nepal of about 95.5% till 2017. It shows that one of the targets of SDG 6 has been achieved. In 2019, September, The Nepal Government declared Nepal to be "open defecation free" an important sanitation milestone (SNV, 2019). However, a recent study by the Global Sanitation Fund Program in Nepal showed that 3% of households in communities declared 'open defecation free' did not have toilets, and in 5% of families at least one member still defecated outside despite having a toilet at home as stated in NepaliTimes (Tuladhar, 2018). Moreover, although it has raised awareness and reduced child mortality, the campaign has concentrated on building latrines but not on sludge disposal and ensuring water supply leading the danger of spreading infections they were supposed to control (Dixit, 2018; Uprety, 2017).

1.3. RATIONALE FOR STUDY

1.3.1. LIMITATION OF CONVENTIONAL SYSTEM IN NEPAL: A NEED FOR AN ALTERNATIVE

Conventional sewerage is accredited to be based on criteria such as minimum gradients and minimum cover levels that must meet very conservative values (WHO, 2006). This often results in deep pipes and the necessity for pumping and thus increased operation costs (Action, 2008). While the conventional sanitation system progresses towards zero liquid effluent discharge, the technology comes at a significant cost and energy requirement. Developing countries like Nepal, continue to struggle to implement such systems, due to factors associated with financing, and affordability revenue, and thus rely heavily on on-site systems. Connection to a sewer system can also be costly and the cost per person of connecting to a sewer network is 5 to 50% higher than on-site alternatives (Bhagwan et al., 2019).

Conventional on-site sanitation systems are largely linear, end-of-pipe systems where drinking water is misused to transport waste into the water cycle, causing environmental damage and hygienic hazards, and contributing to the water crisis (GTZ, 2000). Moreover, in many areas soil conditions are inappropriate for conventional types of sanitation as latrines or septic tanks with infiltration due to high water table making ground water susceptible to pollution. In addition, conventional latrines often discharge into the environment with little or no sanitisation, or nutrient removal (WAN, 2008).

Out of five (shown in Figure 3), the only wastewater treatment plant in operation as of January 2003 is the activated sludge system at Guheshwori, Kathmandu. Nitrogen and phosphorous removable before disposal of treated effluent in the river is not possible at Guheshwori wastewater treatment plant as it lacks biological treatment unit. Routine maintenance of the units including the pumps and other accessories are missing and some of the equipment's are also in critical condition (Shahi, 2012) making it useless anyways. Only a small number of houses are connected to treatment plants and therefore most houses end up disposing the wastewater directly into the rivers and other water bodies (Ellingsen, 2010).

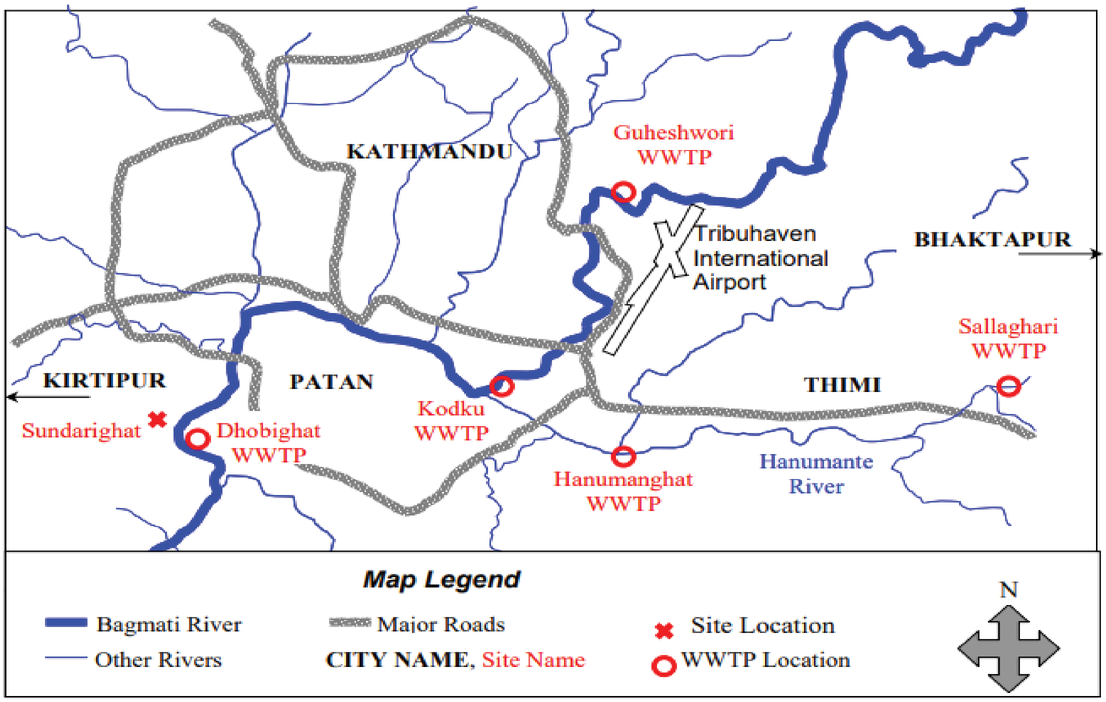

Figure 3 Overall view of existing wastewater Treatment Plants in Kathmandu Valley

Source: (Asian Development Bank , 2000)

In the urban centers like Kathmandu valley, sewers are often present, but sewage treatment is lacking (Shrestha, 2001). Human waste is collected by private trucks and is just dumped into the Bagmati river without any treatments (Tuladhar, 2018). In rural areas, the sanitation promotion has mostly been focused on hygiene education and on-site sanitation in the form of family toilet and septic tank construction. Adequate attention has not been paid to environmentally and hygienically safe handling and disposal of septic waste from the on-site sanitation facilities such as resource recovery from human faeces and urine for use as agricultural manures. Allowing menstruating and postnatal women and Dalits using family water points and toilet facilities is still a social taboo widely practiced in many rural communities in some parts of the country. Public toilet facilities on public transport stops along roads and highways are few and are not user friendly to women, children and physically challenged people (GoN, 2014).

Often poor quality of material and workmanship are used in the construction resulting in higher operation and maintenance costs. Moreover, maintenance technicians lack needed skill and are inadequately supervised whereas out-sourcing of maintenance works is not common as most maintenance works are done in-house by its regular or long-term employed staff members. Maintenance of sewerage and sanitation services receives lower priority (GoN, 2014).

Therefore, in Nepal even a bigger challenge is what to do with the excreta in toilets built in the last few years that have pits or septic tanks starting to fill up (Tuladhar, 2018). Hence, there is a definite need to find a better and sustainable solution in Nepal to solve sanitation problems alternative to conventional and hence the option of ecological sanitation toilets.

1.3.2. ECOLOGICAL SANITATION

The Ecological sanitation technology, ecosan in short, provides the effective alternative solutions in a three-step process of dealing with human excreta: i.e. containment, sanitisation and recycling (WAN, 2008). Ecosan is a sustainable, closed-loop system that treats human excreta as a resource for agriculture and are processed on site and then, if necessary, further processed off site until they are completely free of pathogens (Esrey et al., 1998).

However, the ecosan system must be compatible with the socio-cultural and economic conditions of the user area, simple, robust and easy to operate and maintain and protect the environment by isolating or destroying the faecal pathogens (WAN, 2011). Keeping this in mind, it is easier to introduce the ecosan concept in Nepal, as some part of Nepal has a history of reusing human excreta in their agriculture. Gopal Singh Nepali in his 1965 book *The Newars* has mentioned that human excreta as fertiliser cost 50 paisa per ton in Kathmandu Valley at that time. Newar, one of many communities in Nepal, traditionally understood the value of waste, they realised it needed to be recycled, and had developed a system in which the private sector and waste generators worked hand in hand to manage this resource. Urine was collected separately in brass containers, *kopra* and emptied in *naugaa*, the ash pit. Urine was then mixed with ash or farm residue with high carbohydrate content made excellent compost (Tuladhar, 2018, WAN, 2008). With the rise in flush-toilets, these traditions have been stopped and forgotten. The challenge now is to revive such traditions in treating waste as a resource and re-establish waste management as a sustainable circular system (Tuladhar, 2018).

1.3.3. CLOSING THE NUTRIENT LOOP

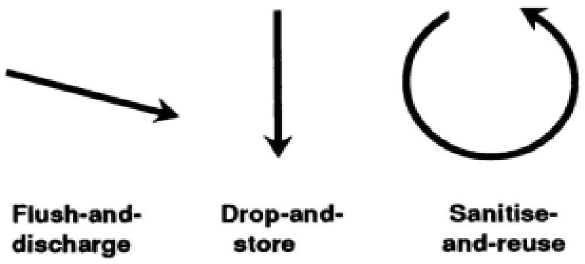

Figure 4 Three different principles to dispose human excreta

Source: (Drangert, 1998)

Conventional sanitation systems adopted for disposal of human excreta are primarily based on either “flush and discharge” or “drop and store” principles (Figure 4) (Drangert, 1998). These methods aim to dispose of human excreta rather than viewing it as a resource and treating at source. Conventional sanitation systems are “linear sanitation approach” and “end of pipe” technology, leading to disposal of enormous quantities of nutrients present in human excreta unproductively into water bodies causing pollution, apart from wastage of precious fresh water (Drangert, 1998, WAN, 2011). As the alternative to the flush and discharge or drop and store concept of conventional systems, the basic concept of sanitise and reuse is necessary. This approach to sanitation is based on three fundamental aspects of rendering human excreta safe, preventing pollution rather than attempting to control it after we pollute, and using the safe products of sanitized human excreta for agricultural purposes. This approach is ecological sanitation, a cycle of sustainable, closed-loop nutrient systems (Esrey, et al., 1998).

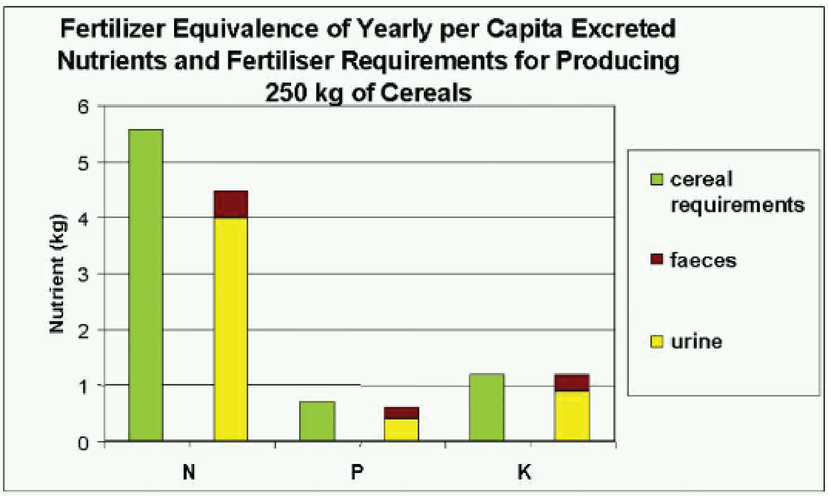

Figure 5 Balance between nutrients excreted by humans and nutrients required for producing their food.

Source: (Werner et al., 2004)

Closing the nutrient loop enables the recovery of organics, macro and micronutrients, water, and energy if necessary, after adequate treatment - in agriculture, or for other reuse options. As seen in Figure 5, there is a balance between the nutrients excreted by humans and nutrients required for producing their food. Ecosan systems help restore this natural balance between the quantity of nutrients excreted by one person in one year and that required to produce their food (Werner et al., 2004). However, an essential step in this cycle is the appropriate treatment and handling of the materials throughout the entire process, from collection through to reuse, ensuring a series of barriers are erected that reduce the risk of disease transmission to within acceptable limits, thus providing comprehensive protection of human health (Werner et al., 2004, Esrey et al., 1998).

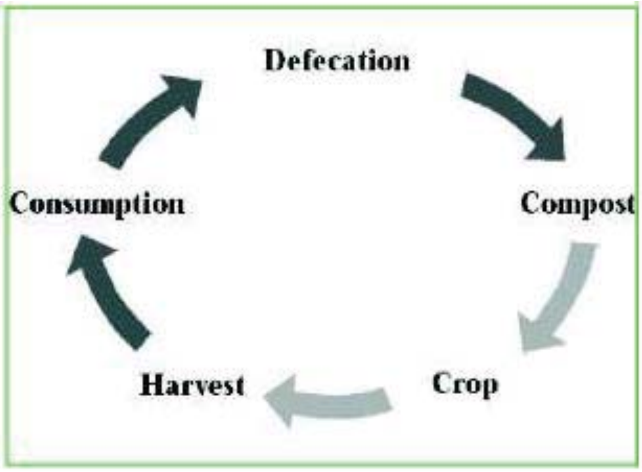

Figure 6 Closing the nutrient loop: Ecological Sanitation.
Source:(Sakthivel and Charair, 2011)

Closing nutrient cycles as shown in Figure 6 by recovering and using nutrient contained in excrement is therefore not only important because it helps to minimise the energy and resource intensive production of mineral fertilisers, but also because it makes such agricultural inputs available even to the poorest farmers in developing countries often engaged in subsistence farming (Werner et al., 2004).

2. OBJECTIVES

The main aim of this study is to understand the need of closing the nutrient loop in Nepal with ecological sanitation. The specific goals are:

1. to study the current situation of ecological sanitation in Nepal by literature review and to recommend a better solution to the existing problem of sanitation,
2. to discuss the importance of ecological sanitation in the context of Nepal by literature review and field visits,
3. to study the use of source separated human urine as a liquid fertilizer in Nepal by literature review,
4. to study the use of human excreta to produce biogas in the context of Nepal by literature review and,
5. to study the use of bio slurry, partial digested sludge, in Nepal to amend soil by doing literature review.

3. METHODOLOGY

This thesis was first designed to study the present situation of ecological sanitation systems in Nepal with literature review and field visits. The field visits were planned for Siddhipur, Khokana, Gundu (Thimi), and Imadol. Siddhipur and Khokana are the areas where first ecosan toilets were installed. It was planned to see the present state of the ecosan toilets. Unfortunately, due to COVID-19 lockdown, field visits were not possible except to Gundu (Thimi). The area was chosen as it was suggested by Mr. Shushil Nhemhaphuki, Assistant Technical Officer of ENPHO, who had worked in Gundu during installation of latrines. Due to the time constraints, semi-structured informal interviews were then conducted with the owner of ecological sanitation toilets in Gundu, Thimi only.

