ROLE OF ECOLOGICAL SANITATION
FOR IMPROVING LIVELIHOOD
IN RURAL AREAS OF NEPAL

SHARDA K C

DECLARATION

I, K C Sharda, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed ………K C Sharda…………………. Date: 2020/08/05

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EXECUTIVE SUMMARY

Food security and sanitation is becoming a challenge especially for low- and middle-income countries. Agriculture is the major occupation of people in Nepal sustaining 70% of the population. Decline in soil fertility, high price of chemical fertilizers and untimely delivery has become a major challenge for sustaining agricultural production. Similarly, improved sanitation technology including proper disposal of human excreta is the national goal to be achieved in Nepal. The practice of wastewater irrigation has been old tradition and had linkage with culture and livelihood especially in Kathmandu Valley. Similarly, the practice of collecting wastewater is traditionally linked to recovery of nutrients in some communities. Ecological sanitation is emerged as a sustainable solution to sanitation which is defined as the practice of converting human excreta into compost and liquid fertilizer for beneficial reuse of nutrients. Thus, this thesis examines how ecological sanitation helps to improve livelihood in rural areas of Nepal. For this, it tries to evaluate the effects of human urine and ecosan manure on crop production and soil fertility as an indicator for livelihood improvement. It also tried to examine farmers and consumers attitude towards ecosan toilet and ecosan manure reuse potential. In order to understand the risk of fecal microorganisms on ecosan users, this thesis examined E. coli as an indicator of fecal microorganisms.

The study was conducted in two places of Central Nepal., Palung Village Development Committee (VDC) of Makawanpur district and Gundu VDC of Bhaktapur district. To understand the effects of urine and ecosan manure as a soil amendment, field experiment was conducted in three sites (Angare, Bhot Khoriya, and Deurali) in Palung VDC in year 2017 and 2018 with randomized block experimental design. Cauliflower was cultivated with five treatments: Control (C), Chemical fertilizer (CF), Urine (U), Excreta + Urine (E + U), and Excreta (E). The results indicated the positive effect of urine and excreta application on crop productivity and nutrient uptake by plant. The yield from E + U and E treatments was comparable to that of CF treatments and higher than that of C treatment. The result suggested the application of a moderate amount of urine in combination with excreta, rather than urine alone had a potential to improve vegetable production and nutrient uptake in Central Nepal.

To understand people's attitudes towards such technology, questionnaire survey was carried out in Gundu VDC. Fifteen ecosan users and 15 non-ecosan users were interviewed to understand their perception towards ecosan toilet, fertilizer value of urine and excreta and how consumers react on the products grown from ecosan manure fertilizer. The result showed ecosan users acknowledged the positive effects of ecosan manure as fertilizer without any problem on use of toilet. Although majority of the non-ecosan users are aware of the benefits of ecosan toilet, very few people showed willingness to construct ecosan toilet. This showed the need of proper management and awareness campaign together with time to time supervision of ecosan toilet to minimize the drawbacks associated with ecosan toilet. It could motivate younger generation to use ecosan proving it sustainable. E. coli tests conducted as an indicator of fecal contamination suggested that ecosan manure is not only the source of E. coli transmission in the study area. However, fecal contamination might occur which can be

mitigated by proper handling of it.

The thesis concluded that human urine and ecosan manure have positive effect to increase crop productivity and soil fertility. Also, the thesis concluded the positive attitude of people towards ecosan manure use as fertilizer suggesting less risk from ecosan manure if handled appropriately.

Chapter 1. Introduction

This chapter describes research background before providing the overall research framework, including the statement of the problem, objectives and research questions. Firstly, because the thesis tried to understand how effective is the human urine and ecological sanitation (ecosan) manure for crop production and soil fertility improvement, it is important to understand the current global food security issues and soil fertility amendment issues in Nepal. Secondly, as this study also emphasizes on the application of human urine and ecosan manure, it is necessary to understand the history of conventional sanitation system in Nepal and current waste management practices. More particularly, the author describes Water, Sanitation and Hygiene (WASH), which is gaining popularity these days in improving health issues, and essentialities of sustainable sanitation including advantages and challenges of ecosan in Nepal and how far it is achieved in the context of Nepal.

1.1. Global food security and context to Southern Asia

Food security is defined as economic access to food along with food production and food availability (FAO 2009). A family is food secure when its members do not live in hunger or fear of hunger. About 805 million people in the world were chronically undernourished in 2012-14, with insufficient food for an active and healthy life (FAO 2014). The majority of them live in developing countries. Two out of three undernourished people live in Asia (FAO 2014). Food availability remained a major element of food insecurity in the poorer regions of the world, notably Sub-Saharan Africa and parts of Southern Asia. The major food security challenge in Southern Asia is the slow progress in improving the low levels of food utilization (FAO 2014). The total population in Nepal was 27.47 million in 2011 (CBS 2011). Agriculture is the main source contribution to the economy, sustaining the livelihood of 70% of the population, which accounts for more than one third of Nepal's GDP (Water Aid 2015). Nepal Demographic and Health Survey 2011 states that only 49% households of Nepal are food secure and has access to food throughout the year (NDHS 2011). It results in poverty. Poverty is still a big problem, with an absolute poverty of 21.6%, which is among the highest in Southern Asia. Poverty may lead to low income, poor health, and inability to cope with the changing environment.

1.2. Soil fertility amendment in Nepal

Considering that average size of the agricultural land was 0.7 ha and 52% of the households operated only less than 0.5 ha (CBS 2014), intensification of agriculture by means of external input of nutrient is very crucial for the farmers in Nepal. Nevertheless, nutrient depletion in soils adversely affects soil quality and reduces crop yield and consequently poses a potential threat to food security and sustainable agriculture. Soil fertility decline has been widely recognized as a limitation of crop production in Nepal (Tripathi 2019). It has become a major challenge for sustaining agricultural production. Four major causes responsible for the overall decline of soil fertility in Nepal are soil erosion, reduced organic matter or organic sources, nutrients mining and indiscriminate or imbalanced use of agrochemicals (Tripathi 2019). Nepalese soil is very much deficient in nitrogen content, low to medium in phosphorus content and medium to rich in potassium content (Joshi 2002). Hence nitrogenous fertilizer is the necessary supplement in soil in order to increase the productivity of the country (Upreti et al. 2011). Fertilizer supply remains critically below its demand in Nepal. The state-owned Agriculture Inputs Company Limited (AICL) and the public corporation Salt Trading Corporation Limited (STCL) have not been able to achieve timely, sufficient and profitable fertilizer supply and distribution (ADS 2014). Chemical fertilizers in Nepal are imported from different manufacturing countries like Turkey, China, Egypt and India by global tender and by government to government negotiation especially from India. Potential demand for fertilizer in

Nepal is about 700,000 MT of which actual supply in the year 2016/17 was 324,977 MT (Panta 2018). Although very large amount of government fund is being invested in fertilizer procurement for subsidy, expected results in terms of agricultural production and productivity have not been met. Alternatives like improvement of farmyard manure (FYM) and promotion of organic production may save considerable revenue and maintain soil and human health (Panta 2018).

1.3. Conventional sanitation systems and its history in Nepal

Sanitation is defined as all activities which improve and sustain hygiene in order to raise the quality of life and health of an individual (WHO and UNICEF 2004). Generally, it includes appropriate methods of disposal of human excreta, personal hygiene, food hygiene, appropriate handling, storage and use of drinking water, appropriate solid, liquid and animal waste disposal. In low- and middle-income countries, 38% of health care facilities do not have an improved water source, 19% do not have improved sanitation and 35% do not have water and soap for handwashing (WHO 2015). There are 663 million people lacking access to improved drinking water sources, among which 34 million falls under Southern Asia (FAO 2015). In 2015, it is estimated that 2.4 billion people globally still use unimproved sanitation facilities, among which 40% live in Southern Asia (2018). Approximately 6,000 children die every day from diarrheal diseases related to inadequate sanitation and hygiene (WEHAB Working Group 2002). The main factors that lead to diarrhea include lack of sanitation and hygiene, consumption of unsafe water and other diseases including helminthic infection. About 3 billion people in the world do not have basic handwashing facilities at home. The wastewater reuses would be an attractive option for rural areas in developing countries where poverty, poor infrastructure, low efficiency, government/ political instability, and severe environmental condition are challenges (Ushijima et al. 2014).

1.3.1. Changes in defecation style in Nepal

Although open defecation has decreased globally from 25% in 1990 to 17% in 2008, it is still widely practiced in Southern Asia by 44% of the population, where seven out of ten people without improved sanitation facilities, and nine out of ten people still practicing open defecation, live in rural areas (WHO/UNICEF 2015). In low-income countries, pit latrines are the most common form of sanitation because it is easily available with low cost and basic form of improved sanitation (WHO 1996). Although pit latrines are common, they have several challenges such as smells, flies, and the chance of groundwater contamination. In many countries, pit latrines are emptied manually, and the contents are discharged into water ways without treatment, exposing many people to infection and disease (Peal et al. 2014). Waterborne sanitation (flush toilets) are considered as improved sanitation systems but several challenges made them unsustainable. The high capital, operational and maintenance costs is necessary to meet increasing pressures associated with rapid urbanization (Haq and Cambridge 2012; IWA 2014). Considering the lack of space for replacing pit latrines, the difficulties of emptying pit latrines and the environmental pollution caused by the discharge of untreated fecal sludge into water ways, sustainable sanitation is the key objective of development goals. To be sustainable, a sanitation system must be economically viable, socially acceptable and technically and institutionally appropriate, while also protecting the environment and natural resources (Luthi et al. 2011). In order to meet Goal 6 of clean water and sanitation in the Sustainable Development Goals (SDGs), improved access to basic sanitation requires implementation of sustainable technological solutions. The world spends the required amount of money on sanitation but inappropriately, there is need for appropriate technologies to achieve universal access to sanitation (Mara et al. 2010).

Pit latrines which were common in Nepal were gradually replaced by pour flush latrine. Although pour flush (or water seal) latrine is similar to the pit latrine, the main difference is that the pour flush latrine does not have a squatting hole in the floor slab, but a squatting pat with a water seal (WHO 1996). The pit may be below or offset from the shelter. The water requirements for a pour flush latrine are estimated to be between one to three liters for flushing which helps to prevent odors and flies from coming back from the pipe (Tilley et al. 2014). Once the excreta have been flushed into the pit, the liquids will filter into the ground. Some of the solids will decompose and filter into the ground while others remain in the pit. It is suitable technology for different local factors because it can be adjusted to the user's preferences whether they desire a sitting toilet or squatting toilet and whether they use water or paper for anal cleansing (Wafler and Spuhler 2008). Though Nepal's sanitation coverage in terms of toilet establishment such as the pour flush toilet has increased, the attention to the proper waste management is still lacking.

1.3.2. Water, Sanitation and Hygiene (WASH) in Nepal

After 2000, Water Supply and Sanitation Collaborative Council (WSSCC) expanded its work to include advocacy and communications (Jong 2003). It introduced WASH as an umbrella term for water, sanitation and hygiene. Since then, WASH has been broadly adopted in international development circles. Due to their interdependent nature, these three core issues are grouped together to represent a growing sector. For example, without toilets, water sources become contaminated and without clean water, basic hygiene practices are not possible. WASH services provide with water availability and quality, presence of sanitation facilities and availability of soap and water for handwashing (WHO 2015). The provision of WASH in health care facilities serves to prevent from infections and spread of disease, protect staff and patients, and uphold the dignity of vulnerable populations. In Nepal, hygiene and sanitation programs began from the late 1990s (GoN 2011). During the initial years, sanitation was usually combined with water supply projects. Only from the early 2000s, sanitation focused program packages were launched by different agencies with different names, approaches and models. From around 2005, total sanitation approaches were introduced in Nepal to increase Open Defecation Free (ODF) communities, school catchment areas or VDC through Community Led Total Sanitation (CLTS) and School Led Total Sanitation (SLTS) by setting a target of 100% ODF by 2017. Nepal has made huge progress in 20 years in improving water and sanitation (Fig 1.1). Only 6% toilet coverage was found in 1990 which increased to 43% in 2009 with an annual growth rate of 1.9% over the years (GoN 2011). Generally, in rural areas of Nepal, household toilets are being constructed on the basis of low-cost technology. Among them, the common types of the toilet are water seal offset type of single pit latrine, water seal latrine (direct pit type), ventilated improved pit latrine, ecological sanitation latrine and latrine with septic tank and soak pit. The census report showed that 85% of Nepalese households have access to improved drinking water sources in 2011 (CBS 2012) (Fig. 1.1). However, the supply system and water quality still have substantial challenges. Only 25% of the drinking water supply systems have good water quality and functionality. Seventy one percent of households are at the risk of *E. coli* contamination at the source of water, and 82% are at risk from re-contamination at the household level (Heitzinger et al 2015). When the government started the ODF movement in 2011, only 62% of the people lived in an ODF area (UNICEF 2016). In 2017, 68% households used latrines, most of which use nearby rivers or streams as recipient of their untreated wastewater.

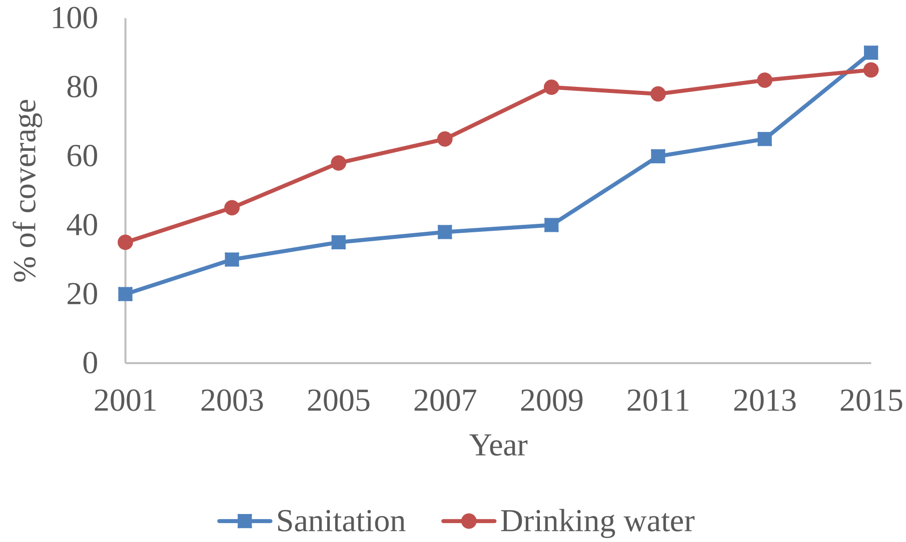

Figure 1.1. Trend of improved drinking water and sanitation coverage in Nepal (Source: Dhimal et al. 2018)

Most of the sanitation intervention programmes in the past have merely focused on providing access to toilet facilities such as promotion of pit latrines or pour flush toilets with poorly designed septic tanks and pits. Not much attention has been given to the type and design of toilets and this has often resulted in negative impacts on the environment such as groundwater pollution from overflow of effluents from septic tanks or from intrusion of fecal matters.

1.3.3. Wastewater management practices in Nepal

Although the progress in drinking water and defecation was achieved, solid waste management (SWM) is one of the major environmental issue in cities of many developing countries, including Nepal (ADB 2013). Urban population growth and economic development increases generation of municipal solid waste. Wastewater, critically exaggerated as a result of anthropogenic influence, was noted to have increased significantly in Nepal since 1970, especially in the urban areas because of high growth rate of urban population, disorganized expansion of infrastructure and services for water supply, defecation and wastewater management (Shukla et al. 2012). Common waste management practice in Nepal involves discharging of untreated sewage, domestic waste, industrial waste and municipal waste into aquatic environments without proper treatment (Jha et al. 2011). Only small number of houses are connected to sanitary wastewater system and therefore most houses discharge the wastewater directly into the rivers and other water bodies (Ellingsen 2010). In the urban centers, sewers are often present, but sewage treatment is lacking (Shrestha et al. 2001). Only 12% of urban households, mainly in Kathmandu Valley are connected to the sewer system (WaterAid 2008). In other cities also, the wastewater even containing very high pollutants and pathogens is discharged into the nearby rivers or water streams. Sewage, the subset of wastewater contaminated with feces or urine, is discharged into water resources, which are then turned into open sewers. Due to unplanned urbanization and lack of basic sanitation facilities, water stream and rivers contain harmful materials including biodegradable organic matter, toxic substances, pathogens and chemicals. Major rivers flowing via Kathmandu Valley are deeply polluted and consequently infected by a variety of pathogens (Haramoto et al. 2011).

In Nepal, the practice of wastewater irrigation has been old tradition and intricately linked to culture and livelihood system of the people in Kathmandu Valley. In Kathmandu Valley, in the agricultural land located within the city centers and in the urban fringes, the farmers are known to practice wastewater irrigation in significantly larger areas (Rutkowski 2004). The practice of wastewater management is also strongly linked to tradition of recovery of nutrients in wastewater for agricultural application (Shrestha 2011). The practice of collecting wastewater in traditional Newar households in Kathmandu Valley is provided in Box 1.1.

Box 1.1

Traditional Wastewater Collection and Management in Traditional Newar Settlements in Kathmandu Valley

In traditional Newar houses, a traditional sink, locally called Dhow Pwo is generally made in the kitchen for the disposal of wastewater produced in cooking and hand washing and mouth rinsing. This traditional sink consists of bowl shaped burnt clay with narrow open burnt clay pipe called Chee Dha, conveying wastewater to a multipurpose wastewater collection pit known as Saagah (Saa in Newari means manure and ga means pitm thus Saagah stands for pit excavated for the collection of wastewater preparation of compost manure). The wastewater collection pit or Saagah is generally found developed on an open space at the backyard of the house where solid and liquid wastes generated in the house are dumped for composting.

There is also practice of making a common saagah in the courtyard. Traditional Newar settlements generally involve clustered housing stem with a courtyard at the middle which is a common open space shared by the inhabitants. Wastewater from kitchen, biodegradable wastes and excreta from livestock are all collected and dumped in Saagah for composting. A small outlet made in the Saagah, called Byeku Pwo is connected to an earthern conduit called Nali which drains the wastewater to the collector drains, collecting wastewater from all the households in neighborhood. The level of outlet in saagah is set at a level that sas soon as the pit is filled with wastewater to the level of the outlet it starts draining into the channel. Once the wastewater comes out of the individual houses through the earthern duct, its subsequent management becomes the community responsibility. The wasterwater thus collected is either conveyed directly to the crop lands for irrigation uses or stored in the system of ponds where from the wastewater is recycled for subsequent irrigation uses. The ponds serve the purpose of oxidation tanks and hence they are part of traditional wastewater treatment system.

The traditional newar households also practice their own sustainable system of solid waste management within the homestead. In traditional houses, an ash collection pit known as Naugah is made on the ground floor inside the house, usually located underneath wooden staircase, where the family members urinate wchich forms a mixture of urine and ash, This mixture gets matured in about three months time and then removed and transferred for use in the farm lands. In the early days an open space was kept close to the settlements for open defecation called Mhola or Gaa for use by the female and male members in the community. This practice of open defecation is almost vanished in most settlements although this was widely in practice prior to 1960s.

(**Source: Shrestha, 2011**)

1.4. Sustainable sanitation

The main objective of sustainable sanitations is to protect and promote human health by providing a clean environment and breaking the cycle of disease (Luthi et al. 2011). To be sustainable, a sanitation system must be economically viable, socially acceptable, and technically and institutionally appropriate, while also protecting the environment and natural resources (Luthi et al. 2011). One way to reach sustainable sanitation is the adoption of ecological sanitation.

1.4.1. Ecological sanitation

Ecological sanitation (Ecosan) is a concept formulated through an approach that integrates various schools of thought such as circular economy, general systems theory, industrial ecology, biomimicry and lifecycle thinking (Langergraber and Muellegger 2005). Ecosan can be characterized as 'Sanitize-and-recycle'. It is the practice of converting human excreta into compost and liquid fertilizer for beneficial reuse of the carbon and nutrients naturally occurring in feces and urine. This system has strong potential to be a sustainable sanitation system if technical, institutional, social and economic aspects are fully taken into consideration. The working strategy and distinguishing feature in ecosan are the concept of source separation, split-stream collection and individual treatment of various wastewater fractions such as urine (yellowwater), fecal matter (brownwater), blackwater (urine + excreta) and greywater (excreta-free household wastewater) (Simha et al. 2017).

1.4.2. Design of ecological sanitation (ecosan) toilet

There are different designs and versions of the technology behind the ecosan toilets and the most relevant designs are presented in this section.

Urine-Diverting Dry Toilet (UDDT)

The principle of UDDT is to collect feces and urine separately through a squatting pan with separate holes for urine, feces and water for anal cleansing (Figure 1.2). Most people in Nepal have the habit of anal cleansing with water. No water is used for flushing and feces are composted in vaults with addition of ash or sawdust used as cover to increase pH (Adhikari 2012).

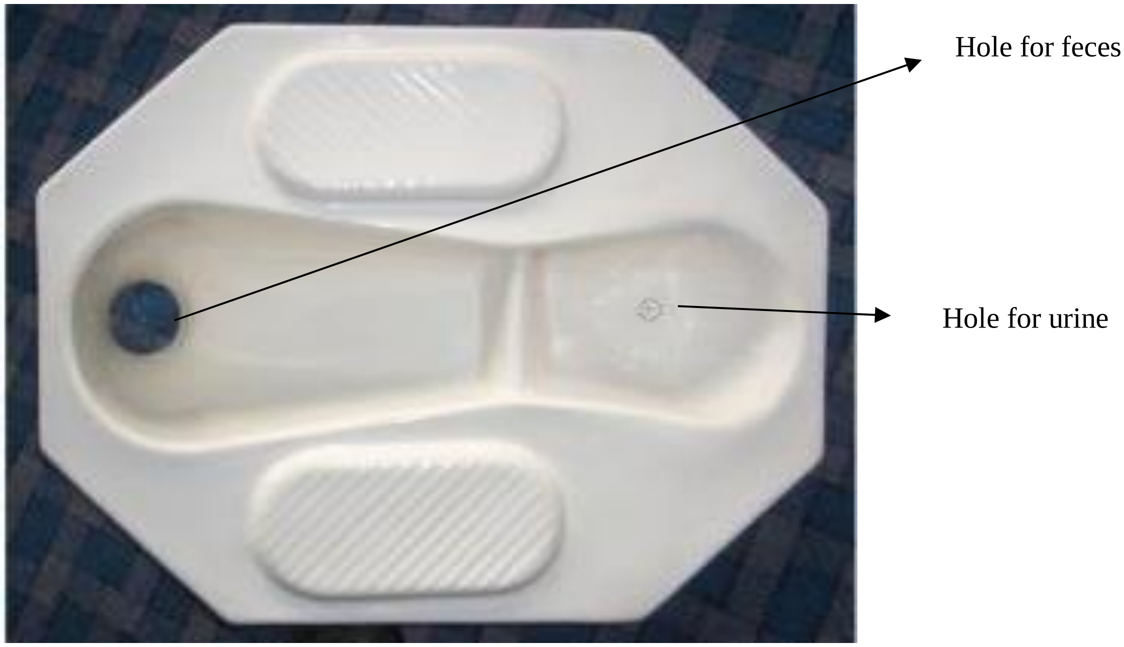

Figure 1.2. UDDT pan with separate hole for urine and feces

The DVUD has two separate watertight chambers of mason or concrete for storage of feces, both with connected ventilation pipes (Figure 1.3). In addition, there is a urine collection vessel and a system for collecting anal cleansing water (Water Aid 2008). The two chambers for collection of feces are constructed above ground to eliminate any groundwater contamination, even though the chambers ought to be watertight (Figure 1.4). The size of each chamber is ca. 0.35 m^3 where the inner wall is plastered with cement or mortar (ENPHO 2006). The vault doors are as large as about 1.82 m x 1.82 m, which can allow easy removal of dry excreta after composting (Water Aid 2008). A polythene pipe with 50 mm in diameter is connected to the pan and diverts the urine to a urine collection tank (ENPHO 2007). The urine collection vessel varies in material from brick masonry to plastic barrels or jerry cans. The most used collection tanks are plastic barrels where the capacity varies from 50 to 100 liters. In the DVUD, a separate hole for anal cleansing water is provided and its wastewater is diverted into a soak pit (Water Aid 2008).