The remaining part of the thesis is based on literature review. Google Scholar was used to collect different peer review articles for literature research.

3.1. DATA COLLECTION AND ANALYSIS

Several literatures were reviewed to draft this thesis. Project completion reports, documents, wastewater master plans of the Kathmandu, and thesis of master's students were reviewed to collect information on the sanitation situation of Kathmandu. In addition, other published scientific literature was reviewed to collect data for the thesis. Relevant document search was carried out on the internet using the keywords "ecological sanitation in Nepal", "Closed loop", "Closing the Nutrient loop", "Recovery, reuse of nutrient", "Human Excreta", and "Human Urine." The focus of search was on recovery and reuse of human excreta.

4. LITERATURE REVIEW

4.1. HUMAN EXCRETA

Human excreta are composed of two basic components, urine and faeces. Urine and faeces produced in different quantities, have different nutritional values and require different care in processing. There is a high variability on how much a person excretes depending on diet, lifestyle and geographical location (Rose, et al., 2015). On an average a person urinates 0.8-1.5L (Feineigle , 2011) and 100–200 g of faeces per day (GTZ, 2000). Efforts to recover resources from human excreta or streams containing human excreta have typically targeted water, energy, carbon, nutrients, metals, or a combination of these resources (Harder, et al., 2019). In this study, nutrients and energy are focused.

4.1.1. NUTRIENT CONTENT IN HUMAN EXCRETA

URINE

The human urine fraction has 98% of the Nitrogen (N), 65% of the Phosphorus (P), and 80% of the Potassium (K). 95% of urine produced by a person per day is water, and the remaining 5% is composed of N, P, and K as well as some trace micro-nutrients (Feineigle , 2011).

Each person urinates annually about 4 kg of N, 0.4 kg of P, and 1 kg of K (Feineigle , 2011). Source separated urine, therefore, has the potential to be used as a fertilizer because of its nutrient content, availability and easy application to soils. The main nutrients (N,P, K and S) occur in water-soluble ionic form and are therefore readily available for plant uptake (Schönning, 2006). The majority of the nutrients are excreted via urine (Schouw et al., 2002; Rose et al., 2015 as cited in (Viskari, et al., 2018).

FAECES

Faeces are composed of water, protein, undigested fats, polysaccharides, bacterial biomass, ash, and undigested food residues of which the major elements are Oxygen (O) 74%, Hydrogen (H) 10%, Carbon (C) 5%, and N 0.7% (Snyder et al., 1975 as cited in (Rose, et al., 2015).

Although faeces contain fewer nutrients than urine, they are a valuable soil conditioner (Esrey, et al., 1998) as most of the carbon excreted, up to 70%, is found in faeces (GTZ, 2000). The total amount of faeces produced per person per year is 25-50 kg containing up to 0.55 kg of N, 0.18 kg of P and 0.37 kg of K (Esrey, et al., 1998). Human faeces also contain very rich ecosystems of versatile micro-organisms (GTZ, 2000).

Other elements, such as Calcium (Ca) and Magnesium (Mg), are excreted in nearly equal amounts in urine and faeces (GTZ, 2000).

4.2. PLANT'S NUTRIENT NEEDS

Plants need light, water, soil and nutrients to grow (Jönsson 2004 as cited in (Filling, 2018)). Nutrients can be divided into two groups; macronutrients and micronutrients. Macronutrients, nutrients that have high uptake capability for the plant and are mainly taken up from the soil by the roots, are N, P, K, S, Ca and Mg. Micronutrients are the nutrients that are taken up in very small amounts but are as essential for plant growth as macronutrients. Micronutrients that are common in plant uptake are Boron (B), Copper (Cu), Iron (Fe), Chloride (Cl), Manganese (Mn), Molybdenum (Mo) and Zinc (Zn). Some of 11 the macro- and micronutrients appear naturally in the soil, and some we add with fertilizers (Palmstierna I 1993) as cited in (Filling, 2018)

Table 1 The nutrients in human excretion and the fertilizer need to produce 250 kg grain/year.

Most important nutrients	Urine 500 l	Faeces 50 l	Total	Fertilizer need for 250 kg grain
N	5.6 kg	0.09 kg	5.7 kg	5.6 kg
P	0.4 kg	0.19 kg	0.6 kg	0.7 kg
K	1.0 kg	0.17 kg	1.2 kg	1.2 kg
N + P + K	7.0 kg (94%)	0.45 kg (6%)	7.5 kg (100%)	7.5 kg

(Source: Wolgast, 1993 as cited in (Ganrot 2005))

Table 1 contains calculations by Wolgast, 1993 of annually excreted nutrient in 500l urine and 50 l faeces excreted in a year per person, compared to the average fertilizer used to produce 250 kg grain necessary to cover the calories and protein intake of an adult person for one year. The table illustrates that it is possible to use nutrients in human excreta of a single person in a year as fertilizer to grow grains necessary for a person in a year closing the nutrient loop.

4.3. TREATMENT AND RECOVERY OF NUTRIENT

As mentioned above, human excreta contain nutrients which are valuable for plants and should be recovered for agricultural use. Figure 7 shows the possible ways to recover nutrients from various sources and ways to reuse them. Urine can be used as liquid or dry fertilizer, faeces can be used to produce biogas and or soil conditioner, water from shower and washing can be used in irrigation, while rainwater can be harvested for water supply, groundwater recharge. However, this thesis focuses on recovery and reuse of urine and faeces only.

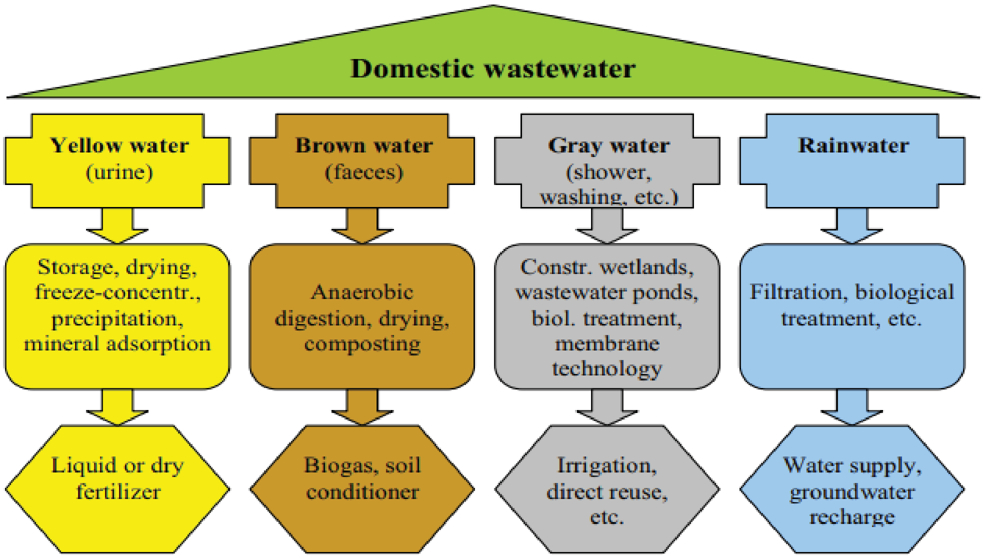

Figure 7 Ways to recover nutrients and energy from human excreta.

Source: (Werner, et al., 2003) as cited in (Ganrot 2005)

Recent research effort has been focused on developing cost-efficient and implementable technologies to concentrate, recover and recycle nutrients from the waste fractions to shift towards a more circular way of resource management. One of the ways to recover nutrients from human excreta is separate human excreta in the source and treating human excreta as a resource. Human excreta are then processed on site and then, if necessary, further processed off site until they are completely free of pathogens (Esrey, et al., 1998). The nutrients contained in the excreta are then recycled by using them in agriculture or by producing biogas or bio slurry.

4.3.1. TREATMENT AND RECOVERY OF NUTRIENT FROM URINE

There are three ways to recover the resources in urine: diversion, separation, and combined processing. Diversion is when urine is diverted away from faeces, they are never mixed with each other. Separation is when urine and faeces are mixed together then separated from each other. In combined processing urine and faeces are mixed together, processed together and their resource value is captured together (Esrey, et al., 1998).

The urine of a healthy person contains only a small amount of pathogens, originating mostly from faecal contamination (Höglund et al., 1998 as cited in (Viskari, et al., 2018)). Therefore, separating urine at the source makes it almost pathogen free. However, in the case of any contamination, storing the urine for 6 months at a temperature over 22°C prevents it from any infection (Höglund, 2001; Jönssön et al., 2004; Schönning, 2006; WHO, 2006 as cited in (Viskari, et al., 2018)) as well as prevents odors and the loss of nitrogen to the air (Esrey, et al., 1998). Moreover, research on the disinfecting effects of urea showed that no *E. coli* or *Salmonella spp*. were found after 5 days of storage and there was also a significant reduction in phage after 21 days and no viruses were found after 50 days. The stored urine is rich in N and P and contains some Organic Material (Wielemake, et al., 2018).

4.3.2. TREATMENT TO RECOVER NUTRIENT FROM FAECES

Human faeces are responsible for most diseases spread by human excreta as one gram of faeces contain about 100 million bacteria some of which are pathogenic (Drangert, 1998). The faecal matter contains high numbers of naturally occurring enteric bacteria, and occasionally disease-causing pathogens like *Salmonella*, *Campylobacter*, *Shigella*, enteric viruses, and parasites. Studies have shown that temperatures high enough to achieve adequate hygienization are normally not reached during faecal storage in single household compost toilets (Carlander and Westrell 1999; Møller *et al*., in press). Therefore, other treatment methods must be used to supply a safe end-product that can be disposed of or used for agricultural purposes. In many developing countries, wood ash is added to toilets and the increased pH leading to sanitation of the faecal material (Franceys *et al*. 1992; Austin 2001; Moe *et al*. 2001). A safer and more controllable method would be to collect faecal material from several toilets and compost it under thermophilic temperatures. Temperatures obtained under thermophilic composting of faecal material, i.e. 55ºC for two weeks, would be expected to inactivate or kill pathogens (Feachem *et al*. 1983). However, other factors are also involved in the inactivation, like changes in pH, accumulation of toxic NH_3 and microbiological competition for nutrients (Golueke 1991; Dumontet *et al*. 1999) as cited in (Holmqvist, et al., n.d.). In a compost with elevated temperature (50-70 °C) and low moisture content, their survival times are not very long. Therefore, pathogens need to be inactivated either by dehydration or decomposition process before its application (Drangert, 1998).

Dehydration is easier if faeces are not mixed with urine and water (Esrey, et al., 1998). It deprives pathogenic organisms, particularly helminth eggs, of the moisture they need to survive by lowering the humidity of the contents to less than 25% through evaporation and addition of dry material (ash, sawdust, husks). At this low humidity there is little odour and no fly-breeding. Sanitation systems based on dehydration require diversion of urine and water for anal cleaning and are suitable for dry climates but with simple heaters, they can also work in a humid climate (Sakthivel & Charair, 2011).

Decomposition is a complex biological process in which organic substances are mineralized and turned into humus that ideally requires a humidity of around 60% in the compost heap. If humidity is much lower, or higher the process comes to a standstill because the organisms involved in the process are deprived of water or oxygen. High temperature reaching >60ºC, time, unfavourable pH value, competition for food, antibiotic action and the toxic by-products of decomposing organisms help destroy pathogens. Most composting toilets are designed for a retention time of 8-12 months. It also ideally needs a carbon to nitrogen (C/N) ratio of about 30:1 which means carbonaceous material such as sawdust, kitchen refuse, toilet paper, weeds, grass clippings need to be added to use it as a fertiliser (Sakthivel & Charair, 2011).

To be on the safe side, it is often recommended to keep the compost for six months to ensure that pathogens and ova have disappeared (Drangert, 1998).

4.4. WAYS OF APPLICATION

4.4.1. URINE APPLICATION

Urine as a fertilizer is suitable especially to plants with high nitrogen demand such as grain, grass crops, oil plants, spinach, cauliflower, corn, lentils, red beans, and soybeans. Urine has some amounts of chlorine and therefore it is not recommended in commercial cultivation for chlorine sensitive plants such as potato, onion, tomato, cucumber, and rhododendron. An overdose of chlorine can disturb crop yields of some plants. On the other hand, good qualities of urine may compensate for harms of chlorine (Saiju, 2013).

The ways of applying urine as a liquid fertiliser is discussed below:

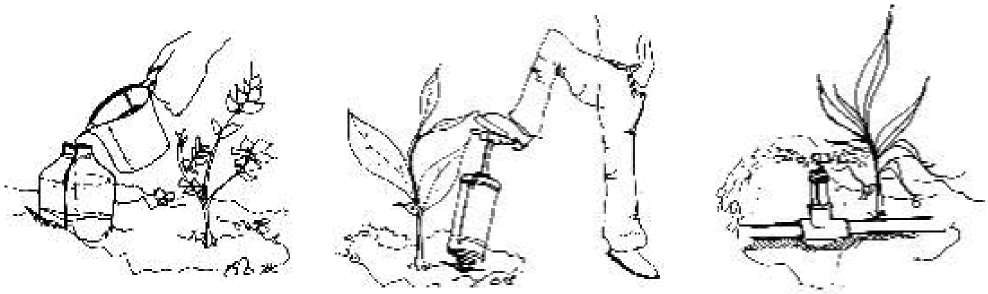

Figure 8 Various methods of application of urine to agricultural crops.

Source:(Sakthivel and Charair, 2011)

DIRECT APPLICATION OF URINE TO CROPS:

Urine can be directly applied to crops using following ways (Sakthivel & Charair, 2011):

Surface Application: During land preparation and after planting crops, urine is applied directly on the surface of agricultural lands by creating furrows which should be covered with soil after application of urine to prevent loss of nitrogen through ammonia gas. If undiluted urine is applied, watering the plants after application of urine is necessary. Use of watering cans which are used in home gardens is ideal for the application of urine.