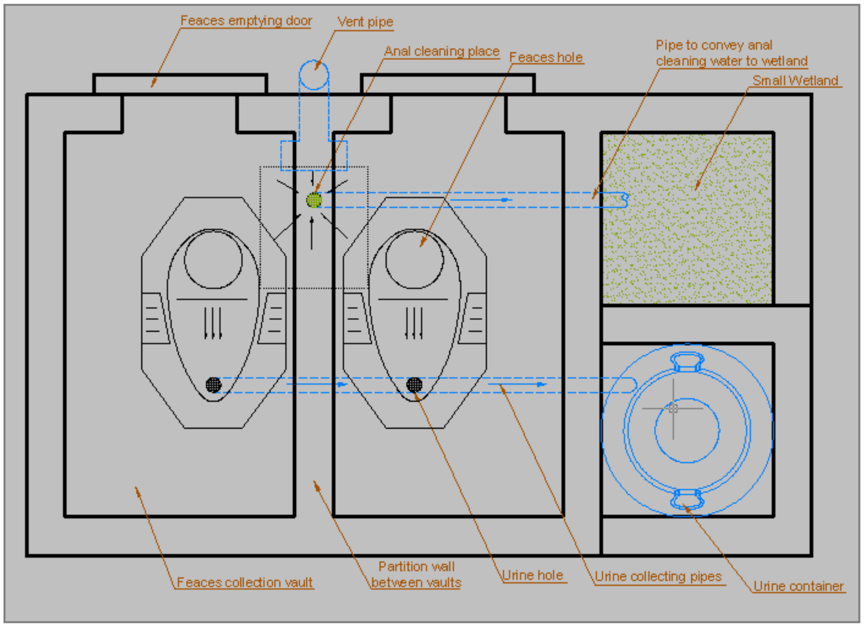

Figure 1.3. Design of DVUD ecosan toilet (ENPHO 2007)

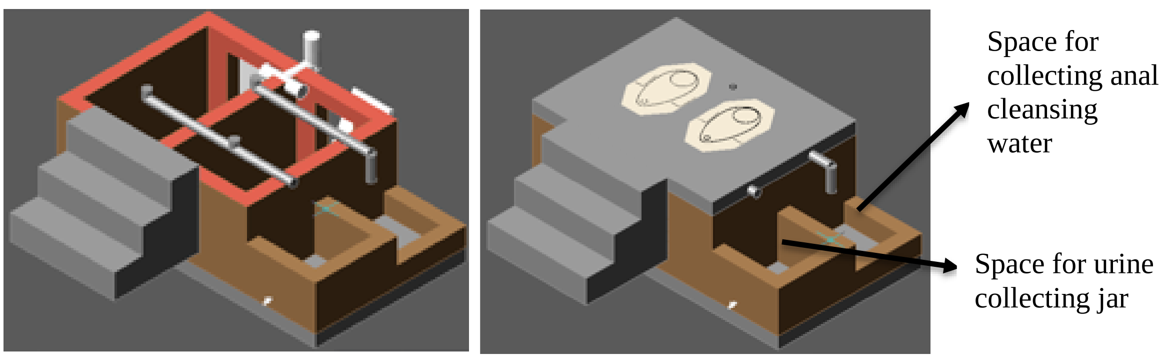

Figure 1.4. Layout of DVUD ecosan toilet (ENPHO 2006)

ecosan toilet in Nepal is modified twin-pit pour flush latrine by adding urine diversion slab (Figure 1.5) or pedestal and a urine collection chamber. The collected urine can be easily used as a nitrogen-rich fertilizer. As liquid leaches from the pit and migrates through the unsaturated soil matrix, pathogenic germs are soaked onto the surface. The advantage of UD twin pit flush toilet is that cleansing water does not need to be diverted but can be flushed down together with the feces (Eawag and Spuhler 2016).

One of the disadvantages with the UDWT is that only urine is collected and stored for use as fertilizer and that the amount of water used makes it difficult to utilize feces after six months of composting (Water Aid 2011). The recommended time for retention of feces is two years. Thus, maximum benefits from the concept of ecosan are not obtained.

Figure 1.5. UDWT in Nepal

1.4.3. Ecosan toilets in Nepal

Environment and Public Health Organization (ENPHO), in association with WaterAid Nepal introduced the urine-diversion dehydrating toilets (Ecosan toilets) in Khokana for the first time in the country during 2002/2003 (ENPHO 2006). The concept of ecosan in its modern sense was first introduced in Nepal in year 2002 by the Department of Water Supply and Sewerage and WHO (ENPHO 2006). Since its introduction in Nepal, there are several modifications in ecosan toilet pans in terms of materials and types in order to suit local culture and ecology and have been constructed in difference parts of the country. There were 36 toilets in 2003 with rapid increment up to 517 toilets in 2006 (ENPHO 2006). Majority of ecosan toilets have been built in the peri-urban areas of Kathmandu valley, with few constructed outside the Kathmandu valley. A total of 2,095 ecosan toilets till 2014 have been installed in 19 districts in different regions showing potential for scaling up in diverse socio-cultural setting and geography (Aryal et al. 2015). As part of the pilot program, ENPHO constructed 10 Ecosan units in Khokana. 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 village in Lalitpur district. The ecosan toilets constructed within Nepal have some variation in design, construction materials and use. Based on the principle of operation some major designs of ecosan toilet are as follows.,

i. *Double vault type*: This is one of the oldest and widespread designs of ecosan toilets in Nepal. This is the modification of Vietnamese double vault dry toilets.

ii. *Double vault solar type*: The difference of this type with double vault type is keeping metal sheet painted with black color as a cover (Figure 1.6). The main principle behind the solar model is that the sheets oriented towards sunlight will be heated and rises the temperature inside the chamber, which would enhance the composting process.

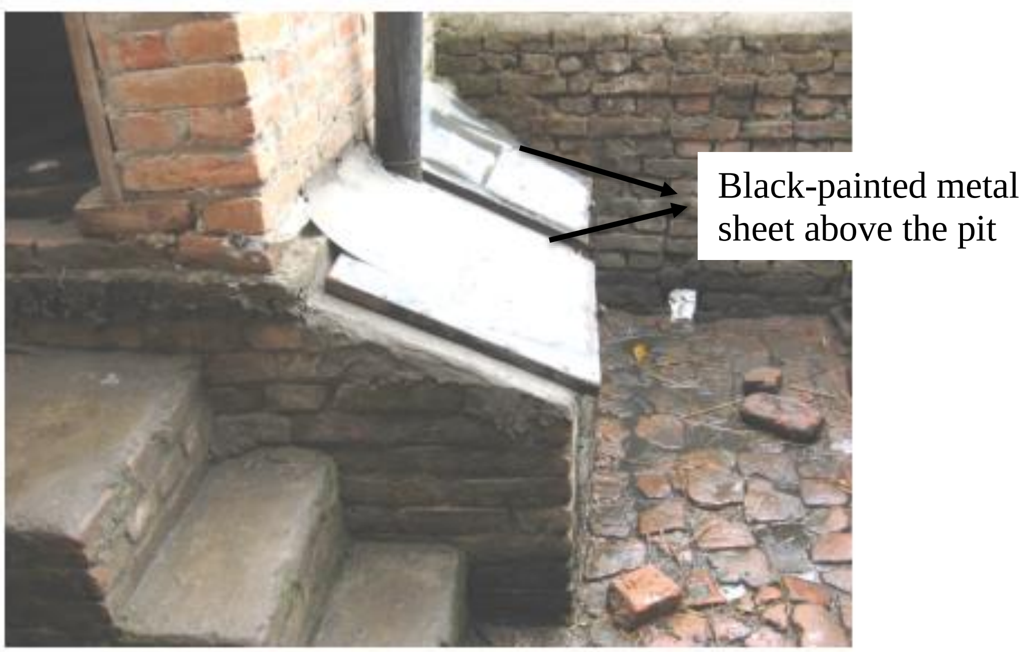

Figure 1.6. Double vault solar model toilet (Source: ENPHO 2006)

iii. Single vault type with replaceable buckets: This model is designed for the indoor type of dry toilet (Figure 1.7). A plastic container mounted on the metal box is placed just below the squatting pan of toilet.

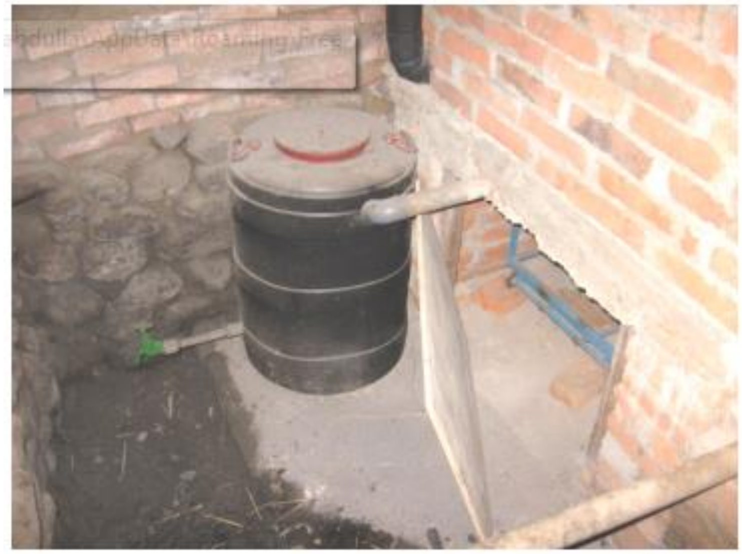

Figure 1.7. Single vault toilet with replaceable bucket (Source: ENPHO 2006)

iv. Urine diversion pour flush type: This system is twin pit pour flush toilet. The difference from pit latrine is that urine is separated and not mixed with the faeces (Figure 1.5).

1.4.4. Advantages and challenges of ecological sanitation

Unlike the conventional linear take on sanitation, ecological sanitation is a closed loop system. It views human excreta as a resource containing nutrients that are vital to agriculture. In this system, urine and feces are stored and processed on site, or if necessary, further processed offsite to remove pathogens. The refined urine and excreta can then be applied to agriculture or ornamental crops as a fertilizer (Winblad et al. 2004). Although ecological sanitation offers users several benefits, getting people to accept and use the technology has proven to be a big challenge (Abraham et al. 2011; Rosenquist 2005). Previous studies have identified several challenges associated with the technology.

i. The installation cost of ecosan toilet is too high for low income households as they must purchase new materials and hire skilled labor charging more (Abraham et al. 2011; Uddin et al. 2012). There is a misconception among potential users that ecosan is more costly and water consuming toilets are the best, which has led them to install water carriage toilets. At present, most ecosan toilets are constructed in poorer communities with financial subsidies as a promotional tool. Unfortunately, this feeds the existing misconception that the ecosan toilets are specifically developed for poorer communities.

ii. Using ecosan toilet is new. There is a need to orient and familiarize outsiders or guests about the use of toilet.

iii. Odor/smell from the ecosan toilet might be due to lack of proper functionality and maintenance of ecosan toilet.

iv. Lack of agricultural land to apply ecosan manure discouraged some community to install ecosan toilet. In addition to this lack of space within people's houses is the constraint.

1.4.5. Success story in Darechowk

In spite of these disadvantages and challenges, Darechowk Village Development Committee (VDC), Chitwan district could be referred as an example of success story of ecosan and can be seen as a motivating factor to spread ecosan technology. Darechowk VDC had altogether 1,665 households with population of 10,712. The author investigated in 2017 that among these households, 901 had slab toilets (pit latrine), 733 had ecosan toilets and the rest did not have permanent toilet. Darechowk VDC had the highest density of ecosan toilets in Nepal (WASH Resource Centre Network Nepal 2013). The VDC has targeted to establish itself as the first ecosan village of the country by constructing ecosan toilet in all the households. To support poor people in constructing ecosan toilets, the VDC provided toilet pans and pipes and the VDC provided 752 households with two bags of cement. SEWA Nepal, a local NCO dedicated to promoting ecosan toilet with support from various national and international organizations, provided with ecosan pan and a pipe to motivate villagers to construct ecosan toilet. The organization also established an Ecosan Resource Centre in the village and initiated campaigns with a logo "Take a Pee, Make a Rupee" to raise awareness on ecosan and the value of urine. In all public toilets in Nepal, people must pay certain amount to use the toilet. In contrast, in this VDC, ecosan wet toilet was constructed for public where those who urinate in this toilet will receive money.

After ecosan toilet was first installed in this VDC in 2006, many households started using urine in their fields. In Ecosan Resource Centre, they make different useable items such as garland, bag, basket using waste and sell to make money (Figure 1.8). Figure 1.9 shows collection and storage of urine for use in field. Some households mentioned that urine and ecosan manure is enough to fertilize their field. Crop produce applied with urine and ecosan manure is tagged as organic vegetables. Recently those organic vegetables are gaining popularity among the villagers and outside of the village also. The villagers also mentioned that not only the fertilizer value of urine, it could be used as a pesticide for killing insects in vegetable and as a drug for snake bite to minimize its poison. Since this village lies in the roadside of highway, customers who recognize the crop produce in this village come to buy while passing through the highway. Not only in households' level, Siddhakamana Primary School in this VDC with 41 students installed wet ecosan toilet to collect urine (Figure 1.10). It was reported from the interview that about 5 liter of urine is collected in about 15 days. They sell that collected urine to the needy villagers and make some income to run their school. Similarly, in the VDC level, resource allocation program is implemented to promote ecosan toilet in the village.

Figure 1.8. Ecosan resource centre at Darechowk VDC

Figure 1.9 Urine collection by ecosan users at Darechowk VDC

Figure 1.10. Wet ecosan toilet in the primary school and urine collection can outside the toilet

National daily newspaper published news report on the Darechowk sanitation activities and Darechowk ODF declaration program and that report was also telecasted on national television program on 16 July 2010. The news clip with a title “Urine solution proves useful” was published in The Rising Nepal on 21 July 2010 (Box 1.2). This success story concludes that if there is proper guidance and cooperation among the households, it is possible to disseminate new technology into the village. The idea and benefits of the new technology should be advocated by the seniors or the renowned person of the village. Without the participation of such person, the project could not run for longer period of time. The village now is recognized as the pioneer of ecosan and recycling in the whole village and gaining popularity being an example of such activities.

Box 1.2

Urine solution proves useful

By a Staff Reporter

Chitwan, July 21

Meena Pokharel, a local women of Darechowk-7, Chitwan district has increased the yield of her vegetable production by applying urine solution in her cultivars. She has been sprinkling her crops with diluted urine solution for last five months. According to her, she learnt about the use of urine from a training programme that was organized in her VDC about few months ago. She was not familiar to the nutritive value of urine before that training, she said. These days, anyone visiting to her place can see more than 100 urine filled bottles scattered near her toilet. She informed that she collects and stores urine for 7/8 days before applying it on the crops. The stored urine is diluted by adding water three times the volume of urine, she added. She is more satisfied from this practice because it has increased agricultural productivity and helped her reducing the expenditure, which she would have to spend on buying chemical fertilizer. Pokharel is not only the woman in her community, who is practiving the method. Urine is collected and applied on cultivars as manure at all households in her community.

An EcoSan Resource Centre has been recently established in their community which has also motivated tham in practicing such as effective method to increase agricultural productivity. The resource centre pays one rupees for a pee, which has made the people here enthusiastic to learn and understand the value of urine Pokharel said. The EcoSan Resource Centre was established by a local organization. The SEWA Nepal with suppor of Environment and Public Health Organizaiton (ENPHO) with the purpose to promote ecosan toilet in Darechowk VDC. The resource centre has aimed to establish Darechowk of Nepal, said Shreerendra Pokharel, coordinator at EcoSan Resource Centre. It also proveds training on ecosan toilet and its uses to the villagers. To facilitate the visitors in learning about ecosan toilet, the models of different types of ecosan toilets have been demonstrated at the centre. Various informative wall posters and other materials have been displayed to provide additional information to the villagers. The resource centre has also put a notice to 'Take a Pee and Get one Rupee' to introduce and sensitise people to the value of urine and motivate them for utilizing it.

Source: Media exposure visit to Darechowk VDC.

1.5. Human waste reuse potential

1.5.1. Historical background

Human excreta have traditionally been used for crop fertilization in many countries (Schonning 2001). In Japan, the recycling of urine and feces was introduced in the 12th century and in China, human and animal excreta have been composted for thousands of years (Winblad and Kilama 1978). In Nepal, the tradition of use of human urine and feces is not new in some Newar and Sherpa communities.

1.5.2. Nutrients in human waste

Human urine contains largest proportion of plant nutrients in the household wastewater fractions and represents only 1% of the total volume of wastewater. In undiluted fresh human urine, the elements that were found are nitrogen (N) 7-9 g L^{-1}, phosphorus (P) 0.20-0.21 g L^{-1}, potassium (K) 0.9-1.1 g L^{-1}, sulphur (S) 0.1-0.22 g L^{-1}, calcium (Ca) 13-16 mg L^{-1} and magnesium (Mg) 1.5-1.6 mg L^{-1}. Human feces consist of about 75% of moisture by weight and 25% of solid material, mainly organic matter (Rose et al. 2015). C is a major constituent of the dried solid material and constitute about 50%. N, P and K content in feces are 5-7%, 3-5.4% and 1-2.5% of dried solids respectively (Rose et al. 2015).

Urine contains few disease-producing organisms, while faeces may contain many. Storing undiluted urine for one month will render urine safe for use in agriculture. Increase in storage time, temperature, dryness, pH, ultraviolet radiation, competing natural soil organisms could kill off fecal disease organisms, making it safe for use in agriculture (Winblad and Simpson-Hebert 2004). Urine and feces are fertilizer of high quality and with low levels of contaminants such as heavy metals. The best fertilizing effect is fully achieved if they are used in combination with each other, but not necessarily used in the same year in the same area (Jonsson et al. 2004). Urine can be applied in a variety of ways (Winblad and Simpson-Hebert 2004)

- Undiluted before or at sowing/planting or to the young plant.
- Urine can be applied in one large dose or several smaller ones during the cropping season.
- Diluted urine can be added to the soil where vegetables (and plants like maize) are growing once a week or even twice or three times a week, provided that the plants are watered frequently at other times. This addition of urine makes a big difference to the growth of plants.

- Undiluted urine can be added to the soil beds before planting. Bacteria in the soil change the urea into nitrate which can be used by the plants.
- Concentrated fermented urine can be applied to beds of dried leaf mold, as a medium for growing vegetables and ornamental plants.

1.6. Overall objective and research gaps

As mentioned in Section 1.2, Nepal is facing a major challenge for sustaining agricultural production due to nutrient depletion in soil. In rural areas of developing countries like Nepal farmers rely upon agriculture for their livelihood. Decreasing soil quality, high prices of chemical fertilizers and untimely delivery are the common problems faced by the rural population. These problems are associated especially with poor infrastructure like transportation and storage facilities. In addition to this, as described in Section 1.3, open defecation and unimproved sanitation facilities lead to the death of people in countries like Nepal. Waterborne sanitation is considered as improved sanitation systems, but several challenges made them unsustainable. To overcome these problems, WASH service was provided for water availability and sanitation facilities as mentioned in Section 1.3.2. Waste management is the problem need to be solved as mentioned in Section 1.3.3. After the declaration of ODF areas by the government, majority of the households constructed toilet in their houses. But, due to the unmanaged disposal of sewage and drainage, the environmental pollution including river pollution is increasing both in rural and urban areas.

Considering the above-mentioned situations, the technology that could generate fertilizer from the toilet has the potential to improve the livelihood in the rural areas of Nepal. Thus, the overall objective of this study was to examine its potential by filling the research gaps depicted below.

1. Several studies have been conducted on the urine application as a fertilizer but the feasibility of combined use of human urine and ecosan manure for vegetable farming are limited and its potential as a fertilizer is still unclear.

2. There is limited information about the attitudes and perception of ecosan users towards ecological sanitation. Similarly, limited studies on socio-technological perspective on farmers and consumer attitudes over the design and use of urine diverting toilets have been conducted till date. The perception and attitude of users will offer useful information about the drawbacks of the technology that might help to improve in future. However, the studies to understand ecosan users' perceptions after installation of ecosan toilet is unclear. Similarly, the perception and attitude of non-ecosan users towards ecosan is necessary to understand the target group to disseminate the ecosan toilet in future.

3. Hygiene and health risks are frequently mentioned as a key barrier preventing population from adopting ecosan technology. Sanitation researchers have recommended at least 6 months storage period of excreta before use as fertilizer, use of ash as an additive to accelerate decomposition and remove moisture content. Although most of the ecosan users think that urine and ecosan manure is safe to use as fertilizer because of its long use history, the risk of fecal microorganisms on ecosan users is unclear. It is necessary to evaluate the risk of fecal microorganisms.

1.7. Specific research objectives and dissertation organization

The specific research objectives were:

- Evaluate how effective the combined use of human urine and ecosan manure to increase productivity of vegetable
- Examine the effect of human urine and ecosan manure on soil physicochemical properties
- Examine the perception of people on use of human urine and ecosan manure on agriculture

- Examine the hygiene of human urine and ecosan manure to evaluate the risk of transmission of bacteria on human health

This thesis has five chapters. Chapter one provides background of ecological sanitation, the advantages of human urine and ecosan manure, challenges associated with such technology. Chapter two describes the study area. The aim of chapter three is to evaluate the effects of human urine and ecosan manure on crop production and soil properties. Chapter four examines the perception and attitudes of ecosan and non-ecosan users to understand the positive and negative sides of ecosan through questionnaire survey. This chapter also tries to evaluate the risk of *E. coli* transmission through ecosan manure. Due to the limitation of time and resource only *E. coli* tests was performed as an indicator of fecal microorganisms. Chapter five summarizes the key findings of the thesis and illustrates future research scope.