***Deep Injection*:** The loss of ammonia can be reduced by deep injecting urine up to 6 inches below the ground surface. Using subsoil injectors and pot irrigation methods, for example, use of PET bottles having small holes at bottom, can be used for deep injection of urine. This method is more suited for horticultural plantations where plant density is usually lower, however, for large scale application to traditional crops, custom made mechanised agricultural tools can be designed.

Drip irrigation: In drip irrigation, urine is applied along with irrigation water. Regular maintenance of emitters and tubes are necessary to prevent clogging while doing drip irrigation.

Dosage: Urine is applied to crops based on the nitrogen content in the urine and the nitrogen requirement of the crops. Urine can be spread one or many times depending on the duration of the growing season and the demand of the plants. Main/first spreading should take place in the beginning of the growing season, for example on the planting stage. Plants with small roots like carrot, onions and lettuce can benefit from many spreading occasions. At least one month of gap is needed between last spreading and harvest. Urine must be spread early in the morning or in the evening to avoid evaporation of nitrogen and smell (Global Dry Toilet Association of Finland, 2017).

RECOVERY OF STRUVITE

Struvite **($MgNH_4PO_4.6H_2O$)**, a white crystal, obtained from addition of the magnesium to urine, is a favourable product for easy transportation and application of agricultural crops. Struvite can be precipitated from urine when urine is stored in the closed container of pH over 8, magnesium dose in the molar ratio of 1.1 Mg to 1 P is stirred for 10 minutes after which struvite can be separated from urine using a filtration process. Struvite can be then dried and be used as a fertiliser. Struvite slowly releases phosphate and has low metal concentration, which makes struvite beneficial in agriculture (Sakthivel & Charair, 2011).

CO-COMPOSTING:

Application of urine while composting organic waste accelerates the composting process and enhances the nutrient value of compost. This method is more suitable if farmers do not prefer handling the liquid urine directly to the crops (Sakthivel & Charair, 2011).

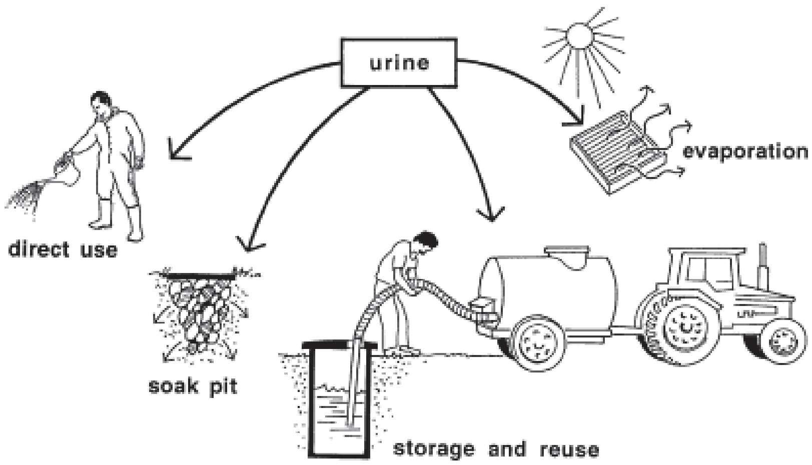

Figure 9 Alternative ways of handling/using urine diverted from toilets.

Source:(Esrey et al., 1998)

If there is no interest in actively using urine, it is possible to dispose of it in an evapotranspiration bed or by evaporation as well (Sakthivel & Charair, 2011).

As discussed previously, since urine contains most of the nutrients but generally no pathogens, it may be used directly as a fertilizer without the need for further processing.

4.4.2. FAECES APPLICATION

Although faeces contain fewer nutrients than urine, after pathogen destruction through dehydration and/or decomposition, the compost can be applied to the soil to increase the organic matter content, improve water holding capacity, ion buffering capacity of the soil, and increase the availability of nutrients. It also helps to maintain a healthy population of beneficial soil organisms that protect plants from soil-borne diseases (Sakthivel & Charair, 2011).

4.4.3. ENERGY RECOVERY

BIOGAS

Biogas is a renewable energy produced as the by-product of anaerobic digestion of the organic material in the absence of air as shown in Figure 10. Anaerobic digesters convert the energy stored in organic materials present in manure into biogas which can be used as a fuel for cooking, lighting and generating electricity. Cooking is the most convenient use of biogas (Andriani, et al., 2015).

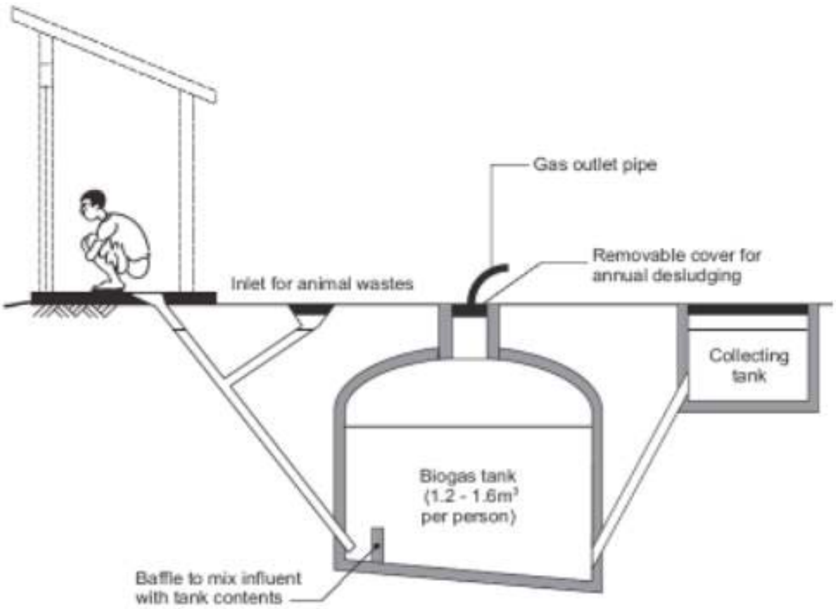

Figure 10 In-situ biogas system.

Source: Reed and Shaw as cited in (Buxton and Reed, 2010)

Figure 10 is an in-situ biogas system, both urine and faeces can be collected in the digester, or urine can be separated as well. Biogas contains primarily methane (CH_4) and carbon dioxide (CO_2) and small amounts of hydrogen sulphide (H_2S), hydrogen (H_2), Nitrogen (N_2) and moisture (Nakarmi, et al., 2015). The Table 2 shows the average chemical composition of biogas:

Table 2 Average chemical composition of Biogas.

Substance	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon dioxide	CO_2	30 - 40
Hydrogen	H_2	5 - 10
Nitrogen	N_2	1 - 2
Water Vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Source: (Nakarmi, et al., 2015)

THE ANAEROBIC PROCESS

Anaerobic process is a process that uses naturally occurring microbes to break down food materials into methane and carbon dioxide in the absence of oxygen. A biogas plant has a closed container that is free from light and oxygen and runs at a temperature of 35 °C. It should also be gas tight, so that the biogas can be collected (Andriani, et al., 2015). The process involves many steps usually simplified to three or four main steps: (Figure 11).

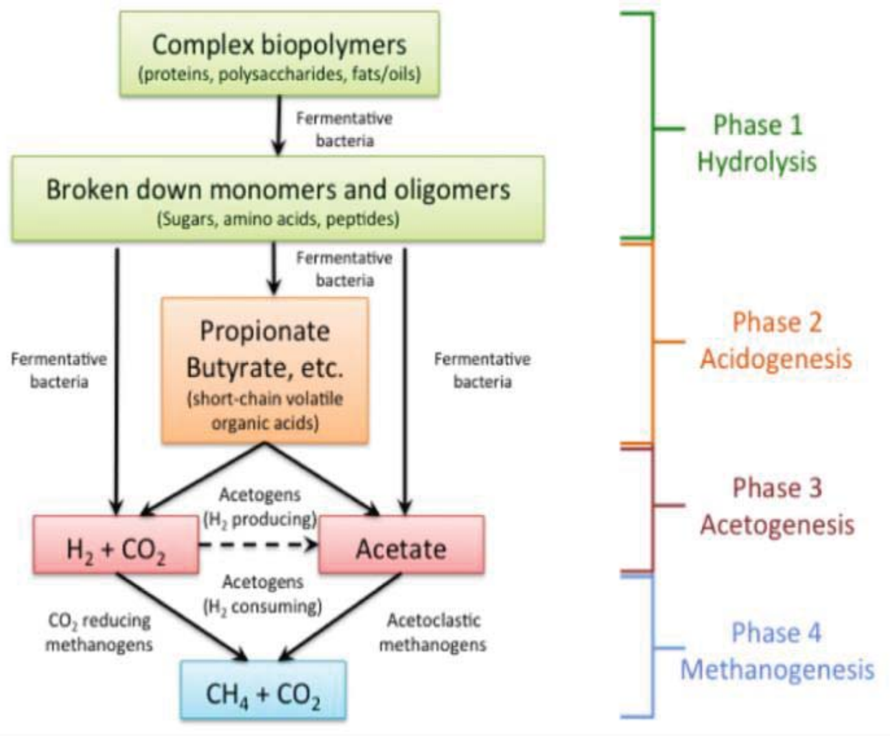

Figure 11 Schematic of four phases of biogas production.

Source:(Dutton, 2018)

Stage 1 (Dutton, 2018)

Hydrolysis: In this step, the larger molecular complex substances are solubilized into simpler ones with the help of extracellular enzymes released by the bacteria. For example, proteins are split into peptides and amino acids.

$(C_6H_{10}O_5)$ n + n H_2O → n $C_6H_{12}O_6$ + n H_2 ………..……………………………………… (1)

Stage 2:

Acidogenesis: At this stage, the molecules of glucose from stage 1 into the less atom of carbon acids which are in reduced state than glucose with the help of enzymes produced by the acid forming bacteria under anaerobic condition. The principal acids produced in this process are acetic acids, propionic acids, butyric acids, and ethanol.

$C_6H_{12}O_6$ ↔ 2 CH_3CH_2OH + 2 CO_2 …………………………………………………… (2)

$C_6H_{12}O_6$ + 2 H2 ↔ 2 CH_3CH_2COOH + 2 H_2O ……… ……………………………… (3)

$C_6H_{12}O_6$ 6 → 3 CH_3COOH ……………………………………………………………… (4)

Stage 3

Acetogenesis: The acidogenesis intermediates are attacked by acetogenic bacteria; the products from acetogenesis include acetic acid, CO_2, and H_2.

$CH_3CH_2COO^-$ + $3H_2O$ → CH_3COO^- + H^+ + HCO_3^- + $3H_2$ …………………………… (5)

$C_6H_{12}O_6$ + $2H_2O$ → $2CH_3COOH$ + $2CO_2$ + $4H_2$ ………………………………………… (6)

CH_3CH_2OH + 2H2O → CH_3COO^- + $2H_2$ + H^+ ……………………………………..... (7)

$2HCO_3^-$ + $4H_2$ + H^+ → CH_3COO^- + $4H_2O$ ……………………………………………… (8)

Stage 4:

Methanogenesis: the principal acids produced in stage 2 and 3 are processed by methanogenic bacteria to produce methane. Methanogenic bacteria decompose compounds with a low molecular weight using hydrogen, carbon dioxide and acetic acids to form methane and carbon dioxide.

CH_3COOH → CH_4 + CO_2 ………. (9)

CO_2 + 4 H_2 → CH_4 + 2 H_2O ………… (10)

2 CH_3CH_2OH + CO_2 → CH_4 + 2 CH_3COOH ………. (11)

CH_4, is virtually odorless and invisible. It burns with a clear blue flame, is smokeless and non-toxic in nature. It has higher calorific value than kerosene, wood, charcoal, cow-dung chips and any other traditional biomass fuels (Nakarmi, et al., 2015).

The other by-product of anaerobic digestion is slurry with an improved fertilizer value over the use of raw dung. The fertilizer value can be increased by further processing, such as by mixing it with dry biomass material and composting it. Composting also further reduces pathogens present in the slurry (Fulford, 2015).

HUMAN EXCRETA IN BIOGAS PRODUCTION

Human excreta (separated or combined) have similar potential in biogas generation as cattle manure. Based on the data on Table 3 and 4, there is a possibility of potential biogas per kg human faeces compared to the manure. Moreover, human excreta have pH of 7.3, the optimum pH range for biogas production (Andriani, et al., 2015) human excreta has potential to be used as feedstock in digester.

Table 3 Chemical Content of human faeces

Component	Unit (per wet mass)	Amount
Dry mass (at excretion)	g/kg	216
Total nitrogen (TN)	g/kg	11
Total phosphorus (TP)	g/kg	4
Potassium	g/kg	8
Moisture content	%	78
Dry matter content (at excretion)	%	22
pH	-	7 – 9

Source: (Andriani et al., 2015)

The Table 4 compares the raw materials like cattle manure and human faeces and their yielded biogas which shows that human faeces can also be used as source for biogas production:

Table 4 Comparison of raw material and yielded biogas.

Source	Waste amount/day/kg	% Water	Dry matter	Biogas m^3/kg dry waste
Cow	20-30 (28)	80	20	0.023-0.040
Dairy cow	20-30 (28)	80	20	0.023-0.040
Buffalo	30-40 (35)	83	20	0.023-0.040
Roaster/Hen	0.15-0.20 (0.18)	72	28	0.065-0.116
Pig	3.00-4.00 (3.40)	67	9	0.04-0.059
Human	0.10-0.40 (0.15)	77	23	0.02-0.028

Source: (Andriani et al., 2015))

The Table 4 shows the yield from human waste is low in comparison to other manures. The gas produced in the digestion should be seen as a bonus according to Xuereb 1997 as the main purpose is an alternative disposal method of human excreta, "reducing the amount that would otherwise be released naturally into the atmosphere and so reduces the excessive greenhouse-effect" as cited in (Buxton & Reed, 2010))

BENEFITS OF BIOGAS

According to *Biogas as Renewable Source of Energy in Nepal. Theory and Development* attaching latrine (Figure 10) with biogas plants has two-fold benefits. First, the disposal problem of human waste that is hazardous to human health is solved thereby improving environment and sanitation; and second, the additional amount of gas as well as manure is produced as a result of using latrine waste in conjunction with animal dung (Nakarmi, et al., 2015) also mentioned in (Buxton & Reed, 2010).

Biogas is considered as a potential waste-to-energy technology which greatly contributes in reducing environmental pollution and the most important in reducing greenhouse gases caused by the waste (Andriani, et al., 2015). The greenhouse gases methane, and carbon monoxide (CO) when combusted or oxidized with oxygen releases energy allowing biogas to be used as a fuel, for heating purpose, such as cooking or can also be used in a gas engine to convert the energy in the gas into electricity and heat as illustrated in Figure 12. Biogas can be compressed, the same way natural gas is compressed to CNG, and used to power motor vehicles (Fulford, 2015).

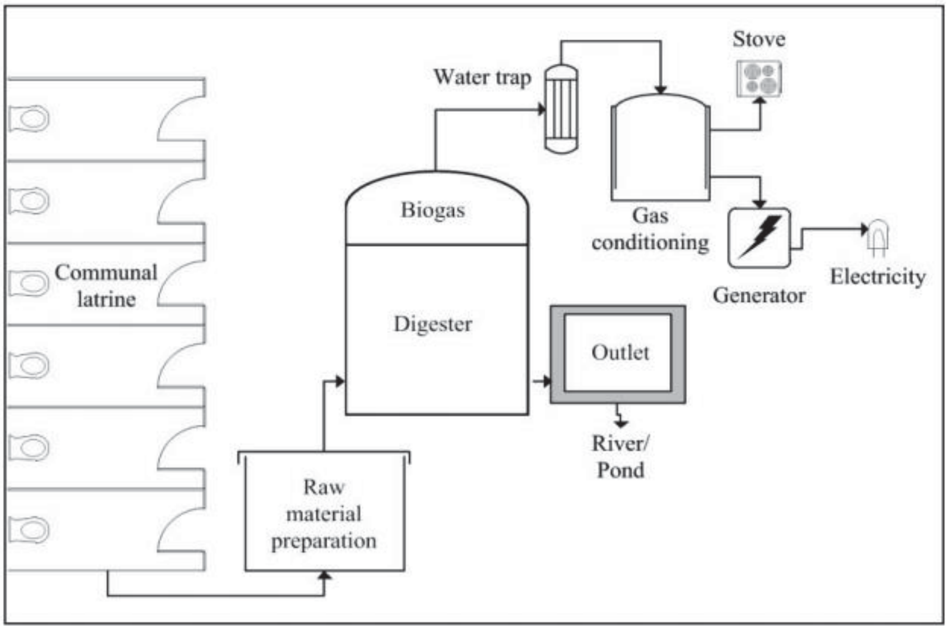

Figure 12 Biogas generation using human excreta.

Source: (Andriani et al., 2015)

Table 5 shows the estimation of benefit from the installation of domestic biogas plant:

Table 5 Biogas Usability and equivalent.

Application	1 m^3 biogas equivalent
Lighting	equal to 60 -100 watt bulb for 6 hours
Cooking	can cook 3 meals for a family of 5 - 6
Fuel replacement	0.7 kg of petroleum
Shaft power	can run a one horse power motor for 2 hours
Electricity generation	can generate 1.25 kilowatt hours of electricity

(Source:(Andriani et al., 2015))

WAYS OF MAXIMIZING BIOGAS PRODUCTION

There are several factors that affect anaerobic digestion. Biogas production depends on the biological degradability and methane potential, the carbon and nutrients available, and the moisture content of each feed material. Therefore, different feedstocks degrade at different rates and produce different amounts of methane (as seen in Table 4) (Dutton, 2018).

The main limitation of human excreta is the low C/N ratio which is about 6/10. In human excreta the amount of nitrogen is greater than the amount of carbon, which resulted in a lot of ammonia formation from the decomposition process making the system pH alkaline. To overcome this shortcoming, the addition of high C/N ratio raw material such as rice straw (C/N ratio 12.5-25), rice husk (C/N ratio 100-125), or corncob (C/N ratio 50) is needed. Another problem in using human excreta is the *E. coli* content in the waste to be disposed of into the environment. However, Pramod and Michelle, 2011 from their research showed that the percentage of survival colonies decreases with the length of time of incubation. They also found that at thermophilic temperature, *E. coli* inactivation and biogas production were faster than that of at moderate and mesophilic temperatures (Andriani, et al., 2015).

Figure 13 shows the complete picture of an anaerobic digester facility showing some undigested slurry as well:

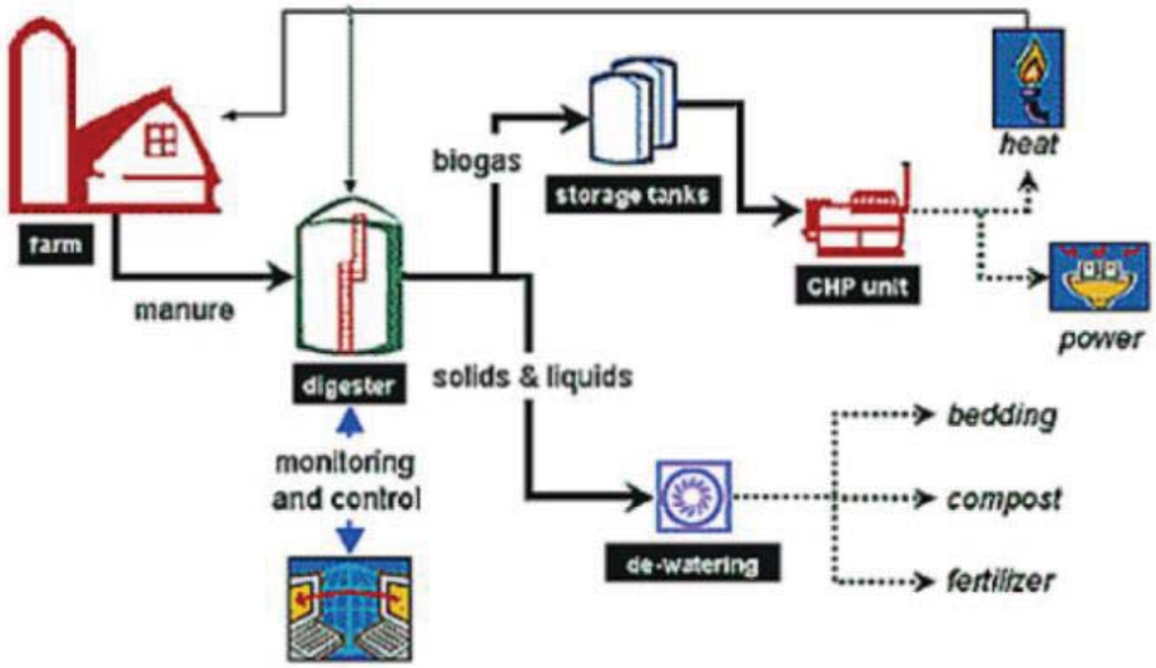

Figure 13 Schematic of an anaerobic digester facility and product output.
Source:(Dutton, 2018)

4.5. BIO SLURRY

Bio-slurry is an important byproduct of the biogas systems (Nakarmi, et al., 2015). It is homogenous, with an improved NPK balance containing more inorganic nitrogen, easier accessible to the plants. If slurry is used as fertilizer in conformity with good agricultural practice, N-efficiency increases considerably and nutrient losses by leaching and evaporation is also minimized (Nakarmi, et al., 2015). Slurry as fertilizer should be sufficiently stored minimum 6 months, with a restricted season of application with restricted amount applied per hectare according to fertilizer plan for optimum utilization (Sakthivel & Charair, 2011; Nakarmi, et al., 2015).

Table 6 shows the percentage of NPK of slurry from Biogas plant using human faeces:

Table 6 Chemical composition of Slurry from Biogas Plant using human faeces and percent on dry weight basis.

Item	Percent on Dry Weight Basis
Nitrogen	3.0 – 5.0
P_2O_5 (%)	2.5 – 4.4
K_2O (%)	0.5 – 1.9

Source: (Nakarmi, et al., 2015)

4.5.1. SLURRY APPLICATION

As mentioned, slurry generated from biogas plants treating human excreta will contain pathogens. Therefore, secondary composting of the slurry is essential before it is applied to agricultural fields. Slurry can be applied in the field in liquid, dried or compost forms as described below (Sakthivel & Charair, 2011):

Liquid Form

The digested slurry except human faeces can be applied directly in the field using a bucket or it can directly be discharged through an irrigation canal. This method is more suited to the farmers growing vegetables in the kitchen garden or raising fish in the pond as the slurry contains readily available forms of plant nutrients. If it is applied to standing crops, it should be diluted with water at the ratio of 1:1.5 -2.0. Otherwise, it will have a burning effect on the lower leaves of plants due to high concentration of ammonia and phosphorus in it.

Dried Form

If the transportation of the liquid slurry is difficult, the slurry can be dried before transporting it to the field, however, when the slurry is dried, the nitrogen, particularly in the form of ammonium is lost by volatilization and the nutritive value of the slurry is diminished. Hence this is the least efficient method of slurry application to the field.

Composted Form

The best way to overcome the drawbacks of using slurry in liquid or dried form is to utilize it in the form of compost. To minimize the loss of nutrient contents in the compost, it should be taken to the field only when required and should be mixed with soil as soon as possible. The dry materials around the farm and homestead such as litter and kitchen waste can be properly utilized; and the composted slurry can also be used for algae production, fish rearing and mushroom product.

4.6. STATUS OF ECOLOGICAL SANITATION IN NEPAL

In Nepal, the ecosan latrine concept was first introduced by ENPHO in 2002/2003 under the support of WaterAid Nepal with the implementation of Double Vault urine-diverting dry toilets.

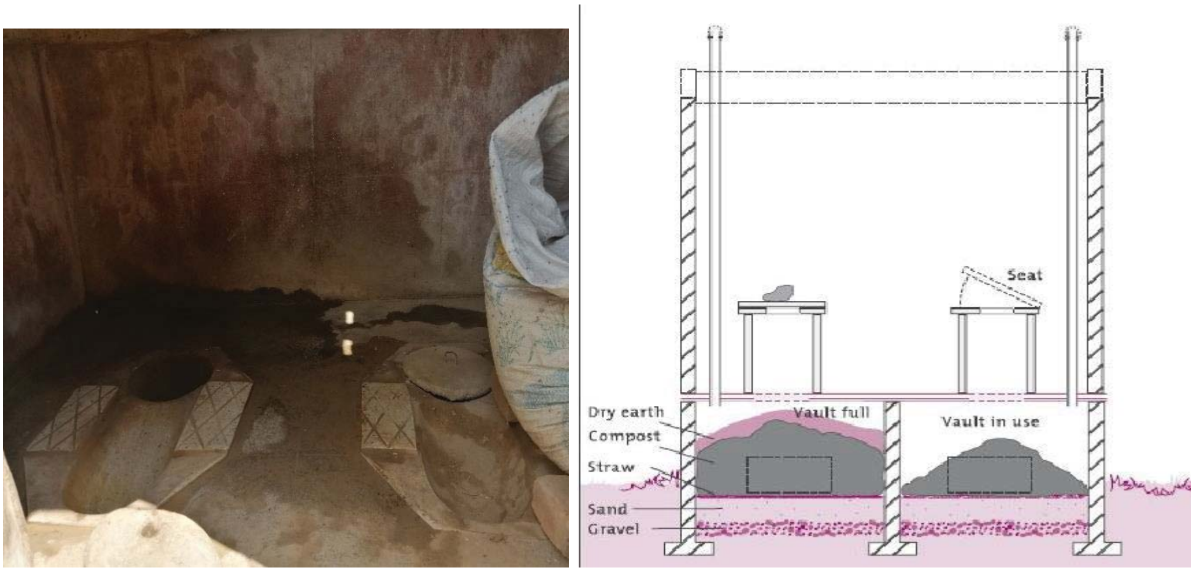

Figure 14 Double Vault Urine diverting dry Latrine

Source: left (Maharjan, 2020), right (Kaczala, 2006)

A Double Vault urine-diverting dry toilet consists of two chambers built above the ground with a squatting slab with two holes on top of the chambers as shown in Figure 14. The faeces drop into one of the chambers, whereas the urine drains away being collected in a jar behind the toilet. When the chamber is nearly full (about three-quarters), it is topped up with soil and the drop hole sealed with mud. Reasonably an anaerobic dehydration begins and meanwhile the second chamber starts to be used. It is recommended to store at least for two months after using the container (Kaczala, 2006), however the Nha Trang Pasteur Institute recommends a retention time of 6 months and in cold climates for 10 months ((Kaczala, 2006, Trong Phi et al., 2004).

As a part of the pilot program, ENPHO constructed 10 Ecosan units in Khokana, a traditional and small Newari village about 8 kilometres south of Kathmandu (Wikipedia). In the same year, the Department of Water Supply and Sewerage (DWSS) under the support of WHO also constructed 10 Ecosan units as a pilot project in Siddhipur, also a Newari village about 7.5 kilometres southeast from Kathmandu (Wikipedia). Due to the traditional practice of the Newari community of using faeces and urine as fertilizer in their agriculture farm, adopting innovative technology but with a similar concept of usage was not new for the locals of Khokana and Siddhipur. Hence both the programs in these communities were successful and well-received locally (ENPHO, 2006).

After the success of these pilot projects in Khokana and Siddhipur, the ecosan concept was extensively expanded to other peri-urban areas of Kathmandu by ENPHO, and other organisations working for ecosan toilet concept in Nepal, under the financial support from various donors like WaterAid Nepal, UN-HABITAT, etc. During the last few years there has been rapid progress in the promotion of Ecosan toilets. There were 36 toilets in 2003 and by 2008 there were around 517 Ecosan toilets in Nepal (ENPHO, 2006). By 2010, more than 770 Ecosan toilets had already been constructed (Messmer, 2011) and there is a demand for 3000 urine diverting pans (Shakya, 2015).