References

Abraham, B., Kakumbi, G. M., Alam, M.M. and Von Muench, E. 2011. Alternative solutions for challenging environments: *A look at UNICEF- assisted ecosan projects worldwide*. http://www.wedc.iboro.ac.uk/resources/conference/35/Abraham-B-1220.pdf. (Accessed November 10, 2019)

ADS (Agriculture Development Strategy) 2014. Ministry of Agriculture Development, Singhadurbar, Kathmandu, Nepal.

CBS (Central Bureau of Statistics) 2012. *National population and housing census.* Government of Nepal, Kathmandu, Nepal.

Ellingsen, M. 2010. Sustainability of a decentralized wastewater treatment system in Kathmandu Valley, Nepal- Technical and social challenges, Master Thesis, Norwegian University of Life Sciences.

GoN (Government of Nepal) 2011. *Sanitation and hygiene master plan*. Steering committee for National sanitation action.

Haq, G. and Cambridge, H. 2012. Exploiting the co-benefits of ecological sanitation. *Current Opinion in Environmental Sustainability*. 4: 431-435.

Haramoto, E., Yamada, K. and Nishida, K. 2011. Prevalence of protozoa, viruses, coliphages and indicator bacteria in groundwater and river water in the Kathmandu Valley, Nepal. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 105: 711-716.

Heitzinger, K., Rocha, C. A., Quick, R.E., Montana, S.M., Tilley Jr, D.H., Mick, C.N., Carrasco, A.J., Cabrera, R.M. and Hawes, S.E. 2015. Improved but not necessarily safe: An assessment of fecal contamination of household drinking water in rural Peru. *The American Society of Tropical Medicine and Hygiene*. 93(3): 501-508. [doi:10.4269/ajtmh.14-0802].

Jha, A. K., Li, J., Pradhan, S. and Hoover, M. 2011. Current practices of solid waste management and a sustainable perspective in Kathmandu Valley, Nepal. *Waste Management.* 31: 2647-2651.

Jong, D.D. 2003. *Advocacy for water, environmental sanitation and hygiene. Thematic overview paper*. IRC International Water and Sanitation Centre https://www.ircwash.org/sites/default/files/Jong-2003-Advocacy.pdf (Accessed July 25, 2020).

Jonsson, H., Richert-Stinzing, A., Vinneras, B. and Salomon, E. 2004. Guidelines on the Use of Urine and Faeces in Crop Production. *EcoSanRes Publication Series Report*. 1-35 Stockholm Environment Institute, Sweden.

Langergraber, G. and Muellegger, E. 2005. Ecological sanitation- a way to solve global sanitation problems? *Environ Int*. 31: 433-444.

Luthi, C., Panesar, A., Schutze, T., Norstrom, A., McConville, J. and Parkinson, J. et al. 2011. Sustainable sanitation in cities: a framework for action. *Sustainable Sanitation Alliance* (SUSANA), International Forum of Urbanism (IFoU), Papiroz Publishing House.

Media exposure visit to Darechowk VDC. 2010. Media Report.

Water, Sanitation and Hygiene Resource Centre Network Nepal. http://www.wash-rcnn.net.np/vdc-with-the-highest-density-of-ecosan-toilet-declared-odf-area (Accessed December 5, 2019).

NDHS (Nepal Demographic and Health survey) 2011. *Population Division, Ministry of Health and Population*, Government of Nepal. Kathmandu. [doi:10.1007/978-94-6091-391-4_15].

Panta, H.K. 2018. Supply chain of subsidized chemical fertilizers in Nepal. *J. Inst. Agric. Anim. Sci*. 35: 9-20.

Peal, A., Evans, B., Blackett, I., Hawkins, P. and Heym, C. 2014. Fecal sludge management (FSM): analytical tools for assessing FSM in cities. *Journal of Water, Sanitation and Hygiene for Development*. 4(3): 371-383.

Rosenquist, L.E.D. 2005. A psychosocial analysis of the human-sanitation nexus. *Journal of Environmental Psychology*. 25(3): 335-346. [doi: 10.1016/j.jenvp.2005.07.003].

Ruthkowsi, T. 2004. Study of Wastewater Irrigation in Kathmandu Valley. *Water Nepal*. 11(2): 63-71.

Shrestha, J. 2011. Traditional practices and knowledge system in Integrated Wastewater Management in Kathmandu Valley. Unpublished M.Sc. Thesis, Pokhara University, Nepal.

Shrestha, R. R., Haberl, R., Laber, J., Manandhar, R. and Mader, J. 2001. Application of constructed wetlands for wastewater treatment in Nepal. *Water Sci. Technol*. 44 (11-12): 381-386.

Shukla, A., Timilsina, U. R. and Jha, B. C. 2012. *Wastewater production, treatment and use in Nepal.* http://www.ais.unwater.org/ais/pluginfile.php/232/mod_page/content/127/Nepal_Country paper.pdf. (Accessed November 19, 2019)

Simha, P., Lalander, C., Vinneras, B. and Ganesapillai, M. 2017. Farmer attitudes and perceptions to the reuse of fertilizer products from resource-oriented sanitation systems – The case of Vellore, South India. *Science of the Total Environment* 581-582: 885-896.

Tripathi, B.P. 2019. Sustainable soil fertility management practices in Nepal. *Acta Scientific Agriculture*. 3(4): 112-113.

Uddin, S., Muhandiki, V.S., Fukuda, J., Nakamura, M. and Sakai, A. 2012. Assessment of social acceptance and scope of scaling up urine diversion dehydration toilets in Kenya. *Journal of Water Sanitation and Hygiene for Development*. 2(3): 182-189. [doi:10.2166/washdev.2012.078].

WaterAid. 2008. *Decentralized wastewater management using constructed wetlands in Nepal*. WaterAid, Kathmandu, Nepal.

WHO (World Health Organization)/ UNICEF (United Nations International Children Education Fund). 2015. *Water, sanitation and hygiene in health care facilities*: Status in low- and middle-income countries and way forward.

Winblad, U. and Simpson-Hebert, M. 2004. Revised and enlarged. *Ecological Sanitation*. Stockholm Environment Institute.

Chapter 2. Study sites

2.1. Location of study sites

In Nepal, officially, Federal Democratic Republic of Nepal, agriculture is the mainstay of around 60% of the population and contributes 32% of the country's gross domestic product GDP (World Bank 2016a). The country is divided into 77 districts in 7 provinces.

The research was carried out in two areas of Central Nepal; Palung Village Development Committee (VDC), Makawanpur district and Gundu VDC, Bhaktapur district (Figure 2.1).

2.2. Makawanpur district

The Makawanpur district is located on the south of Kathmandu, the Capital city of Nepal and lies in Province 3 (Figure 2.1). It is situated within latitude 27º10'N – 27º40'N and longitude 84º41'E – 85º31'E (DTMP 2012). It covers an area of 2,418 km^2 hill and plain lands. The district is surrounded by Kathmandu and Dhading district at north, Chitwan district at west, Lalitpur, Kavre and Sindhuli districts at east and Bara, Parsa and Rautahat districts in the south (DTMP 2012). The maximum temperature rises up to 30ºC and minimum temperature falls as low as -1.6ºC (DTMP 2012). The mean annual precipitation varies from 1971 mm to 2331 mm, approximately 80% of which falls between June to September (DTMP 2012). The majority of soils is classified as Dystric Cambisols (FAO 1997). It had a population of 420,477 in 2011 comprising 206,664 males and 213,812 females (CBS 2011). Approximately 83% of the population mostly depends on agriculture (DTMP 2012, 16). The major agricultural product in this district is cereal crops including paddy, maize and millet. Fruits and vegetables are the other main agricultural products in this district for domestic use and for export to other districts, particularly to Kathmandu. Subsistence farming is the main livelihood activity for the majority of the population. Figures 2.2 and 2.3 show the landscape of study area and terrace farming system which is common in the hilly areas of Nepal.

The major occupation in the Makawanpur district is agriculture. Economically active population is 82.7% in total who depend mostly on agriculture. But this has shifted with high youth force migration due to social conflict and unemployment problem. About 52.83% of people are being involved in agriculture as subsistence livelihood and 30.66% in service and 16.51% in others. It has 239,076 ha total hands out of which 167,453 ha is forest land, 40,842 ha is cultivated land, 18,815 ha is non cultivated land, 3,136 ha is pastureland and 8,830 ha are other land. Major agriculture production of the district is cereal crops (paddy, maize and millet). Paddy production, fruit and vegetable are the main agricultural production in this district for the domestic use and exporting to other districts, particularly in Kathmandu.

The climate of Makawanpur district ranges from lower tropical to temperate. The physiography of the southern side is fertile plains, while the northern side is hills. It comprises four climatic zones: lower tropical (below 300 m), upper tropical (300 – 1000 m), subtropical (1000 – 2000 m), and temperate (2000 – 3000 m).

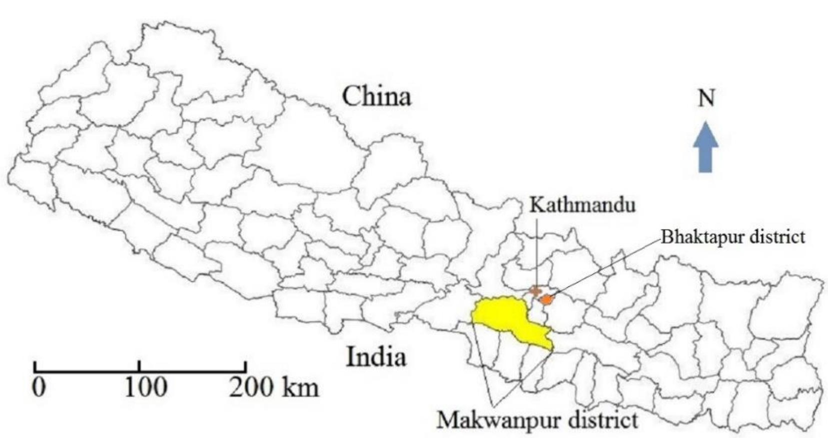

Figure 2.1. Map of Nepal showing study sites (Makawanpur district and Bhaktapur district)

Figure 2.2. Landscape of Palung VDC Figure 2.3. Terrace farming system in Palung

2.3. Bhaktapur district

Bhaktapur is the smallest district of Nepal, which occupies an area of 119 km^2, and lies in Province 3 (Figure 2.1). It is situated within latitude 27º36'N – 27º44'N and longitude 85º21'E –85º32'E. The altitude ranges from 1331 m to 2191 m above the sea level. The entire eastern region and nearly half of the northern and southern region of the district is covered with hills, which are part of the Mahabharata series. The annual average temperature is 17.9ºC and the average rainfall is 1583 mm. The district is surrounded by Kathmandu (Capital city of Nepal) in the west and North. The population of the district is 304,651 (CBS, 2012) with an annual population growth rate of 2.96%. About 54% of the district area belongs to urban areas due to the access of road, transportation, health, education facilities and due to boundary with Kathmandu.

Figure 2.4 shows the landscape of Bhaktapur district. The district is an ancient agrarian town with a predominantly Newar population. Agriculture is the primary occupation of the households in the district and is considered as the pocket areas for wheat crops, commercial vegetable production, cereal production, and organic agriculture. Livestock is one of the primary sources of income for the rural areas in the district and is associated with agricultural farm.

Figure 2.4. Landscape of study site in Bhaktapur district

References

CBS (Central Bureau of Statistics) 2012. *National population and housing census*, Government of Nepal, Kathmandu, Nepal.

DTMP (District Transport Master Plan) 2012. *Main report,* Makawanpur District. Volume I Main report.

FAO (Food and Agriculture Organization) 1977. *Soil map of the world*. Volume VII Southern Asia UNESCO, Paris.

Chapter 3. Effects of human urine and ecosan manure on plant growth and soil properties in Central Nepal

3.1. Introduction

Global food security is recognized as one of the major challenges for sustaining the 9 billion people projected to live on Earth by 2050. In a sustainable society, the production of food must be based on returning plant nutrients to the soil to feed the growing population. The challenge of finding new options to improve soil fertility for sustainable crop production has resulted in the option of recycling waste materials, including human urine and excreta. Ecological sanitation (ecosan) which is defined as a water conserving and nutrient recycling system for the use of human urine and excreta in agriculture and is seen as a potential strategy to both enhance soil fertility and to address sanitation challenges (Langergraber and Muellegger 2005, 441). The urine and decomposed excreta collected from ecosan toilet is used as a fertilizer in agriculture. The majority of the Nepalese population has traditionally practiced open defecation (Water Aid 2004, 2). Since 2011, the toilet coverage in urban areas is 78% against the rural coverage of only 37% with annual growth rate of sanitation increment at 1.9% (SHMP 2011, 4). The trend analysis showed that if the present trend is continued, the toilet coverage will be only 80% against the national target of universal coverage in 2017 (SHMP 2011, 4). This somehow added a burden on households to construct a toilet.

The high price of chemical fertilizer and its low or untimely availability are challenges for farmers. The use of human waste (urine and excreta) as a fertilizer should be explored to enhance productivity and to address the problems mentioned above. Human urine is a valuable source of nutrients that has been used since ancient times to enhance the growth of plants, notably leafy vegetables (Jonsson et al. 2004, 17), and is universally available at no cost. Every day, human beings produce urine, which contains some nutrients that are needed for plant growth (Adeoluwa and Cofie 2012, 292-93). Each year, one person produces 500 kg of urine and 50 kg of excreta. The amount of excreted organic matter in faeces in many countries seems to be in the range of 10 kg (Sweden in addition to 8 kg toilet paper) to 20 kg (China). In both countries, excreta contain 10 kg of organic matter per person per year after being dried (Jonsson et al. 2004, 28). These amounts depend on the person's body weight, water intake, and diet characteristics, especially protein content, and on the climate (Heinonen-Tanski and Van wijk-Sijbesma 2005, 404).

The nutrients in urine are in ionic form, and their plant availability has been found to be comparable with that in chemical fertilizers (Kirchmann and Pettersson 1995, 152-53; Yogeeshappa and Srinivasamurthy 2017, 1599-1600). The fertilizer value of human urine and its use as a crop nutrient source has received greater attention from researchers in recent times. Human excreta have been used frequently as night soils in some areas of the world such as China, Vietnam and Japan for agricultural production (Heinonen-Tanski and Wijk-Sijbesma 2005, 404). Different sources of urine increase soil pH, total N, organic carbon, available phosphorus and exchangeable cations of soil as well as maize grain yield (Nwite 2015, 35). The experiment was conducted in the tunnel house in South Africa by Kutu (2010) with seven human faeces N : urine N combinations (1 : 7 to 7 : 1) each supplying 200 kg N ha^{-1}. The study revealed highest dry yield in 1:7 human faeces to urine N combination and comparable yield in 1 : 1.2 and sole urine application. The study also revealed that highest N uptake was in sole urine and 1:7 human faeces to urine combination and highest P uptake was in 7 : 1 human faeces to urine combination suggesting that application of human faeces and urine, either separately or in combination, results in increased fresh and dry matter yields of spinach. A study conducted in Ghana with combined urine and poultry droppings suggested urine as a potential source of inputs to use for vegetable production and to increase soil fertility (Amoah 2017, 11). Similarly, the study conducted by Guzha (2005, 844) concluded that the use of urine and excreta led to better maize production than that with urine alone in Zimbabwe. Pradhan et al. (2009) conducted an experiment in tomato cultivation in a greenhouse to evaluate the efficacy of mineral fertilizer (NPK 9-6-17.7 g per plant), mixture of urine and wood ash (81 ml + 10.7 g per plant), only urine (81 ml per plant) and control (no fertilization). The result revealed that the urine fertilized tomato plants produced equal amount of tomato as mineral fertilized plants and 4.2 times more fruits than non-fertilized plants. Also, experimental trials in a skyloo humus (soil mixed with faeces and ash) with different urine application rate (water urine ratio of 3 : 1, 5 : 1, 10 : 1) were conducted for maize in Zimbabwe. The result showed 6 to 35 times increase in yields of maize when fed with urine than with that of water only as a result of the addition of urine as a liquid fertilizer (Morgan 2003) suggesting humus as an excellent medium for growing plants. The study was also carried out in Nepal by Upreti et al (2004) to find out the appropriate urine dose and time of application. In the study potato was fertilized with N : P : K at the rate of 150 : 100 : 30 kg ha^{-1}. The result suggested that 2-3 splits urine application in addition with phosphorus and potassium fertilizer from other sources are efficient plant nutrients and can have comparable yield as that of chemical fertilizer.

However, most of these previous studies focused only on use of human urine in agriculture and a few limited studies have dealt with the usage of human feces in crop production. Even less studies dealt with its impact on soil properties. Kutu (2010) used the human feces obtained from the urine diverting toilets for the agronomic experiment in South Africa, where the feces were dried and mixed with wood ash before using. Moya (2017) explained positive effect of human excreta on crops in which human excreta obtained from dry toilets were anaerobically digested before using in field. Studies on the feasibility of combined urine and feces for vegetable production are still unclear.

Moreover, the agricultural practices are fundamentally influenced by social and cultural dimensions and is influences farmers' attitudes and choices (Andersson 2014). In ancient days, farmers in Nepal practicing vegetable production with urine and excreta would empty pit latrines onto the farmland. Gradually, the farmers shifted towards constructing toilets with septic tanks and started disposing of toilet waste into nearby rivers or drainage rather than using it on their farm. Hence, the possibility of the systematic use of urine and ecosan manure from ecosan toilets should be explored to enhance the productivity of rural agriculture and to maintain the cleanliness of the rural environment. Hence, this research was conducted in Central Nepal with the objective of evaluating the effects of human urine and ecosan manure on cauliflower production, nutrient uptake and soil chemical characteristics. Because there is no clear definition of ecosan manure yet, the ecosan manure was defined in this study as manure obtained from ecosan toilet in which ash is added to feces after every defecation.

3.2. Materials and methods

3.2.1. Study area

The study area was carried out in Palung Village Development Committee (VDC) of Makawanpur district. The details of the study area are described above in Chapter 2. Angare, Bhot Khoriya and Deurali was selected from the Palung VDC to conduct field experiments. These three villages are located at 1822 m, 1981 m, and 2125 m above sea level respectively. Based on the soil particle distribution, the soil texture was classified as sandy loam, loam, and silty loam for Angare, Bhot Khoriya and Deurali respectively.

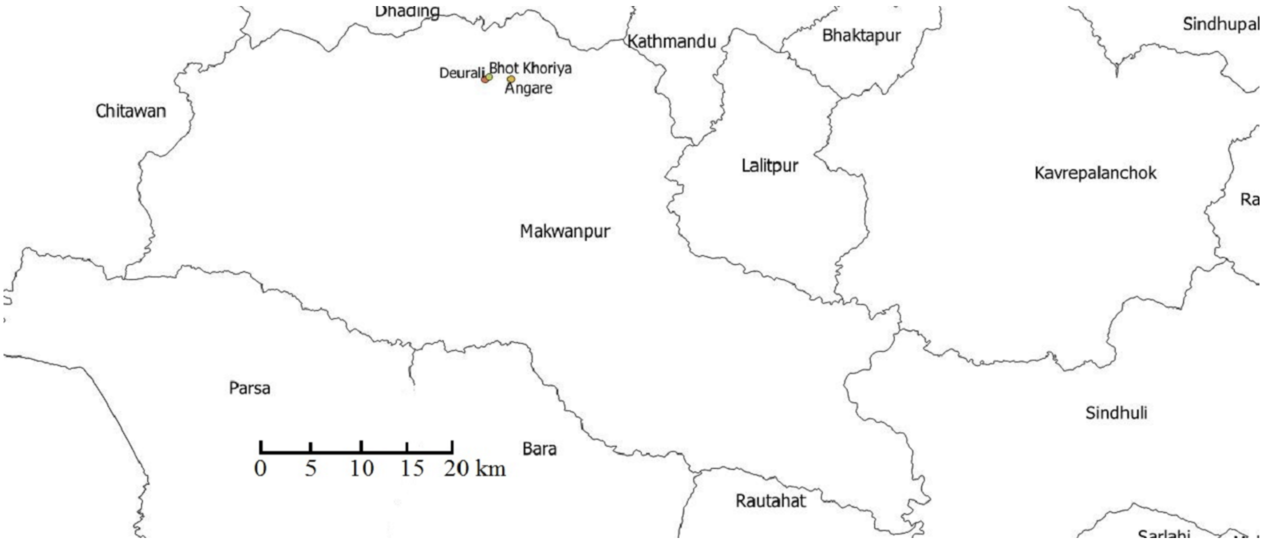

Figure 3.1. Map of Makawanpur district showing experimental sites in Palung VDC (Angare, Bhot Khoriya and Deurali)

3.2.2. Experimental site and preparation of urine and ecosan manure

Five ecosan toilets were constructed for five households in the Palung VDC in 2016 as a demonstration project. Among them, at one household farm in each of the three villages (Angare, Bhot Khoriya and Deurali), a field experiment was carried out from June to September 2017 and July to October 2018 during the rainy seasons (Figure 3.1). The field experiment was conducted for the three households with differences in household economy and altitude. Angare, Bhot Khoriya and Deurali are located at 1822 m, 1981 m and 2125 m above sea level, respectively. The average soil temperatures at depths of 0-5 cm during the cropping season (9 July – 3 September) in 2018 at Bhot Khoriya and Deurali were 21.3°C and 21.5°C, respectively, and did not show large differences among the sites. Rainfall at Bhot Khoriya during the cropping season in 2018 was 973 mm, and rainfall could be assumed to be similar among the sites because they were located within 3 km of each other. Daily rainfall at Bhot Khoriya was measured using a rain gauge after each rainfall event and was presented in Figure 3.2.