The majority of Ecosan toilets have been built in the peri-urban areas of Kathmandu valley. As few as 8% toilets have also been constructed outside the Kathmandu valley like in Gorkha, Tumlingtar, Sankhuwasabha, Surkhet, Parsa and Makawanpur. The toilets built outside the valley have been built for the purpose of demonstration (WAN, 2008) because the occupation of people living in these areas is agriculture, and according to many surveys done ENPHO, majority of people believe that faeces and urine application to crops helps increase crop yield (Shakya, 2015).

According to the reports by WaterAid in Nepal, 97% of toilets are in operation, kept clean, well kept, and later use the compost as fertiliser for their local agricultural fields. Similarly, around 100 Ecosan toilets are under construction under WAN's support through its implementing partners (WAN, 2008).

Among 440 surveyed households by ENPHO about the use of excreta, about 19% of the respondents said they take it straightly to the field, about 54% of the users store the content in sun or shed for few days before applying in to the field and rest of the households mix the content with other composting materials for co-composting (ENPHO, 2006).

The status of the toilets has been provided in Table 7.

Table 7 Status of ecosan toilets in Nepal.

Cluster	In Operation	Under Construction	Not Completed	Dismantled	Not in use	Total
Siddhipur	95	-	1	-	-	96
Khokana	57	-	2	3	2	64
Lubhu	5				1	6
Imadol	12		1			13
Thecho	91					91
Gamcha	8					8
Sankhamul				2	2	4
Tokha	136	12				148
Bode	8			2	2	12
Thimi	4					4
Tigani	21					21
Duwakot	10					10
Private House/office	2					2
Gorkha	10					10
Parsa	20					20
Surkhet	2					2
Tumlingtar	4					4
Makawanpur	2					2
Total	**487**	**12**	**4**	**7**	**7**	**517**

Source: (ENPHO, 2006)

Similarly, about 42.37% of the respondents used urine directly to the field when needed, about 48% toilet owners prefer to put the urine in compost instead of taking the urine directly to the field. Some of the families do both according to their need. About 20% of the total pour the urine into the drain when the tank is full as they do not need it and a small portion of respondents give the collected urine to neighbors who need it (ENPHO, 2006) as shown in Figure 15.

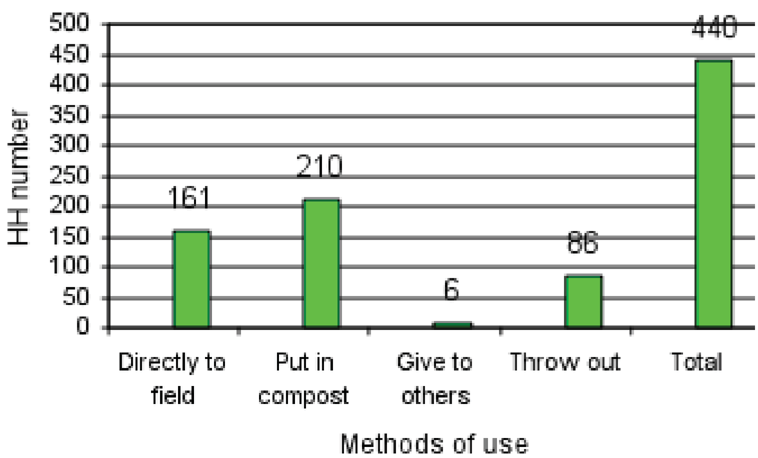

Figure 15 Application of Urine in Nepal
(Source: (ENPHO, 2006))

Based on the acceptance of the technology by these communities, ENPHO, DWSS and other agencies are also replicating the modified Ecosan toilet technology in rural areas (WAN, 2008).The ecosan technology is also being gradually piloted in rural areas of Nepal by ENPHO and DWSS, with slight modifications in the concept and design (ENPHO, 2006).

But despite all the projects, there are still many people that are unaware about Ecosan systems and application of faeces and urine in agriculture fields. In order to help spread awareness and train more people about the use and maintenance of Ecosan, an Ecosan Resource center has been established in Dahrechowk, located west of Kathmandu, and has organized several training programs and awareness campaigns (Shakya, 2015).

4.6.1. CHALLENGES FOR THE DEVELOPMENT OF ECOSAN SYSTEMS IN NEPAL

According to a survey taken in 2007, people in Nepal experienced some challenges that Ecosan systems had such as difficulty in teaching young children and guests, who are unfamiliar with Ecosan, how to use the toilets. Male members of the family also found it difficult to urinate in these toilets. The only reason they used these ecosan toilets was to obtain fertilizer for their crops, but the challenge was purchasing ash, lime and saw-dust for the toilets as flies and insects are present if the toilets aren't taken care of properly. However, it was difficult to clean the toilets since water could not be used (Shrestha, 2007 as cited in (Shakya, 2015)).

Another study done in 2010 showed that certain groups of villagers were found to be coprophilic. They did not like handling faeces in the fear of touching faeces might make them impure (Messemer, 2011 as cited in (Shakya, 2015)). Moreover, in certain parts of Nepal people who had already installed Ecosan toilets, still preferred open defecation. Mainly the male and the elder members of the family preferred open defecation (Shakya, 2015).

5. FINDINGS

5.1. FINDINGS FROM LITERATURE REVIEW

5.1.1. NUTRIENTS IN HUMAN URINE

According to Pradhan et al., the nutrient content in urine differs in one person to another depending on the meal habits and physical activities as cited in (Rose, et al., 2015). The amount of urine excreted is about 1–1.3 l per person per day with 93–96% moisture content and 50–70 g dry matter content depending on meal habits (Feachem et al., 1983; Tanguay, 1990). Other literature data on the amount of urine (total liquid) present 1,500 g per person per day (Vinnerås et al., 2006), 610–1,090 g per person per day in Switzerland (Jönsson et al., 1999), 600–1,200 ml per person per day in Thailand (Schouw et al., 2002 as cited in (Nagy & Zseni, 2017). A study in Sweden found that a person in a year excretes in the form of urine 2.5-4.3 kg nitrogen, 0.7-1.0 kg of phosphorus and 0.9-1.0 kg of potassium (Kirchmann and Petterson 1994 as cited in (Hatfield , 2018).

Table 8 shows the macro element content of urine in grams per person per year based on different literature analysed in different countries due to different meal habits.

Table 8 Calculated average macro element content of urine (g/person/year).

Urine	Based on Tanguay (1990)	Based on Jönsson et al. (2005)	Based on Vinnerås et al. (2006)	Based on Malkki (1995)
C	2,008–4,344	no data	no data	no data
N	2,738–4,855	4,015	3,687–3,833	5,600
P	201–559	329	248–339	400
K	453–953	876	821–1,190	1,000
S	no data	256	no data	no data
Ca	588–1,095	no data	no data	no data

Source: (Nagy & Zseni, 2017)

Human urine also contains salts (Krichmann and Pettersson 1995; Mnkeni et al., 2005, 2008), pathogens (Höglund, 2001; Pradhan et al., 2007, 2009; Heinonen-Tanski, 2007), and pharmaceuticals (Winker et al. 2008, 2010 as cited in (SENE, 2013).

SALTS

The applications of human urine as liquid fertilizer in agriculture may have potential to accumulate sodium (Na) ions in soil and eventually be detrimental for plant growth and production, especially in dry land when urine is planned to be reused at several years' scales. Besides, it has been reported earlier that salts including chlorides may be toxic to some plants (Holliman, 1998) and consequently there has been concern about the toxicity of human urine

(Höglund, 2001) as the concentration of sodium (Na) and chlorine (Cl) in undiluted fresh human urine analysed by Kirshmann and Pettersson (1995) were amounting 0.94-0.98 g/L and 2.3-2.5 g/L respectively. While a value of 2.34 g/L of sodium content in urine was recently reported in the literature (Pradhan et al. 2010 as cited in (SENE, 2013)).

PATHOGENS

The urine of healthy individuals is sterile in the bladder (Höglund, 2001). However, in general pure human urine contains very few enteric microorganisms (Heinonen-Tanski, 2007) nevertheless, it is widely known that many microorganisms die off during the hygienization of human urine (SENE, 2013).

PHARMACEUTICALS AND HORMONES

Human urine also contains pharmaceuticals residues even after prolonged storage of urine as a treatment step (Winker, 2008). Thereby, the reuse of human urine is associated with a risk of transfer of pharmaceutical residues to the agricultural fields. About 70% of pharmaceuticals taken in, are excreted in urine, and is accounting for 50% of the ecotoxicological risk (Lienert et al., 2007a, 2007b). Little is known in the fate of pharmaceuticals (anti-malarial drugs, antibiotics and so forth) present in urine about their accumulations in soil, transfer in ground water and uptake in plants. Therefore, further research is required to provide a greater knowledge of their occurrence, their distribution in the environment and what effects they have on organisms when these organisms are exposed to low levels of pharmaceutical compounds (Pal et al. 2010) as cited in (SENE, 2013).

5.1.2. NUTRIENTS IN HUMAN FAECES

Human faeces consist of about 75% H_2O by weight and 25% solid material, mainly organic matter. C is a major constituent of the dried feces. N, P, and K make up 5–7%, 3–5.4%, and 1–2.5% of the dried solids respectively (Rose, et al., 2015). Faeces also contain a range of micronutrients such as Mg and selenium (Se). The amount of excreted nutrients depends on dietary intake, while the digestibility of the diet determines the partitioning of nutrients between urine (digested) and feces (undigested) (Jonsson et al., 2004 as cited in (Harder, et al., 2019)). Faeces are rich in P and K and contain the majority of C (Heinonen-Tanski & Van Wijk-Sijbesma, 2005 as cited in (Harder, et al., 2019)).

The major factors leading to variation in faecal generation rate are total food intake, body weight, and diet. Parker and Gallagher (1992) found that mean daily stool weight was correlated ($p < .001$) with calorie intake (energy intake can act as a measure of food intake); however, they found that this only accounted for 28% of the variation seen in individual stool output (Rose, et al., 2015).

Table 9 shows the effect of diet type on fecal characteristics:

Table 9 The effect of diet type on fecal characteristics.

Diet type*	Fiber intake (g/day)	Number of subjects in study	Fecal mass wet (g/day)	Fecal mass dry (g/day)	Stool frequency (motions per 24 hr)	Moisture (%)	Fecal pH	References
Omnivore	23	17	153		1			Davies et al. (1986)
Vegetarian	37	17	168		1.2			Davies et al. (1986)
Vegan	47	17	225		1.7			Davies et al. (1986)
Omnivore		14			1.4	73.5		Goldberg et al. (1977)
Vegetarian		14			1.8	73.3		Goldberg et al. (1977)
Omnivore		66	131.9					Lewis and Heaton (1997)
Omnivore	16.6	22	117	30.8		72.6	6.65	Reddy et al. (1998)
Vegetarian	16.2	22	186	36		78.9	6.18	Reddy et al. (1998)
Vegetarian	29.3	18	160	38.4		74.6	6.55	Reddy et al. (1998)
Omnivore[a]	12	8	129	32.8		74	7	Silvester et al. (1997)
Omnivore[b]	11	8	118	32		70.7	7.2	Silvester et al. (1997)
Omnivore	27.3	149	119	27.1	0.9		6.8	Van Faassen et al. (1993)
Vegetarian	40.8	11	189	27.9	1.5		6.8	Van Faassen et al. (1993)

*O: Omnivore, V: Vegetarian, VN: Vegan. [a]Low meat diet (68 g/day protein). [b]High meat diet (192 g/day protein).

Source: (Rose et al., 2015)

The Table 9 shows the effect of diet in the fecal characteristics. The table shows that there is a slight difference in the fecal mass, wet and dry, moisture as well as in pH. The vegetarian group with lower fibre intake has higher fecal mass than the vegetarian group with higher fibre intake. The Table 9 illustrates that higher the fibre intake, lower the dry mass of faeces is as fiber intake is often cited for causing variation in feces production, for example, by Vuksan et al. (2008) (Rose, et al., 2015).

5.1.3. NUTRIENT RECOVERY

Human urine has been shown to be as efficient as commercial fertilizers without pathogen risk, low NH_3 emissions, no flavor effect, and has been tested positively on 6 different plant orders and families including tomatoes, cabbages, beans, corns, etc. It can also be used to fertilize tree seedlings and fruit trees. Urine is used as a fertilizer according to its nitrogen value. Usually one litre of stored urine contains approximately 3–7 grams of nitrogen. If specific instructions of the use of nitrogen fertilizer are not available, all plants can be fertilized as urine produced by one person in a day (ca 1-1.5 litres) fertilizes one square meter per growing season (Global Dry Toilet Association of Finland, 2017)

Many literature supports treatment and utilization of urine for the agriculture purpose as urine contains the greater part of excreted nitrogen, phosphorus and potassium, and its handling is easier than faeces (Jöhnsson et al., 2004; Maurer et al., 2006; Niwagaba, 2009; Pradhan et al., 2010; Richert et al., 2010; Wohlsager et al., 2010; Semalulu et al., 2011; Anderson, 2015). Also, Malkki, 1995; Höglund, 2001; Schönning & Stenström, 2004 supports the separation of urine from the solid excrement making the handling of excreta easier, reducing the volume of excreta, reducing the odor problems and decreasing the runoffs of pathogens and nutrients to soil, groundwater and surface waters (Nagy & Zseni, 2017).

Table 10 Use of Urine as a liquid fertilizer in different plants in different experiments.

Order	Family	Plant Name	Species Name	Reference
Brassicales	*Brassicaceae*	Cabbage	*Brassica olercea*	(Pradhan et al., 2007)
Brassicales	*Caricaceae*	papaya	*Carica papaya*	(David Beaune, 2018)
Caryophyllales	*Amaranthaceae*	Beet	*Beta vulgaris*	(Egigu et al., 2014)
Cucurbitales	*Cucurbitaceae*	cucumber	*Cucumis sativus*	(Heinonen-Tanski et al., 2007)
Cucurbitales	*Cucurbitaceae*	Pumpkin	*Cucurbita maxima*	(Pradhan et al., 2008)
Fabales	*Fabaceae*	Beans	*Phaseolus vulgaris*	(Ranasinghe et al., 2016)
Fabales	*Fabaceae*	Faifai	*Serianthes myriadenia*	(David Beaune, 2018)

Malpighiales	*Passifloraceae*	passion fruit	*Passiflora edulis*	(David Beaune, 2018)
Malvales	*Malvaceae*	Okra	*Abelmoschus esculentus*	(Akpan-Idiok et al. 2012)
Malvales	*Malvaceae*	Hibiscus	*Hibiscus tiliaceus*	(David Beaune, 2018)
Poales	*Poaceae*	maize	*Zea mays*	(Guzha et al., 2005)
Poales	*Poaceae*	Barley	*Hordeum vulgare*	(Heinonen-Tanski et al., 2007)
Poales	*Poaceae*	Wheat	*Triticum sp*	(Tidåker et al., 2007)
Solanales	*Solanaceae*	tomato	*Solanum lycopersicum*	(Egigu et al., 2014, Mnkeni et al., 2008, Pradhan et al., 2009)

Source:(Nagy and Zseni, 2017)

These papers also support that urine has been used successfully as a fertilizer for cereals and some vegetables. According to the literature, urine fertilized plants may have produced higher, similar or slightly lower yields than mineral fertilized plants, but they invariably resulted in higher yields than non-fertilized plants. There have been no microbiological risks associated with any products. The taste and chemical quality of the products are like plants treated with mineral fertilizers (Heinonen-Tanski, et al., 2010).

According to *A review of recycling of human excreta to energy through biogas generation: Indonesia case* the yields of barley grown in Sweden were similar as those treated with the same amount of nitrogen from mineral fertilizer and the ammonia losses were moderate if harrowing was done soon after urine application. Cattle urine gave a better germination yield than human urine in barley and cress tests. Similarly, in Finland, cabbage, outdoor cucumber and red beet produced as good or higher yields than those treated with mineral fertilizer. Pumpkin outdoors and tomato grown in a greenhouse fertilized with urine led to clearly higher yields than those grown without fertilization, but less than those produced with mineral fertilizer. The taste and chemical content of cucumber, cabbage, pumpkin, tomato or red beet were very similar compared to those treated with mineral fertilizer. Furthermore, there was no enteric microbial contamination in the edible parts of the plants. The chloride content of vegetables fertilized with urine was higher but on the other hand, the nitrate and nitrite contents were lower than those fertilized with mineral fertilizers or non-fertilized plants. In the cabbage experiments, there was less damage caused by insects compared to mineral fertilization (Andriani, et al., 2015).

Moreover, following studies also found human urine to be an efficient liquid fertilizer to be used in the soil for growing crops:

Table 11 Use of Urine as a liquid fertilizer in different plants in different experiments.

Crop	M. Sc. Thesis of	Year	Country	Reference
Maize	Lucy Hatfield	2018	Tanzania	(Hatfield , 2018)
Sorghum	Lucy Hatfield	2018	Tanzania	(Hatfield , 2018)
Cabbage	Bikash Adhikari	2011	Nepal	(Adhikari, 2011)
Cauliflower	Laxmi Saiju	2013	Nepal	(Saiju, 2013)

Urine can be applied either undiluted or diluted, depending on the requirement of plants (Nagy & Zseni, 2017) and non-edible plants can also be cultivated using human urine as fertilizer and thus roses have grown well in the Indonesian climate (Andriani, et al., 2015). The Table 12 explains the ways of application of urine in different plants. For example, cabbage needs 0.5 l of urine to be applied for 3 times a week, while carrot needs 1 time per week and orange needs 12 times per year.

Table 12 Ways of application of urine in different plants.

crops	cabbage	carrot	Millet	banana	orange	tomato	potato	cucumber
Application period (0.5 Litre / plant)	3 times/ week	1 time/ week	2 times/ week	4 times / week	12 times/ year	3 times/ week	1 time/ week	2 times / week
Urine required(L)	18	6	12	24	6	18	12	12

Source: Anderson, C.R., 2000, as cited in(Nagy and Zseni, 2017)

5.2. ENERGY IN HUMAN EXCRETA

5.2.1 ENERGY RECOVERY

One of the best ways to dispose of human waste is to treat it in the anaerobic digester and produce biogas as energy and effluent as fertilizer. The application of anaerobic digestion during biogas production reduces the potential for odour, and destroys pathogens, from faeces (Karki, n.d.; Buxton & Reed, 2010; Nakarmi, et al., 2015)

Even though there is enough gas produced per kg of faeces as compared to cattle and poultry dung as shown in the Table 13, human have been used for methane generation in limited scale in most of the developing countries due to social or religious reservation whereas in developed countries, biogas is produced on a large scale (Karki, n.d.).

Table 13 Biogas production potential of various types of dung.

Types of Dung	*Gas Production / kg dung (m^3)*
Cattle	0.023 - 0.04
Pig	0.04 – 0.059
Poultry	0.065 – 0.116
Human	0.02 – 0.028

Source:(Buxton and Reed, 2010)

DEVELOPING COUNTRIES:

Biogas production from excreta can be produced at household level, community level as well as in institutional level.

HOUSEHOLD LEVEL

In developing countries, domestic biogas plants are installed to meet the immediate needs of electricity, heat and fertilizer. Biogas plants are providing a mainstream renewable energy solutions in rural Nepal, allowing people to produce methane by fermenting human and animal waste to provide a cleaner and safer source of energy. Andreas Michel, energy expert with the German Technical Cooperation (GTZ) explains that the dung produced by two or three cows per day is sufficient to make enough methane gas for five hours of cooking or light (Cheung, 2010). Therefore, in rural areas of Nepal, the biogas plants are largely dominated by the household level biogas plants that use animal and human excreta as feeding materials (Nakarmi, et al., 2015).

According to the Alternative Energy Promotion Centre (AEPC), a government agency responsible for promoting renewable energy, there are now more than 300,000 biogas plants providing for the fuel needs of nearly 6% of Nepal's households. However, some households in Nepal are reluctant to use human faeces as feedstock for producing biogas. People, especially those who are not aware of the advantages of producing biogas at household levels, are against the idea of using their faeces for cooking food. In some cases, those who installed biogas plants are even ostracized by their neighbors whereas now, with awareness, they are increasingly being persuaded that small biogas installations are using human waste to provide fuel for cooking and heating (Rai, 2014).

COMMUNITY LEVEL

The biogas plant needs a continuous supply of feedstock, so poor households which do not have any cattle or are only few family members cannot operate one of their own. They can, however, benefit from a community biogas plant. The gas produced is distributed to all participating households, even those who have no cattle (Sharma, 2011). For example, in Nepal, three community biogas plants in Sarlahi District (in wards 1 and 2 of Bhaktipur VDC and ward 9 of Jabdi VDC) have been successfully constructed. In Jabdi VDC, six households, two of which have no cattle, benefit from the community biogas plant attached with toilets (Sharma, 2011).

Figure 16 illustrates how community biogas plants work. Depending on the number of households willing to participate, the size of the digester can be finalized. Toilets can be attached directly to the digester, and if needed, animal waste can be added to the digester as well. Then the gas thus produced can be supplied to the households, and the slurry can be applied to the agriculture field as well.

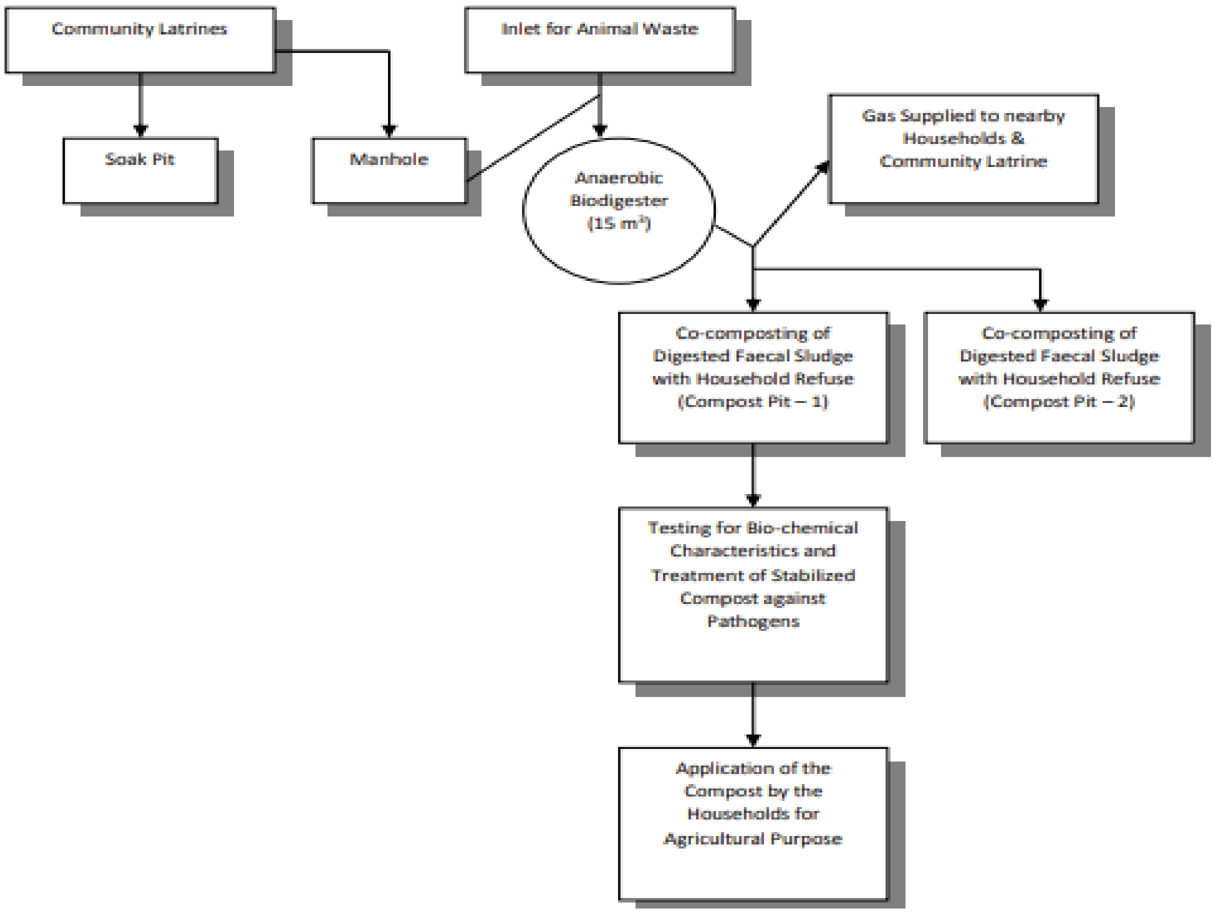

Figure 16 Conceptual framework to produce biogas and stabilized compost from the community latrines.

Source: (Nakarmi, et al., 2015)

INSTITUTIONAL LEVEL

There are several examples of Biogas technology being a success in institutions such as prisons in Kaski, Nepal (Aryal, 2009), and school in Chitwan in Nepal (Buxton & Reed, 2010).

Institutional Biogas Plant at Narayani High School Chitwan

The program for setting up bio-digester at Narayani High School was undertaken by Yashoda Sustainable Development (P) Ltd (YSD) under the framework of AEPC in 2005/06 as the school was interested to solve the sanitation problems by attaching the latrines with bio-digester and to utilize the gas for cooking as well as in science laboratory. The school has around 1,200 people including students, teachers, other staff and visitors attending the toilets attached with biodigester. Apart from human faeces, it was estimated that around 70 kg of biodegradable waste from kitchen resulting from 4 meals served every day to hostel students including waste from canteen used by day scholars and other staffs and 10 kg of wastepaper was available per day to feed the bio-digester. Similarly, there was always the possibility of adding soft garden grasses into the bio-digester as supplementary feedstock (Nakarmi, et al., 2015).

The biogas use has completely replaced two LPG cylinders, which were consumed earlier. During the time of monitoring, it was identified that the burning hour of gas is around six hours a day (Nakarmi, et al., 2015).

Figure 17 shows the yearly installation of biogas plants in Nepal since 1992/93-2015/16. It presents the increasing number of biogas plants installed each year further showing the acceptance of biogas production from different feedstock as a technology that they can use to not only benefit it to use for cooking, heating or as electricity but also to help in faecal management. However, we can see the drastic decrease in the installation of biogas plants in the year 2015 because since mid 2015 there is no monetary subsidy support as strong as before from the central government (Nakarmi, et al., 2015).

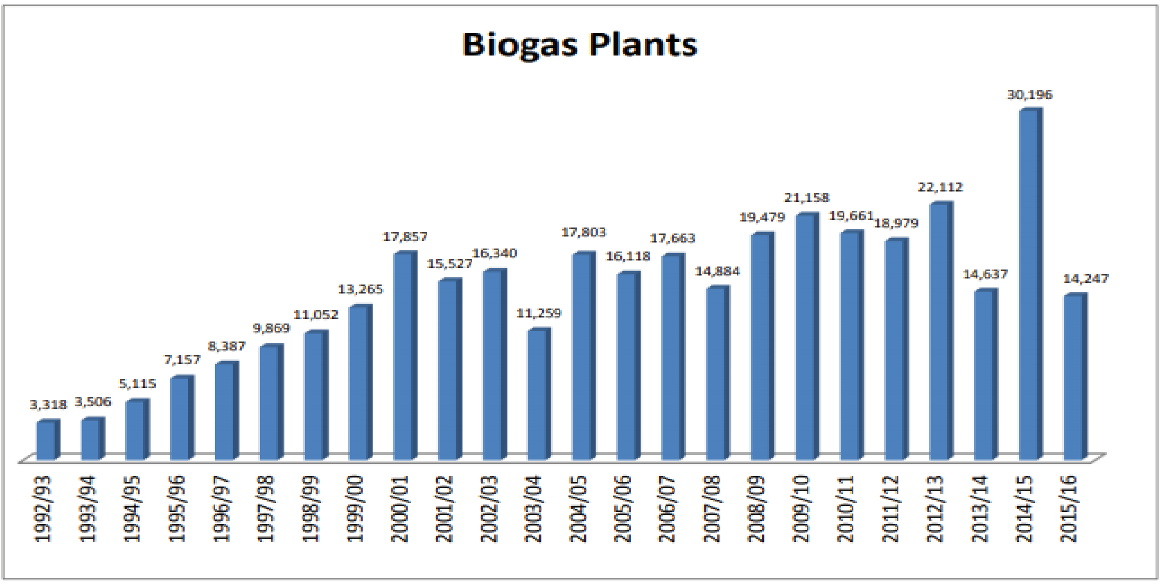

Figure 17 Installation of biogas plants from 1992/93 to Dec 2015.