Moreover, the rainfall received at the sites is sufficient to ensure the normal growth of cauliflower. Although the sites are located at different altitudes, the farming practice was similar in all sites. The household economic status in Angare was observed to be the poorest among the three households with less technical knowledge about farming. The highest financial status was observed in the household of Deurali, which had more technical knowledge about farming and could afford chemical fertilizers and pesticides as needed. The experimental sites for 2017 are different from those for 2018 in order to avoid residual effects of the treatment and to minimize the cauliflower clubroot disease, which was common in most farms in the village. The soils of the experimental sites were classified as Dystric Cambisols (FAO 1997). Based on the soil particle distribution, the soil texture was classified as sandy loam, loam, and silty loam for Angare, Bhot Khoriya, and Deurali, respectively. The basic physicochemical properties of the soils where field experiments were conducted in 2017 and 2018 are presented in Table 3.1. The urine needed for the experiment was collected from the ecosan toilet of each household. The urine collected in 100 L jar was used for the experiment and is considered to be the fresh urine. The ecosan manure from the ecosan toilets of these households was not ready to be used. Therefore, the necessary amount of ecosan manure for the experiment was collected from an ecosan toilet from another village (Gundu village of Bhaktapur district). The ecosan manure used in this experiment is the human faeces collected from the ecosan toilet. As a rule of the ecosan toilet, it was confirmed from the households that ash was sprinkled after every defecation and the excreta was ready to be used as a fertilizer with more than 6 months storage time. The urine and ecosan manure samples were collected for chemical analysis. Total nitrogen (TN) in the urine was determined by combustion catalytic oxidation method using a total organic carbon analyzer (Shimadzu TOC-LCSH). Total phosphorus (TP) was determined calorimetrically using a spectrophotometer, and total potassium (TK) was determined using a flame photometer (AA-700, Shimadzu, Japan). TN in the ecosan manure was measured using ground samples using a high-temperature combustion method with an EA IsoLink CN analyzer. Dried ground ecosan manure samples were digested using a ternary mixture ($HClO_4$, HNO_3, H_2SO_4) for the determination of TP and TK as described by Effebi et al. (2017). TP was determined after color development following the ascorbic acid method. The intensity of the lines was evaluated by a detector (880 nm) in spectrophotometer (UVmini-1240, Shimadzu, Japan). TK was analyzed using atomic absorption spectroscopy (AA-700, Shimadzu, Japan). The N, P, and K contents of urine (calculated based on wet weight (g kg^{-1})) and ecosan manure (calculated based on dry weight (g kg^{-1})) used during the field experiment are listed in Table 3.2. The variation in N, P, and K in the urine from three households was due to variation in feeding habits and the amount of water consumed (Heinonen-Tanski and Wijk-Sijbesma 2005, 404). Only the TN concentration in the Bhot Khoriya urine (7.1 g L^{-1}) was found to be within the range (7.0-11.0 g L^{-1}) reported in the study of Karak and Bhattacharyya (2011, 402). Due to the variation in N concentration in urine among the households, N application in different treatments varied in 2017. The amount of urine needed to be applied in the later year (2018) was calculated based on the N present in urine in the former year (2017). Hence, in 2018, an equal amount of N was applied in the CF and U treatments. This led to the difference in the amount of N applied in the two years.

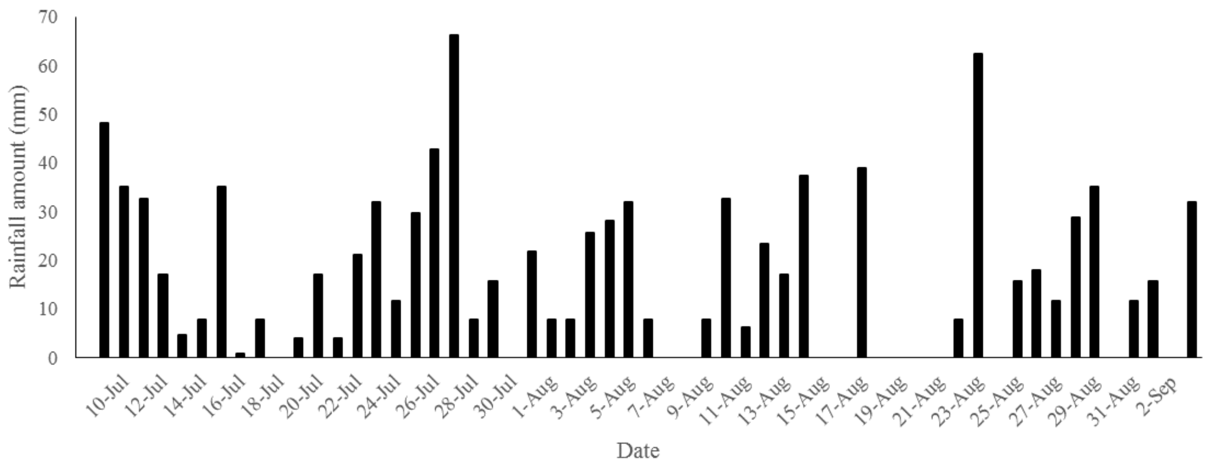

Figure 3.2. Daily rainfall event in Bhot Khoriya in 2018

Table 3.1. The basic physicochemical properties of soil collected before field experiment in year 2017 and 2018

	Angare		Bhot Khoriya		Deurali	
Particle size distribution (g kg^{-1}dry soil)						
Sand (0.05 - 2.0 mm)	597.2		346.3		213.8	
Silt (0.002 - 0.05 mm)	326.5		479.0		602.1	
Clay (<0.002 mm)	76.3		174.7		184.1	
Chemical Properties	2017	2018	2017	2018	2017	2018
pH (H_2O)	6.93	5.69	5.18	5.16	5.27	5.11
EC (mS m^{-1} dry soil)	15.84	10.13	21.09	19.21	14.05	11.21
CEC ($cmol_c$ kg^{-1} dry soil)	10.01	7.90	14.76	18.83	13.88	18.32
Total N (g kg^{-1} dry soil)	1.89	1.24	3.18	2.47	2.26	2.22
Total C (g kg^{-1}dry soil)	20.8	18.53	33.44	37.09	25.57	35.47
Mineral N (mg kg^{-1} dry soil)	43.22	9.83	76.52	16.84	52.29	13.08
K ($cmol_c$ kg^{-1} dry soil)	0.32	0.28	0.26	0.27	0.29	0.33
Available P (g kg^{-1} dry soil)	0.69	0.69	0.59	0.89	0.29	0.61

Table 3.2. Composition of urine and ecosan manure used during field experiment

Fertilizer type	Site	2017			2018		
		Total N	Total P	Total K	Total N	Total P	Total K
		g kg^{-1}					
Urine	Angare	2.8	0.8	1.3	2.7	0.8	1.3
	Bhot Khoriya	7.2	2.8	1.8	7.1	2.8	1.8
	Deurali	2.0	1.4	1.0	3.2	1.4	1.0
Ecosan manure		13.4	11.2	36.2	13.2	11.2	36.2

The experiment was laid out in a randomized complete block design. The total plot size was 75 m^2, and each plot was 2.5 m x 2 m, consisting of five rows of 30 plants (Figure 3.3 and Table 3.3). Each treatment was replicated three times. Hybrid seeds of the cauliflower (*Brassica oleracea*) variety 'White Shot' were used in this study. Cauliflower was chosen as a test crop because it can respond well to N. Since urine is rich in N, it was suggested to give priority to a crop that responds well to N (Jonsson et al. 2004, 17, 31). Cauliflower transplanting was performed four weeks after sowing with the following five treatments: Control (C), Chemical fertilizer (CF), Urine (U), Ecosan manure + Urine (E+U), and Ecosan manure (E). The rate of fertilizer application is presented in Table 3.4.

Figure 3.3. Experimental site in Angare and Deurali in year 2018

Table 3.3. Experimental setup

Farm Site	Altitude	Total plot size	No. of replication	No. of treatment	No. of plants grown per treatment	Sampling interval of plants	No. of plants sampled per treatment
Angare	1822 m	75 m^2	3	5	30	Sampling in three weeks	3
						Sampling at harvest	5
Bhot Khoriya	1981 m	75 m^2	3	5	30	Sampling in three weeks	3
						Sampling at harvest	5
Deurali	2125 m	75 m^2	3	5	30	Sampling in three weeks	3
						Sampling at harvest	5

Urea and diammonium phosphate (DAP) were applied in the CF treatment at a rate of 180 kg ha^{-1} N (according to the farmer's typical practice). The liquid form of urine collected from the ecosan toilet of each household was applied in U and as a top-dressing in E + U. The urine was applied by making a hole in the soil, as mentioned by Rodhe et al. (2004, 197), to avoid ammonia losses, and ecosan manure was applied in the periphery of the crop above the soil. The completely decomposed ecosan manure collected from the same ecosan toilet was applied as basal fertilizer in the E + U and E treatments at all sites. The amount of urine applied as a treatment in 2017 was calculated based on the assumption that 550 L of urine contains 4 kg of N (Esrey et al. 2001, 10) to make the application equivalent to the amount of N applied in the CF treatment. The amount of urine to be applied in the later year (2018) was calculated based on the N present in urine in the former year (2017). The fertilizer was applied in split doses (twice), basal (first application) and top-dressing (second application) (Figure 3.4). The basal application was performed ten days after transplant, and the top-dressing was performed two weeks after the basal application. Weeds were controlled as necessary. Each "treatment" in this study can be regarded as a "scenario" that reflected the situation of the households who have the potential to apply urine and ecosan manure, because the amount of nutrients applied was different among the treatments and the nutrient application calculation was based only on the N concentration in urine.

Figure 3.4. Application of ecosan manure

Figure 3.5. Cauliflower at the time of harvest

Table 3.4. Fertilizer application rate in different treatments during field experiment

Treatment	Application rate (kg ha^{-1})						Remarks
	2017			2018			
	N	P	K	N	P	K	
Angare							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing - Chemical fertilizer
U	35+35	10+10	16+16	90+90	26+26	42+42	Basal/ top dressing – Urine
E + U	90+35	74+10	242+16	90+90	74+26	242+42	Basal- Ecosan manure/ top dressing - Urine
E	45+45	37+37	121 + 121	45+45	37+37	121 + 121	Basal/ top dressing - Ecosan manure
Bhot Khoriya							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing -Chemical fertilizer
U	90+90	35+35	22+22	90+90	35+35	22+22	Basal/ top dressing – Urine
E + U	90+90	74+35	242+22	90+90	74+35	242+22	Basal - Ecosan manure/ top dressing - Urine
E	45+45	37+37	121 + 121	45+45	37+37	121 + 121	Basal/ top dressing - Ecosan manure
Deurali							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing -Chemical fertilizer
U	26+26	17+17	12+12	90+90	60+60	42+42	Basal/ top dressing – Urine
E + U	90+26	74+17	121+12	90+90	74+60	242+42	Basal - Ecosan manure/ top dressing - Urine
E	45+45	37+37	121 + 121	45+45	37+37	121 + 121	Basal/ top dressing - Ecosan manure

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

3.2.3. Soil sampling and physicochemical analysis

The soil samples were collected twice, once prior to the experiment and again after the cauliflower was harvested (after the curds were judged to be mature), from the topsoil (0-15 cm) at all the sites. Five soil samples were collected per plot and homogenously mixed together to form a composite for each treatment. All soil samples were air-dried, ground and sieved using a 2 mm sieve to remove pebbles. Then, chemical analyses were conducted. The particle size distribution was determined by the pipette method (Gee and Bauder 1986, 383-84) and sieving for only one year, assuming that soil texture does not change under normal agricultural conditions. Soil pH was measured in a deionized water and KCl solution at a soil: solution ratio of 1:5 using a pH meter with a glass electrode (LAQUA F-74BW, Horiba). The exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted using 1 mol L^{-1} ammonium acetate buffered at pH 7.0 and determined by atomic absorption spectroscopy (AA-700, Shimadzu, Japan) after extracting with 1 M ammonium acetate at pH 7.0. To determine the cation exchange capacity (CEC), the residual soil was washed with ethanol after ammonium acetate extraction, and the remaining ammonium (NH_4) was extracted with 10% sodium chloride (NaCl). The NH_4 concentration was determined by using a flow injection auto analyzer (Flow Analysis Method, JIS K-0170, AQLA-700 Flow Injection Analyzer, Aqualab INC., Japan). Total carbon (TC) and total nitrogen (TN) content was measured from ground samples, and the measurement was taken using the high-temperature combustion method with an EA IsoLink CN analyzer. Mineral N (NH_4-N and NO_3-N) was analyzed colorimetrically using FIA (details mentioned above) after extraction with 2 mol L^{-1} KCl. Available phosphorus (Avai. P) determination was performed colorimetrically using molybdate by the Bray-2 method (Nanzyo 1997, 267-73).

3.2.4. Plant sampling and analysis

Aboveground part of three cauliflower plants at three weeks after transplanting and five cauliflower plants at harvest per treatment were sampled from all the plots. The leaves and flowers of cauliflower at harvest were immediately separated after sampling and weighed to determine the fresh weight of cauliflower. The samples were then chopped into pieces and sub-sampled for further analysis. The sub-samples were oven dried at 70°C until they were completely dried. The samples were then weighed and homogenized using a rotating-disk mill. The dry weight taken was expressed on a per-hectare basis. For plant nutrient content analysis, dried samples were milled and digested using HNO_3. Phosphorus concentration was determined by colour development using molybdate. The concentrations of K, Na, Ca, and Mg were analyzed using atomic absorption spectroscopy (AA-700, Shimadzu, Japan).

3.2.5. Plant nutrient uptake and nitrogen use efficiency

Plant nutrient uptake was calculated separately for leaves and flowers and summed as a total. Nutrient uptake was calculated as shown in equation (1):

Nutrient uptake (kg ha^{-1}) = *Nutrient content* (%) X *Sample dry weight* (kg ha^{-1})/100 ……. (1)

The apparent N recovery efficiency (ARE) and agronomic N use efficiency (AUE) of cauliflower were calculated as shown in equations (2) and (3):

$ARE = (Nf - N0)/N \times 100$ ………………………………………………………………. (2)

$AUE = (CauYf - CauY0)/N \times 100$ ………………………………………………… …... (3)

where Nf = nitrogen uptake from fertilized plots (kg N ha^{-1}), $N0$ = nitrogen uptake from control plots (kg N ha^{-1}), $CauYf$ = cauliflower yield from fertilized plots (kg cauliflower ha^{-1}), $CauY0$ = cauliflower yield from unfertilized plots (kg cauliflower ha^{-1}), and N = total nitrogen applied per hectare (kg N ha^{-1}).

3.2.6. Calculation and statistical analysis

The crop production parameters observed were dry weight (kg ha^{-1}) at three weeks and dry weight (kg ha^{-1}) of leaves and flowers at harvest using a digital scale. The data obtained were subjected to analysis of variance (ANOVA). Statistical analysis was conducted with IBM SPSS Statistics (version 20), where a significant difference was reported at the 5% probability level.

3.3. Results

3.3.1. Cauliflower biomass and yield

The mean values of dried biomass of cauliflower at the three experimental sites are presented in Table 3.5. The results indicated that in both years, the dried cauliflower biomass was significantly ($p<0.05$) different among the treatments in Bhot Khoriya and Deurali, but no significant difference was observed in Angare either in three weeks or at harvest. Although the difference was not statistically significant, the dried cauliflower biomass at harvest in Angare was increased in the soils treated with U, E + U and E compared with that of the no-treatment control and was similar to the biomass from soil treated with CF. Furthermore, there were significant ($p<0.05$) differences in biomass among the sites in 2018 (Figure 365), resulting in higher biomass in Angare than in Bhot Khoriya and Deurali. A similar growth trend for cauliflower was observed in Bhot Khoriya and Deurali in both years.

Table 3.5. Mean values of dried biomass of cauliflower as affected by different treatments

Treatment	2017				2018			
	Dried biomass (kg ha^{-1})							
	Sampled in three weeks	Sampled at harvest			Sampled in three weeks	Sampled at harvest		
		Leaves	Flower	Total		Leaves	Flower	Total
Angare								
C	77	604	184	788	82	1105	292	1397
CF	137	1028	511	1539	106	1772	564	2336
U	65	675	312	987	103	1723	445	2168
E + U	158	1412	498	1910	167	1426	440	1866
E	86	1216	416	1632	157	1668	600	2268
Bhot Khoriya								
C	200	811 b	350	1161	105 b	549 b	96 b	645 c
CF	219	949 ab	424	1373	144 b	753 ab	159 ab	912 bc
U	320	953 ab	439	1392	271 a	1249 ab	282 ab	1531 ab
E + U	238	1383 a	582	1965	171 ab	1416 a	541 a	1957 a
E	186	1301 ab	600	1901	168 b	1400 a	338 ab	1738 a
Deurali								
C	38 b	379 b	97 b	476 b	93	619 b	83	702
CF	71 ab	927 ab	410 ab	1337 a	176	887 ab	151	1038
U	97 a	852 ab	368 ab	1220 a	136	991 ab	123	1114
E + U	99 a	784 ab	474 ab	1258 a	183	1296 a	242	1538
E	97 ab	1084 a	669 a	1753 a	163	888 ab	290	1178

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

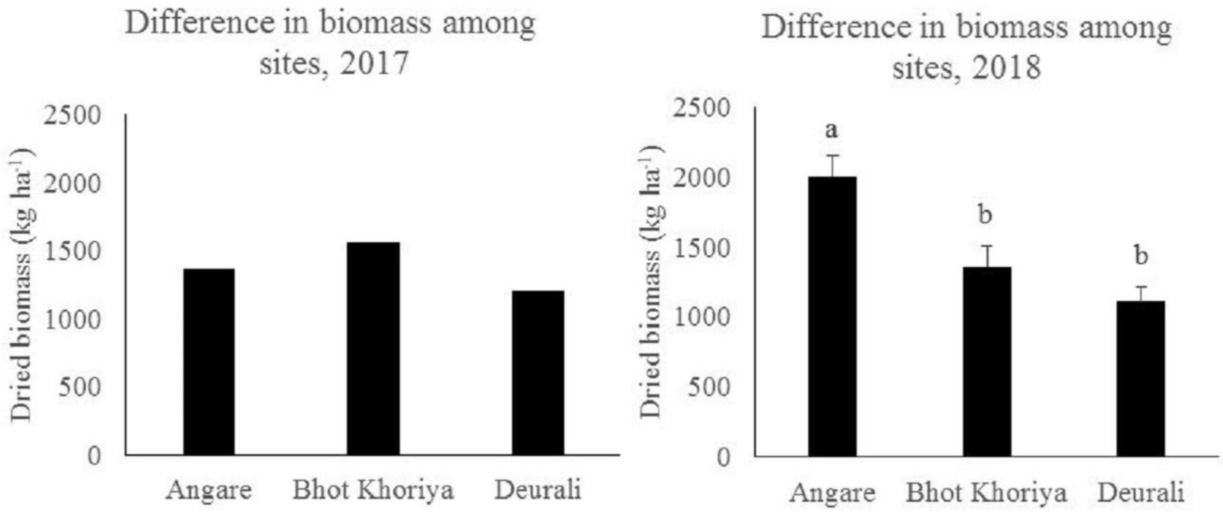

Figure 3.6. Difference in biomass among sites in two different years

3.3.2. Nutrient uptake and N use efficiency

N, P, and K uptake by the plants and ARE and AUE in 2017 and 2018 are presented in Tables 3.6 and 3.7. A significant ($p<0.05$) difference in N uptake was observed in Deurali in 2017, with less uptake by plants in the C treatment than by the plants grown with the other treatments (Table 3.6). In 2018, a significant ($p<0.05$) difference in N uptake was observed in Bhot Khoriya, with the highest uptake by the plants grown in E + U treated soils and the least in the soils of the control treatment (Table 3.7).

3.3.3. Na uptake by the plants

A significant ($p<0.05$) difference among treatments in Na uptake by plants in 2017 and 2018 was observed for Bhot Khoriya (Table 3.8). The highest Na uptake both in the leaves and flowers obtained in the urine treatment. Although the difference in Na uptake among treatments at other sites was not significant, the highest Na uptake was observed in plants grown in the urine treatment.

Table 3.6. Effects of treatment on nutrient uptake and nitrogen use efficiency in 2017

Treatment	Uptake by plant (kg ha^{-1})						Apparent N Recovery Efficiency (ARE)	Agronomic N Use Efficiency (AUE)
	N		P		K		%	%
Angare								
C	77.3		3.8		49.3		-	-
CF	162.4		9.4		126.3		47.3	4.1
U	81.4		4.8		84.7		5.9	2.8
E + U	142.1		10.3		143.3		51.8	9.0
E	117.4		10.2		120.4		44.6	9.4
Bhot Khoriya								
C	81.3		4.9	c	73.8		-	-
CF	155.2		6.2	bc	79.6		41.1	1.1
U	121.7		6.5	bc	100.9		22.4	1.3
E + U	159.3		10.3	ab	160.8		43.3	4.5
E	133.7		11.1	a	147.9		58.2	8.2
Deurali								
C	27.1	b	2.1	b	18.2	b	-	-
CF	127.9	a	6.7	ab	62	ab	56.0	4.8
U	87.2	a	6.5	ab	77.5	ab	115.6	14.3
E + U	89.1	a	5.2	ab	104.8	ab	53.4	6.7
E	110.1	a	9.9	a	133.1	a	92.2	14.2

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

Table 3.7. Effects of treatment on nutrient uptake and nitrogen use efficiency in 2018

Treatment	Uptake (kg ha^{-1})						Apparent N Recovery Efficiency (ARE)	Agronomic N Use Efficiency (AUE)
	N		P		K		%	%
Angare								
C	44.2		8.7		45.0	b	-	-
CF	93.5		13.6		55.1	b	27.4	4.0
U	71.5		13.9		60.9	b	15.2	3.1
E + U	62.7		13.6		66.9	b	10.3	1.1
E	72.6		14.8		116.3	a	31.6	8.8
Bhot Khoriya								
C	21.1	b	3.4	b	14.3	b	-	-
CF	39.2	ab	6.6	ab	28.6	b	10.1	1.3
U	54.2	ab	10.3	ab	45.3	b	18.4	4.7
E + U	64.9	a	12.4	a	112.8	a	24.3	7.1
E	54.5	ab	12.4	a	76.5	ab	37.1	11.7
Deurali								
C	24.2		3.3		19.4	b	-	-
CF	51.8		4.6		36.8	b	15.3	1.9
U	40.0		5.3		30.7	b	8.8	2.3
E + U	52.7		7.7		58.8	ab	15.8	4.6
E	44.9		6.9		88.6	a	23.0	5.3

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

Table 3.8. Na concentrations in leaves and flower of cauliflower after treatment in two years

Treatment	2017				2018			
	Leaves		Flower		Leaves		Flower	
	g kg^{-1} dry weight							
Angare								
C	1.02		1.22		3.42		2.15	
CF	0.97		1.89		2.53		1.94	
U	1.75		2.02		4.38		3.72	
E + U	1.34		2.08		2.99		2.54	
E	1.64		2.57		2.41		2.05	
Bhot Khoriya								
C	2.09	ab	2.73	ab	3.32		3.28	ab
CF	0.82	b	2.41	ab	3.32		2.71	ab
U	3.09	a	4.96	a	6.58		4.24	a
E + U	2	ab	2.88	ab	4.59		2.53	b
E	2.54	ab	2.34	ab	4.38		2.72	ab
Deurali								
C	1.32		2.54		3.61		1.78	
CF	0.78		1.75		1.87		1.28	
U	3.24		0.68		3.89		2.77	
E + U	2.59		2.19		3.76		3.07	
E	2.88		2.24		2.71		1.66	

C: Control, CF: Chemical fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different at $p<0.05$

3.3.4. Physicochemical characteristics of soil after treatment

Figure 3.9. shows the positive correlation between soil pH (H_2O) and base saturation (%) in all treatments in both years.

Significant ($p<0.05$) differences in soil pH, EC, and NO_3-N among treatments were observed only for Bhot Khoriya in 2017 (Table 3.9) and for all sites in 2018 (Table 3.10). The soil treated with CF showed a significant decrease in soil pH, whereas in the soil treated with U and E treatments, a significant increase in soil pH was recorded compared to the pH of the control soil (Tables 3.9 and 3.10). Soil NH_4-N increased, and soil NO_3-N decreased as an effect of all treatments at harvest compared to those levels in the control (Tables 3.9 and 3.10). No significant difference in soil exchangeable cations at any site was observed in 2017 (Table 3.11). It was observed that exchangeable magnesium and exchangeable potassium were significantly different among the treatments in Bhot Khoriya, and exchangeable calcium and exchangeable sodium were significantly different among the treatments in Deurali in 2018 (Table 3.11).

3.4. Discussions

3.4.1. Effects of the treatments on cauliflower yield

Although there were altitudinal differences among the sites (Angare - 1822 m, Bhot Khoriya - 1981 m, Deurali - 2125 m above sea level), the climate and rainfall pattern at all sites was assumed to be similar and to have no particular effect on the treatment. This is because no drought was experienced during the cropping season and the soil temperature in Bhot Khoriya and Deurali were found to be identical. The urine and ecosan manure used in the field experiment contain appreciable levels of nutrients (Table 3.2). This reflects that urine and ecosan manure can be essential sources of plant nutrients and soil conditioners for agriculture. However, the variation in N, P, and K concentration in the urine among the households (Table 3.2) caused variation in the treatment among the sites and between the years. This resulted in the variation in the growth and yield during the harvest.

Table 3.9. Effects of treatment on soil chemical characteristics in three sites in year 2017

Treatment	Soil chemical characteristics after harvest				Change in soil chemical characteristics after harvest			
	Soil pH	EC	NH_4-N	NO_3-N	Soil pH Increase	EC Decrease	NH_4-N Increase	NO_3-N Decrease
		mS m^{-1} dry soil	mg kg^{-1} dry soil			mS m^{-1} dry soil	mg kg^{-1} dry soil	
Angare								
C	7.29	11.97	6.41	13.16	0.41	3.80	2.05	6.75
CF	7.03	11.07	6.03	14.25	-0.72	4.58	1.70	8.21
U	7.22	10.47	5.65	12.41	-0.01	5.37	1.75	6.76
E + U	7.17	11.91	6.28	13.50	0.30	3.61	-0.11	7.21
E	7.01	11.35	8.28	20.75	0.13	4.34	3.06	12.46
Bhot Khoriya								
C	5.51 a	6.94	9.78 b	13.66	0.24 a	14.15	0.53 ab	70.63 a
CF	5.19 b	10.74	9.18 b	36.08	0.05 bc	10.35	-1.93 b	16.96 b
U	5.27 ab	6.51	10.75 ab	17.16	0.13 abc	14.58	0.91 ab	36.75 ab
E + U	5.28 ab	7.50	10.15 ab	21.66	-0.03 c	13.59	-1.51 b	34.16 ab
E	5.25 ab	7.81	11.80 a	18.58	0.19 ab	13.28	4.23 a	67.50 a
Deurali								
C	5.45	5.67	9.86	10.83	0.19	8.20	-3.56	27.33
CF	5.22	7.13	10.08	30.83	-0.11	6.89	-1.10	8.83
U	5.34	5.97	9.13	12.41	0.07	8.07	-2.63	31.83
E + U	5.49	6.08	8.36	11.66	0.24	7.94	-4.16	29.58
E	7.59	6.26	8.63	10.91	0.27	7.74	-3.88	25.75

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

Table 3.10. Effects of treatment on soil chemical characteristics in three sites in year 2018

Treatment	Soil chemical characteristics after harvest: Soil pH		EC (mS m^{-1} dry soil)		NH_4-N (mg kg^{-1} dry soil)		NO_3-N (mg kg^{-1} dry soil)		Change in soil chemical characteristics after harvest: Soil pH Increase		EC Decrease (mS m^{-1} dry soil)		NH_4-N Increase (mg kg^{-1} dry soil)	NO_3-N Decrease (mg kg^{-1} dry soil)	
Angare															
C	5.98	a	6.74	b	3.70		2.41	b	0.11	a	3.30	c	1.35	7.58	a
CF	5.35	b	12.81	a	4.55		8.91	a	-0.30	b	-2.32	d	1.38	-3.41	b
U	5.59	ab	4.40	b	2.98		1.43	b	-0.16	b	5.54	a	0.65	7.23	a
E + U	5.78	ab	5.89	b	7.30		1.80	b	0.16	a	4.21	b	4.81	4.36	ab
E	5.86	ab	6.26	b	3.36		1.90	b	0.28	a	3.85	bc	0.70	3.93	ab
Bhot Khoriya															
C	5.58	a	6.59	b	8.13		7.26		0.39	a	12.20	a	2.18	2.98	
CF	4.88	b	25.60	a	10.10		9.96		-0.21	b	-6.22	c	4.98	0.20	
U	5.35	a	5.81	b	7.30		2.26		0.18	ab	12.92	a	-0.26	7.98	
E + U	5.67	a	8.95	b	6.31		2.50		0.39	a	10.50	b	0.68	11.41	
E	5.59	a	8.24	b	6.20		2.13		0.26	a	10.97	b	0.78	7.78	
Deurali															
C	5.53	a	4.22	b	0.63	b	1.86		0.34	a	6.95	a	1.86	6.11	
CF	4.93	b	14.78	a	7.60	a	4.96		-0.15	b	-3.55	d	4.96	2.90	
U	5.48	a	4.34	b	0.73	b	1.63		0.33	a	6.91	a	1.63	8.01	
E + U	5.58	a	5.28	b	1.10	b	2.48		0.53	a	5.95	b	2.48	8.40	
E	5.68	a	7.62	b	0.70	b	3.06		0.58	a	3.72	c	3.06	7.71	

C: Control, CF: Chemical Fertilizer, U: Urine, E + U:Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

Table 3.11. Effects of treatment on soil exchangeable cations in two years

Treatment	Soil chemical characteristics after harvest							
	2017				2018			
	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Ex. Ca	Ex. Mg	Ex. K	Ex. Na
	cmol$_c$ kg^{-1} dry soil							
Angare								
C	10.27	1.55	0.34	0.05	5.91	0.90	0.24	0.10
CF	9.01	1.07	0.25	0.08	4.69	0.72	0.21	0.11
U	9.80	1.62	0.45	0.18	4.47	0.60	0.15	0.13
E + U	8.93	1.27	0.62	0.04	5.00	0.79	0.28	0.13
E	8.94	1.46	0.23	0.11	5.06	0.91	0.27	0.10
Bhot Khoriya								
C	4.47	0.97	0.34	0.08	7.27	1.59 abc	0.20 ab	0.10
CF	3.78	0.73	0.25	0.06	6.01	1.10 bc	0.23 ab	0.12
U	4.20	0.74	0.49	0.12	5.88	1.00 c	0.14 b	0.12
E + U	3.85	0.67	0.20	0.10	6.94	2.11 a	0.46 a	0.17
E	3.74	0.70	0.32	0.15	7.42	1.89 ab	0.38 ab	0.13
Deurali								
C	4.36	0.87	0.53	0.07	4.86 ab	0.79	0.20	0.10 b
CF	3.88	0.58	0.29	0.05	3.64 b	0.60	0.22	0.07 b
U	3.76	0.51	0.18	0.10	4.60 ab	0.78	0.22	0.11 b
E + U	3.52	0.80	1.09	0.17	4.74 ab	1.11	0.63	0.19 a
E	4.14	0.79	0.84	0.11	5.84 a	1.14	0.60	0.09 b

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Means within each column followed by same letter or none at all are not significantly different for each site at $p<0.05$

The similar growth of cauliflower from the soil treated with U, E + U or E in this study (Table 3.5) indicates that human urine and ecosan manure are good sources of plant nutrients, confirming the results from other countries such as South Africa, Zimbabwe (Guadarrama, Pichardo, and Morales-Oliver 2001, 1-2), Finland (Pradhan et al. 2007, 8659; Pradhan et al. 2010, 2036). Fertilization treatments increased the growth of cauliflower at all sites in both years, but a significant increase at harvest was observed in E and E+ U in 2018 in Bhot Khoriya (Table 3.5). In Angare, although there was no significant difference in the dry biomass of cauliflower in both years, cauliflower growth was accelerated due to fertilizer application by 48%, 20%, 58% and 51% in the CF, U, E + U and E treatments, respectively, in 2017 and by 40%, 35%, 25% and 38% in the CF, U, E +U and E treatments, respectively, in 2018 compared to growth in the control treatment; these results demonstrate the positive effects of urine and ecosan manure as soil amendments. The amount of nitrogen applied in the U and E + U treatments in both years was the same. Increased or comparable growth patterns were seen with U, E + U and E treatments because of the increased nutrient availability from the higher supply of P and K that was applied through urine and ecosan manure in U, E + U and E than through CF (Table 3.4) or from improvements in the soil quality even though the amount of nitrogen applied was relatively small. This result is similar to the situation with increased maize production due to the improvement in water productivity from faeces + urine (Guzha 2005, 844). The nutrient content in urine is easily accessible, as it is in liquid form, but the nutrient contents in ecosan manure release more slowly and might have an effect at later stages of crop growth. In 2018, although the same amount of N in the CF, U, E + U and E treatments was applied at all three sites (Table 3.2), no significant difference in dried biomass among the treatments in Angare was observed (Table 3.5). This might be the result of N loss from urine either by volatilization or leaching and the slow release of nutrients in the E + U and E treatments. The amount of urine applied in 2018 was higher compared to that applied in 2017 to make the N concentration equivalent in all treatments, which might have resulted in more N loss in 2018 than in 2017. This result is similar to the result from Di (2007, 289), who reported significant NO_3-N losses as the amount of urine nitrogen application increased. This result suggests that the application of urine in moderate amounts (26 kg ha^{-1} – 35 kg ha^{-1}) might be beneficial for minimizing NO_3-N losses and improving productivity. It is also likely more convenient to farmers to minimize the workload of transporting urine onto the farm. Additionally, urine collected from ecosan toilets could be utilized across large farm areas, making ecosan toilets feasible for fertilizer use. The possibility of N volatilization and leaching from urine increases the risk of N being unavailable to plants. The household economic statuses and farming skills among the three households were different; the highest were observed in Deurali, followed by Bhot Khoriya and Angare. Clubroot disease was observed less in Angare than in Bhot Khoriya and Deurali. These might have fundamentally affected the treatment effect on growth performance among the sites. Additionally, the difference in soil particle distribution and residual effects on soil from previous farming practices might have some effects on the treatment of the present study. Another possibility for poor crop performance in Angare (especially in soil treated with U) might be the result of heavy rainfall and more flooding, especially due to the high sand content (597 g kg^{-1} dry soil) in the soil in comparison to the sand content in the soils of Bhot Khoriya (346 g kg^{-1} dry soil) and Deurali (213 g kg^{-1} dry soil) (Table 3.1). The study on the effect of urine, poultry manure and dewatered fecal sludge conducted by Amoah (2017, 11) in Ghana in the dry and rainy seasons showed poor plant growth and low yields in the rainy season compared to those in the dry season. Hence, this study results show similarity to those in the study by Amoah (2017, 11). The growth of cauliflower in all treatments was higher in both years in Angare compared to that in the other sites (Table 3.5) and showed significantly ($p<0.05$) higher biomass in Angare among the sites in 2018 (Figure 3.6). This might be the result of the lesser effect of clubroot disease compared to that in Bhot Khoriya and Deurali. These results demonstrate that mineral fertilizer or nutrients applied through urine and ecosan manure lead to better crop performance. It can also be concluded that applying urine either in combination with ecosan manure or with other organic manure is much more effective than applying urine alone.

Figure 3.7. Cauliflower root affected by clubroot disease

Figure 3.8. Anti-clubroot fungicide available in local market in study area

3.4.2. Effects of nutrient uptake and utilization by cauliflower

Kutu (2010) revealed that N uptake by plant increase with the increase in the proportion of urine-N in the human faeces/urine combinations treatment. The highest N uptake in the solo urine treatment followed by treatments with greater proportion of urine-N was due to the readily available N contained in the urine. In contrast, this study showed that the N uptake by plants in 2017 at all sites was higher than the N uptake by plants in 2018, although more N through urine was applied in 2018 (Tables 3.6 and 3.7). This might be because nitrogen applied in the later year was not fully taken up by the plant and could not contribute to the growth of the plant. This result of low N uptake is in agreement with the finding that if a moderate amount of urine fertilizer is carefully incorporated directly into the soil at the correct time, urine nitrogen has the same agricultural values as the nitrogen in commercial mineral fertilizers (Richert et al. 2002, 47-50). ARE was higher in all sites in 2017 than in 2018, ranging from 5.9% – 115.6% in 2017 and from 8.8% – 37.1% in 2018 (Tables 3.6 and 3.7). No significant difference among treatments was observed in ARE in either year, whereas AUE varied among treatments (Tables 3.6 and 3.7). The AUE values in the E + U treatment (9.0, 4.5, and 6.7 in 2017 and 1.1, 7.1, and 4.6 in 2018 in Angare, Bhot Khoriya and Deurali, respectively) and the E treatment (9.4, 8.2, and 14.2 in 2017 and 8.8, 11.7, and 5.3 in 2018 in Angare, Bhot Khoriya and Deurali, respectively) were higher than those of the CF and C treatments in both years. This result reveals that N uptake by plants grown in CF did not contribute to plant growth as much as the nitrogen taken up in the E + U and E treatments. The high AUE in plants grown in soil treated with E + U, E and U suggests the potential of using urine and ecosan manure as a fertilizer. The lack of a consistent increase in yields from increased N application suggests that N is not the only factor limiting the growth of cauliflower.

P uptake by plants was significantly ($p<0.05$) higher in the E treatment than in the other treatments in Bhot Khoriya in both years (Table 3.6) and in Deurali in 2018 (Table 3.7), but there was no significant difference among treatments in P uptake by plants in Angare. This result is similar to the study conducted by Kutu (2010) who showed that higher P uptake by plants was from the treatments treated with high proportion of human faeces. Although there was no significant difference in P uptake by plants in Angare in both years and in Deurali in 2018, P uptake by plants in the U-, E + U- and E-treated soil was comparatively higher than that in the soil with no treatment (Tables 3.6 and 3.7). Phosphorus was applied during the experiment through DAP in the CF treatment and through urine and ecosan manure in U, E + U and E. The amount of P applied in the E treatment was almost double the amount applied via CF (Table 3.4), since the application rate was based on N content. This might be the reason for the high uptake of P in E-treated soil. The observed result indicates that P is another important nutrient for cauliflower growth, in addition to N. If enough P was added, the biomass and P uptake could have been higher. This finding also agrees with the results on cauliflower reported by Cutcliffe and Munro (1975, 128-30) and the results on spinach reported by Kutu (2010). Another study revealed that the uptake of phosphorus from urine during the first growth year was 12% higher than that from mineral fertilizers (Kirchmann and Petterson 1995, 153).

Significantly ($p<0.05$) higher K uptake by plants in E-treated soil than in the other treatments in Deurali in 2017 and at all sites in 2018 (Tables 3.6 and 3.7) might be due to the high concentration (36.26 g kg^{-1} dry soil) of K in human ecosan manure (Table 3.2). This result shows that applied K might have some effect on the increased yield of cauliflower. Increased cauliflower yields due to K application compared to yields under no K application were reported by Cutcliffe and Munro (1975, 130). The significantly ($p<0.05$) higher Na concentration (almost 50% higher than that in the control treatment) (Table 8) in the leaves and flowers of cauliflower grown in U-treated soil in Bhot Khoriya was due to the high Na concentration in urine. Although there was no significant difference in Na concentrations among the plants at other sites, it is worth mentioning that the concentration was higher in the plants from the U-treated soil than in the plants from the other treatments (Table 3.8). This could lead to a soil salinity problem in the long term. The EC in the soil doubled in the urine + poultry dropping treatment studied by Amoah (2017).

3.4.3. Effects of treatment on soil characteristics and soil N status

Compared to 2018, soil pH in Angare in 2017 before treatment was higher. The reason behind this is that the experimental farm used in two years was different to minimize the residual effect of the treatment and clubroot effects in cauliflower. Less technical knowledge about farming, improper management of farm sites and previous crop grown might have caused higher soil pH in year 2017. Similar to the effect seen in other studies, CF treatment acidified the soil, whereas soil pH was significantly ($p<0.05$) increased by 0.16-0.58 compared to that of the control as a result of urine and ecosan manure application at all sites in 2018 (Table 3.10). The lack of a significant increase in soil pH in 2017 (Table 3.9) might be due to the lower amount of urine and ecosan manure applied as a treatment. The decrease in soil pH in both years in CF ranging from 0.01-0.72 demonstrates the acidification of soil by urea fertilization. EC decreased in the soil after harvest in all treatments except for the chemical fertilizer treatment in 2018. Adeoluwa and Cofie (2012, 293) and Adeoluwa, Aworuwa and Ogunsanya (2015, 8) reported improvements to fertility and the general conditions of the soil after urine application, indicating its potential as a soil treatment. Many studies have reported a significant increase in soil NO_3-N as a result of urine application. This study, in contrast, showed that the decrease in NO_3-N concentration might be due to the low concentration of NO_3-N in the soil at the initial stage (Tables 3.9 and 3.10) and might be due to the loss of NO_3-N through volatilization and leaching into the environment. In 2017, it was observed that ARE was higher in all treatments at all sites than in 2018 (Tables 3.6 and 3.7). Although ARE was higher in the soil, it could not contribute to the overall growth of the plant. The study was carried out in the rainy season, and the soil was wet due to the rain falling every day (Figure 3.2). The amount of urine applied in 2018 was much higher in volume compared to that in 2017. This resulted in an overflow of urine, which contributed to volatilization and leaching, despite the urine being applied by making a hole in a soil, as mentioned by Rodhe et al. (2004, 197). This result also suggests applying less urine to minimize volatilization and leaching. The exchangeable cations in the soil were not significantly different among the treatments in 2017 (Table 3.11). However, exchangeable calcium and exchangeable sodium were significantly increased in the E- and E + U-treated soils, respectively, in Deurali after treatment compared to those of the control (Table 3.11). Both exchangeable magnesium and exchangeable potassium were significantly increased in E + U- treated soil in Bhot Khoriya after treatment compared to those of the control (Table 11). The lack of a significant increase in exchangeable cations in 2017 might be due to the lower amount of N applied in the U and E + U treatments. This result suggests that urine and ecosan manure applied as fertilizer might have some effect on the soil. The nonsignificant differences in some soil characteristics after treatment (Tables 3.9, 3.10 and 3.11) could be related to the short period of cultivation, the experiment being conducted in the rainy season and the past land use practices. Therefore, further long-term cultivation studies are still needed to monitor the continuous effects of urine and ecosan manure on soil fertility together with leaching phenomena.

3.4.4. Economic analysis of ecosan toilet

The economic analysis was conducted to understand the benefits of ecological sanitation. In 2016, ecosan toilet was built for 5 households for the research purpose. The cost to build one ecosan toilet was NPR 45,000 (USD 387). This cost is high for the households of rural village, but the cost could be reduced if locally available resources such as bamboo, mud is used for constructing wall and roof.

On average, 2000 L urine collected from one household with 4 family members in a year (Simha and Ganesapillai 2017). Also, from the questionnaire survey it was understood that 220 kg ecosan manure is from one ecosan toilet in a year with 4 family members. Assuming application rate of ecosan manure during field experiment (90 kg ha^{-1}) and considering four cropping seasons in a year the collected ecosan manure could cover 80 m^2 area. However, if that ecosan manure is sold, NPR 7,700 (USD 66) could be gained by the household that could help to invest that money for other household activities. If we calculate necessary amount of chemical fertilizers for 80 m^2, 12.5 kg, 6 kg and 5.8 kg urea, diammonium phosphate and ammonium sulphate is needed respectively. The amount needed to buy those urea, diammonium phosphate and ammonium sulphate are NPR313, NPR270, NPR203 respectively. The cost is not much high but untimely delivery of fertilizer is the major constraint in rural areas. If we consider all these, ecosan could help to improve livelihood of rural areas.

3.5. Conclusion

The results of this study suggest that urine combined with ecosan manure could be applied to the soil as fertilizer to improve the soil nutrient status and the agronomic yield parameters of cauliflower. Human urine and ecosan manure, which are seen as waste and as an environmental nuisance, could be harvested and used as fertilizer. Thus, the dependency on chemical fertilizer could be reduced. Human urine performed better in terms of improving soil fertility (increasing soil pH), while human ecosan manure might have residual effects on successive crops and is good for soil with both low and high nutrient contents. The application of a moderate amount of urine at least twice is recommended for vegetable production. The application of urine in combination with ecosan manure might have a more significant effect on crop growth than the application of urine alone. Further research in different locations, different soils, and different seasons with different crops is necessary to address the issue of low N recovery and to increase soil fertility. This research analyzed the effect of urine and ecosan manure on crop production after conducting field experiments through different treatments. However, it is still lacking in this research about the leaching phenomena and soil N loss especially through the urine application. The application rate of urine might vary depending upon the season and crop. Further research should be carried out in different climatic varied locations with different soil types and different crop cultivation experiment. It might be helpful to address the issue of low N recovery from urine treatment and to increase its value as a soil amendment. Additionally, the application rate of urine in crops can be explored in future research.

References

Adeoluwa, O. O., Cofie, O. 2012. Urine as an alternative fertilizer in Agriculture: Effects in Amaranths (*Amaranthus caudatus*) Production. *Renewable Agriculture and Food Systems* 27 (4): 287–294. https://doi.org/10.1017/S1742170511000512

Adeoluwa, O. O., Aworuwa, C. O, and Ogunsanya, O. E. 2015. Influence of Human Urine-compost Mixture on Some Soil Fertility Properties, Yield and Shelf-life of Tomato (*Solanum lycopersicon*). *Americal Journal of Experimental Agriculture* 11 (1): 1–10. https://doi.org/10.9734/AJEA/2016/19823

Amoah, P., Adamtey, N. and Cofie, O. 2017. Effect of urine, poultry manure, and dewatered faecal sludge on agronomic characteristics of cabbage in Accra, Ghana. *Resources* 6(2): 19. https://doi.org/10.3390/resources6020019

Andersson, E. 2015. Turning waste into value: using human urine to enrich soils for sustainable food production in Uganda. *Journal of Cleaner Production* 96(1): 290–298. https://doi.org/10.1016/j.jclepro.2014.01.070

CBS (Central Bureau of Statistics) 2012. *National Population and Housing Census*. National Planning Commission Secretariat, Government of Nepal, Kathmandu.

Cutcliffe, J. A. and Munro, D. C. 1976. Effects of nitrogen, phosphorus and potassium on yield and maturity of cauliflower. *Canadian Journal of Plant Science* 56(1): 127–131. https://doi.org/10.4141/cjps76-019

Di, H. J. and Cameron, K. C. 2007. Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor: a lysimeter study. *Nutrient Cycling in Agroecosystems* 79: 281–290. https://doi.org/10.1007/s10705-007-9115-5

Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR)2012. *Final Report: District Transport Master Plan (DTMP) -Volume I. Main Report*. Ministry of Local Development, Government of Nepal, Kathmandu. Online. http://ddcmakwanpur.gov.np/wp-content/uploads/2015/11/Report-of-DTMP.pdf (Accessed on February 17, 2019).