Source: (Nakarmi, et al., 2015)

DEVELOPED COUNTRIES AND BIOGAS PRODUCTION

In the developed countries, biogas is produced primarily large-scale using dung, food wastes, or agricultural crops grown to produce energy. The energy and climate policies in the European Union (EU) and the introduction of support schemes for promoting the utilization of renewable resources have encouraged the development of biogas plants for energy production in EU countries (Scarlat, et al., 2018). For example, in the German programme, the electricity generated from biogas plants ranges from less than 150 kW up to 20 MW per unit. A 500-kW plant uses a digester tank of 15,000 m^3 working volume and uses about 1,000 tonnes of biomass material a day (Achinas, et al., 2017).

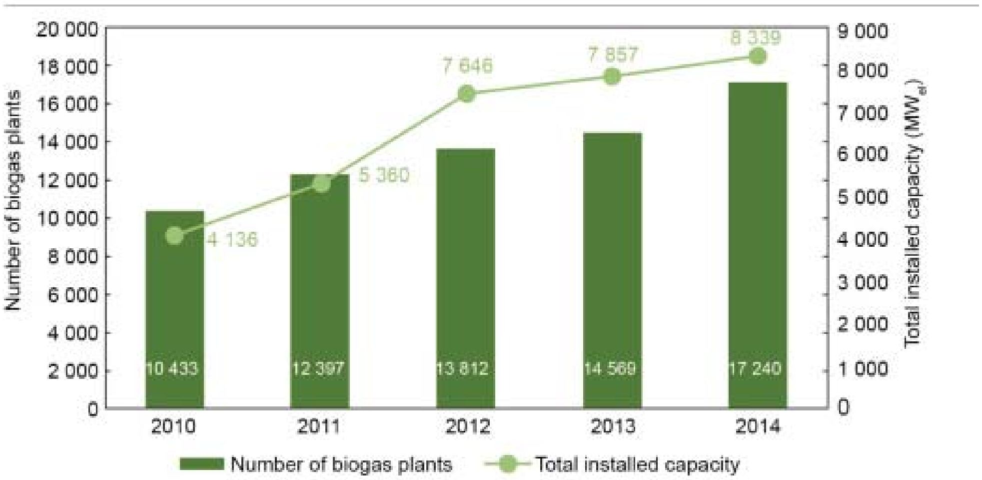

Figure 18 The increasing number of biogas plants and total installed capacity in Europe during the period 2010-2014.

Source: (Achinas et al., 2017)

Figure 18 shows the number of biogas plants and total installed capacity in Europe during the period 2010–2014. For example, according to *A Technological Overview of Biogas Production from Biowaste*, a high share of the electric power in Germany comes from biogas as a result of governmental initiatives promoting power generation from wastes. Most biogas production is currently based on sewage sludge; however, it is estimated that by 2030, an increasing amount of biogas will be produced from wet manure, landfill, undigested sewage sludge, and food-processing residues (Achinas, et al., 2017).

In recent years, the large-scale approach has been exported to India, China, Philippines, Thailand, Taiwan, and Brazil (Kotrba, 2007), where it is being used with food-processing wastes such as brewery effluents and sugar residues. (Fulford, 2015).

5.2.2. ENERGY CONSUMPTION IN NEPAL

Nepal has no oil, gas, or coal reserves, and its energy sector is dominated by the traditional energy sources like firewood, crop residues, and animal dung for domestic use. Most rural populations are meeting their energy needs by burning biomass in traditional stoves, and mostly fossil-derived fuels like LPG and kerosene are imported. The major sources of renewable energy are mini and micro hydropower, solar energy, various forms of biomass energy, biogas, and wind energy etc. But still around 85% of the total final energy consumption in Nepal is met by traditional biomass energy and around 28% of households in Nepal do not have access to electricity (Ghimire & Naeen, 2017). Nepal aims to achieve universal access to clean, reliable, and affordable renewable energy solutions by 2030. It is expected to reduce dependence on traditional and imported energy by increasing access to renewable energy (Ghimire & Naeen, 2017).

Due to the load-shedding problem affecting the country for years, people were forced to arrange for alternative power until Nepal Electricity Authority (NEA) declared the nation as load-shedding free on 13th May, 2018 after finally freeing industrial sectors of 3-4 hours of daily power cuts (The Kathmandu Post, 2018) whereas the residential load shedding had ended since early 2017 (Sah, 2019). Before, factories and industries were compelled to use generators for the smooth operation using petroleum fuels. The country spent billions of rupees on the import of petroleum fuels (Maharjan, 2018). Power cuts spanned a maximum of 16 hours a day, with Nepal meeting only 80% of its electricity demand from 2008-2016 (Sah, 2019). NEA is now embarking on an ambitious plan to connect all 77 districts to the national grid by 2021 as adequate electricity supply can replace the heavy reliance on imported LPG for cooking. According to Madhusudhan Adhikari, Executive Director of AEPC, the government is putting more emphasis on clean cooking solutions and aims to achieve one electric stove in every home (The World Bank, 2019). The government has been talking time and again to facilitate people to purchase electrical appliances like induction cookers targeting to reduce the surging import of petroleum products to minimize the widening trade deficit (Khanal, 2020).

However, the difficulties have been experienced in rapid extension of the National Grid for rural electrification due to remote topography, dispersed settlement pattern, and the limited financial resources of the Government of Nepal. Only limited efforts have been done in providing clean and reliable energy in the rural areas. (GoN, 2006). Therefore, exploring alternative sources of energy is also equally important (Maharjan, 2018).

5.2.3. POTENCY OF BIOGAS GENERATION IN NEPAL USING HUMAN EXCRETA

For the development of biogas as the alternative source of energy, it is necessary to know its potential in the country. In the developing countries, for example in India, China and Nepal, cattle (cows and buffalo) dung is the main source for biogas production. Thus, biogas potential is generally based upon the cattle population and quantity of dung collected from these animals (Karki, n.d.). Compared to animal waste, human faeces and latrine waste have been used for methane generation in limited scale in most of the developing countries due to social or religious reservation. In recent years, the acceptability of latrine waste is increasing in Nepal as about 40 percent of the installed biogas plants are found attached to the latrines (Karki, n.d.). Moreover, the government is giving emphasis to carry out necessary research and studies to increase efficiency, reduce cost of the household, community and institutional biogas production and technologies. Establishment of biogas related information centers and exhibitions are also encouraged in coordination and support of the local institutions (GoN, 2006). According to AEPC, over 300,000 household scale biogas plants have been built by 2015 (NBPA, 2015) while the total potentials of biogas plants in Nepal is about 1.9 million (Gautam, 2003).

5.3. BIO-SLURRY

Anaerobic digestion of biowastes in a biogas plant can be considered as an effective treatment method for the reduction of indicators and pathogens (Poudel, et al., 2010). There has been considerable awareness of household and institutional biogas plant needs, but the problems of handling and safe utilization of digested residue (bio slurry) which may contain pathogens have received less attention. Safe utilization of bio slurry is important for the health of humans, animals and plants, and for the social and environmental effects (Poudel, et al., 2010).

To get an overall picture on the effect of bio-slurry on crop production, the results of selected studies conducted by some developing countries where biogas technology is well developed is presented in Table 14 from (Nakarmi, et al., 2015).

Table 14 Average yield of Vegetables with bio slurry application.

Name of Crops and Vegetables	Yield of Crops and Vegetables (in tons/ha)		Increment in Yield over the Control (%)
	Without Bio-slurry (Control)	With Bio-slurry	
Rice	2.7	3.0	10.0
Tomato	15.0	17.8	15.7
Cauliflower	4.6	5.6	17.8
French bean	0.3	1.0	70.0

Source: Biogas Newsletter, 1978 as cited in (Nakarmi, et al., 2015)

The data presented in Table 14 indicates that the increment in the yield of paddy due to slurry application is 10%, while it is around 16% and 18% in case of tomato and cauliflower respectively. Very encouraging results have been observed in the case of French beans (70%) (Nakarmi, et al., 2015).

In Nepal the trend of bio-slurry utilization in the form of fertilizer is gradually increasing among the biogas user farmers. However, not all farmers seem to realize the importance of the digested slurry assuming slurry coming out of biogas has lost its fertilizer value as gas is generated during the anaerobic digestion process. For example, although about 65 percent of the installed biogas plants have been attached to family latrine in Nepal, the users still hesitate to handle the slurry. However, the viability of biogas plants without slurry utilization is inadequate (Nakarmi, et al., 2015).

5.4. FINDINGS FROM FIELD VISIT IN GUNDU, THIMI

As mentioned earlier, in Nepal, ecosan toilets are of two-pits, therefore, when one pit is full, the incoming excreta is diverted to the second pit, known as double vault dry latrines. In about two years, the excreta get digested and becomes dry and pathogen-free, and safe for handling as manure. Digested sludge is odourless and is a good manure and soil-conditioner (ENPHO, 2006).

For this thesis, field visit was done in the communities where ENPHO has installed ecosan toilets. The original plan was to visit Siddhipur, Khokana and Thimi. However, lockdown due to COVID-19 gave little to no time to visit all these communities. Therefore, Mr. Sushil suggested visiting the nearest community, Gundu in Thimi. Gundu is a part of Suryabinayak Municipality in Bhaktapur District in the Bagmati Zone of central Nepal (Wikipedia, 2019).

After choosing the community randomly, semi structured questionnaires were prepared to conduct informal interviews. The houses were also chosen randomly as these latrines were distinct because of the ENPHO logo they had on the doors of ecosan latrines.

Interviewees were asked for verbal permission to take photos of their ecosan latrines as well as for informal interviews to present them in this thesis. Interviewees were happy to share their story of using ecosan latrines, advantages, challenges, and suggestions to make it more user friendly. A total of four households were visited and interviewed.

Figure 19 Ecosan Toilets in Gundu, Thimi. Nepal.

Source:(Maharjan, 2020)

These photos are from Gundu, Thimi where four of the ecosan toilets are in operation (ENPHO, 2006). As seen in the photo, the toilets are not clean, not meeting the required level of hygiene.

PERCEPTION OF ECOLOGICAL SANITATION SYSTEMS

All the four interviewees seemed to have a positive attitude towards ecosan toilet systems. They knew about the importance of ecological sanitation systems in providing natural fertilizer for their agricultural fields. The interviewees confirmed to be using the excreta along with their cattle dung in their agriculture fields for maximum benefits.

CHALLENGES OF ECOLOGICAL SANITATION SYSTEMS

One of interviewee, Seer Kumari Pant has a family of five She discussed the problem of the structure of the ecosan toilets being problematic for the old aged people in her family. Therefore, older members of her family do not use this toilet which leads to not getting enough excreta to reuse as fertilizer in her agriculture fields. Hence, she mixes cattle manure along with the excreta to use in her farm. It was also found out that the younger generation of the families do not know the importance of the ecosan toilet systems, and they are not interested in using excreta as fertiliser as well. The younger generation prefer “modern” flush-toilets to double vault ecosan toilets, therefore, the use of ecosan toilets are decreasing in this area. As discussed with the interviewees, it was found out that younger generations of their own families are reluctant to use these toilets even though the interviewee themselves seem to have knowledge about the use of the toilets and the excreta collected. Sun Maya, one of the interviewees said that she is the only one in her family using the toilet. She has recently built a new house with a flush toilet, therefore her whole family of six use the new modern water toilet. Her ecosan toilet was constructed in their old farmhouse. Now, it is only her using the ecosan toilet. Therefore, she must also mix the cattle manure, especially cow dung as she has 3 cows, with the excreta to apply in her farm during corn and mustard season.

As we can see in Figure 20, many new buildings were seen to be constructed in this area. The interviewees established that with the increasing rate of construction of new buildings, there is a decreasing rate in use of ecosan latrines in this community. More people are attracted to use water-flush toilets. Further studies should be done about these challenges.

IMPROVEMENT REQUIRED IN THE ECOSAN TECHNOLOGY

As discussed by interviewees as well as discussed in chapter 4, there are challenges, ecosan toilet users are facing regarding the perception and acceptance of the ecosan technologies in the communities, the physical structure (Figure 19) not being male, children or old people friendly, and the increasing interests of younger generation in flush toilets. These challenges should be resolved and more robust, more user friendly, simple, and innovative technologies should be applied and update the system. This should include adopting specific design measures which account for men's easy use requirement without forgetting women's menstrual hygiene, personal safety, and dignity-related needs. Ultimately, an enhanced dialogue must take place among designers, policy makers, WASH practitioners, and other relevant actors about how to adapt toilets in a range of development operations to better address these critical needs of male and female, young and old. Moreover, before introducing any technology, it is important to study and discuss with the community about their needs of the technology and must adapt it according to their demand. Similarly, awareness about the technology is also necessary to introduce such technology, otherwise the user will not know what to do and how to do with that latrines, for example.

6. DISCUSSIONS AND CONCLUSIONS

This study showed that the modern misconception of "excreta is waste" is at the root of the pollution problems which result from conventional approaches to sanitation, particularly flush-and-discharge approach. Hence, ecological sanitation systems are the best solution of sanitation for developing countries like Nepal. Ecological sanitation is a circular economy based "waste to resource" closed nutrient loop sanitation system (WAN, 2008). Since the nutrients used in agriculture fields today comes from non- renewable sources, by using excreta instead of chemical fertilizers, such as NPK, the agriculture and the environment both will benefit (Andersson 2000 as cited in (Viskari, et al., 2018). The fundamental problem in Nepal concerning the conventional systems is of the technology being expensive and unaffordable and the conventional system not facilitating the nutrient recovery and reuse leading to a linear flow of nutrients from agriculture, via humans to recipient water bodies, which can be solved by ecological sanitation system (WAN, 2008). Nutrients recovered from human excreta can also be used to enhance the productivity of horticulture and agriculture in home gardens and farms, in urban as well as rural areas (Esrey, et al., 1998). Ecological sanitation, thus, creates a circular flow of nutrients from essentially toilet to table as conferred by Maurer, Pronk et al. 2006 as cited in (Hatfield , 2018)).