Effebi, K. R., Ballet, G. T., Seka, M. A., Baya, D. T. and N'takpe, B. L. 2019. Physiochemical and microbiological characterization of human faeces and urine from composting toilets in Abidjan, Côte d'Ivoire. *Environmental Technology* 40(3): 293–301. https://doi.org/10.1080/09593330.2017.1387610

Esrey, S. A., Andersson, I., Hillers, A. and Sawyer, R. 2001. *Closing the Loop: Ecological Sanitation for Food Security*. SIDA (Swedish International Development Cooperation Agency), Stockholm.

FAO (Food and Agriculture Organization) 2011. *The state of the world's land and water resources for food and agriculture (SOLAW): Managing systems at risk*. FAO and Earthcan, Rome and London.

FAO (Food and Agriculture Organization) and UNESCO (United Nations Educational, Scientific and Cultural Organization) 1977. *Soil Map of the World: Volume VII. South Asia*. UNESCO, Paris.

Gee, G. W. and Bauder, J. W. 1986. Particle-size Analysis. In Klute, A. (ed.) *Methods of Soil Analysis: Part 1. Physical and Mineralogical Methods*, 2nd ed. pp. 383–411. ASA (American Society of Agronomy) and SSSA (Soil Science Society of America), WI: Madison.

Guadarrama, R. O., Pichardo, N. A. and Morales-Oliver, E. 2001. Urine and compost efficiency applied to lettuce under greenhouse conditions in Temixco, Morelos, Mexico. *Proceedings of the First International Conference on Ecological Sanitation*.

Guzha, E., Nhapi, I. and Rockstrom, J. 2005. An assessment of the effect of human faeces and urine on maize production and water productivity. *Physics and Chemistry of the Earth, Parts A/B/C* 30(11–16): 840–845. https://doi.org/10.1016/j.pce.2005.08.028

Heinonen-Tanski, H. and Wijk-Sijbesma, C. 2005. Human excreta for plant production. Bioresource Technology 96(4): 403–411. https://doi.org/10.1016/j.biortech.2003.10.036

Jonsson, H., Richert-Stinzing, A., Vinneras, B. and Salomon, E. 2004. *Guidelines on the Use of Urine and Faeces in Crop Production*. SEI (Stockholm Environment Institute), Stockholm.

Karak, T. and Bhattacharyya, P. 2011. Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality. *Resources, Conservation and Recycling* 55(4): 400–408. https://doi.org/10.1016/j.resconrec.2010.12.008

Kirchmann, H. and Pettersson, S. 1994. Human urine: Chemical composition and fertilizer efficiency. *Fertilizer Research* 40: 149–154. https://doi.org/10.1007/BF00750100

Kutu, F. R., Muchaonyerwa, P. and Mnkeni, P. 2010. Complementary nutrient effects of separately collected human faeces and urine on the yield and nutrient uptake of spinach (*Spinacia oleracea*). *Waste Management & Research* 29(5): 532–539. https://doi.org/10.1177/0734242X10374900

Langergraber, G. and Muellegger, E. 2005. Ecological sanitation: a way to solve global sanitation problems? *Environmental International* 31(3): 433–444. https://doi.org/10.1016/j.envint.2004.08.006

Magdoff, F., Lanyon, L. and Liebhardt, B. 1997. Nutrient cycling, transformations and flows: implications for a more sustainable agriculture. *Advances in Agronomy* 60: 1–73. https://doi.org/10.1016/S0065-2113(08)60600-8

Morgan, P. 2003. *Experiments using urine and humus derived from ecological toilets as a source of nutrients for growing crops*. Paper presented at the 3rd Water World Forum, March 16–23. Kyoto, Japan. Online. https://aquamor.info/uploads/3/4/2/5/34257237/paper._experiments_with_urine_and_toilet_humus.pdf (Accessed September 12, 2019).

Nanzyo, M. 南條正巳 1997. Kakyu Tai Rin San 可給態リン酸 (Available Phosphorus). In Nihon Dojo Hiryo Gakkai 日本土壌肥料学会 (Japanese Society of Soil Science and

Plant Nutrition) *Dojo Kankyo Bunseki-ho* 土壌環境分析法 (Methods of Soil Environmental Analysis). pp.267–273. Hakuyusha, Tokyo.

National Planning Commission 2017. Nepal's Sustainable Development Goals, Baseline Report, 2017. Government of Nepal, Kathmandu. Online. https://www.npc.gov.np/images/category/SDGs_Baseline_Report_final_29_June-1(1).pdf (Accessed June 18, 2020).

Nwite, J. N. 2015. Effect of different urine sources on soil chemical properties and maize yield in Abakaliki, Southeastern Nigeria. I*nternational journal of Advance Agricultural Research* 3: 31–36. http://www.bluepenjournals.org/ijaar/pdf/2015/May/Nwite.pdf .

Pradhan, S. K., Nerg, A. M., Sjoblom, A., Holopainen, J. K. and Heinonen-Tanski, H. 2007. Use of human urine fertilizer in cultivation of cabbage (*Brassica oleracea*): Impacts on chemical, microbial and flavor quality. *Journal of Agricultural and Food Chemistry* 55(21): 8657–8663. https://doi.org/10.1021/jf0717891

Pradhan, S. K., Holopainen, J. K. and Heinonen-Tanski, H. 2009. Stored human urine supplemented with wood ash as fertilizer in tomato (*Solanumlycopersicum*) cultivation and its impacts on fruit yield and quality. *Journal of Agricultural and Food Chemistry* 57(16):7612–7617. https://doi.org/10.1021/jf9018917

Pradhan, S. K., Holopainen, J. K., Weisell, J. and Heinonen-Tanski, H. 2010. Human urine and wood ash as plant nutrients for Red Beet (*Beta vulgaris*) cultivation: Impacts on yield quality. *Journal of Agricultural and Food Chemistry* 58(3): 2034–2039. https://doi.org/10.1021/jf9029157

Richert-Stintzing, A., Gensch, R., Jonsson, H., Stenstrom, T.A. and Dagerskog, L. 2010. *Practical Guidance on the Use of Urine in Crop Production*. SEI (Stockholm Environment Institute), Stockholm.

Rodhe, L., Richert-Stintzing, A. and Steineck, S. 2004. Ammonia emissions after application of human urine to a clay soil for barley growth. *Nutrient Cycling in Agroecosystems* 68: 191–198. https://doi.org/10.1023/B:FRES.0000019046.10885.ee

Simha, P. and Ganesapillai, M. 2017. Ecological sanitation and nutrient recovery from human urine: How far have we come? A review. *Sustainable Environment Research* 27: 107-116.

Steering Committee for National Sanitation Action. Sanitation and Hygiene Master Plan (SHMP). 2011. Government of Nepal. Kathmandu. Online http://washinschoolsmapping.com/wengine/wp-content/uploads/2015/10/Nepal-Government-Sanitation-and-Hygiene-Master-Plan.pdf (Accessed on September 12, 2019)

Upreti, H. K., Shrestha, P. and Paudel, P. 2013. Effect of human urine as fertilizer on crop production. *Agronomy Society of Nepal* 2: 168–172. https://doi.org/10.3126/ajn.v2i0.7532

WaterAid Nepal 2006. *WaterAid Nepal: Position Paper on Sanitation (2005–2010)*. WaterAid, Kathmandu.

Winblad, U. and Simpson-Hébert, M. 2004. *Ecological Sanitation*, revised and enlarged edition. SEI (Stockholm Environment Institute), Stockholm.

WHO (World Health Organization) 2006. *WHO Guidelines for the safe use of wastewater, excreta and greywater: Volume 4. Excreta and greywater use in agriculture*. WHO, Geneva.

Yogeeshappa, H. and Srinivasamurthy C. A. 2017. Effect of Human Urine and Cattle Urine on Growth and Yield of Tomato (*Solanum lycopersicum*) in Red, Laterite and Black Soils of Karnataka, India. *International Journal of Current Microbiology and Applied Sciences* 6(12): 1597–1605. https://doi.org/10.20546/ijcmas.2017.612.179

Chapter 4. People's perception on ecological sanitation and health risks associated in Central Nepal

4.1. Introduction

Lack of improved water source, improved drinking water, improved sanitation facility are the challenges for low- and middle- income countries as explained in Chapter 1. To overcome this situation, ecological sanitation (ecosan) could play an important role. Ecosan is the practice of converting human urine and excreta into liquid fertilizer and compost for beneficial reuse of the nutrients contained in the urine and excreta. Materials such as ash, sawdust, and rice husks are used to cover fecal material, to eliminate odors and to absorb moisture from the excreta. Combined reuse of the fecal compost and stored urine can supply nutrients to vegetables as chemical fertilizers do (Hijikata et al. 2014). Many advantages such as water conservation, recycling of nutrients, affordable sanitation is associated with ecosan toilet. Ecosan practice is effective at reducing the fecal contamination of the surrounding water environment, thereby liming/reducing the health risk from unavoidable accidental ingestion of water (Harada and Fujii 2020).

Social attitudes and perceptions towards use of excreta should be also considered because they would vary with age, sex, religion, education, employment, region and physical capacity (Mariwah and Drangert 2011). People's behavior towards the urine-diverting toilet and in utilizing human excreta as fertilizer would be guided by their perception towards it. As Nimoh et al. (2014) found, the respondents' attitudes and perceptions toward excreta and their decision to use excreta for agricultural purpose differ according to their socioeconomic characteristics. Andersson (2015) reported in Uganda that the supportive attitude of farmers for urine fertilization was due to its ability to ensure food and economic security given that they have few other options for soil nutrient management. Lienert et al. (2003) indicated that 57% of Swiss farmers liked the idea of using urine-based fertilizers with 42% stating their willingness to buy such products. The main factors that motivated farmers to respond positively to reuse of urine were improved soil quality and potential of cost savings with reduced use of chemical fertilizers (Simha et al. 2017). However, limited studies on socio-technological perspective on farmers and consumers attitudes about the design and use of urine diverting toilets have been conducted till date.

The re-use of human excreta and organic waste as fertilizer is not new in Nepal. Many communities have developed systems for collecting waste and using it in their fields. In mountainous regions where open defecation is difficult due to the very cold weather condition, toilets are made inside the house, generally in the ground floor which is connected with the pig shelter in the basement (Poudel and Adhikari 2015). Similarly, knowledge on using urine and feces as agriculture fertilizer is not new for Newar community in Nepal. However, these traditional practices are slowly diminishing as the younger generations hesitate to adopt it in the name of modernization (Poudel and Adhikari 2015). Those waste and excreta which were being used as fertilizer are now disposed of through sewer systems.

Since concept of ecosan in its modern sense was first introduced in Nepal in 2002, more than 2,000 ecosan toilets were installed in 19 districts (Section 1.4.3). Most of the UDDT projects are currently launched in communities with long-standing traditions of using human waste on crops and UDDT acceptance reported was 71% (WaterAid, 2008). However, ecosan users' perception after installation of an ecosan toilet is not fully understood. In order to extend an ecosan toilet and to identify the target group for dissemination, perception of both ecosan users and non-ecosan users should be incorporated. Ecosan users' perception will help to understand the drawbacks associated with ecosan toilet and to minimize those drawbacks in future. Non-ecosan users' perception will help to understand their concept towards ecosan technology, willingness to install such technology and to have modification in the system as per needed.

This study also tried to evaluate the risk of excreta reuse due to handling of ecosan manure because there is a risk of transmission of bacteria during handling of ecosan manure for which better treatment and management is necessary. These resources potentially contain microbial pathogens that mainly cause gastrointestinal infections (WHO 2006). Fecal contamination of incompletely treated excreta and other frequently contacted objects (i.e., handheld tools, toilet pits) strongly influenced hand contamination, and influenced ingested dose of fecal microorganisms, governed by hand-to-mouth contact frequencies (Julian et al. 2018). To understand the fecal transmission, only *Escherichia coli* tests was conducted in this study due to limitation of resource. *E. coli* is a member of the fecal coliform group and is a more specific indicator of fecal pollution than other fecal coliforms.

Generally, due to the long tradition of urine and excreta reuse in Nepal, most of the users think that it is safe to use urine and excreta in agriculture. However, some study showed that the waste produced from those ecosan toilets is unsafe for use in agriculture and increases the health risks to the communities (Morgan and Mekonnen 2013). The addition of ash and lime reduces smell, covers the excreted material which in turn reduces the risk for flies and improves the aesthetical condition, decreases moisture content and promotes pathogen die-off through the elevated pH effect (Schonning and Stenstrom 2004). But, if an ecosan toilet is not well managed, it may increase the transmission of diseases like diarrhea and helminthis in the community (Jimenez et al. 2007; Schonning et al. 2007). The risk of fecal matter to the ecosan users varies depending upon the handling behavior or the application practices. The use of human excreta in agriculture is beneficial if it is composted well and did not associate risks with the use of composted excreta if it was dry and lacked odour (Jensen et al. 2008). Hence in this study, risk perception of users and *E. coli* tests were combined so as to understand the handling behaviors and fecal contamination associated due to such practices.

4.2. Methodology

4.2.1. Study Area

The study was conducted in a village of Bhaktapur district in October 2018. The details of the study area are described above in Chapter 2. This village was chosen because both ecosan users and non-ecosan users were found in the same area. This helped to understand the perspective of farmers and consumers about excreta use in agriculture.

The houses are traditionally made of clay and bricks. The traditional houses were well adapted to the local climate with the use of local building materials (Gautam et al. 2019). However, traditional houses are being replaced by the contemporary ways of construction, modern design and technology including artificial materials (Rijal 2012). Ecosan toilets for 60 households were installed in the village by the financial and technical help from Environment and Public Health Organization (ENPHO) in 2007/2008. During that time, ecosan was the new term in the study area. ENPHO informed the households with no toilets about the benefits and use of ecosan toilet. ENPHO tried to motivate them to use toilet and to help households technically and financially for toilet construction in order to meet the country's agenda to make a country open defecation free (ODF). There was no hard and fast rule for the households to choose and construct ecosan toilet. The households were given options of biogas toilet, normal pit latrine and ecosan toilet. The decision to choose the type of toilet was with the household's head (some might discuss with the household members). Depending upon the land availability, household's preferences, ecosan toilet was constructed for 60 households. After several years, a sanitation campaign was started in 2011 to declare the district ODF and became the first ODF district in Kathmandu valley. This village was chosen as a study area because the area represented an example of both ecosan and non-ecosan toilet and hence the perception of ecosan users and non-ecosan users would be well understood.

4.2.2. Population sampling, data collection and compliance

This study was based on questionnaire survey and *E. coli* tests. Ecosan toilet users' in the community of the study area were listed from the data of ENPHO. The respondents were randomly selected for questionnaire survey from the list mentioned above. Interviewing and sampling for *E. coli* tests were conducted only after people's consent with explanation of study objectives, anonymous data handling, and a publication way.

The total number of respondents was 30 comprising 15 households (25% of ecosan toilet installed) with ecosan toilet in their house and 15 households (same number as ecosan users') from 1193 households with toilet other than ecosan. As this study tried to focus on perception of households about ecosan use, the number of interviewed households was limited because many of the ecosan users gave up ecosan at the time of survey. The major reasons for giving up ecosan were building of new house with flush toilet, destruction of house and toilet due to earthquake of 2015, difficulty to get ash and inconvenience to use by new members. All interviewed households (except one) belonged to the Newar communities, who in ancient days used toilet wastes collected from several households outside of their village. The questionnaire for the study was comprised of three main sections. The purpose of section I was to establish the socio-economic and cultural profile of the respondents, section II sought details of their farms and the type of farming they pursued, livestock reared, section III looked for insights into the respondents' perceptions, attitudes, inclinations, and willingness to shift towards use of ecosan toilet and human excreta based fertilizers.

Five households with ecosan toilet were selected to conduct *E. coli* tests. The sample was taken from both hands and both shoes back of the member handling ecosan manure. The samples were collected two times by using a swab test kit (ST-25 PBS). The first sample was collected before touching ecosan manure, i.e. before ecosan manure was applied in the field. The second sample was collected from the washed hand after the application was completed. Similarly, the soil before and after the application of ecosan manure was tested to understand the difference in presence of *E. coli* on soil before and after application. Urine samples were not collected for *E. coli* tests because in the study area very few households (13.3%) were found collecting urine separately for agricultural use.

4.2.3. Microbiological analysis

The collected soil samples and ecosan manure samples were analyzed for fecal indicator (*E. coli*) (Figure 4.1, Figure 4.2). In this study, *E. coli* was considered to be the fecal indicator bacterium to infer the presence of fecal microorganisms, potentially including fecal pathogens. *E. coli* has been widely applied in risk assessment studies in the form of fecal indicator ratio. *E. coli* were cultured following a method 9215A in Standard Methods (APHA 1998) using XM-G Agar (Nissui). This is one of the essential indicators when evaluating microbial risk from various fertilizer products including faeces (Faechem et al. 1983; Sidhu and Toze 2008). Soil sample (10 g) and ecosan manure sample (10 g) were homogenized using a minishaker separately in 100 ml of buffer phosphate solution. After this 10-fold dilution series with buffer solution was prepared as extract liquid. The extracts were filtered through a membrane filter with pore size of 0.47 µ m, upon which the bacteria were trapped. The filter was then placed on petri dish with XM-G Agar and incubated at 37°C for 24 h. According to the colar profile of colonies, the number of *E. coli* colonies on each petri dish were counted and the results were expressed as colony-forming units per gram of sample (CFU/g) according to FAO (2001).

The sample in the swab test kit was mixed properly before pouring into the membrane filter with pore size of 0.47 µ m. The filter was placed on petri dish with XM-G Agar and incubated at 37°C for 24 h. According to the color profile of colonies, the number of *E. coli* colonies on each petri dish were counted and the results were expressed as colony-forming units (CFU/hand or CFU/shoe' back).

Figure 4.1. Laboratory of ENPHO

Figure 4.2. *E. coli* cultured in a petri dish

4.2.4. Calculation and statistical analysis

E. coli concentration data were normalized by log transformation before analysis of variance (ANOVA). Statistical analysis was conducted using IBM SPSS Statistics (version 20), where a significant difference was reported at a 5% significance level.

4.3. Results and discussion

4.3.1. Socio-economic characteristics of respondents in the study area

The results of the socio-economic characteristics of respondents for ecosan users and non-ecosan users are presented in Table 4.1. During the questionnaire survey, 53% respondents were female in the households with ecosan toilet and 47 % respondents were female in the households with no ecosan toilet. The average age of respondents was 46.6 years and 40.1 years in ecosan users and non-ecosan users respectively. The average household size was 5.5 and 4.9 in ecosan users' and non-ecosan users, respectively. The average size of family in Nepal is 4.6

with 17.1% nuclear households (family size 1-2) (CBS 2016). The transition from joint family to nuclear family is found increasing in the study area.

Table 4.1. Socio-economic characteristics of respondents

Variable		Frequency (%)	
		Ecosan users	Non-ecosan users
Gender	Male	8 (53.3)	7 (47.0)
	Female	7 (47.0)	8 (53.3)
Age	20-29	1 (6.6)	1 (6.6)
	30-39	3 (20.0)	7 (46.6)
	40-49	6 (40.0)	5 (33.3)
	50-59	3 (20.0)	2 (13.3)
	60 and above	2 (13.3)	0 (0.0)
Household size	5 and below	10 (66.6)	9 (60.0)
	6 and more	5 (33.3)	6 (40.0)
Source of income	Farming only	2 (13.3)	1 (6.6)
	Farming + service	10 (66.6)	10 (66.6)
	Farming + casual labor	3 (20.0)	2 (13.3)
	Farming + family business	0 (0.0)	1 (6.6)
	Farming + remittance	0 (0.0)	2 (13.3)
Landholding size	Below 0.1 ha	9 (60.0)	10 (66.6)
	0.1 - 0.5 ha	6 (40.0)	5 (33.3)
Livestock	Cow	3 (20)	2 (13)
	Goat	11 (73)	9 (60)
	Chicken	8 (53)	10 (67)
	No livestock	0 (0)	3 (20)

The average farm size was similar (0.10 ha) in both types of households. The largest amount of vegetable producer among three districts in Kathmandu valley is Bhaktapur with an average landholding size of 0.15 ha for crop farming (MoAC 2006). Land holding size per family and field size have both decreased markedly in recent years (Deshar 2013). All households in the study area were found using LPG for cooking purpose. The study area in previous days used to use firewood for cooking purpose but gradually shifted from traditional cooking practice to use LPG due to lack of firewood and high availability of LPG with additional benefits such as its convenience, smoke free and time saving nature. All non-ecosan users have pour flush toilet facilities in their house. Poor households are less likely to use the improved sanitation facility whereas most of the rich households have access to improved pour/flush toilet (MoH, New Era and ICF 2017). The study conducted in Nepal by Budhathoki (2019) reported that poor households are less likely to have piped water connection in their home which limits access to the improved flush toilet. The principal occupation of both households was farming where rice, green vegetables, cauliflower were cultivated. Less than 7% of the farmers belonged to the age category <30 years, showing consistency with the result from Sharma (2007) and Rajan (2013), reflecting the ongoing demographic crisis in Indian agriculture in which young people are increasingly less inclined to look to farming for their livelihood. Nepal's agriculture is also facing labor crisis, resulting in barren lands due to youth's migration either to the city or to abroad in search of quality living and to earn money. In Nepal, the proportion of economically active population depending on agriculture had fallen from 81 percent in 1991 to 66 percent in 2004 with significant drop in GDP (GoN 2009). Most of the household members of rural Nepal have been abroad for foreign employment. Remittance has become the major part of the national economy as it shares 26.9% in GDP in 2016/17 (Sapkota 2018). After returning home, only a few of them have been engaging in agriculture (Chaudhary 2019). Almost all respondents surveyed did not wish to disclose their income whereas most of them mentioned no savings from their income.

Higher number of households (11 ecosan users, 13 non-ecosan users) have land less than 0.1 ha. The study conducted by Maltsoglou and Taniguchi in 2004 in Nepal concluded that the househods that have the average largest herd size (3.5 Tropical Livestock Unit (TLU) are located in the mountains compared to rural hills (3.1 TLU), Terai (2.7 TLU), urban areas in Kathmandu (1.0 TLU) and in other urban areas (1.5 TLU). Fewer households' own livestock in the urban areas in Kathmandu and in other urban areas (FAO, 2004). The higher number of livestock in the households with ecosan toilet (0.85 TLU) might reflect the need of manure to use in their farm no matter through any source., chemical fertilizer or cattle manure or ecosan manure. Farm size and livestock number reared were related to each other among non-ecosan users (higher the landholding size higher is the livestock number, $r = 0.988$ ($p<0.01$)) as in other parts of the country but the result was contrast in the households with ecosan users with low land holding size.

Landholding size and TLU was negatively correlated among ecosan users with low landholding size. Ecosan user households with low landholding size prefer to have more cattle's in order to fulfill fertilizer demand for their land. Because the available land size is small, ecosan manure in addition to cattle manure is preferred as a substitute to chemical fertilizer. This is the reason that even after the collapsing of the house due to devastating earthquake of 2015, households would like to keep their ecosan toilet by repairing the damage. In contrast, the non-ecosan user households whose house was collapsed by the earthquake of 2015 built new houses and did not want to keep cattle because of their thought that livestock decrease the aesthetic value of modern house. Non-ecosan users more likely depend upon chemical fertilizer to fulfill the fertilizer demand. Recently, people are selling land in the high price and interested to construct so called modern building or sophisticated house. The young generations do not want to engage in the activities like farming and livestock rearing. Most commonly used chemical fertilizers in the study area are urea, di-ammonium phosphate and murate of potash. The price of these fertilizer are Rs. 18, 45, and 32 per kg respectively (MOAD 2016). In addition, sea freight, port clearance and the cost of transportation can account for as much as 20% of the cost of delivered fertilizer. Being the study area is not far from the Kathmandu valley, there is no constraint of chemical fertilizer as in other rural hilly areas. The households involved in agriculture does not have pressure to seek for the alternatives of chemical fertilizers in terms of availability. These might be the reasons of having lesser livestock number in the households. In contrast, large number of households in Palung VDC have land 0.1 – 0.5 ha followed by >0.5 ha and <0.1 ha (Figure 4.4). As Gundu VDC lies in the outskirt of Kathmandu Valley, several households in recent days are selling their land with high prices and constructing new buildings. The condition in Palung VDC is different. Still majority of the households are dependent upon agriculture. Due to the transportation constraint, they won't get high prices of their land even though they would like to sell.

4.3.2. Ecosan toilet in the study area and user's perception

Table 4.2 presents the results of the facts in today's scenario of ecosan toilet in the Gundu VDC.

Table 4.2. The facts associated with ecosan users

Variable	Level of agreement (%)	
	Yes	No
ENPHO as a motivator to install ecosan toilet	100.0	0.0
Continuous use of urine and excreta as fertilizer till date	100.0	0.0
Urine is collected separately to use as a fertilizer	13.3	86.6
Use protective measure while handling urine and excreta	46.6	53.3

All interviewed ecosan users mentioned that the motivating factor in installing ecosan toilet in their house was the campaign started by ENPHO during 2007/08. The financial and technical help from ENPHO was the attraction to install ecosan toilet in their house at that time. The decision to construct either pit latrine, ecosan toilet or biogas toilet was decided by the family members depending upon the choice and need. Cultural and social norms play an essential role in deciding which type of sanitation system to use. According to Harada and Fujii (2019), even without cultural background of human excreta use, a high demand for feces use could be successfully created through association with a perception of the value of feces in agriculture. There are many traditional examples of wastewater and excreta management in several parts of Nepal. Sherpas in mountainous regions still feed their feces to pigs, Newar of Kathmandu valley still use feces in producing vegetables, a farmer in middle hill still uses greywater in their kitchen garden (Poudel 2015). Local people are worried about the use of chemical fertilizers, as they believe that these fertilizers cause soil compaction, which hinders other farming operations (Poudel 2015). Human excreta are considered to be the richest manure and are collected in a special dry latrine pit. Such systems are accepted in those communities not only because people are poor but because of the long traditions of using human waste in crops. However, these traditional practices are slowly diminishing as the younger generations hesitate to adopt it in the name of modernization. Thapa (2019) mentioned modernization as a regular process of change that happens by adopting new tools and technology. It provides opportunities for people to leave the village and joint family system and shift to the industrial areas. It has affected the family structure, marriage system, prevailing social norms, values and cultures in Nepal. The study also reported that in the rural areas of Nepal where the impact of modernization is less, the joint family is practiced whereas in the cities and urban dwellings, nuclear family system is in existence. A similar culture of using human waste in farm was adopted in ancient days in the study area. The use of human excreta as a fertilizer has a history of more than 200 years in Nepal (Ho and Mathew 2002). They mentioned in their book that sanitation systems in cities, where night soil was collected door to door and taken to surrounding farms for crop fertilization can be dated as far back or further.

According to the ENPHO personnel, because of the long tradition of using human waste, 60 households agreed to construct ecosan toilet in their houses in 2007/08. All ecosan users interviewed during this study were using ecosan toilet continuously till date. Figure 4.3 shows inside of the ecosan toilet in one of the respondent's house. All users were found using urine and excreta as a source of fertilizer. After years, majority of the households (86.6%) (Table 2) changed the habit of urine collection (Figure 4.4). Although similar result of using urine by lesser households compared to the households using feces was reported in Malawi in the study by Harada and Fujii (2019) the reason for not using urine is different. According to Harada and Fujii (2019), no use of human urine from ecosan toilet in Malawi was related with no use of animal urine leading to psychological constraint for use of human urine. In contrast, in this study the respondents mentioned that they do not collect the urine from the ecosan toilet separately but use them by mixing with the kitchen waste and cattle manure. Although the respondents are aware of the positive effects of urine as fertilizer value, the reason for not collecting urine is related to the fast filling of the collecting tank, problem associated with storage of urine and difficulty to carry out urine in the field because of its large volume after dilution. The study area is located in the hilly region and terrace farming is common practice. Because majority of the farms are located farther from the house, the family members found it difficult to carry the urine jar to the field. Instead, to recover the fertilizer value of urine, the households mix urine with the households' manure (kitchen waste and cattle manure collected outside of the house). They believe that the urine accelerates the manure decomposition rate and manure could be utilized whenever necessary. It also solved the problem of storage, carrying urine to the field and need of water for dilution. It was found from the survey that after defecation, ash was used as an additive to sanitize fecal matter. All interviewed households mentioned that they wait for six months to use excreta as a fertilizer. The ash had a higher effect on the operational parameter (increase pH and decrease moisture content) during storage compared to the sawdust (Niwagaba et al. 2009). Demonstration on urine and feces use for agriculture enables the participants to recognize the effects of human waste on agriculture (Harada and Fujii, 2019). However, the perception of people on agricultural value of urine and feces is associated to the continuous use. In this survey the author found that the ecosan users are not much conscious about health risk, which was justified by the result that 53.3% respondents were found not using any protective measures while handling ecosan manure (Table 2). All interviewed respondents agreed on the positive effect of ecosan toilet in terms of fertilizer use of urine and excreta. Eighty percent of the respondents mentioned that they do not have any problem caused by ecosan toilet and is the reflection of positive side of ecosan toilet. Majority of the respondents mentioned that they could harvest 220-250 kg of ecosan manure in one year (half in six months period). Being majority of households have land less than 0.1 ha, the amount of ecosan manure harvested is enough if cattle manure incorporated with urine is applied together with ecosan manure. In the case if number of cattle reared is small or zero, the farmers need to supply chemical fertilizers to meet the fertilizer demand. The amount of fertilizer that the households does not need can be easily sold. They could sell those collected ecosan manure at the rate of Rs 35 per kg, where Rs is Rupee, local currency used in Nepal. Among 15 respondents, 2 household (13.3%) had 6 members in the family and 13.3% had more than 6 members in the family. No complaints or burdens regarding emptying pit was explained by the respondents during the survey. Despite of awareness about the use of ecosan manure, construction of modern house, interest on employment activities other than farming, less availability of land size, water availability, and easy accessibility of chemical fertilizers were observed as factors that distract households to adopt or to continue ecosan toilets.

Figure 4.3. Ecosan toilet

Figure 4.4. Urine collected from ecosan toilet in the study area

4.3.3. Perception of non-ecosan users toward excreta reuse for agricultural purpose

This section presents the results on the respondent's (non-ecosan users) perceptions and knowledge towards using urine and excreta for agricultural purpose, their willingness to construct ecosan toilet and their attitude towards the products grown by using ecosan manure. Among the respondents, it was found that although these non-ecosan users are using either pit latrine or flush toilet, 87% of the interviewed respondents had experience of ecosan toilet use. Twenty-seven percent respondents (4 households) mentioned that they had used ecosan toilet in their previous house (old ecosan users') and 60% (9 households) respondents replied that they had used ecosan toilet in their neighbors' house. Among 15 respondents, only 13% (2 households) respondents were found who has not used ecosan toilet till date. It was understood from the survey that during the devastating earthquake in 2015, 3 households lost their houses along with their ecosan toilets. Once the house was recovered after earthquake, the households switched from ecosan toilet to the ordinary or flush toilet. The reason for not constructing an ecosan toilet in the new house is due to the perception that such ecosan toilet is suitable only for old and traditional house. Availability of large space around the house, use of firewood for cooking in those houses making ash available to use in ecosan toilet and engagement of household members in agriculture best suited to ecosan toilet in traditional houses. In contrast, lack of space in the newly constructed house as a result of increased land price, family members wish to install toilet inside the house, gradual decrement of agricultural land tended to make the ecosan toilet unsuitable for modern houses. Construction of a new house with modern toilet is the necessity of new generation. One of the previous users among the interviewed respondent mentioned that they shifted from ecosan toilet to modern toilet due to the wish of the younger family members. The respondents also mentioned that people gradually started nuclear family and seek other income generating sources giving up farming.

Among the total respondents, 83% replied that they had tasted the products grown from ecosan manure which represented that the respondent consumers do not mind consuming products grown from ecosan manure (Figure 4.5). They got those products from their neighbors who had an ecosan toilet in their house and raised the crops or vegetables using ecosan manure. It is common mostly in the village of Nepal to share or exchange newly grown vegetables among the neighbors. Among those respondents who tasted products from ecosan manure, 60% mentioned better taste of product grown compared to the one grown from chemical fertilizer while 33% mentioned no difference on taste in the product grown from ecosan manure and other fertilizer (Figure 4.5). This result showed the possibility of ecosan toilets still exists if toilet could be served with some modification and if it could be adjusted to modern toilets. The market for organic vegetable is gradually growing in Kathmandu valley but not all the farmers have the access to that market. Since the vegetables grown in this study area are less in amount, the farmers sell the vegetables together with the vegetables grown by using chemical fertilizers. It would be an advantage for the farmers if the market for the products grown from ecosan manure worth more monetary value based on the taste and quality. It is also interesting to note from this study that even though the respondents did not have ecosan toilet in their house, they were seen irrigating their farms with sewage and greywater, pipes linked from their toilet to farm. They would like to use it as an agricultural value on their farm. This will save their money necessary to pay for the disposal of toilet waste and add nutrients to their field. Generally, in the Kathmandu valley with pour flush toilet, the toilet waste is collected in a septic tank. Once the tank is filled, the designated authority will visit the house to remove the toilet waste after paying the specified amount (money). They have mentioned that the authority charges around Rs. 5000 to remove the waste from their toilet.

Table 4.3. Non-ecosan users' statement to no interest for ecosan toilet construction

Reasons for not having willingness to construct ecosan toilet	Respondents No (%)
No space/ No ash	6 (40)
Not user-friendly	1 (6.6)
Already have toilet	3 (20.0)
No idea	2 (13.3)

In Nepal, farmers take raw (fresh) excreta from latrines to their vegetable gardens and grow good quality vegetables, which are tasty and are in high demand (Mishra 2003). In Siddhipur village of Nepal, most of the farmers use animal manure and raw human excreta as fertilizer for crops and vegetables. They have been doing this practice since ancient days, although it was considered unhygienic by the villagers (Mishra 2003). In the study area, although the respondents are aware of positive effect of ecosan toilet and do not hesitate to consume products grown from ecosan manure, the willingness to construct an ecosan toilet is less (20%) (Table 4.3). Ishii and Boyer (2016) also mentioned that 84% of students in the university of Southeastern region of United States would demand source separation systems to be installed in their halls of residence although their demand declined significantly when the respondents were asked their willingness to pay for it by themselves. In contrast, Lamichhane and Babcock (2013) reported that more than 60% of their test sample of 132 people from the University of Hawaii indicated their willingness to pay an extra $50 to install a urine diverting toilet. One reason that discourages interviewed respondents (40%) from constructing an ecosan toilet is the need of ash to sprinkle after defecation. People living in the outskirt of Kathmandu valley shifted from firewood to gas stove to cook their food. It became challenging to manage ash for ecosan toilet. Only few people (6.6%) mentioned that such type of toilet is suitable for the family with 4-5 members in their house. They mentioned that if the household size is large, the toilet pit fills earlier before six months' time frame, storage time will be less, and frequent emptying of vault would be additional work. Building an ecosan toilet for a family of 5-7 members is ideal but in case that household members are more, the faeces collection chamber should be designed to accommodate higher number of users (UNICEF 2011). The number of pathogens in fecal material during storage will be reduced with time due to natural die off, without further treatment (Schonning and Stenstrom 2004). Less storage time of excreta than recommended (6 months) increase health risks for farmers due to the incomplete sanitization of feces.

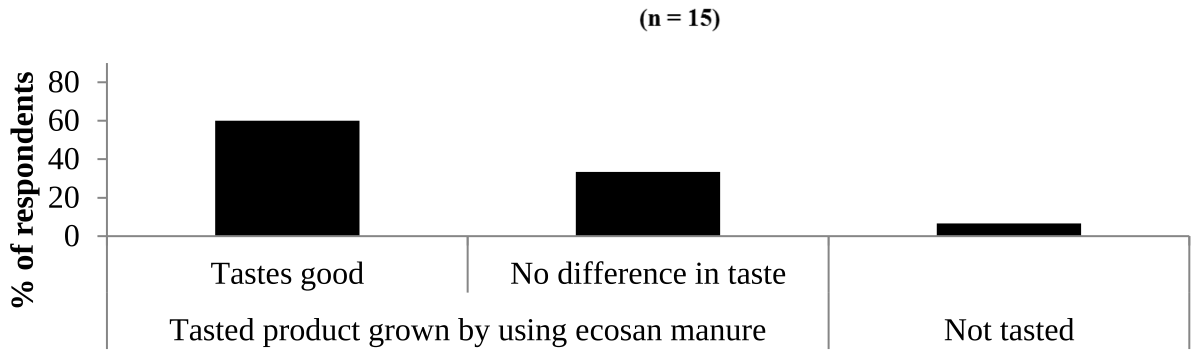

Figure 4.5. Non-ecosan users' response on taste of products grown by using ecosan manure

4.3.4. Microbial risk assessment

Farmers and consumers exposure to ecosan manure was analyzed for risk assessment and are presented in Table 4.4. Majority of the farmers who planted crops three times in a year refers to the fact that they deal with ecosan manure for at least three times in a year (Table 4.4). Compost amending, plowing, seeding, weeding and harvesting are the major works that have direct or indirect contact with ecosan manure. Some farmers were found irrigating their field with the greywater using the pipe linked from their toilet to the farm. During irrigation, farmers did not wear protective clothing and were in direct contact with the irrigation water. Accidental ingestion of irrigation water and consumption of irrigated vegetables are the exposure paths. According to Julian et al. (2018), *E. coli* contamination of excreta and other frequently contacted objects strongly influence hand contamination and *E. coli* contamination of excreta and hand-to-mouth contact frequency influence ingested dose. The effects of contaminated soil on health were lower than direct handling of greywater and compost (Hijikata et al. 2017). Mostly Nepalese people consume green vegetables or other crops after cooking. The risks and existence of fecal microorganisms might be lower if consumed cooked, compared to vegetables consumed raw. Regarding the risks in compost reuse, it is recommended to store human manure for 6-12 months for adequate handling of UDDT (Schonning et al. 2007). The ecosan user households in the study area were found adopting a similar storage period of at least 6 months before applying to the farm as instructed by ENPHO. All interviewed ecosan user used ash as an additive after defecation. The ash or lime is added after each defecation to lower the moisture content and raise the pH to 9 or higher thus creating dryness (Winblad and Simpson-Hebert 2004). Regarding the use of personal protective equipment (PPE), it was confirmed from the ENPHO staffs that during the installation of ecosan toilets in the study area they had instructed to use gloves and masks while taking out the ecosan manure from the filled pit and while using ecosan manure as a fertilizer.

Table 4.4. Exposure scenario of farmers and consumers for risk assessment

Target	Event	Ingestion means	Ingestion scenario	Event no./year
Farmers	Compost amending	Direct contact with compost	Handling of compost with bare hands	3
	Plowing	Soil contaminated by compost	Soil touching after applying compost	3
	Seeding	Soil contaminated by compost	Soil touching after plowing	3
	Irrigation	Greywater	Handling of a watering can or bucket or pipes running through greywater	6
	Weeding	Soil contaminated by compost and greywater	Soil touch twice or thrice for weeding	3
		Greywater on leaves and stems	Touching of plant leaves containing greywater	
	Harvesting	Soil contaminated by compost and greywater	Soil touching for removing vegetables	3
		Greywater on leaves and stems	Touching of plants	
Consumers	Eating	Raw eating vegetables	Eating vegetables raw or not properly washed	-

Though proper instruction on PPE was delivered, from the questionnaire survey result it was observed that more than 50% respondents (Table 4.2) did not use any precautions like gloves or masks while dealing with ecosan manure (Figure 4.6). It reflects the respondents are less concerned about health risks due to handling of ecosan manure or do not want to invest money on those precautions. As reported in Knudsan et al. (2008), personal protective equipment, although perceived to be beneficial, is often neglected due to costs and/or perceived convenience. The households did not hesitate to touch the ecosan manure with the bare hands. It was also observed that after finishing their work on the farm, they are conscious of washing hand but not conscious of washing legs or shoes. From the survey, it was found that ecosan users in the study area believe that it is safe to use human urine and ecosan manure as a fertilizer and did not show more concerns for health risk. This perception about ecosan manure came from older generations who used to use these products in their farm. In rural India, farmers have been observed to rely on the advice of people they know, family members, and in many cases, helpful neighboring farmers rather than expert advice (Simha et al. 2017). Proper guidance and knowledge about possible health risk due to mishandling and improper management of ecosan toilet and ecosan manure should be delivered to the locals so as to minimize the health risks.

Figure 4.6. An old man spreading ecosan manure in his field

4.3.5. Microbial contamination in soil and ecosan manure

For soil samples collected from five households before and after application of ecosan manure, *E. coli* concentration (CFU/g) was measured. *E. coli* was detected in the all the soil samples. Presence of *E. coli* in soil in the initial state before applying ecosan manure suggested that the source of fecal microorganisms in the soil was not only the ecosan manure (Figure 4.7). Besides ecosan manure, other sources such as irrigating water, cattle manure, chicken manure might be the contaminating source of fecal microorganisms, including *E. coli*, in soil. Several factors such as temperature, moisture, nutrients either alone or in combination with soil organisms influence the growth and survival of *E. coli* in soil (Ishii et al. 2010).

Among five ecosan manure samples collected, *E. coli* (CFU/g) was detected in samples of three households (HH 1,4,5) whereas no *E. coli* was detected in ecosan manure samples of two households (HH 2, 3) (Figure 4.7). No *E. coli* detection on two households might suggest that proper management of an ecosan toilet could play a role to sanitize the excreta, lowering the health risks of using excreta.

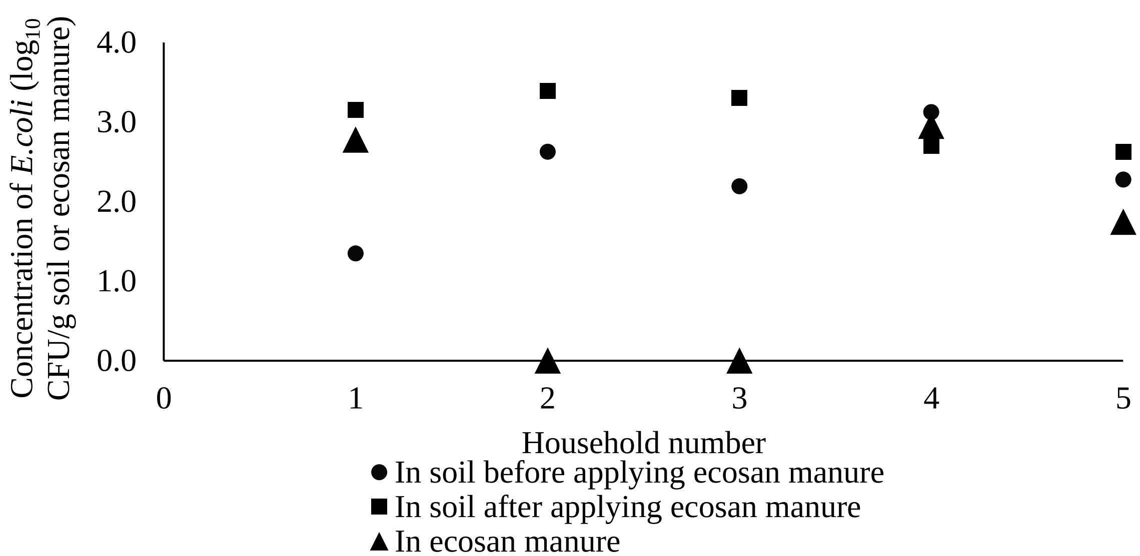

Figure 4.7. Concentration of *E. coli* in soil and excreta due to ecosan manure among five households

4.3.5. Microbial contamination in hands and shoes back

For all five households, 10 hand samples (5 right hand, 5 left hand) and 10 shoes back samples (5 right shoes, 5 left shoes), *E. coli* concentrations was measured. Although the households are concern of washing hands after dealing with ecosan manure, higher concentration of *E. coli* ($\log_{10}$ CFU/hand) even after washing hand (Figure 4.8) was observed. Although there was no significant change in *E. coli* concentration in hand before and after handling among the households, no *E. coli* concentration in hand samples was found in HHs 2 and 4. Higher concentrations of *E. coli* in hand before handling ecosan manure might also indicate that only ecosan manure is not the source for fecal contamination on hand. *E. coli* counts in the faeces with ash decreased with decreasing moisture content and gradual increase in pH during the storage period (Niwabaga et al. 2009). No change in *E. coli* concentration even after washing hand suggests that the concentration could be affected by water used for washing hand and the way of washing.

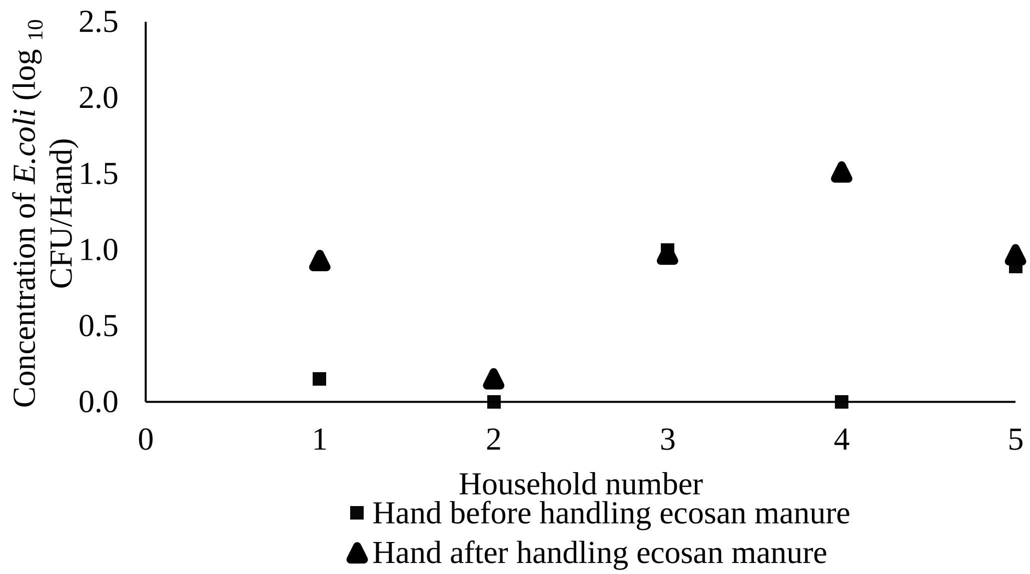

Figure 4.8. Concentration of *E. coli* on hand before and after using ecosan manure among five households

Among five shoes back samples, in HHs 3, 4, and 5, no *E. coli* ($\log_{10}$ CFU/shoe) was detected on shoe sample even before and after dealing with ecosan manure (Figure 4.9). Significant difference in *E. coli* concentration on shoe back before and after washing was observed with high concentration of *E. coli* in shoes back after dealing with ecosan manure or after coming back to home from outside. It is related with the facts that household members were conscious on washing hand but not for washing legs and shoes after finishing their work. It also reflects to the fact that if we give proper attention to the washing not only while dealing with the ecosan manure but during other households activities, it might have positive effects on reducing fecal contamination on hands, leading less fecal exposure and better human health. Along with sanitation, proper hygiene management training and provision of clean drinking water might be the components necessary to achieve the health improvement in the area.

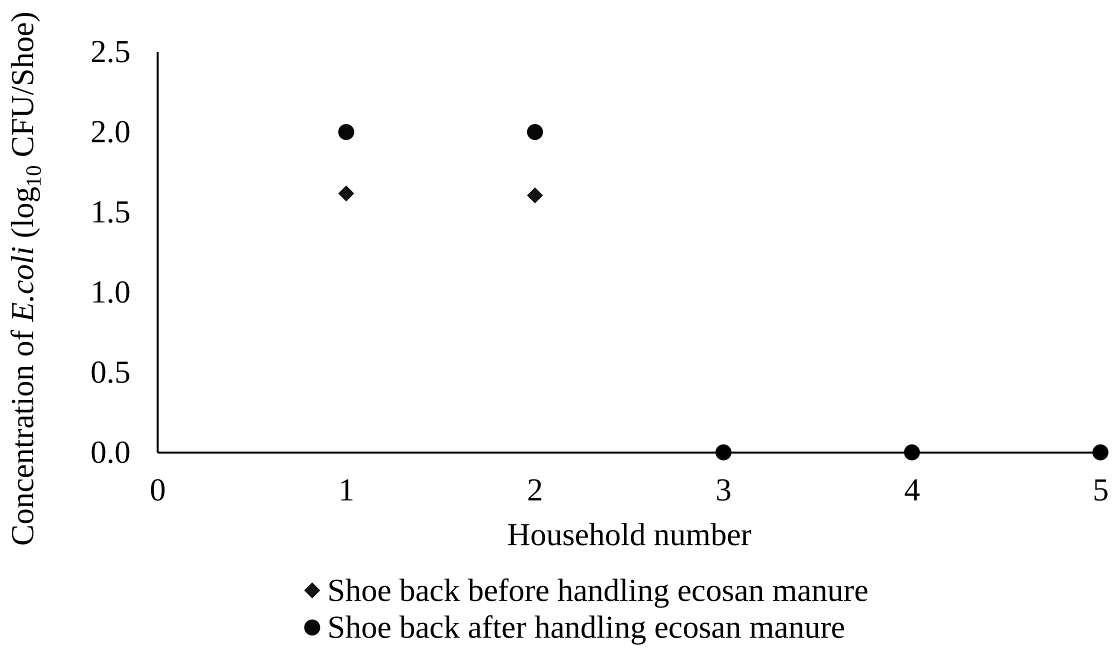

Figure 4.9. Concentration of *E. coli* on shoe before and after using ecosan manure among five households

The current situation about locals' perception might help to address health risk issues associated with ecological sanitation technology and can play a role in dissemination and expansion of such technology. Simha et al. (2017) indicated that for farmers in India to adopt human waste as a fertilizer, they must know someone who uses/used it and/or must be convinced of its crop productivity potential.

4.4. Conclusion

This study investigated both ecosan user and non-ecosan user households' attitudes, and perceptions toward human excreta reuse for agricultural purpose in the study village of Bhaktapur district in Nepal. Farming is the predominant occupation in the study area, and ecosan toilet was disseminated for several households by the financial and technical help from ENPHO. The study found that majority of the respondents disagreed that excreta is the waste. Some households were found continuing ecosan toilet till date while some previous users had already shifted from ecosan to other toilets due to the choice of younger generation to build modern toilet. This result reflects that though non-ecosan users are also motivated to use products from ecosan manure as a fertilizer amendment, the desire of the new family members in the house and recognition that ecosan toilet is not suitable in modern house disabled users to continue it. To minimize the rate of discontinuation after the dissemination of new technology, it is necessary to monitor the condition of toilet and provide suggestions for the betterment of the toilet, to increase ecosan users and to promote excreta reuse in farming. Open discussions on the benefits and risks associated with excreta reuse in agriculture could enrich farmer's knowledge on the handling and appropriate use of excreta as fertilizer. The study concluded that ecosan manure was not only the source of fecal microorganisms. Ecosan manure might get contaminated by fecal microorganisms through other sources if handled inappropriately. Proper attention should be done to reduce such contamination which is found generally neglected by most users. Further research on the factors that influence farmers' decision on excreta reuse for agricultural purpose and perceptions on health risks is recommended to avoid contamination of ecosan manure and associated negative health impact by fecal microorganisms. Time to time and door to door supervision on toilet management and modification to meet the need of younger generation is also recommended for the long-term sustainability of the ecosan. This study is based on the questionnaire survey of ecosan users and non-ecosan users of only one community. Since the adoption of such sanitation technology and the usage of urine and excreta in agriculture vary due to change in socioeconomic characteristics. Future research should try to combine the results from users and non-users from different parts of the country to address the issues about space and wish of households to build ecosan toilet inside the house. In some cases, the adoption and motivation to use ecosan toilet is less due to the problem of space and ash addition after defecation especially for urban residents. Future research should examine how these technologies should be designed and built to support urban residents to maximize the number of users. As mentioned above, the adoption of ecological sanitation varies depending upon the socioeconomic and demographic characteristics. The perception of non-ecosan users also varies depending upon social status, financial status, land availability and awareness towards such technology. Further research should try to include communities with different socioeconomic background to understand the target users and their needs. Additionally, the factors affecting adoption rate should be explored and necessary steps should be carried out to maximize the beneficiaries from such sanitation technologies. In this thesis only *E. coli* tests was conducted as an indicator to fecal contamination for hand, shoe, soil and ecosan manure. Further research should increase examination of fecal microorganism and increase parameter related to crop. The fecal contamination in the vegetables or crops might have effect on the human health.

References

Andersson, E. 2015. Turning waste into value: Using human urine to enrich soils for sustainable food production in Uganda. *Journal of clean production* 9: 290–298. https://doi.org/10.1016/j.jclepro.2014.01.070

Aryal, B., Adhikari, K. and Panthi, S. 2015. Assessment of ecological sanitation approach in Nepal. Technical Journal of Water, Sanitation, Health and Environment. Issued on the occasion of World Water Day- 22 March 2015. 13(1): 7-10.

Budhathoki, 2019. Water supply, sanitation and hygiene situation in Nepal: A review. *Journal of Health Promotion* 7: 65–76. https://doi.org/10.3126/jhp.v7i0.25513

Chaudhary, D. 2018. Agriciltural policies and rural development in Nepal: An overview. *Research Nepal Journal of Development Studies* 1(2): 34–46. https://doi.org/10.3126/rnjds.v1i2.22425

CBS (Central Bureau of Statistics) 2011. *National population and housing census*. National Planning Commission Secretariat, Government of Nepal, Kathmandu.

——— 2014. *Population monograph of Nepal*. Nepal planning commission secretariat, Government of Nepal, Kathmandu.

Clesceri, L. S., Greenberg, A. E. and Eaton, A. D. (eds) 1998. *Standard methods for the examination of water and wastewater*, 20th ed. American water works association and water environmental federation, Washington DC.

Cofie, O., Adeoti, A., Nkansah-Boadu, F. and Awuah, E. 2010. Farmers' perception and economic benefits of excreta use in Southern Ghana. *Resources, Conservation and Recycling* 55(2): 161–166. https://doi.org/10.1016/j.resconrec.2010.09.002

Deshar, B. 2013. An overview of agricultural degradation in Nepal and its impact on economy and environment. *Global Journal of Economics and Social Development* 3(1): 1–20. https://www.ripublication.com/gjesd/gjesdv3n1_01.pdf

ENPHO (Environment and Public Health Organization) 2006. *Assessment of ecosan toilets in Nepal: Final report*. ENPHO. https://sswm.info/sites/default/files/reference_attachments/ENPHO%202006%20Assessement%20of%20Ecosan%20Toilets%20in%20Nepal.pdf. (Accessed March 3, 2016)

FAO (Food and Agriculture Organization) 2001. Manual of food quality control: Microbiology analysis, 10th ed. UK.

FAO (Food and Agriculture Organization) 2004. Poverty, livestock and household typologies in Nepal. Agricultural and Development Economics Division. FAO, United Nations.

FAO (Food and Agriculture Organization) 2017. *The future of food and agriculture: Trends and challenges*. FAO, Rome.

Gautam, B., Rijal H. M. and Shukuya, M. 2019. Regional differences of wintry indoor thermal environment of traditional houses in Nepal. *IOP Conference Series: Earth and Environmental Science* 294: 012034. https://doi.org/10.1088/1755-1315/294/1/012034

Feachem, R. G., Bradley, D. J., Garelick, H. and Mara, D. D. 1983. *Sanitation and disease health aspects of excreta and wastewater management*. John Wiley & Sons, Chichester.

Harada, H. and Fujii, S. 2020. Challenges and Potentials of Ecological Sanitation: Experiences from the Cases in Vietnam and Malawi. *Sanitation Value Chain* 4(1): 3–16. https://doi.org/10.34416/svc.00015

Hijikata, N., Sangare, D., Sou/Dakoure, M., Toure, I., Ushijima, K., Ito, R. and Funamizu, N. 2014. Evaluation of vegetable yields for income estimation using human urine and compost originated from on-site resource oriented sanitation system, a case of Burkina Faso. *Proceedings of IWA Specialist Conference on Global Challenges: Sustainable Wastewater Treatment and Resources Recover*; 15-25.

Hijikata, N., Sou/Dakoure, M., Sossou, S. K., Brou, A. L., Maiga, A. H. and Funamizu, N. 2017. Microbial risk assessment for agricultural production cycle of on-site resource oriented sanitation systems: A case of Burkina Faso. *Sanitation Value Chain* 1(1): 15–25. https://doi.org/10.34416/svc.00002

Ho, G. and Mathew, K. (eds) 2004. Sustainability of water resources. *Preceedings of the International Conference at Murdoch University on 13–14 November 2002*; 91-101.

Ishii, S., Yan, T., Vu, H., Hansen, D. L., Hicks, R. E. and Sadowsky, M. J. 2010. Factors controlling long term survival and growth of naturalized *Escherichia coli* populations in temperate field soils. *Micorbes and Environments* 25(1): 8–14. https://doi.org/10.1264/jsme2.ME09172

Ishii, S. K. L.and Boyer, T. H. 2016. Student support and perceptions of urine source separationin a university community. *Water Resource* 100: 146–156. https://doi.org/10.1016/j.watres.2016.05.004

Jensen, P. K. M., Phuc, P. D., Knudsen, L. G., Dalsgaard, A. and Konradsen, F. 2008. Hygiene versus fertilizer: The use of human excreta in agriculture: A Vietnamese example. *International Journal of Hygiene and Environmental Health* 211(3–4): 432–439. https://doi.org/10.1016/j.ijheh.2007.08.011

Jimenez, B., Austin, A., Cloete, E., Phasha, C. and Beltran, N. 2007. Biological risks to food crops fertilized with ecosan sludge. *Water Science & Technology* 55(7): 21–29. https://doi.org/10.2166/wst.2007.122

Julian, T. R., Vithanage, H. S. K., Chua, M. L., Kuroda, M., Pitol, A. K., Nguyen, P. H. L., Canales, R. A., Fujii, S. and Harada, H. 2018. High time-resolution simulation of *E. coli* on hands reveals large variation in microbial exposures amongst Vietnamese farmers using human excreta for agriculture. *Science of The Total Environment* 635: 120–131. https://doi.org/10.1016/j.scitotenv.2018.04.100

Kundsen, G., Phuc, P.D., Hiep, N.T., Samuelsen, H., Jensen, P.K., Dalsgaard, A., Raschid-Sally, L., Konradsen, F., 2008. The fear of awful smell: risk perceptions among farmers inVietnam using wastewater and human excreta in agriculture. Southeast Asian J, Trop. Med. Public Health 39, 341-352.

Lamichhane, K. M. and Babcock, R. W. 2013. Survey of attitudes and perceptions of urine diverting toilets and human waste recycling in Hawaai. *Science of The Total Environment* 443: 749–756. https://doi.org/10.1016/j.scitotenv.2012.11.039

Lienert, J., Haller, M., Berner, A., Stauffacher, M., Larsen, T. A. 2003. How farmers in Switzerland perceive fertilizers from recycled anthropogenic nutrients (urine). *Water science & technology* 48(1): 47–56. https://doi.org/10.2166/wst.2003.0013

Mariwah, S. and Drangert, J.-O. 2011. Community perceptions of human excreta as fertilizer in peri-urban agriculture in Ghana. *Waste Management Resource* 29(8): 815–822. https://doi.org/10.1177/0734242X10390073

Maltsoglou I., Taniguchi K. 2004. *Poverty, Livestock and Household Typologies in Nepal* (ESA Working Paper No. 04-15). Agriculture and Development Economics Division, FAO, Rome.

Mishra, N. K. 2003. Ecosan in past and present effort in Nepal. *Proceedings of the 2nd International Symposium on Ecological Sanitation*; 277–278.

MoAD (Ministry of Agriculture Development) 2016. *Statistical information on Nepalese agriculture 2072/73 (2015/16)*. Government of Nepal, Kathmandu.

MoAC (Ministry of Agriculture) 2006. *National Agriculture Policy*. Government of Nepal, Kathmandu.

MoH (Ministry of Health), New Era and ICF 2017. *Nepal Demographic and Health Survey 2016*. Ministry of Health, Kathmandu.

MoF (Ministry of Finance) 2016. Economic survey. Government of Nepal, Kathmandu.

Montgomery, M. A., Bartram, J. and Elimelech, M. 2009. Increasing functional sustainability of water and sanitationsupplies in rural Sub-Saharan Africa. *Environmental Engineering Science* 26(5): 1017–1023. https://doi.org/10.1089/ees.2008.0388

Morgan, P. and Mekonnen, A. T. 2013. *Paving the way to scaling-up: Factors contributing to the adoption of ecosan toilets and safety of humanure in Malawi*. Department for International Development, London. Online. https://assets.publishing.service.gov.uk/media/57a08a42e5274a27b20004e9/Morgan_and_Mekonnen_2013_Paving_the_Way_to_Scaling_Up_Ecosan.pdf (Accessed June 10, 2020)

Nimoh, F., Ohene-Yankyera, K., Poku, K., Konradsen, F. and Abaidoo, R. 2014. Farmers' perception on excreta reuse for peri-urban agriculture in southern Ghana. J*ournal of Development and Agricultural Economics* 6(10): 421 ― 428. https://doi.org/10.5897/JDAE2014.0575

Niwagaba, C., Kulabako, R. N., Mugala. P. and Jonsson, H. 2009. Comparing microbial die-off in separately collected faeces with ash and sawdust additivies. *Waste Management* 29(7): 2214–2219. https://doi.org/10.1016/j.wasman.2009.02.010

Poudel, B. and Adhikari, K. 2015. *Ecological sanitation: Solution for the public places and mass events, experiences from Nepal.* Paper presented at the 5th International Dry Toilet Conference, August 8–21, 2015. Tampere, Finland.

Rajan, S. I. 2003. *Internal migration and youth in India: main features, trends and emerging challenges* (Discussion paper). UNESCO, New Delhi.

Sapkota, K. B. 2018. Labour market, foreign employment and remittance in Nepal. *Tribhuvan University Journal* 32(1): 237–250. https://doi.org/10.3126/tuj.v32i1.24790

Schonning, C. and Stenstrom, T. A. 2004. *Guidelines for the safe use of urine and faeces in Ecological sanitation systems*. EcoSanRes, SEI (Stockholm Environment Institute), Stockholm.

Schonning, C., Westrell, T., Stenstrom, T. A., Arnbjerg-Nielsen, K., Hasling, A. B., Linda Hoibye, L. and Carlsen, A. 2007. Microbial risk assessment of local handling and use of human faeces. *Jounal of Water & Health* 5(1): 117–128. https://doi.org/10.2166/wh.2006.049

Sharma, A. 2007. The changing agricultural demography of India- evidence from a rural youth perception survey. *International Journal of Rural Management* 3(1): 27–41. https://doi.org/10.1177/097300520700300102

Sidhu, J. and Toze, S. 2009. Human pathogens and their indicators in biosolids: A literature review. *Environment International* 35(1): 187–201. https://doi.org/10.1016/j.envint.2008.07.006

Simha, P., Lalander, C., Vinneras, B. and Ganesapillai, M. 2017. Farmer attitudes and perceptions to the reuse of fertilizer products from resource-oriented sanitation systems:

The case of Vellore, South India. *Science of the Total Environment* 581–582: 885–896. https://doi.org/10.1016/j.scitotenv.2017.01.044

Thapa, B. K. and Kattel, S. P. 2019. Impact of modernization on family and marriage system of Nepal. *World Wide Journal of Multidisciplinary Research and Development* 5(12): 6–9. http://wwjmrd.com/upload/impact-of-modernization-on-family-and-marriage-system-of-nepal_1576653035.pdf

Ushijima, K., Funamizu, N., Nabeshima, T., Hijikata, N., Ito, R., Sou/Dakoure, M., Maiga, A. H. and Sintawardani, N. 2015. The postmodern sanitation: Agro-sanitation business model as a new policy. *Water Policy* 17(2): 283–298. https://doi.org/10.2166/wp.2014.093

UNICEF (United Nations International Children's Education Fund) 2011. Ecological Sanitation, Practitioners handbook. Online. http://web.iitd.ac.in/~chariarv/files/EcologicalSanitationHandbook.pdf (Accessed June 13, 2020)

WaterAid Nepal 2008. *Assessment of urine-diverting ecosan toilets in Nepal*. WaterAid, Kathmandu. Online. https://www.ircwash.org/sites/default/files/WaterAidNepal-2008-Assessment.pdf (Accessed July 11, 2016)

WHO (World Health Organization) 2006. *WHO Guidelines for the safe use of wastewater, excreta and greywater: Volume 4. Excreta and greywater use in agriculture*. WHO, Geneva.

——— 2015. *Water, sanitation and hygiene in health care facilities: Status in low- and middle-income countries and way forward*. WHO, Geneva.

Winblad, U. and Simpson-Hebert, M. 2004. *Ecological sanitation*, revised and enlarged ed. SEI (Stockholm Environment Institute), Stockholm.

Chapter 5. Summary and conclusion

Through field experiment and questionnaire survey, this thesis examined the role of ecological sanitation (ecosan) technology on livelihood improvement after understanding the effects of urine and ecosan manure as soil amendment, the perceptions and attitude of ecosan users towards ecosan and health risk associated with the ecosan. This chapter summarizes the key findings.

5.1. Contribution of ecological sanitation to crop production and soil fertility

The field experiment conducted in three households' farm with difference in altitude and financial situation suggested that the altitudinal difference among the sites did not have particular effect on the treatment. Whereas the financial situation of the households had effect on consumption of diet resulting to the variation in N, P, and K concentration in the urine. From the result of field experiment it was concluded that applying urine and ecosan manure is effective for crop growth due to the appreciable amount of nutrient present in ecosan manure and urine. Similarly, the physicochemical analysis of soil analyzed before and after treatment concluded human urine and ecosan manure as a valuable soil amendment to improve productivity In the rural villages of low-income countries like Nepal, harvesting human urine and ecosan manure could be suggested as an alternative to reduce the dependency on chemical fertilizer. However, it was also suggested that moderate amount of urine fertilizer should be carefully incorporated into the soil at the correct time to increase the effectiveness of urine fertilizer by minimizing the loss of volatilization and leaching.

5.2. Perceptions towards ecosan and the health risk associated with its use

The questionnaire survey conducted in ecosan users and non-users verified the potential of ecosan manure in agriculture because of its acceptability with the belief that it is safe and does not possess health risk. The majority of both ecosan users and non-ecosan users had positively perceived the benefits of ecosan manure reuse in agriculture. However, the motivation to install ecosan in their houses was found to be decreasing probably due to lack of monitoring activities and suggestions as per expected and needed. In addition to this, although *E. coli* tests conducted as an indicator of fecal microorganisms concluded ecosan manure was not the sole source of fecal microorganisms, it posed the risk of being contaminated if handled inappropriately.

5.3. General conclusion

The field experiment concluded that human urine and ecosan manure contained appreciable amount of nutrients necessary for increasing crop productivity. The combined use of human urine and ecosan manure was found to be beneficial than using urine alone. Hence human urine increases soil fertility and ecosan manure has residual effect on successive crops, it was found that both has the effect to use as a soil amendment. The questionnaire survey concluded that ecosan users and non-users do not think ecosan as a waste and could use as a soil amendment if certain modifications were implemented in the design of ecosan. The thesis also concluded that ecosan does not possess health risk if handled appropriately.

Hence, from the overall result and conclusion, the thesis concluded that ecosan could be best alternative to chemical fertilizer in terms of increasing production thereby improving the livelihood of rural farmers in Nepal. On one hand, rural farmers are coping to fulfill the fertilizer demand for their crops. Whereas on the other hand, government is trying to make country free from open defecation. In order to address these both issues, ecosan technology could be a best option which can generate fertilizer from the human waste and resolve the problem of open defecation. Although use of human urine and excreta is not new tradition for people in many places of country, ecosan toilet is still not the primary choice of households thus resulting to limited number of users. This is because of less interest of young generation towards such technology, lack of proper guidance if any problem arises, less feasible for new modern houses and drawbacks associated with ecosan toilet. Hence, future research is recommended which could study about the modification of toilet design that could attract younger generation and can be installed in newly constructed modern houses. Also study on organization level working in the sector of sanitation is recommended to address policy regarding dissemination of ecosan toilet in national scale.

Publications

Chapter 3

K. C., S., Shinjo, H., Effects of human urine and ecosan manure on plant growth and soil properties in Central Nepal. *Sanitation Value Chain*, **4**, 19-37.

Chapter 4

K. C., S., Shinjo, H., Harada, H., People's perception on ecological sanitation and health risks associated in Central Nepal. *Sanitation Value Chain, Accepted*.