6.1. IMPORTANCE OF ECOLOGICAL SANITATION IN NEPAL

This thesis also discusses the concept of ecological sanitation already being practiced in some rural areas and Newar communities in Nepal. What Nepal needs now is to revitalize those traditions and develop large-scale applications of the ecological sanitation concept. In Nepal, after the introduction of the ecosan latrine concept in 2002/2003, about 517 ecosan latrines have been built majority in the peri-urban areas around Kathmandu with acceptance of the concept. By 2010, more than 770 Ecosan toilets had already been constructed (Messmer, 2011) and there is a demand for 3000 urine diverting pans (Shakya, 2015).

The excreta from the latrines are being used in agriculture, some store it before using and some use it directly in their fields. With a shift in thinking from nutrient removal to nutrient recovery, focus is now on pathways to recover these nutrients successfully. Ecosan systems offer appropriate and sustainable solutions for different circumstances and demands. They permit acceptable and affordable sanitation for poor and rural areas, as well as for high-income areas and industrialized countries (Ganrot , 2005).

However, despite the benefits of using ecological sanitation system of using urine as liquid fertilizer in the farm for better and quality yield and productivity, generating biogas from excreta and using the slurry for soil fertility, users must become aware that improper use of any toilet system may threaten public health and pollute the environment. These problems can best be avoided by awareness of the ways of using the toilets and adopting the appropriate treatment processes before the application of excreta in the nutrient recovery or energy recovery as well (Esrey et al., 1998).

Moreover, the utilization of human excreta in agriculture has also been associated with socio-cultural issues. Since, people do not want to deal with excreta in any form, one must study the compatibility of the technology with the socio-cultural acceptance and economic conditions of the users. The technology to be introduced must also be simple, robust and easy to operate and maintain and protect the environment by isolating or destroying the fecal pathogens. An alternative use of human excreta is the fertilization of crops that are not for human or animal consumption, e.g., energy plants, ornamental plants, and public gardens (Arias, et al., 2019). However, the significant aspect to address for the better use of human excreta as fertilizer, and acceptance of ecosan systems, is the social perception. People must transform the misconception of excreta as waste and dirt to view it as a resource.

Once, the user accepts the concept of the ecological sanitation systems, it can be the best way to solve the sanitation problem in Nepal and other developing countries where flush and discharge systems are expensive and drop and store systems are not possible due to rocky ground, high ground water level or in flood-prone area or urban areas where access to land is not possible. However, more user-friendly, simple, and robust technologies must be introduced.

6.2. USE OF SOURCE-SEPARATED HUMAN URINE AS A LIQUID FERTILIZER IN NEPAL

Nepal is an agricultural country having more than 66 percent people directly engaged in subsistence farming. Rice, maize, millet, wheat, barley and buckwheat are the major staple food crops in Nepal and oilseeds, potato, tobacco, sugarcane, jute and cotton are the important cash crops whereas lentil, gram, pigeon pea, blackgram, horsegram and soybean are the important pulse crops (FAO, 2020).

For increased agricultural productivity secured supply of quality fertilizer in time and affordable price is utmost necessary. However, the present supply of chemical fertilizer in

Nepal is not meeting its demand (ADS, 2014). According to NEAT (2014), in 2011/12 potential demand for chemical fertilizer in Nepal was about 700,000-800,000 MT. However, the effective demand was 500,000 MT of which the formal sector supplied only 75,000 MT and the rest was supplied by informal sources including small private traders (Panta, 2018). Due to a fertilizer shortage, farmers are forced to buy fertilizer at an expensive rate in the open market in India which is then imported illegally which are substandard and could damage soil health, but they don't have other options (Panthi, et al., 2019). This gap in demand and supply of fertilizers gives the huge opportunity for ecological sanitation system in Nepal, especially use of human urine as liquid fertilizer as source-separated urine has been found to be the most safe and efficient liquid fertiliser for many crops and vegetables and has been studied in many different contexts since the late 1990s (Kirchmann and Pettersson, 1995; WHO, 2006; Heinonen-Tanski et al., 2007; Mnkeni et al., 2007; Pradhan et al., 2007; Chowdhury and Islam, 2008; Viskari et al., 2009; Pradhan, 2010) as cited in (Viskari, et al., 2018), for example maize (Guzha et al., 2005) , barley (Heinonen-Tanski et al., 2007), wheat (Tidåker et al., 2007) which are also main food crops in Nepal (FAO, 2020).

Human urine has shown to be as efficient as commercial fertilizers without pathogen risk, low NH_3 emissions, no flavor effect, and has been tested positively on 6 different plant orders and families including tomatoes, cabbages, beans, corns, etc. It can also be used to fertilize tree seedlings and fruit trees. Urine is used as a fertilizer according to its nitrogen value. Urine can be applied either undiluted or diluted, depending on the requirement of plants (Nagy & Zseni, 2017) and non-edible plants can also be cultivated using human urine as fertilizer (Andriani, et al., 2015).

Different papers also support that urine has been used successfully as a fertilizer for cereals and some vegetables. According to the literature, urine fertilized plants may have produced higher, similar or slightly lower yields than mineral fertilized plants, but they invariably resulted in higher yields than non-fertilized plants. There have been no microbiological risks associated with any product. The taste and chemical quality of the products are like plants treated with mineral fertilizers (Heinonen-Tanski, et al., 2010). Urine as a fertilizer is suitable especially to plants with high nitrogen demand such as grain, grass crops, oil plants, spinach, cauliflower, corn, lentils, red beans and soybeans (Saiju, 2013) .

Nevertheless, urine contains some amounts of chlorine and therefore it is not recommended in commercial cultivation for chlorine sensitive plants such as potato, onion, tomato, cucumber and rhododendron. An overdose of chlorine can disturb crop yields of some plants. On the other hand, good qualities of urine may compensate for harms of chlorine (Saiju, 2013).

The potential health risks associated with the use of urine and faeces as fertilisers have been extensively studied, and WHO guidelines have been developed for the urine treatment and use (WHO, 2006 as cited in (Viskari, et al., 2018)). The urine of a healthy person contains only a small amount of pathogens, originating mostly from faecal contamination (Höglund et al., 1998) and storing the urine can disinfect it in case of any contamination (Höglund, 2001) as cited in (Arias, et al., 2019). Also, urine must be applied to crops based on the N-content in the urine and the N requirement of the crops. Urine must be spread one or many times depending on the duration of the growing season and the demand of the plants.

6.3. USE OF HUMAN EXCRETA TO PRODUCE BIOGAS IN NEPAL

A developing country like Nepal needs a system that aims to treat the sludge generated from the septic tanks and reuse the end products such as biogas, treated sludge, compost manure and treated water obtained after the treatment process (The Kathmandu Post, 2016) as the excreta in toilets built in the last few years in pits or septic tanks starting to fill up (Tuladhar, 2018). As discussed earlier, the biogas plants, produced in a household level, community level or in an institutional level are suitable solutions for a combined treatment of faecal sludge in developing countries like Nepal.

In Nepal, especially in Kathmandu and other major cities, installing biogas plants address two major problems being faced by the municipalities at present, the persistent energy crisis and waste management issues, (Nakarmi, et al., 2015) discussed in previous chapters. For the installation of biogas systems in the municipalities, the government has decided to subsidize such systems by a maximum of 50% of their installation cost (Nakarmi, et al., 2015). From 1992 until 2012, the plants were subsidized under the Biogas Support Program (BSP) and since 2012 under the National Rural Renewable Energy Programme (NRREP) (NBPA, 2015). However, since mid 2015 there is no monetary subsidy support as strong as before from the central government (Nakarmi, et al., 2015).

According to Rastriya Gobar Gas Company, by 2003, over 50,000 biogas plants were already in operation in over 60 districts of Nepal, which is less than 4% of the total potentials of 1.9 million biogas plants (Gautam, 2003) and over 300,000 household scale biogas plants have been built by 2015 (NBPA, 2015). One of the constraints of biogas technology is that the production of biogas by anaerobic digestion process through methanogenic bacteria is greatly influenced by temperature. The optimum temperature for satisfactory gas production is 30°C–35°C (Nakarmi, et al., 2015).

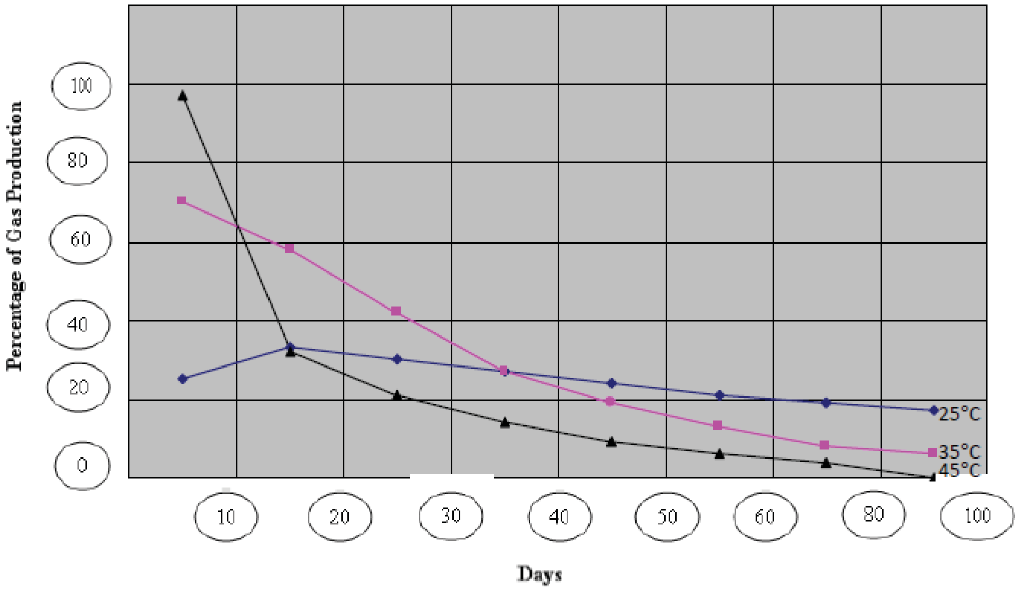

Figure 20 Production of Biogas is the function of time and temperature
Source: Lagrange, 1979 as cited in (Nakarmi, et al., 2015)

Figure 20 indicates that the production of gas is dependent upon temperature. With an increase in temperature, the time of digestion (retention period) can be decreased considerably. This means shorter retention time is needed in case the temperature of the digester is augmented to a desired level, for example, from mesophilic (30°C and 40°C) to thermophilic (45°C and 55°C) range. Satisfactory gas production takes place in the mesophilic range, the optimum temperature being 35°C. Therefore, in cold climate the temperature of fermenting substances in the digester needs to be raised up to 35°C (Nakarmi, et al., 2015).

However, such temperature is difficult to attain in hilly regions or at temperate zones. During winter season and at higher altitude, production of biogas is drastically reduced due to decreased temperature. For example, Kathmandu valley, which lies at 1300m altitude, experiences a temperature below 0°C up to 15°C as maximum particularly during winter. Indian drum-type plants have been known to stop gas production in Kathmandu during winter, while the underground dome types register as much as 75 percent drop in gas production (Biogas Newsletter, Number 17, 1983 as cited in (Nakarmi, et al., 2015)).

Various methods have been explored to raise the temperature of bio-digester in cold climates to increase biogas production including the ones tried in the context of Nepal. A trail of Actizyme was made in Nepal at an altitude of 1800 m. Actizyme mixed with slurry was introduced into the pit and within a few days, gas began to form and soon the plant was in full operation (Biogas Newsletter, Number 1, 1979 as cited in (Nakarmi, et al., 2015).

Apart from biological methods, external heating of the substrate inside biodigester has also been tried for maintaining thermophilic condition. It can also be achieved by using a part of biogas for heating biodigester. Integration of solar energy in the biodigester to produce biogas during wintertime has been practiced in some parts of the world. However, one disadvantage with this system is that during winter/cold season water may freeze inside the pipe. In such cases liquid having lower boiling point must be used instead of water. Through the integration of the solar system in the digester, the temperature inside the digester can be raised up to mesophilic (25°C-30°C), which is optimum to enhance biogas production. However, cost of the system can become a barrier in the adoption of this technique as additional solar systems need to be installed into the bio-digester (Nakarmi, et al., 2015).

Moreover, the main limitation of using human excreta as feedstock is its low C/N ratio which is about 6/10. To overcome this shortcoming, the addition of high C/N ratio raw material such as rice straw, rice husk, or corncob is needed. Another problem in using human excreta is the *E. coli* content in the waste to be disposed of into the environment. However, at thermophilic temperature, *E. coli* inactivation and biogas production are faster than that of at moderate and mesophilic temperatures (Andriani, et al., 2015). Nevertheless, operators must handle human waste with precautions (Nakarmi, et al., 2015).

6.4. USE OF SLURRY AS FERTILIZER

Slurry as a by-product of the anaerobic digestion process can be produced locally and used to increase soil fertility. The data presented in Table 14 indicates the increment in the yield of paddy due to slurry application is 10%, while it is around 16% and 18% the case of tomato and cauliflower respectively. Very encouraging results have been observed in the case of French beans, 70% (Nakarmi, et al., 2015).

However, the biogas plants owners pay more attention towards gas production and neglect the slurry utilization aspect indicated by. Though utilization of slurry as a soil amendment factor is increasing recently, one also needs to confirm the pathogen concentration in the slurry. If pathogen concentration is significant, it must be treated further to avoid health hazards (Nakarmi, et al., 2015).

In case of incomplete anaerobic digestion, the digested slurry prepared from latrine attached biogas plant may harbor pathogens or parasitic worms, it is necessary that the households be instructed to adopt necessary protective hygienic measures while handling the slurry. Recent researches have also revealed that increasing the retention time of the slurry inside the biodigester decreases the pathogenic content due to complete digestion. Double stage anaerobic digesters are considered beneficial in case of large sized institutional biogas plants (Nakarmi, et al., 2015).

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Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway