ENVIRONMENTAL CONSEQUENCES OF ADOPTING SOURCE SEPARATED SANITATION SYSTEM: FIRST AND THIRD WORLD PERSPECTIVES

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DEDICATION

I want to dedicate this dissertation to my family especially to:

My late parents Yamnath and Tika Lamichhane who always inspired me to aim high

My wife Mira for her patience, understanding and continuous support

My daughter Swastika and son Swamik who did not get enough attention from me during the whole study period but supported me continuously

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ABSTRACT

Urine constitutes only about 1% of domestic sewage but contains major fractions of nutrients (90% N, 50% p and 55% K) and chemicals like pharmaceutical residues and estrogens (95%) excreted from the human body. Agricultural food crop yield in many countries is decreasing because of nutrient mining and human undernourishment is 20% or higher in 41 countries. The annual human excretion of nutrients only in urine is more than the average fertilizer application rates in 22 countries. Urine, thus, can serve as a "free" but locally available nutrient source. Urine diverting toilets (UDTs) can be used to separate urine at the source. Coordinated and simultaneous intervention on water sanitation and agriculture could be the most effective and economical means of increasing agricultural yield and reducing water pollution, poverty and hunger in these countries. The human excreted estrogens are recognized endocrine disrupting chemicals (EDCs) and are considered about hundred to thousand times more estrogenic than known EDCs like bisphenol A. The effects can vary from cancer to sex reversals at levels as low as parts per trillion in sensitive organisms. To remove 99% of estrogenicity in discharged waters from source separated urine would require approximately 12 kWh/p-y whereas it would require 23 kWh/p-y to achieve the same removal from bulk wastewater by adding advanced oxidation processes to existing municipal wastewater treatment plants. From an energy standpoint it makes sense to practice source separation and treatment of urine to limit estrogen discharges into the environment. By employing UDT, a typical family in the US could realize a saving of $101/y and a decrease of 100 kg green house gas emissions. A social acceptability study conducted in Hawaii showed that 82% of respondents were willing to use UDTs and more than 60% were willing to pay extra

while only 22% knew that such systems existed. With a public education program, it is possible that most people would be willing to adopt UDTs and human waste recycling with incurred societal benefits of reduced water and fertilizer use, reduced greenhouse gas emissions, and collection of EDCs at the source to prevent their entry into waterways

THESIS ORGANIZATION

This thesis is divided in six chapters. Chapter 1 is the introductory section and literature review that gives a general overview of water and sanitation problems in developed and developing countries. This chapter includes brief explanations of the relevancy of the research from economic, socio-cultural and scientific points of view relevant to both developing and developed worlds. Also briefly covered in this chapter are the practice of sanitation currently in use and the possibility of introducing more environmentally friendly sanitation technologies like urine diverting (UD) systems. Chapter 2 is a manuscript of a published paper that discusses the economics of source separation of urine in order to remove endocrine disruptors, especially estrogens, from wastewater if more stringent legislation were imposed and 99% removal of estrogenic potential was required. Chapter 3 is a manuscript of a published paper that covers the results and analysis of existing social acceptability studies from both worlds. Also included in this chapter is the result of online survey that was conducted in order to gauge public acceptability of UD sanitation system and human waste recycling in Honolulu, Hawaii. Chapter 4 is a manuscript almost ready for submission that describes the possibility of integrating UD systems in the poverty reduction agenda of many developing countries in order to better enhance food security. Chapter 5 is a more in-depth case study analysis of water sanitation conditions, undernourishment (food security), dietary energy intake, fertilizer and farm productivity and economic issues that was conducted for a few countries. This will be developed into a manuscript for publication. Chapter 6 is the beginning of a manuscript for later submission which includes discussion on public and environmental health vulnerability issues based on DPSIR framework of the city of Kathmandu (Nepal) due to poor water and sanitation conditions triggered by rapid urbanization.

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CHAPTER 1. INTRODUCTION

1.1 Background

Rapid population growth and uneven distribution of population, industries, and water resulting from rapid urbanization is imposing huge pressures on natural resources including water supplies and water pollution control (Asano, 2005). Competition for water, the productive resource, among different use sectors is increasing.

Water is a basic survival need and poor sanitation threatens public health. The environmental and human health benefits of proper management of wastewater have been realized for many years. (UN, 2010) has recognized access to water and sanitation as a basic human right and acknowledged that clean drinking water and sanitation are essential to the realization of all human rights. Sanitation and hygiene are among the most cost effective public health interventions to reduce childhood mortality (JMP, 2008). Access to a toilet alone can reduce child diarrheal deaths by over 30%, and hand washing by more than 40 %. Diarrheal diseases (including cholera) claim 1.8 million lives every year: 90% are children under five (mostly in developing countries) and 88% of diarrheal disease is attributed to unsafe water supply, inadequate sanitation and hygiene (WHO, 2004). An ESI (Economics of Sanitation Initiative) study conducted in East Asia in 2007 showed annual per capita loss equivalent to \$9.3, \$16.8, \$28.6, and \$32.4 respectively, for Vietnam, Philippines, Indonesia and Cambodia due to not having appropriate water and sanitation facilities (WSP, 2013).

Recognizing the importance of water and sanitation (watsan) on human health and poverty reduction, water and sanitation services were included as a part (Target 7 B) of Goal 7, one of the 8 Millennium Development Goals (MDG), adopted by the UN Millennium Summit in 2000. The watsan target was to reduce by half by 2015 the proportion of population in 1990 (base year) without sustainable access to safe drinking water and basic sanitation. The MDG target on water is met but, globally, there are still approximately 780 million people without access to improved sources of drinking water (JMP, 2012a). However the way progress is measured on the MDG target does not fully address the key components of the target like water quality, quantity and access that are fundamental to human health (Clasen, 2012). Access to drinking water requires the existence of infrastructure in good working order (UNTFM, 2005).The task Force further adds that sustainable access demands secure, reliable, and available on demand access on a long-term basis. The water target might be exaggerated as on average, half of all protected dug wells and one third of protected springs and boreholes may be contaminated (UN, 2011). There exists considerable doubt that the water supply systems, mostly from developing countries, meet these qualities and water collected from sources that are considered improved is safe and people were in fact getting the desired level of service in terms of quantity, quality and access.

Meeting the water and sanitation target will influence, positively, the meeting of all other MDGs as watsan services are critical to sustainable development (UN, 2004). Provision of watsan services contribute to food security, reduce poverty and productivity losses (due to morbidity and malnutrition), and empower women. The MDG on sanitation is slow on progress and is not likely to be met as some 450 million additional households will require services by 2015 to meet the sanitation goal. Globally, there are still approximately 2.4 billion people without improved sanitation(JMP, 2012b). Additional water will be required to provide water and sanitation services to those people who still lack the appropriate watsan services putting additional pressure on already shrinking water and sanitation services. Similar to the water coverage data, there is considerable doubt with respect to sanitation coverage as it takes in to account only the number of people using toilets but does not provide information about whether or not the wastewater (excreta) was safely managed or treated. For example, the proportion of people without adequate sanitation (or practicing unimproved sanitation like pit latrines and open defecation) in the city of Kathmandu (Nepal) is reported as only 1 % (HPCIDBC, 2011) but there are reports that such as (Karn and Harada, 2001) the Bagmati River System in the city of Kathmandu daily receives approximately 31g of BOD per person per day (g/p.d) (mostly coming from domestic wastewater) from a population of more than 1.6

million. This is indicative of the situation of exaggerated sanitation coverage in many developing countries in the world.

1.2 Drinking water supply

The coverage of population with safe drinking water and sanitation facilities is not uniform throughout the world. The demand (and also the supply) of drinking water in developed countries differs from the demand in developing countries both in quantity and quality. Drinking water sources are categorized as improved (considered safe) and unimproved (considered unsafe) (Table 1) (JMP, 2008).

Table 1: Improved and unimproved drinking water sources (Source: JMP, 2008)

1. Improved	**2. Unimproved**
3. Piped water into dwelling	4. Unprotected spring
5. Piped water to yard/plot	6. Unprotected dug well
7. Public tap or standpipe	8. Cart with small tank/drum
9. Tubewell or bore hole	10. Tanker-truck
11. Protected dug wells and springs	12. Surface water
13. Rainwater	14. Bottled water

Most of the houses in developed countries get high quality water with on-demand access (piped connections into dwellings) whereas water supplied in taps in most of the developing countries is rarely safe for drinking purposes without additional treatment. Supply systems in developed countries are considered good at meeting water demand whereas supply systems in developing countries hardly meet the demand (UN, 2008).

Water demand/consumption varies as according to living standard, income level, cultural practices, food habits, climate and weather conditions, availability and proximity of water resources. The water demand can also change over time with change in income, water tariff and education and knowledge changes. In developing countries, the water supply systems in most cities are intermittent type (one third of urban water supplies in Africa and Latin America and one half of Asia) and do not meet the city's demand (population reports, 2002). Various publications (such as Basani et al., 2008; Cheesman et al., 2008; ICIMOD, 2007; Larson et al., 2006; Nauges and van den Berg, 2009; Rietveld et al., 2000) reported that water consumption in urban centers in developing countries ranges from 72-135 lpcd whereas in rural areas water supply systems are designed to supply a minimum requirement of 45 lpcd (Reddy, 1999; Gleick, 1996) and sometimes only 25 lpcd. The health and wellbeing of these rural people are compromised because water supply less than approximately 50 lpcd can affect health (WHO, 2003). Poor people are mostly affected by poor quality water supply (Figure 1).

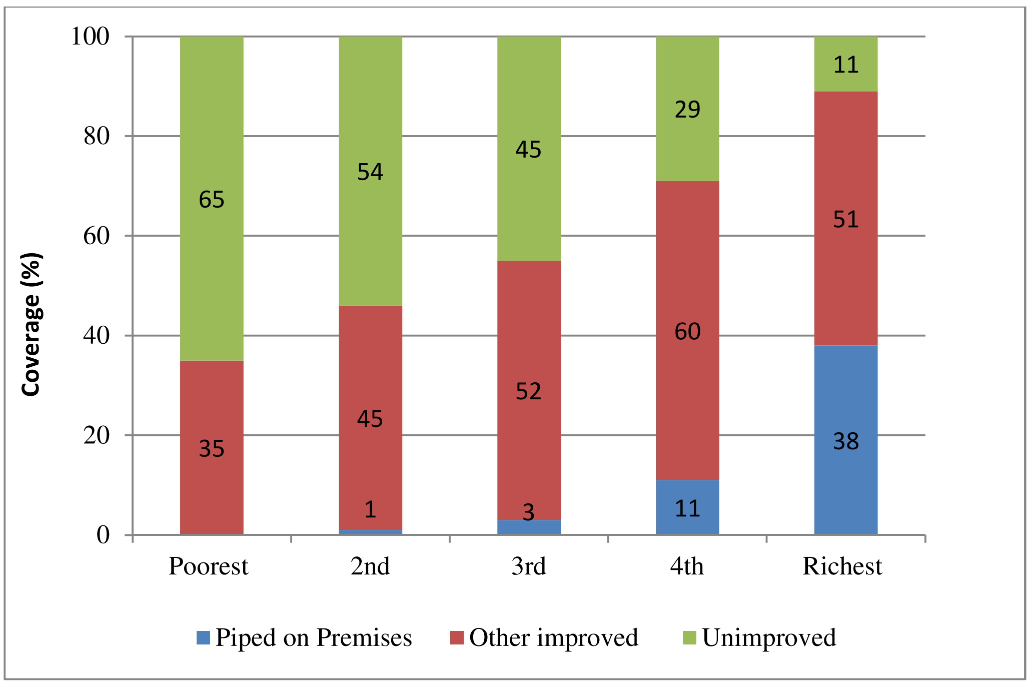

Figure 1: Coverage and sources of drinking water in Sub-Saharan countries (Source: JMP, 2012)

In an industrial society the average personal water consumption is between 200 and 300 liters per day (lpcd) (Fetter, 1994). The daily indoor per capita water use in a typical single family home in the USA is about 263 liters (AWWA, 1999). The breakdown of water uses is shown in Table 2. The largest proportion (more than 25%) of water supplied is used for flushing toilets. Modification of toilet technologies has the potential to save large amounts of water.

Table 2: Daily water use in a typical house in the USA (AWWA, 1999)

Water use category	Quantity (liters/capita)	Percent of daily use
Showers and baths	49	18.5
Cloth washers	57	21.7
Dish washers	4	1.4
Toilets	70	26.7
Leaks	36	13.7
Faucets	41	15.7
Other uses	6	2.2
Total	263	100

However, the average per capita use of the public supplied water in the USA is much more: 185 gallons (about 700 liters) per day USGS (1990). The developing countries should therefore augment the water supply systems to meet the demand both in quality and quantity whereas the developed countries should sensitize people to use water wisely so as to minimize water wastage.

1.2.1 Water sanitation and public health

The value to households of access to improved water services includes a multitude of tangible and intangible benefits. The savings on expenses from buying water with a higher price from alternative providers and time saved are direct benefits and whereas cost saved due to improved health (increased productivity, decreased incidence of morbidity and mortality), better educational outcomes, higher economic productivity (Esrey et al. 1991; Listorti 1996; Kelley 2003; Galiani et al. 2005; UN 2007) to convenience and well-being and also the opportunity costs of time spent on seeking care (Hutton, 2004) are some of the indirect benefits.

Domestic (municipal) wastewater is considered to be one of the main causes of poor water and environmental quality in developing countries (UNEP, 2010). Domestic wastewater is also one of the main causes of water pollution in developed countries like the US (USEPA, 1996a; 2000; USEPA, 1996b). Poor water quality due to microbial contaminations is the main health threat in developing countries. Various studies (such as Esrey et al., 1991; Fewtrell et al., 2005; Clasen et al., 2006; Waddington et al., 2009) have shown that interventions to improve water quality are effective in preventing diarrheal diseases, a leading cause of children's death in developing countries. There are reports of waterborne diseases even if the supplied water is good which is indicative of the improvement needed in collection, storage and handling behaviors (Wright et al., 2004; Clasen et al., 2006). Point-of-use (POU) household water treatment has proved more effective in preventing diarrheal diseases compared to water treated at the source (Clasen et al., 2006). Fewtrell et al. (2005) reported that increasing water quantity reduces the occurrence of diarrheal diseases by 25%. They also reported that POU household water treatment and improved sanitation can reduce diarrheal diseases by about 35% and 32%, respectively. Interventions to improve quantity and access are also effective against waterborne diseases (Esrey et al., 1991; Fewtrell et al., 2005; Waddington et al. 2009). Proper water, sanitation, and hygiene interventions improve health (Montegomery and Elimelech, 2007). The interventions in watsan and hygiene include provision of adequate quantity of potable drinking water, adequate sanitation services, and education and awareness for clean and hygienic behaviors. Investment in the watsan sector makes strong economic sense: every dollar invested on this sector leads to benefits from \$3 to \$34 (Hutton and Haller, 2004; Hutton et al., 2007). Water and sanitation (watsan) services complement each other in breaking the fecal oral route of transmission of diseases.

1.3 Wastewater management practices

The discharge of untreated waste, dumping of industrial effluent, and run-off from agricultural fields are considered the main sources of freshwater pollution (UNEP, 2010). Isolation of excreta from rain water, flies and other vectors and safe disposal is a big challenge in many developing countries as the practice of open defecation is still prevalent (18% of world's population) (UNICEF/WHO, 2008). The discharge of raw sewage into natural waters is one of the main wastewater management methods in developing countries and has also been a common practice even in relatively advanced countries like China, India, and Iran (Carr and Neary 2008). Disposal of partially (inadequately) treated sewage is also a major source of water quality contamination in developed countries. The problem of inadequate sanitation is less of a problem in developed countries. However, regular epidemics witnessed in developed countries (like *Listeria* outbreak in Colorado, USA in 2011) are an indication of improper sanitation (Lens et al., 2001).

The quantity of wastewater produced from a community depends mainly on the quantity of drinking water supplied (or per capita use). The demand of drinking water differs greatly with income, living standard, climate/weather, geographical area and water tariff. Large volumes of wastewater are produced in developed countries as people get a largely unrestricted and continuous water supply connected to their housings. They also have access to improved sanitation facilities (Table 3) mostly connected to public sewers and septic tanks.

Table 3: Improved and unimproved sanitation facilities (Source: JMP, 2012 (2003-10))

Improved	**Unimproved**
Connection to public sewer or septic tank	Service or bucket latrine
Flush/pour-flush latrine	Traditional latrine
Pit latrine with slab	Public latrine or shared toilet
Ventilated improved pit (VIP) latrine	Open pit or pit latrine without a slab
Composting toilet	Open defection
Ecological sanitation$^{\alpha}$	Hanging toilet

$^{\alpha}$Ecological sanitation is a relatively new (innovative sanitation) technology and not a conventional sanitation system

More than 90% of the supplied water becomes wastewater in places with limited landscape irrigation whereas in the USA 60-90% of the per capita water consumption becomes wastewater depending on the weather conditions (higher percentage in places with cold weather and lower wastewater discharges in states with semiarid weather conditions) (Metcalf and Eddy, 2003). As the daily per capita water demand in almost all developed countries is around 300 liters, the wastewater volume to be treated is also enormous. A relatively small volume of wastewater is generated in developing countries compared to their developed counterparts because of none to largely restricted (and intermittent type) water supply and practice of largely on-site (unimproved) sanitation facilities. It is interesting to note that there are millions of people even from relatively affluent and developed countries like Russian Federation, Brazil, and China without access to improved sanitation services (Figure 2).

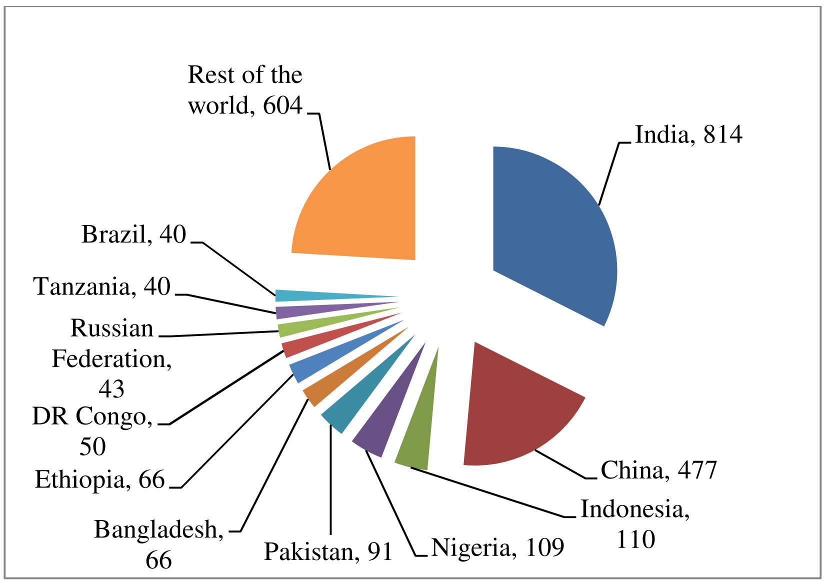

Figure 2: Countries with large number of people (in million) without access to improved sanitation (Source: JMP, 2012)

The poor are the most likely to suffer from these poor sanitation services. Figure 3 below shows the type of facility used and the sanitation coverage in Sub-Saharan Africa based on wealth quintiles.

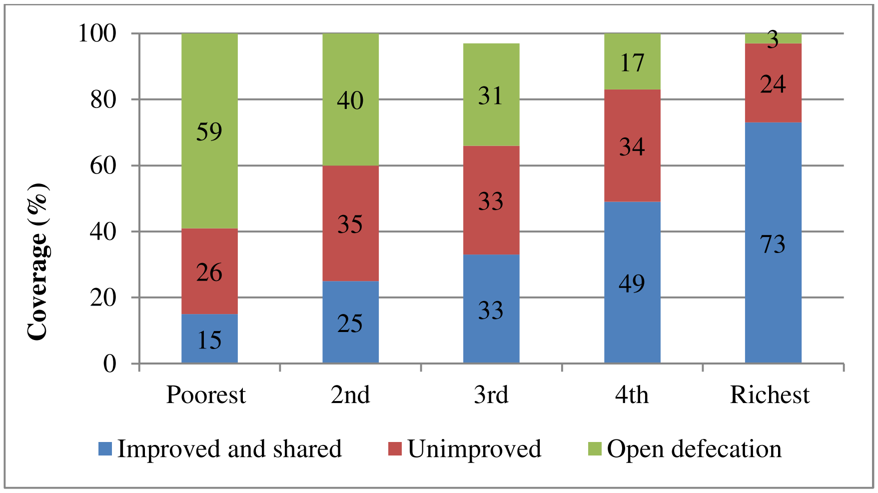

Figure 3: Sanitation coverage in Sub-Saharan countries by wealth quintiles (Source: JMP, 2012)

Because of the difference in health conditions of people from developing and developed countries the microorganism content in wastewater and sludge can be very different (Jiménez, 2008). Tables 4 and 5 below show the microbiological qualities of wastewater and sludge generated in the developed and developing worlds.

Table 4: Comparison of the biological pollutant content in wastewater from developing and developed world (Source: Jiménez, 2009)

Organism	Developed world	Developing world
Enteric viruses, PFU per 100 ml (U, I)	10^2-10^4	10^4 -10^6
Salmonella MPN per 100 ml (E, H, In, M, SA, U)	10^0-10^4	10^6-10^9
Fecal streptococci, No. per 100 ml (U, E, K)	10^4-10^6	10^6-10^7
Protozoan cysts, organisms/l (U, M)	10^1	10^3
Giardia lamblia cysts/l (U, E, K)	1-10^3	10^2-10^3
Cryptosporidium parvum oocysts/l (U, E)	1-10^3	No data
Helminth ova, egg/l	1-9	6-800

PFU: Plaque forming unit, E: England, H: Holland, In: India, I: Israel, K: Kenya, M: Mexico, SA: South Africa, U: USA

The lifestyle and income between communities in the same country can also differ greatly. These facts show that the intervention attempts in reducing the numbers without access to appropriate water and sanitation services with "one-size-fits-all" solutions may not be effective even in communities within the same country. There should be a range of alternatives available for the people (community) to choose from based on their economic, social and cultural settings.

Table 5: Helminth ova (HO) content in wastewater and sludge from different countries (Source: Jiménez, 2008)

Country/region	Municipal wastewater (HO/l)	Sludge (HO/g TS)
Developing countries	**70-3000**	**70-735**
Brazil	166-202	75
Egypt	6-42	Mean: 67; maximum: 735
Ghana	No data	76
Jordan	300	No data
Mexico	6-98 in cities, up to 330 in rural and peri-urban areas	73-177
Morocco	840	No data
Syria	800	No data
Ukraine	60	No data
France	9	5-7
Germany	No data	<1
Great Britain	No data	<6
United States	1-8	2-13

The type of water supply and wastewater management systems people want (should be able to run and maintain) in developing countries can be entirely different from the type of systems people want in developed countries. This fact warrants, and also for the sake of sustainability, demand-driven watsan projects rather than government imposed supply-driven and one-size-fits-all projects (normally is the case in developing countries). When designing wastewater management facilities, care must be taken to consider community income, wastewater characteristics, desired level of treatment, and prevailing regulations.

1.3.1 Wastewater management alternatives

The physical, chemical and biological characteristics of wastewater can change depending on climate, lifestyle and food habits of the community. In developed countries, wastewater volume to be treated can be enormous and dilute because of the higher per capita water demand/supply. The per capita wastewater generation in developing countries is less and thus can be very concentrated compared to the wastewater generated in developed countries. The microbiological qualities of wastewater from developing and developed countries also differ greatly. This fact should be taken into account while designing wastewater treatment/management alternatives. For instance, the conventional indicators of fecal contamination like *Escherichia coli* (*e-coli)* may not work good in tropical and subtropical climates (Fujioka and Shizumura, 1985; WHO, 2004) and may not simulate the behavior of enteric viruses, *Giardia*, *Amoeba*, *Ascaris* and *Helminth ova* that are of concern for low income countries in these climate zones (Jiménez, 2009; Cisneros, 2012). The water and wastewater must therefore be tested for additional indicators depending on the intended use. The additional indicators for sewage contamination in tropical and sub-tropical climates (where *e-coli* can be indigenous) can be *helminth* or *Ascaris* egg for developing countries (Jiménez, 2009; Cisneros, 2012) and organisms like *Clostridium perfringens* (Fujioka and Shizumura, 1985) in developed countries as they survive much longer in the environment than *e-coli* (Figures 4-6).

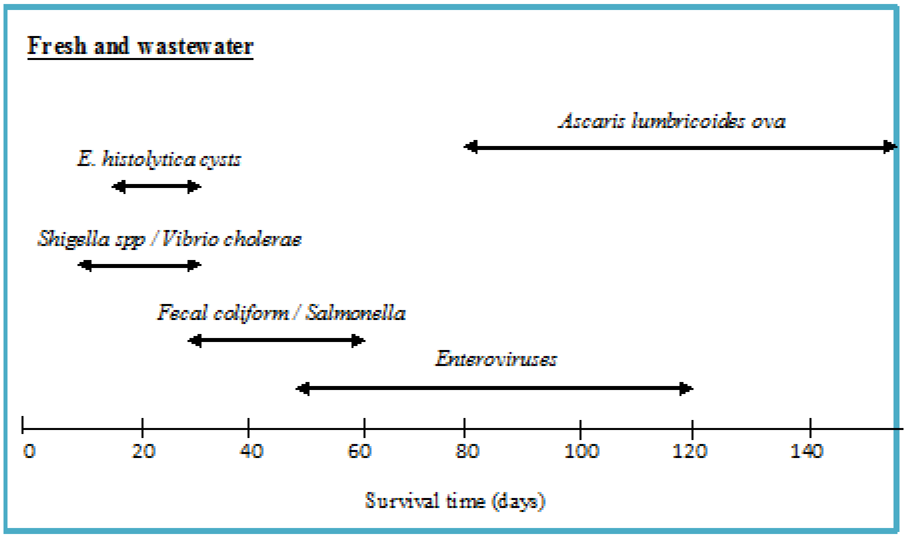

Figure 4: Survival time of different pathogens in fresh water and wastewater at 20-30°C (Source: Feachem R, Bradley D, Garelick H, and Mara D, 1983; cited from Cisneros, 2012)

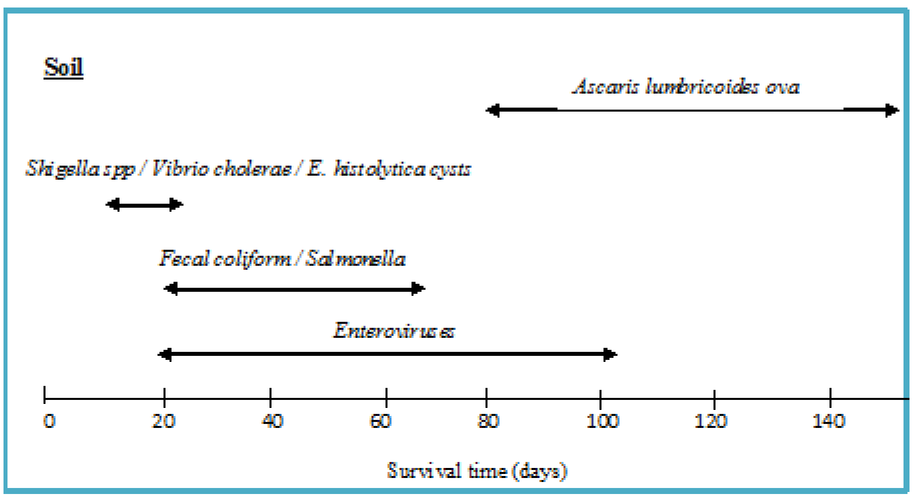

Figure 5: Survival time of different pathogens in soil at 20-30°C (Source: Feachem R, Bradley D, Garelick H, and Mara D, 1983; cited from Cisneros, 2012)

The survival time of these biological pollutants significantly reduces from 3-4 months in water and soil environments to less than 2 months in crops (Figure 6).

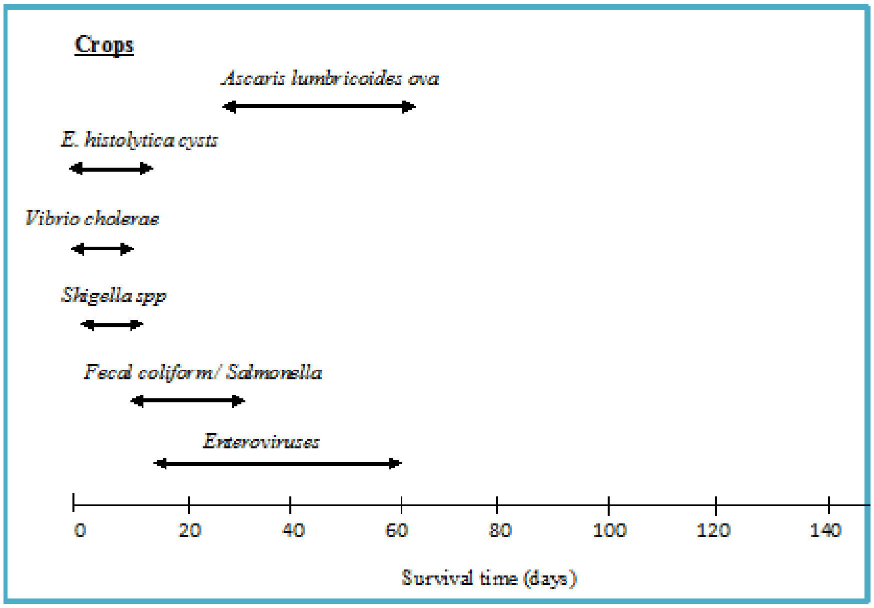

Figure 6: Survival time of different pathogens in crops at 20-30°C (Source: Feachem R, Bradley D, Garelick H, and Mara D, 1983; cited from Cisneros, 2012).

Sanitation systems are categorized into two general types: conventional systems and innovative sanitation solutions.

1.3.2 Conventional sanitation system

The conventional sanitation system can broadly be categorized into two types namely onsite sanitation (pit latrines, VIPs, STs) and modern water borne (flushing) toilet with central sewer system and wastewater treatment plant (WWTP) (Table 3). The simple pit latrine is the most primitive form of excreta management (if open defecation is not considered as a waste management system) and flush toilet arrangement with central sewer systems and WWTPs are currently the most developed and the most preferred sanitation system in the world for wastewater management and widely used in developed countries. Conventional wastewater collection, conveyance and treatment systems are built based on End- of -Pipe (EOP) treatment; water is used as a transport medium for fecal matter and systems are designed as treatment and disposal systems (Rakelmann, 2003). Human excreted nutrients are generally lost in these conventional systems as these systems are not designed to recover nutrients from waste. Most of the central sewer systems and WWTPs in developing countries are constructed with the financial and technical support (loan, grant) of multinational donors like the World Bank (WB), Asian

Development Bank (ADB), Japan International Development Agency (JICA) and developed and OECD countries. These systems in developing countries are also designed based on the data and experience gained in developed countries as the experts working for these donors are from the donor countries/agencies and are thus liable to perform poor as sewage characteristics (like BOD, COD, TN, TP, TSS, ions and pathogen contents) can be much different from the sewage in developed countries.

People from developing countries mostly practice on-site (and unimproved) sanitation systems (Table 3). The wastewater generated from these sanitation systems is not collected and properly managed. This domestic wastewater (fecal sludge) is the main reason for water quality deterioration and environmental degradation in developing countries.

1.3.2.1 Pit latrine

Simple pit latrine is the most widely used sanitation system in rural areas of developing countries. There are various types of pit latrines currently in use: a simple open pit to ventilated improved pit (VIP) and pour flush toilets. Pit latrines are not emptied routinely for the purpose of long term use, rather people abandon the pit and make new pit. Pit latrines are cheap to construct and maintain but problems of flies and smell are common. Excreta in the pit are liable to be spread by vectors and are also prone to flooding during rainy season and pose considerable threat to environment. The practice of abandoning pits and digging new pits is slowly decreasing in the peri-urban areas due to increased awareness of people regarding the benefits of proper sanitation facilities and with decreasing per capita land (due to increasing population density). Simple pit latrines are almost obsolete in developed countries.

1.3.2.2 Ventilated improved pit (VIP) latrine

VIPs are improved pit latrines equipped with a vent pipe in order to prevent odor inside the shelter. Similar to pit latrines, VIP latrines are not used in developed countries (an exception can be in summer houses). VIP latrines are the second most popular in rural and peri-urban areas in developing countries and are also present in urban areas. A fly-proof screen cover at the top of the vent pipe blocks flies from breeding and escaping.

VIPs need periodic sludge removal which can be done manually or using mechanical equipment. Due to lack of safe disposal areas in urban and peri-urban areas, the fecal sludge from these toilets often end up in nearby streams and low-lying areas posing a great threat to human and environmental health.

1.3.2.3 Septic tanks

Septic tanks (STs) are one of the most widely used on-site wastewater management systems in the world. STs are widely used in peri-urban as well as in urban areas in developing countries and are also in use in the USA serving about 25% of the population. STs are commonly used in places with no sewers and in low income settings (Jimenez and Wang, 2006). STs can remove around 50% of the incoming organic matter and suspended solids in 2-4 days (Jimenez, 2009). The cost involved for periodic sludge removal necessary for ST can be of concern to people with low income. ST performance is largely regulated in developed countries whereas they are not regulated in developing countries due to a lack of a strong institutional and legal framework. For example in the city of Kathmandu (the capital of Nepal), overflowing of STs to street side drains and nearby rivers and streams and dumping of sludge in low land public areas or in rivers and streams is common.

1.3.2.4 Land application

Land application of wastewater for fertigation (irrigation water and nutrients) purposes even for crops eaten raw is commonly practiced in many countries including China, Vietnam, Mexico, Nepal and others. Aquaculture farming (fish, shrimp) using sewage or fecal matters as the main feed source is also a common practice in countries like India and Vietnam (Furedy, 1998). This practice of raw sewage application to land/water poses a considerable threat to human and environmental health. WHO (2006) recommends a *helminth egg* concentration of ≤ 1 egg/l if wastewater is intended for irrigating crops that are eaten uncooked. The recommended value for excreta application in crops is 1 egg per gram total solids (TS). The practice of raw sewage application on land does not exist in developed countries as effluent discharges are well regulated.

It can be seen (Figures 1.4-1.6) that *fecal coliform* cannot survive as long as other organisms. And application of wastewater (sewage) to crops seems a better alternative than to release it into water bodies or percolate through soil in terms of pathogen removal. However, epidemiological studies on incidence and prevalence of wastewater related diseases (disease caused to workers/farmers and consumers of food) and other health and well-being related studies (mortality, morbidity and so on) should be carried out before any conclusions can be made.

1.3.2.5 Water borne (networked) system

The flush toilet and sewer arrangement has been very effective in managing/treating wastewaters for many years. However, because of the capital and operation and maintenance (O&M) intensive nature of flush toilet and networked sewer systems, many countries in the world cannot afford these systems. In this type of system nutrients that are excreted in the form of waste are so diluted that nutrient recovery efforts are costly.

The conventional water borne sanitation systems are resource intensive: consume energy during conveyance and treatment of wastewater and are thus not sustainable (Verstraete et al., 2009). Even the best affordable treatment plants have the potential to pollute the aquatic environment and cause severe problems as they discharge over 20 % of nitrogen, over 5 % of phosphorus and more than 90 % of potassium (Otterpohl et al., 1997).

These conventional American style toilets consume 5-12 liters of water in each flush just to transport a small volume of urine and feces. About 15,000 liters of water per person per year is consumed to flush and transport about 500 liters of urine and 35 kg of feces (Drangert, 1997). This system of sanitation is sometimes called “flush and forget” system as people use the toilets and flush and do not worry about the environmental consequences. The possibility of nutrient recycling is complicated, environmental problems will be grave if the system malfunctions, and construction costs are high.

1.3.4 Investment needed for closing the sanitation gap

As mentioned previously, there are more than 2 billion people worldwide without basic sanitation services. These people mostly live in Africa and Asia. UNEP (2004) has identified 10 general sanitation options used in urban, peri-urban and rural areas categorized based on the level of service delivery. The per capita annual unit cost of wastewater treatment by tertiary technologies (practiced normally in affluent communities) is estimated at $800 whereas the low cost sanitation (not networked treatment options) range from $45 (simple pit latrine) to $160 (septic tank). Based on low-cost and sustainable technologies, an estimated investment of at least $11.3 billion/y over and above current investment should be made just for closing the gap between current trends and target trends on water and sanitation under the MDG, Goal 7 (Hutton and Haller, 2004). An estimated cost up to $136.5 billion/y is needed if in-house regulated piped water supply and in-house sewer connection with partial sewage treatment is desired (Hutton and Haller, 2004; UN 2008). Vision 21 estimated that an additional $89 to $105 billion above the current investment is required for managing all aspects of water resource management of which $56 billion/y is required for wastewater treatment alone. Construction and O&M of sewer networks and WWTPs is highly resource intensive and is costly even to developed countries like the USA. Estimates show a spending gap of about $108.6 billion in the drinking water and wastewater sectors in the USA in 5 years (ASCE report card, 2012). The Congressional Budget Office estimates that the spending gap for the wastewater sector alone ranges from $23 billion to $37 billion annually (EPA, 2004). Crites and Tchobanoglous (1998) estimated an annual spending need of $200 billion for treating sanitary sewer overflows only. Several additional billion dollars are needed to provide sanitation services to all and developing countries will be never able to meet the expenses needed in the watsan sector if the current trends of favoring centralized sewer systems and low spending (less than 2% GNP) do not change.

1.4 Sustainability issues

1.4.1 Population growth and pressure on natural resources

The world population has increased by about three times during the 20th century whereas water withdrawals have increased by seven times (UN, 2008). The increase in per capita fresh water use is directly correlated to urbanization and thus the pressure on water and sanitation facilities is increasing at alarming rate because of population growth and urbanization (Hinrichsen et al., 2002). The pressure on natural resources is increasing not only because the population is growing fast but also because of the higher per capita resource use of urban dwellers compared to their rural counterparts. It is believed that approximately 2.8 billion people live in river basins with some form of water scarcity (UN, 2008). The water and sanitation facilities along with other natural resources of developing countries will face more severe stress as the urban population in these countries is increasing at a rate much higher than the population of developed countries (Population Reports, 2002). Withdrawals of water for various uses and subsequent wastewater treatment are processes that at today's scale have large "unpriced" external effects such as land use consequences, water quantity depletion, and ecosystem degradation (Stallworth, 2000) and water cannot be considered as a perfectly indestructible renewable resource as has been treated in the past.

Similarly, agricultural lands are heavily stressed (nutrient mining) to meet the demand of food for ever increasing population. Forests are under pressure to meet the demand of fuel wood and fodder and are also getting encroached due to agricultural land expansion. Though all environmental issues are equally important, this research mainly focuses on excessive pressure exerted on water resources and soil (nutrient depletion).

1.4.2 Sustainable development

Earlier belief that natural resources are free and the nature is capable of assimilating wastes regardless of quantity and toxicity led to environmental destruction which forced governments (public authorities) regulate the use of natural resources and discharges to the environment. Environmental protection and socio-economic development were also recognized as the necessary condition for achieving sustainable development in the UNCED (1992) conference and Agenda 21 was adopted. The adoption of Agenda 21 in UNCED reflects the emphasis assigned to sustainable development by all nations of the world.

Sustainability or sustainable development is defined as "providing for human needs without compromising the ability of future generations to meet their needs" (Brundtland

Commission, 1989). The concept of sustainability is described based on triple bottom line; social concerns (human health and social welfare), natural or ecological issues (environmental stewardship) and economic and technical viabilities (Barrera and Valdes, 2002). Sustainability demands changes in activities through innovations in Science and technology to mutually benefit the environment, the economy and the global society (Anastas et al., 2006). Environmental sustainability is the continuity of the environmental carrying capacity indefinitely into the future (Lee et al., 2005). With the advent of pollution prevention concepts in early 90's, it was realized that for the development to be sustainable and environment to be performing its function well the pollution should be prevented at the source. The US pollution prevention act of 1990 has established the hierarchy of pollution prevention (P2) assigning the source reduction the top priority (Figure 7).

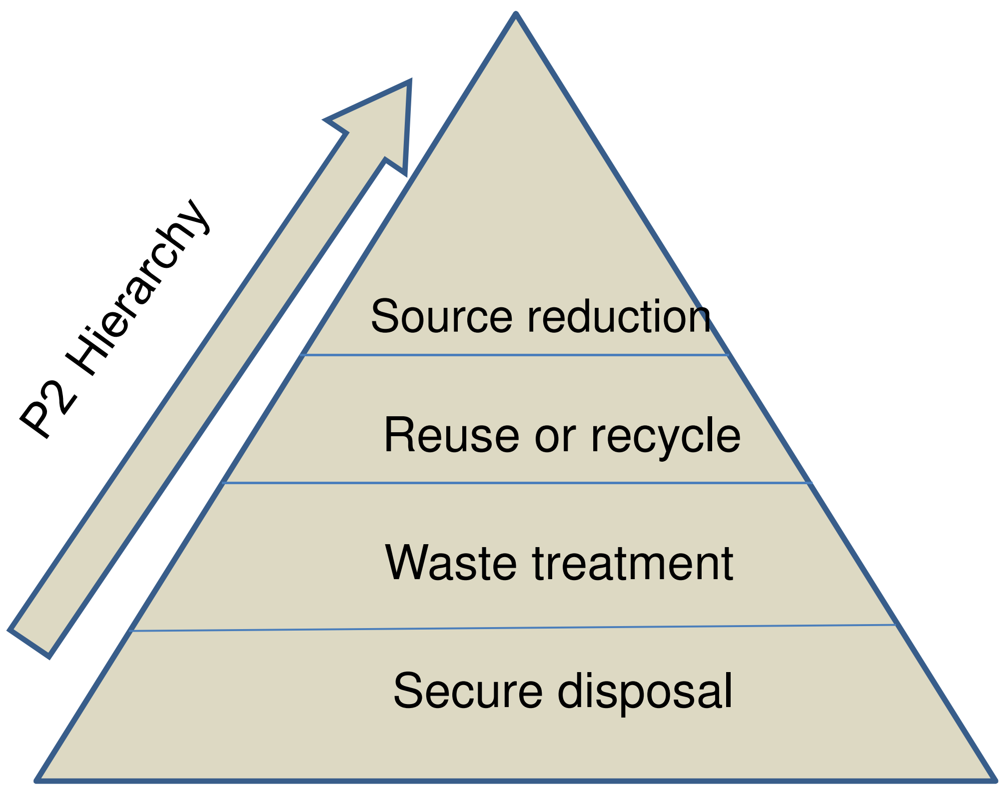

Figure 7: The pollution prevention (P2) hierarchy of US Pollution Prevention Act (1990) (modified from Abraham, 2006)

P2 comprises the increased efficiency in the use of raw materials, energy, and other resources through conservation. As the environmental regulations are becoming more stringent and impose restrictions on process discharges and emissions, efforts are being made to recapture the beneficial materials/energy from the waste stream and convert the remaining in to an innocuous material prior to release to the environment (Abraham, 2006). Pollution prevention warrants demand management (reduction of per capita demand) as every product is associated with environmental wastes some of which cannot be avoided. The P2 principle considers pollution release as a last resort only if it cannot be either recycled safely and economically or treated in an environmentally safe manner. The source separated (UD) sanitation system complies with the P2 principle as it reduces waste at the source and makes resources (water, nutrient) recovery easier.

1.4.2.1 Sustainability of water and wastewater management practices

The focus of technology development and policy for much of the past century has been on the supply side of both the energy and water equations giving priority to extracting, storing, converting, and conveying water and energy from natural systems rather than in demand management and water use efficiency (Wilkinson, 2008). The costs of building infrastructure have risen dramatically and the maintenance cost will soar in coming years as many more drinking water and wastewater treatment systems will be necessary to meet the need of growing population if the current rate of water consumption continues.

Each and every human activity is coming under more detailed scrutiny after the introduction of the concept of sustainable development and so is the case for individual parts for urban water systems (Gumbo, 2000). Production of wastewater at the household level requires more scrutiny as the volume and characteristics of wastewater produced at home are necessary for designing wastewater treatment system (Almeida et al., 1999). Wastewater treatment was primarily meant for enhancing urban hygiene and protecting downstream users in the past but effluent quality cannot be the only criterion of sustainable wastewater treatment. Sustainable wastewater management warrants an integrated management of assets such as water, energy and nutrients (Wilsenach et al., 2003). It is difficult to quantify sustainability but recovery of resources (water, nutrients) from waste increases sustainability. The dilute nature of wastewater makes recovery economically and energetically expensive.

The demand for sanitation systems connected to well-functioning wastewater treatment plants via central sewers is on the rise (both in developing and developed countries) because of the perception that on-site or decentralized systems are inferior and not safe (USEPA, 2002). These central systems demand huge investment and O&M costs and are not easily affordable even to affluent societies in developed countries. Countries with GNP less than $1,000 cannot even maintain the central sewer systems and WWTPs if they were constructed for free (Grau, 2005). Approximately about 1-1.5% of the country's GNP can be expected to be spent on construction of sewers and WWTPs (Grau, 1996). There are more than 30 countries with more than a billion people in the world with average per capita income less than $1,000/y (WB, 2012) and about 1.29 billion living with less than $1.25 per day (WB, 2008). This implies that the maximum amount they can afford (at a rate of 1.5% per year and GNP $1,000) for the construction of sanitary systems is about $15/yr. Because the useful life of sewer lines and WWTPs is 60-80 years and 20-25 years, respectively (Maurer et al. 2006; Grau, 1996) the affordable investment cost in sanitation sector is only about $300 to $375 once in the life time of the WWTP (i.e. 20-25 years). The sewer lines and WWTPs share 80% and 20% of the total construction costs, respectively. In addition to investment costs, other costs involved are annual O&M costs and capital financing costs. Though connection of sewers to functioning wastewater treatment plants has proved instrumental in improving health and the environment, a shift is necessary to more affordable, resource conserving and sustainable wastewater management options. Because of increased environmental awareness, a shift to more sustainable options has been noted during past 15 years even if centralized wastewater treatment still dominates for large infrastructural investments (Kvarnström et al., 2006).

1.4.2.2 Water demand management

Most of the water supply systems are designed to meet the demand of water (i.e. supply-side management) and do not aim at reducing demand and balancing with supply (Loehman & Becker, 2006). With technology and information, demand can be managed, and it was realized that holding back consumption is cheaper than constructing new water supply schemes (Drangert, 2002). Roger (1993) and Martin and Kulakowski (2001) argue that information and education are not effective in promoting conservation without imposing significant price increases to provide a financial incentive for conserving water and the adoption of improved (water conserving) technologies. The drinking water in the first block (minimum requirements) is normally price inelastic (Dale, Fujita et al., 2009) and higher responses to price rise can be expected from lower income people (Renwick and Archibald, 1998).

According to Roger (1993) commons management is successful when societies are small. With the popular community participation in selecting an appropriate sanitation alternative from a range of options, the system selected by the community will be affordable and will also be effective in reducing environmental burdens. Because it is relatively cheap, offer desired service, consumes less water, and makes nutrient recovery easier, the urine-diverting toilet system (UD) in decentralized mode (commons management) can be one of the best alternatives of sanitation in small communities both in developed and developing countries. A large amount of water can be saved by employing UD in decentralized and dehydrated mode. It has the potential to save approximately 11,000 liters of water per person per year (Lamichhane and Babcock, 2012) even if it was operated in centralized mode (connected to central sewer system). This water demand reduction also reduces the cost of subsequent treatment/ management of wastewater. The savings on water, nutrients, energy, and reduction of greenhouse gas emissions via UD systems is covered in detail in Chapter 2.

1.5 Necessity of resource recovery from wastewater

Wastewaters generated from water-flush systems consist of water to more than 99.5% purity with potentially valuable substances but in extreme dilution (Cornel et al., 2011). Wastewater contains nutrients, organic matter (as energy source), fatty acids (raw materials for industries) and several other chemicals. The conventional flushing concept makes it difficult to recover valuable substances economically (Verstreate et al., 2010; Cornel et al., 2011) and thus valuable resources get lost forever and pollute the environment further necessitating substantial resources to clean up. Water conservation and nutrient recycling are drivers for urine diversion. Though, resource conservation is important everywhere, UD system are best suited in places with none or little existing conventional wastewater management infrastructures, water scarce areas, areas with delicate receiving water bodies, and in areas where nutrients can be economically recycled.

1.5.1 Water conservation

Water scarcity and quality problems are a worldwide phenomenon (Clarke, 1993). Water cannot be considered as a perfectly indestructible renewable resource as has been in the past. As the population grows, more and more countries are facing water shortages and the projections show that 48 countries, with more than 2.8 billion people (35% of the projected global population), will be affected by water stress or scarcity by the year 2025 (JHU, Population Reports, 2002). Lack of new economically and environmentally viable water sources has given impetus to a variety of water management issues like reuse of municipal wastewater to augment the raw water supply (NRC, 1998). Compared to the conventional flushing system of sanitation, the UD sanitation system has large potential of saving water. The details of water savings (quantity) and technical and economic feasibility of employing source separated sanitation system is presented in Chapter 2.

1.5.2 Nutrient issues

EPA (2011) reported that approximately 25% of all water body impairments are due to nutrient-related causes (e.g. oxygen depletion, algal growth, ammonia, harmful algal blooms, biological integrity, and turbidity). Stringent regulatory limits are imposed on point-source discharges (like WWTPs) to limit nitrogen and phosphorus and there is a possibility of imposing more stringent regulatory limits in the future. Nutrients accelerate algae growth and also create turbidity necessitating higher doses of disinfection (like chlorination) subsequently leading to higher levels of disinfection by-products that are recognized carcinogens. Excessive amounts of nutrients can also stimulate the activity of microbes, such as *Pfisteria*, which may be harmful to human health (EPA, 1998; 2001).

In many developing countries, the per capita food production is decreasing due to lack of nutrients (nutrient mining) (FAO, 2008) as farmers cannot afford buying costly inorganic fertilizers. The nutrients in excreta that are "free" are wasted creating filthy environmental conditions. The estimates show that approximately 800 million people are suffering from hunger and several million children are suffering from malnutrition (FAO, 2012). People all over the world, especially farmers from developing countries, could greatly benefit if nutrients in excreta could be safely managed and recycled. The conventional flushing concept makes it difficult to recover valuable substances economically (Verstreate et al., 2010; Cornel et al., 2011). There is therefore a need to develop a sanitation system that can help capture nutrients in a sustainable way and UD sanitation systems can serve the purpose. Government from these countries should develop a mechanism such that sanitation and agricultural extension programs can be launched simultaneously. The details of nutrients excreted in urine and feces, possibilities of recycling to crops/agriculture and possible contribution to economy and food security is discussed in Chapters 4 and 5.

1.5.3 Energy issues related to water management

A study conducted in Southern California reported that the energy required to deliver drinking water and wastewater services to a home is as much as 33% of the total average household electricity use (Means, 2003). The electricity demand for water and wastewater systems in the US is approximately 4% of the total national electricity demand (Water and Sustainability, 2002) and WWTPs are one of the largest electricity users in the local governments (California Energy Commission, 2000). The energy consumption in WWTPs is a function of the pollution load, the degree of treatment required (effluent criteria) and also the volumes of wastewater the WWTPs receive. The secondary treatment process is the most energy intensive unit process and consumes up to 60-80% of the total electricity demand of the whole WWTP. The table 6 below shows the energy use for secondary treatment.

Table 6: Summary of energy benchmark parameters and energy use information for the secondary wastewater treatment process and for total plant operations (Source: Pacific Gas and Electric Company, 2001)

S.No.	**Parameters**	**Range of values**	
		Observed	**Generic**
1	Energy kWh/lb BOD	0.40 – 2.60	
2	Energy kWh/MG treated	508.0 – 2,428.0	279.0 – 928.0
3	Electrical use for total plant (kWH/MG)	1,073.0 – 4,630.0	978.0 – 1,926.0
4	% total plant energy used for 2ndary treatment only	27.0 – 60.0	29.0 – 48.0

The energy figures in Table 1.6 do not include the amount of energy needed during wastewater conveyance and during treatment processes like sludge handling and for pumps and machines in WWTPs that run continuously. UD toilet systems, even if it was connected to existing sewer system, would drastically reduce wastewater volume and take away a considerable amount of BOD in urine. This would help WWTPs save energy during secondary treatment (nitrification) and also during wastewater conveyance.

1.5.3.1 Contribution of WWTPs to greenhouse gas production

Wastewater treatment processes contribute significant amounts of greenhouse gas (GHG) emissions. Wastewater treatment can contribute to GHG through production of carbon dioxide (CO_2) or methane (CH_4) during treatment processes and CO_2 production during the production of electrical energy that is required for wastewater treatment. Methane produced from sewage treatment constitutes about 5% of the global CH_4 source (Fadel and Massoud, 2001). The greenhouse gas production by different wastewater treatment technologies is presented in Table 7 below.

Table 7: Green house gas production by WWTPs (Source: Cakir and Stenstrom, 2005)

Process category	CO_2 production	CH_4 production	Sludge production
Energy	0.96 kg CO_2/kWh		
Activated sludge process	1.375 kg CO_2/kg BODu		0.5 g VSS/g BODu
Anaerobic reactor	0.6875 kg CO_2/kg BODu	0.25 kg CH_4/kg BODu	0.05 g VSS/g BODu
Anaerobic digestion	None	0.25 kg CH_4/kg BODu	0.04 VSS/g BODu

1.5.4 Issues of micropollutants (hormones, and PhaRs)

There are various chemicals found in wastewater that are recognized to affect the endocrine systems of human and aquatic life (also known as endocrine disrupting chemicals or EDCs). Figure 8 below shows the type and sources of these chemicals in the environment. Similar to nutrients, the majority of hormones, estrogens (natural as well as synthetic), and pharmaceutical residues (PhaRs) are excreted in urine. Many human-originated estrogens are estrogenic even in normal environmental concentrations and are considered 100 to 1,000 times more estrogenic than recognized estrogenic chemicals like bisphenol A found in wastewater effluents. The synthetic estrogen (ethnylestradiol, EE2) is considered the most estrogenic chemical found in the aquatic environment. Urine separation is advantageous also because of the possibility of containing these chemicals in a small volume. The details of estrogens in the environment, their effect and treatment methods are covered in Chapter 2.

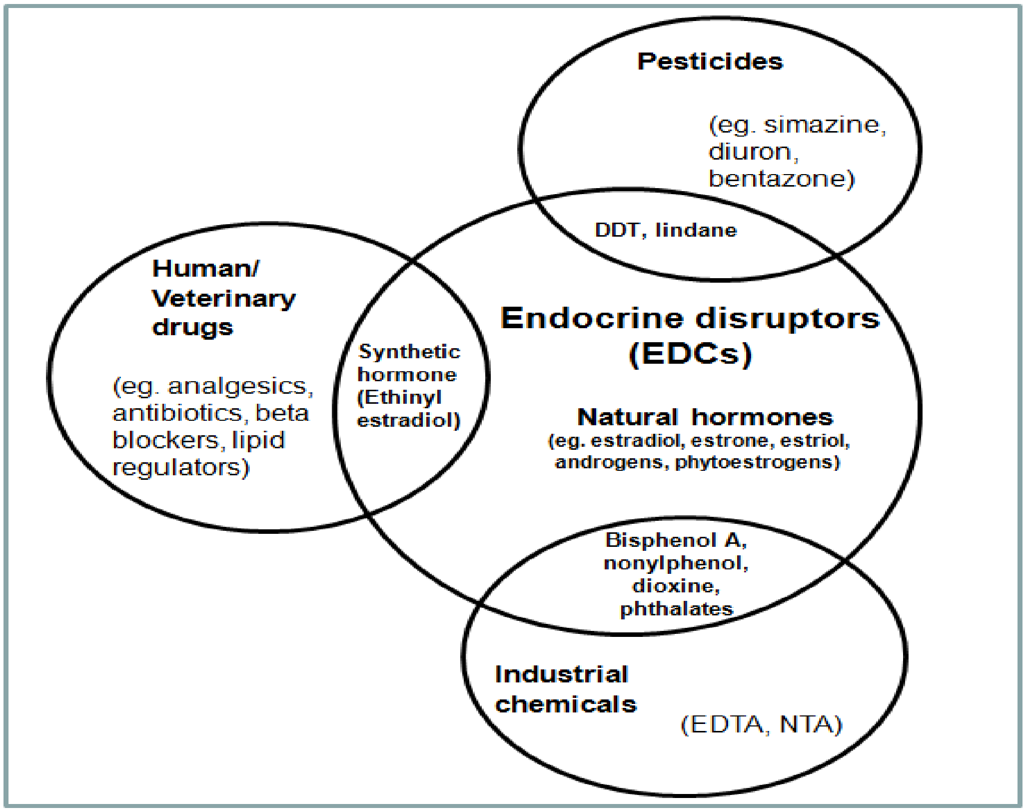

Figure 8: Origin of various endocrine disrupting chemicals (EDCs) in the environment (adapted from Scruggs et al., 2005)

1.6 Health burden of poor water and sanitation

Most water supply systems in developing countries are intermittent type, do not normally meet demands, and supplied water does not meet WHO standards. The pressure on water and sanitation facilities in these countries is continuously increasing due to rapid population growth and urbanization. The governments in these countries have not been able to increase funding on water sanitation and health sector. The spending on health sector in developing countries is also low compared to the investment in developed countries (Table 8). Table 8 below shows the government spending as percent of GDP in various sectors and indicates that developing countries spend the least in the health sector and spend the most on defense.

Table 8: Government spending as percent of GDP on various sectors (Source: UNICEF, The State of the World's Children 2007)

Regions	Indicators				Government's expenditure on		
	Total population (million)	% of population using improved drinking water sources (2006)	% of population using improved sanitation facilities (2006)	% of people living on less than $1.25 a day (2005)	Education	Health	Defense
World	6,655.41	87	62		6	14	11
Least developed countries	804.45	62 (urban 81, rural 55)	33	54	14	5	14
Developing countries	5432.84	84 (urban 94, rural 76)	53	25	9	3	10
Industrialized countries	974.91	100 (urban 100, rural 98)	100		4	18	12

There is a direct correlation of increased per capita use of fresh water to urbanization (Hinrichsen et al., 2002). This fact implies that urban water supply and sanitation systems in developing countries will receive additional pressure because of rapid urbanization. Water supply systems from developed countries are continuous, normally meet demand and supply good quality water.

Lack of adequate sanitation contaminates watercourses worldwide and is one of the most significant forms of water pollution. Improving water, sanitation and hygiene has the potential to reduce 3.7 percent of DALYs (Disability Adjusted Life Years) globally (UNICEF/ WHO 2008) and prevent at least 9.1% of the disease burden DALYs (Prüss-Üstün et al., 2008).WHO reports 5 million recorded deaths each year because of inadequate sanitation, insufficient hygiene and contaminated food and water mostly in poor and developing countries. Water and sanitation (watsan) coverage should be extended to minimize the loss of lives. Hinrichsen et al. (2002) reported that around 2.3 billion people suffer from water-related diseases worldwide and nearly half of urban residents in Africa, Asia, and Latin America suffer from one or more of the main diseases. Diarrheal diseases have been responsible for 90% of health problems (estimated 4 billion cases/year) causing 3-4 million deaths each year.

1.7 Innovative sanitation solutions

Urban sewage disposal results in irreversible losses of resources in numerous ways. The EOP technique does not eliminate pollutants efficiently enough to avoid continuous low-level environmental pollution and the disposal process consists of an energy taking destruction of valuable substances (Rakelmann, 2003). One of greatest limitations of the conventional wastewater treatment model, though successful in developed countries, is that to date coverage has remained low and that failure has been reported across most developing countries (Keraita et al., 2009) and most of the WWTPs are prone to failure even in countries with relatively strong economies like Brazil (Oliveira and von Sperling 2008). The high installation and large O&M costs, low capacity to pay, high energy requirements, lack of skilled labor, and poor governance are cited as the reasons for the failures of conventional model of collection, treatment and discharge of wastewater (Carr and Strauss 2001; UN Habitat 2004; IWMI 2009). The other reason is that developing countries apply developed country standards without considering their local appropriateness and financial and institutional capacities (Nhapi and Gijzen 2004).

The development to current conventional sanitary systems is a must and is no longer a concern only for urban areas but become a global concern. The development should strive for sustainable solutions to sanitation; consuming less water, recycling and reusing resources (nutrients) and consuming less energy than the existing systems which simultaneously decrease greenhouse gas production from water and wastewater treatment plants. Issues of wastewater treatment, reuse and recycling should be dealt with using ecological thinking as everything in nature operates in cycles (closed loop system) (Jenssen, 200). Ecological sanitation (ecosan) implies that principles of ecological thinking are applied to design and implementation of wastewater treatment systems. The fundamental principles of ecosan are pollution prevention (rather than control attempts after we pollute), sanitization of waste (urine and feces), and resource recovery (nutrient use for agricultural purposes) (Winblad and Simpson-Hebert, 2004). Human excreta contain nutrients that are necessary for plant growth. These same nutrients, along with other biological pollutants, are responsible for polluting water bodies. The sanitation technology should be such that they are affordable to rural poor and valuable resources are either conserved or are easy to recover. Ecological sanitation in urine diverting mode allows separate collection of urine and makes nutrient recovery easier as the concentration of N and P are almost one hundred times higher than in dilute flush-type wastewater systems (Wilsenach and van Loosdrecht, 2003).

1.7.1 Urine separation (Urine diversion toilets, UDTs)

Trends show that people want to move towards more resource intensive (water flushed) sanitation systems from relatively cheap and simple on-site alternatives like pit latrines, VIPs and septic tanks. As most of the people even in urban areas in developing countries cannot afford to operate and maintain capital intensive and high tech wastewater management options like central sewer system with WWTP, relatively simple and affordable technologies should be promoted. Several willingness to pay (WTP) studies conducted in many countries such as in India (UN/WB, 1999), Indonesia (Harapap and Hartono, 2007), Nigeria (Whittington et al., 1989), Nepal (Pattanayak et al., 2005), Australia (Hensher et al., 2005), Peru (Fujita et al., 2005) have shown that people have higher WTP for better services. However, the level of additional spending people need to make should be clearly explained for the range of available sanitation options. The community selected (demand driven) wastewater management system/technology would be sustainable as they would not select the type of system that is difficult to operate, and not feasible economically and technically (in construction, and O&M).

The conventional systems consider human excreta as a complete "waste" without any reuse. However, with the growing environmental awareness and public health threat they pose if released to the environment, there are concerns raised to contain, treat, and recycle nutrients and other useful materials in the excreta. Urine is a relatively pathogen free nutrient-concentrated liquid whereas fecal matters are rich in organic matters with high pathogen density. Separate collection of urine is getting attention as it constitutes only about 1% of domestic sewage but contains most of the nutrients (ammonia: 60–90%, phosphorus: 40–70%, and potassium: 55–90%) (Kirchmann and Petersson, 1995; Larsen and Gujer, 1996; Almeida et al., 1999). Due to the finite nature of phosphorous (P) resources there are worries that the world might be short of P in the future. Estimates on the remaining quantity of P and projections on how long it will take to completely deplete the resources vary and the figures range from 60-90 years (Tiessen, 1995) and 60-130 years (Steen, 1998). Collection of urine at the source can capture approximately 50% of the excreted P. Figure 9 shows the range of sanitation options and the possible route for resources recovery from wastewater employing source separated urine diverted (UD) sanitation systems after micropollutants (MPs) like estrogens removal.

Unlike conventional toilets where all waste fractions (urine, feces, grey water) are collected together (mixed), UD toilets allow collection of urine and feces separately. They are innovative also in the sense that they consume less water for flushing (even used in wet mode), reduce volume of subsequent waste that needs to be treated and offer flexibility of treatment methods appropriate to each waste fraction.

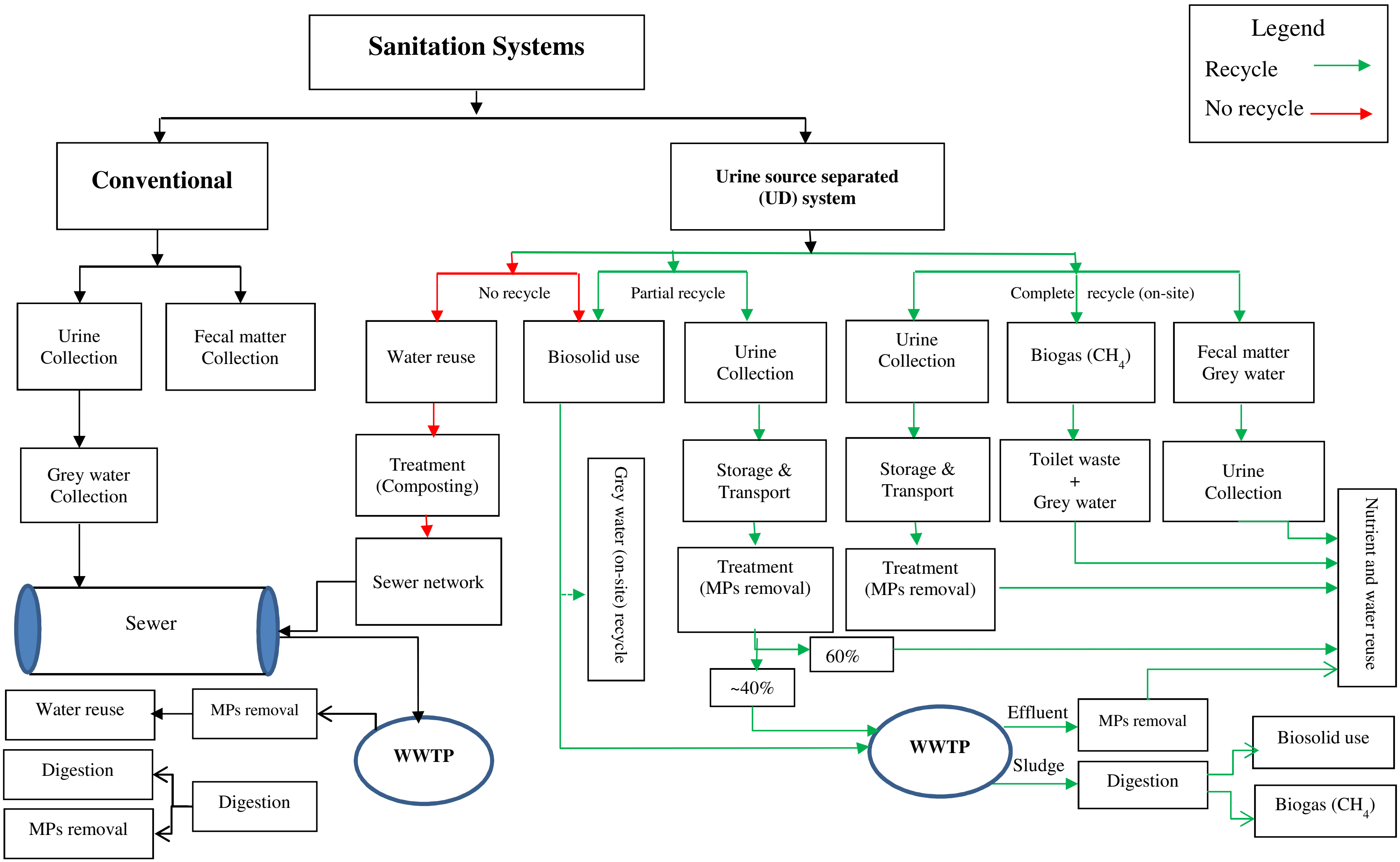

Figure 9: Sanitation system alternatives (green lines in the source separated (UD) system show the possible recycling route), VIP: ventilated improved pit, ST: septic tank, ATU: Aerobic treatment unit, MP: micropollutants, WWTP: wastewater treatment plant, CH4: Methane

Engineers and ecologists have proposed ecological sanitation (ecosan) in urine diverted mode as a sustainable alternative to conventional wastewater systems. Source separated or urine diverting toilets (UDTs) can capture nutrients (urine) at the source (do not mix with feces) which would otherwise need to be removed from wastewater in WWTPs with the expense of lots of energy. UDTs are similar to dual flush toilets in terms of flushing that are currently in use in many countries. UDT systems are largely unfamiliar to many people in the world including US residents. UDTs have two compartments: the small front compartment collects urine and the rear big compartment collects (or directs) feces to sewer line (Figurer 1.10-1.13). Human urine can also contain pathogenic viruses (Vanchiere et al., 2005) if excreted by infected persons but are considered minor in terms of environmental transmission as compared to cross-contamination of the urine fraction through fecal contamination (Ho¨glund et al., 2002). Urine separation also allows treatment methods tailored to the treatment needs of the waste fractions and nutrients can be safely recycled for agriculture.

The degree of investment required for a UDT system is much less than conventional systems and can function both on centralized and decentralized modes and can also be utilized as a transition to decentralized wastewater management (Larsen et al., 2001). UDTs use less water for flushing. Separate collection of urine is important also because phosphorus is finite (Cordell et al., 2009; Smil, 2000; Tinker, 1977) and UDTs help capture major fraction of phosphorus. In places with existing central sewer and WWTPs, approximately 60% of the urine can be collected and directed away from sewer line and remaining 40% would be necessary for secondary biological treatment processes in the WWTP (Wilsenach and van Loosdrecht, 2004).

Figure 10: Modern (pedestal type) UD toilet with flushing mechanism

Figure 11: Modern dry UDT pedestal (Source: Wostman Ecology, Sweden)

Figure 12: Chinese style UD squatting pan

Figure 13: Double vault Chinese style UDDT arrangement

Figures 10-13: Various models of urine diversion (UD) toilet (Photo courtesy of Dr. Arno Rosemarin, EcosanRes Program, Sweden)

UDTs can be of dry type (no flushing needed), also known as dry UDT or urine dehydrating dry toilet (UDDT) or water flushed (wet) type. UDTs come both in American style modern seat or commode (pedestal) type (Figures 10, and 11), and Chinese style squatting pan type (Figures 12, and 13). UDTs can accommodate people of all cultures, geographic regions, varying living standards and income and can also accommodate wipers (use paper, solid for cleaning) as well as washers (use water for anal cleansing). UDTs are good in both rural as well as urban settings if installed, used and maintained properly. There might be location specific concerns of recycling and reuse of excreta depending on the locality (close to delicate water resources, dense areas, population density) and local, state and federal regulations (like Clean Water Act), that might impede in-situ use. For example, Hawaii state law (Section 14-1.6) requires that every lot that has sanitary facilities requiring sewage disposal which is accessible to a public sewer must be connected to it. In such situations the collected excreta should be transferred off site for treatment, disposal and/or reuse.

1.7.2 Urine source separation movement

In the past, urine collection systems, if they existed, were mainly meant for reducing smell and partly for capturing nutrients but they became obsolete with the introduction of water closet systems (Kavastrom, 2006). In Nepal, people used to collect urine for fertilizing purposes. There are now growing interest regarding the benefits of urine separation in terms of resource recovery, reduced energy use and subsequent greenhouse gas emission reduction (during wastewater treatment, fertilizer production), and containment of estrogens. The present day UD toilet system got momentum with the eco-village movements in Sweden in the 1990s targeting single households, summer houses and a few eco villages (Janssen et al., 1996; Kavastrom, 2006). There are now several agencies involved in urine diverted sanitation systems all over the world. With the population explosion during last couple of decades, per capita water resources have dwindled rapidly. Many water utility companies around the world were forced to introduce water rationing as water sources that could be developed economically were used up. With the green movement gaining momentum all over the world and the huge amount of energy required to supply water and treat wastewater (removing nutrients from wastewater), people also started thinking of reducing water use. The other factor that motivated researchers and users for UDTs was the realization that the nutrients in excreta that are wasted are same nutrients produced as fertilizer to supply agriculture at a huge environmental cost. As most of the harmful microorganisms in wastewater can survive longer in water and in soil than in crops (Figure 4-6), direct use of urine in agriculture could be much better alternative than managing wastewater via soak-away pit or infiltration system in terms of microbial contamination of surface as well as ground water. The history and recent development in UD systems is covered in Chapter 2.

1.8 Social acceptability issues

Any product or service, no matter how good, will turn into a failure if users (target audiences) do not accept. The UD toilet is similar to a normal toilet (like American style toilet pedestal/seat) except for a partition in the bowl which separates the bowl into two compartments: one for collecting urine and the other for collecting feces. Though, similar in look, size, shape and function, the UD sanitation system is new technology to most people and the social acceptability of the system should be assessed before introducing UDTs in the market. User acceptability (or rejection) can be gauged with the help of simple surveys. Reports of acceptability surveys conducted in various parts of the world (a few countries from Europe, Africa, and Asia) are available and have reported mixed results: some societies rejected UD (one community in Pakistan, and one community in Ghana) whereas most of the societies were accepting the system. An on-line UD acceptability survey was conducted in Hawaii in 2012 and results were encouraging in the sense that about 80% of respondents were willing to adopt a UD system if the cost were similar to a conventional toilet system. A majority of the respondents (about 60%) were even ready to pay a little extra for the UD system. The results of acceptability survey are covered in detail in Chapter 3.

1.9 Capital and operation and maintenance costs of UD system

Being a relatively new technology, UD systems are in development phase. Literatures show that urine diversion toilets are relatively expensive compared to other onsite sanitation alternatives that are common in developing and developed countries. Not much literature is available regarding the cost of construction and O&M of a UD system in developed as well as in developing countries with different income, living standards and different geographical settings. UNEP (2004) recognizes ecological sanitation systems as a sustainable alternative and estimates the per capita cost of $160-175. This cost seems to be at the lower end for introducing UD systems in affluent communities in developed countries and increased investment can be expected. Lamichhane and Babcock (2012) have estimated a total installation cost of $2,100 per family (a house with 2 UDs including urine collection tanks) in the USA. The estimated annual O&M cost (also includes fecal sludge collection and disposal service) was \$69 and the estimated annual benefit from water conservation and nutrient recycling was approximately \$101. The cost of a UD system in low income countries is much lower. The cost of UD system in Nepal can range from \$150 to \$200 (Shrestha et al., 2006; Lamichhane, 2007). The economics of employing a UD system for urine collection and treatment (99% estrogenecity removal) in developed world settings is included in Chapter 3.

1.10 Sanitation issues in developing and developed countries

As explained in previous paragraphs, sanitation issues between developing countries and developed countries differ largely because of the difference in per capita income, food habits, living standard, personal habits, and on climate and weather. In the developing world, majority of people (major share of 2.5 billion) lack basic sanitation and millions of people practice open defecation. Domestic wastewater has been the main cause of water quality deterioration and incidence and prevalence of water borne (WB) diseases is very high. Preference to flush toilet and networked systems are growing ("catching-up" syndrome) as people in developing countries consider acquiring western life style and technology as 'development' (Iqbal, 2002; Nawab et al., 1998). However, the economy and technology is not yet very supportive for central systems and WWTPs. For example, in the city of Kathmandu, the capital of Nepal, it is estimated that the per capita spending of \$312 (approximately 60% of GDP of about \$540) (WEC, 2009) is required to provide water and sanitation services (KVEO, 2007). The wastewater is highly concentrated and microorganisms can be different from the wastewater in develop countries (both type and abundance).

There are sanitation issues also in developed countries but the issues are different from the issues in developing countries. People in these countries get adequate sanitation services mostly networked sewer systems and WWTPs but in some countries still many people are served by on-site sanitation systems. In the USA approximately 20-25% of homes are served by on-site systems and it is considered that these on-site systems are the third most common source of ground water contamination. Water borne diseases are very rare but occasional epidemic outbreaks due to unsanitary conditions (like *Listeria* outbreak in Colorado in 2011) can be seen. Similar to developing countries, people have preference to networked sewers and WWTPs (EPA, 2000). Economy is better, yet WWTPs are not sustainable based on energy consumption and concomitant green house gas emissions. Tables 9 and 10 show the type and status of conventional wastewater management practices and possible motivating factors for adapting source separated sanitation (UD) system in the developed and developing worlds, respectively.

Table 9: Status of water and sanitation services in developed and developing countries

Services	Developed countries	Developing countries
Water supply	Mostly improved	Improved and unimproved
Supply system	Continuous type and connected to individual dwellings	Mostly intermittent type, only people living in urban centers have piped connections to individual housings Supply system normally are of 'low-level equilibrium trap' type (Singh, 1993)
Quantity	Meet demand	Do not meet demand most of the times
Quality	Good quality (meet national and WHO drinking water quality standards)	Normally do not meet water quality standards

Table 9 Contd.

Utility companies	Have some sorts of autonomy and the board/utility company has the decision making power	Most of the utility companies are government controlled, do not entertain much autonomy; decision makings are affected and impressed by government officials/political leaders even if the company has autonomy
Institutional set up	Good	Very weak and poor performing
Financial health of water/wastewater utility companies	Good to OK	Very weak (almost all of them depend on government budget allocations)
Wastewater treatment		
Treatment type	Mostly improved and central, on-site treatment alternatives are also in use but are regulated	Mostly unimproved and onsite, no monitoring and evaluation program in place (not regulated)

Table 9 Contd.

Urine diversion toilet system	Gaining momentum in some of the European countries (Sweden, Norway, Finland, Germany) but yet largely unfamiliar to US societies	UD systems are being installed, though in pilot scale, in many countries of Africa, Asia, Latin America with the help of INGOs; local/central governments in some of the countries like China, India, Uganda, Burkina Faso are also part of the UD toilet movement.
Environmental issues		
Electricity consumption	Largest user of electricity for local governments (water management sector shares 3-6% of total electricity consumption)	Negligible
Green house gas production	Is an issue and a big concern also for the people	Coming up

Micropollutant (MP) issues	WWTP effluent discharge point suspected as a point source of emerging contaminants like estrogens, PhaRs and other emerging chemicals of environmental concern.	No attention has been paid to control and prevention of micropollutants like estrogens and PhaRs.
	Medicines buy-back program targeting medicinal residues have been in practice but no any effective program for controlling estrogen/hormone is known as of today. Will be good to have pilot scale programs to collect urine from places like hospitals, nursing homes and care homes to contain human borne estrogens	Not a serious issue yet compared to other burning issues like fecal contamination of drinking water. Per capita consumption of hormones, estrogens and medicines is very low compared to developed countries but can be an issue after few years due to increasing education and awareness
Sewage sludge management	Is becoming a big issue (costly sludge treatment/management program and land required for final disposal is also a concern)	Sewage sludge is not an issue yet as not many WWTPs exist but fecal sludge management from septic tanks, VIPs is becoming a serious issue especially in urban centers.

Table 9 Contd.

Sewage use for irrigation	Regulated and used as restricted or unrestricted use depending on the degree of treatment the sewage received	Unregulated and unrestricted use even for root crops, and vegetables that are consumed raw; is widely practiced in Mexico, China, Vietnam, India and several other countries but the (waste)water does not meet WHO (2006) recommendations
Community environmental awareness and involvement in decision making process	Highly aware communities, strong institutional and regulatory set up, governments expect and encourage community for participation/feedback in environmentally susceptible projects during decision making processes	Public awareness is rising; governments are normally reluctant to get feedbacks from communities and involvement in decision making processes (not transparent) but people now voice against any proposed activities that can have environmental consequences. Use of social media for raising concerns related to environment, human rights and alike are becoming extremely popular in countries like China, India and Nepal
Inorganic (mineral) fertilizer	Cheap (affordable) and abundance (available)	Expensive (not affordable to rural farmers) and not easily available

Table 10: Status and motivating factors for source separated (UDT) sanitation system (developed Vs. developing countries)

Motivating factors for urine source separation	Developed countries	Developing countries
Water conservation	Interest is growing in some of the European countries but water conservation potential of UDT is not yet realized in US societies.	Not realized yet
Energy conservation (during wastewater treatment)	Expense on energy during wastewater treatment is a big issue but not yet realized if urine source separation can help reduce energy consumption	Not an issue yet

Containment of micropollutants (estrogens, PhaRs etc.)	Not much attention is paid to separate urine collection for controlling micropollutants. Some of the states in the US have started residual medicine buy-back programs in an aim to control PhaRs in the aquatic environment. Inclusion of natural and synthetic estrogens in CCL 3 of EPA (2008) can be indicative of future regulatory limit impositions	Not an issue yet
Nutrient recycling (fertilizer value)	Not much motivated with the nutrient value of urine as inorganic fertilizers are cheap and easily affordable; Possibility of phosphorus recovery from wastewater is now getting attention	Yes, the urine separation movement is mainly based on fertilizer value of urine

Overabundance of nutrients in water courses and estuaries (eutrophication)	Is an issue, urine is getting attention as one of the important nutrient source in some European countries. Awareness is also rising in the USA as some states like Florida (Department of Health) is considering UD for P recovery and some cities like City of San Jose (Santa Clara Water Pollution Control Plant Master Plan) are considering separate collection of urine as a part of augmenting wastewater treatment plant capacity by reducing nutrients load to existing WWTP.	Slowly growing Water quality of most of the water bodies in rural areas are still acceptable but extremely polluted near urban centers and industrial areas
Sewage sludge reduction (addition of methanol during denitrification adds sludge volume during wastewater treatment)	Sludge volume is an issue but seems that it is not yet realized if taking urine out of the sewer and WWTP system can help reduce sludge production	Not an national issue yet as third world countries lack central sewer systems and WWTPs

Green movement	Governments in some European and Scandinavian countries are also funding research related to urine diversion, several universities, research organization, and NGOs are working on UD system Largely unfamiliar in the US but some groups are advocating for separate urine collection and slowly growing attention to nutrient value of urine	Yes (only partially): the green movement in many developing countries is not very strong The groups has shown, though in different names, strong presence in countries like China and India and in many cases, have been able to force the governments to withdraw their decisions. NGOs in many countries are promoting UDT as pilot projects

1.11 Problems associated with UDT system

The history of UDT system is not long and is still in its infancy. Though there are several advantages of UD system over conventional sanitation systems, there are still several issues to be resolved for UDTs to be one of the favorable sanitation systems in the world. The table 11 below shows the relative advantages and disadvantages of UDT system.

Table 11: Relative advantages and disadvantages of UDT system

Advantages	Disadvantages
Major fraction of nutrients excreted (90% N, 50% P, and 55% K)	Urine is much less concentrated in terms of nutrients compared to inorganic fertilizers; cannot be produced when crops/plants need; need to transport to fields and large storage facilities for long time storage, salt content of urine can be an issues in areas with low rain; collecting urine from all (children, elderly) users can be challenging
Main excretion route for chemicals: 95% estrogens, PhaRs, and X-ray contrast agent	UDTs need behavioral changes; system is more complex and need special maintenance to avoid clogging (struvite, calcite, and hydroxyapatite deposition) of UD pipe; metal pipes cannot be used due to very corrosive nature of ammonia
Reduces waste volume (entry of foreign materials if waste is intended to recycle locally)	There are certain level of health risks associated with collection/handling of waste
Sludge volume reduction (possibility of N removal in waste sludge eliminating nitrification step)	Difficult in already developed areas with large investment on infrastructures and retrofitting is expensive
Energy conservation (sewage treatment works are the single most energy consuming sector in local governments)	Local regulations may prohibit separate collection of waste. For example Hawaii state law (section 14-1.6) makes it mandatory to connect to a public sewer if accessible
Treatment methods can be tailored to specific waste fraction	Many parties involved: health regulators, land and project developers, local community, water authorities and utility companies

1.12 Research need

The issues related to water and sanitation, environmental and public health depend on several factors like level of education, standard of living, per capita income weather and climate and many more. These factors vary a lot between developing and developed countries. The usefulness of introducing source separated sanitation (UDT) system is tested separately for both first and third world countries. The viability of UDT system was tested against the hypotheses:

In developing countries

- UDT has the potential to save water
- UDT reduces pollution load to receiving water bodies
- UDT can improve soil fertility
- UDT can contribute to reduce poverty and hunger (food security)

In developed countries (like USA)

- UDT has the potential to save water and reduce subsequent wastewater volume
- UDT has the potential to separate and contain a majority of EDCs
- Estrogenicity removal from source separated urine is more energy efficient than removing it from bulk wastewater
- UDTs will be socially accepted if publicized

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CHAPTER 2. AN ECONOMIC APPRAISAL OF USING SOURCE SEPARATION OF HUMAN URINE TO CONTAIN AND TREAT ENDOCRINE DISRUPTERS IN THE USA

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An economic appraisal of using source separation of human urine to contain and treat endocrine disrupters in the USA

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Abstract

Elevated concentrations of estrogens in natural waters pose a significant threat to public health and aquatic ecosystems. Both natural (estrone, 17β-estradiol and estriol) and synthetic (17α ethynylestradiol) estrogens, ubiquitous in wastewater effluents and receiving waters, have been shown to affect the endocrine system of human and aquatic life. The effects vary from cancer to sex reversals at levels as low as parts per trillion in sensitive organisms. Separation of urine which constitutes only about 1% of domestic sewage and contains nearly all of the excreted estrogens, potentially offers an energy-efficient way to contain and then treat these chemicals. With a capital expense of $2,100 and operation and maintenance costs of $69/y for a urine diverting toilet system, a family in the USA can realize an estimated savings of $101/y in energy, water, and nutrients and a decrease of 100 kg green house gas emissions. To remove 99% of estrogenicity in discharged waters would require approximately 12 kWh/p-y using continuous electrodialysis followed by ozonation (O_3) of source separated urine. To achieve the same results by adding O_3 treatment after activated sludge at existing municipal wastewater treatment plants would require 23 kWh/p-y. From an energy standpoint it makes sense to practice source separation and treatment of urine to limit estrogen discharges into the environment.

Key words: estrogen treatment, nutrient recycling, **s**ource separation of urine, greenhouse gas emissions

2.1 Introduction

Sewage is a complex of mixture many thousands of chemicals and is major source of environmental pollution. Municipal drinking water produced at treatment plants that use surface water containing treated effluent contains residuals of these chemicals. Some of the chemicals in sewage mimic the actions of steroid hormones and can produce biological responses qualitatively similar to those produced by endogenous hormones (Jobling et al., 1998). Many synthetic chemicals along with chemicals of natural origin that act as endocrine disruptors (Cleary and Scruggs, 2007) are environmentally persistent. These chemicals known as endocrine disrupting chemicals (EDC) include industrial chemicals, pharmaceuticals, antibacterial agents, pesticides, natural estrogens such as estrone (E1), 17β-estradiol (E2) and estriol (E3), natural androgens such as testosterone (T), androsterone (A) and dihydrotestosterone (DHT), synthetic estrogens like 17α ethynylestradiol (EE2) and synthetic androgens like trenbolone (Tr) and phytoestrogens such as isoflavones and coumestrol (Koltz et al., 2007).

Studies by Korner et al. (2001) (Korner et al., 2001b) and Snyder et al. (2001) (Snyder et al., 2001b) conclude that E1, E2 and EE2 (a main constituent of oral contraceptive pills) are responsible for a significant portion (up to 90%) of the endocrine disrupting effects observed in the aquatic environment. Various studies have shown that the concentrations of hormones E1, E2, E3 and EE2 in raw sewage are in the range of 30-80, 5-30, 80-300 ng/L and <10 ng/L, respectively (Combalbert and Hernandez-Raquet, 2010). Huang and Sedlak (2001) (Huang and Sedlak, 2001) reported mean residual concentrations of 3.8 ng/L and 2.0 ng/L respectively for E2 and EE2 in secondary effluents in the USA.

Kolpin et al. (2002) (Kolpin et al., 2002) reported concentrations up to 0.112 ng/L, 0.2 ng/L and 0.831 ng/L of E1, E2 and EE2 respectively in US streams. These chemicals are of great interest in water pollution control as wastewater treatment plants (WWTPs) act as point sources of these compounds (Clara et al., 2005) which are known to disrupt endocrine systems of fish and other aquatic vertebrate species at nanogram per liter concentrations (Panter et al., 1998).

The current EPA drinking water regulations include more than 90 contaminants under the Safe Drinking Water Act (SDWA). The 1996 amendments require EPA to publish a list of contaminants known or anticipated to occur in public drinking water systems known as the drinking water contaminant candidate list (CCL) every five years. The CCL is a list of contaminants that are currently not subject to any proposed or promulgated national primary drinking water regulations but may require regulation under SDWA. The CCL 3, announced in 2008, contained 116 candidates including E1, E2, E3, and EE2 indicating possible regulations for these chemicals in the future.

2.2 Sources of steroidal estrogens in the environment and estrogenic potency

Feces and urine of all farm animals contain steroid estrogens regardless of species and sex(Knight, 1980). Effluents from WWTPs are the major source of EDCs in the aquatic environment(Kirk et al., 2002). Urine is the main excretion route (95%) for estrogens from the human body (Combalbert and Hernandez-Raquet, 2010). They estimated worldwide yearly human discharge of 29.5 tonnes of natural and 0.72 tonnes of synthetic estrogens. Various researchers have estimated relative potencies of estrogens and concluded that EE2 is the most potent. The estimated estrogenic potency (EP) of EE2 is 2.46 times greater than E2 which in turn is 40 times more potent than E1 and 5.7 times more potent than E3 assuming the EP of E2 as unity (Balaguer et al., 1999; Pillon et al., 2005). Almost all of the EP in sewage and treated effluent derives from the estrogen compounds (rather than other EDCs) and E2 alone is responsible for 34 % of EP in raw sewage and nearly 100% in WWTP effluent (Desbrow et al., 1998; Matsui et al., 2000).

2.2.1 Exposure to estrogens and effect on humans and wildlife

Estrogens have low solubility (0.8 to 13.3 mg/L) in water (Desbrow et al., 1998) and are sufficiently mobile and persistent to impact surface and groundwater quality (Hanselman et al., 2003). Exposure to estrogens or estrogen mimics during sexual differentiation has been shown to induce sex reversal and/or intersexuality in fish (Afonso et al., 2002). Jobling et al. (1998) (Jobling et al., 1998) reported that exposure to sewage effluent in a wide range of typical rivers in the UK causes adverse reproductive health effects such as intersexuality (in fish). In humans EDCs cause reduced sperm counts, congenital malformations in children, retarded sexual and neurobehavioral development, increased incidences of hormone-related cancers (breast, ovary, testes, prostate), and increased male newborns with genital malformations(Sharpe and Skakkebaek, 1993). Specifically, Carlsen et al. (1992) (Carlsen et al., 1992) observed decreases in sperm concentration (113 million/ml to 66 million/ml) and sperm volume (3.4 ml to 2.75 ml) over the period 1938-1990 possibly due to EDCs. Also, E2 and EE2 are recognized human carcinogens (Kortenkamp, 2007).

2.2.2 Fate of estrogens in existing wastewater treatment plants

Humans primarily excrete conjugated estrogens (Orme et al., 1984) but de-conjugation readily occurs in sewage treatment works leading to the presence of free and hence biologically active estrogens in the effluent (EA, 1996). Municipal wastewater treatment plants including conventional activated sludge (CAS) do remove EDCs to some extent(Joss et al., 2004) but probably not enough to meet possible future regulatory limits. In order to meet low estrogen concentration limits, existing WWTPs could either modify operations, or be reconfigured with additional treatment processes that target estrogens (Jones et al., 2007), or the current practice of sanitation could be modified to limit estrogen loads to WWTPs. Various research have reported that nitrifying bacteria are responsible for estrogen degradation and suggested increasing the CAS sludge age to greater than 15 days as a reconfiguration step to improve estrogen removal (Andersen et al., 2003; Ternes et al., 2004). Clara et al (2005) (Clara et al., 2005) observed an enhanced removal (from 60% to 90%) of various estrogens (E1, E2, E3), when the sludge age of CAS was increased from 10 days to 20 days. However, even at 20 days, there was less than 60% removal of EE2. It seems that modifying operation mode can improve EP removal, but will not likely be sufficient to meet future low concentration limits that would be protective of the environment. In addition, at conventional treatment plants, 5-10% of estrogens partition in to residual sludge. These untreated estrogens may find the way into the environment via sludge disposal.

2.3 Urine separation to reduce estrogen released into the environment

It is possible to use advanced treatment processes such as reverse osmosis and ozone in order to achieve 99% removal of estrogen residuals in secondary effluent (after CAS).

This would require treatment of the entire wastewater flow. Another option would be to separate the urine at the source and then treat the much smaller volume with advanced treatment processes. Urine diversion (UD) toilets can be used to separate urine from fecal matter at the source. UD toilets are similar to conventional US toilets except they have two compartments; a small front compartment for urine and a larger rear compartment for feces. Table 12 gives a list of recent articles regarding source separation of urine, and nutrient recycling. There are at least five flush-type UD toilet manufacturers in the world; four in Europe and one in China. There are not many UD toilets deployed currently but their use is starting to increase all over the world.

Urine constitute less than 1% of the volume of domestic sewage, but contains 95% of E1, E2 and E3 (ref 6), 70% of pharmaceuticals (Mes et al., 2005) and a major portion of many important nutrients. About 40% of urine is sufficient to supply the nutrient requirements for CAS (Wilsenach and van Loosdrecht, 2004). Therefore, it would be necessary to return about 40% of the advanced treated urine stream (without estrogens) to the WWTP in order for biological wastewater treatment processes to function properly.

The practices that have evolved in relation to waste and wastewater management in one place cannot be readily transferred to other places. A thorough assessment (acceptability study) of the local sociocultural context of the community is needed before introducing new technology (Wegelin-Schuringa, 2000b; WHO, 2006c) and so will be the case for UDTs. Dual flush WCs are currently in use in the US.

Table 12: Articles related to urine separation and nutrient recycling and list of organizations/agencies involved in source separation system

Author	Main focus area	Source/Journal
Mihelcic et al., 2011	Nutrient recovery (Phosphorus)	Chemosphere (Mihelcic et al., 2011)
Lienert and Larsen, 2010	Review of acceptability studies in European countries	Env. Sci. & Technol.(Lienert and Larsen, 2010a)
Guest et al., 2009	Resource recovery	Env. Sci. Technol. (Guest et al., 2009)
Drangert and Nawab, 2010	Cultural-spatial analysis of excreting, human excreta recycling and health	Health place(Drangert and Nawab, 2010)
Larsen et al., 2009	Paradigm shift in wastewater handling, nutrient recovery	Env. Sci. Technol. (Larsen et al., 2009)
Rossi et al., 2009	Efficiency of urine separation	J. Env. Management. (Rossi et al., 2009)
Vinneras, 2008	Inactivation of bacteria and viruses in human urine	Water Research
Borsuk et al., 2008	Ranking of sanitation technologies using multicriteria decision analysis (MCDA)	Env. Sci. & Technol. (Borsuk et al., 2008)
Wilsenach et al., 2007	Nutrient recovery (Struvite precipitation)	Water Research (Wilsenach et al., 2007)
Pronk et al.,2007	Fertilizer production	Water Sci. Technol. (Pronk et al., 2007)
Ronteltap et al., 2007	Thermodynamics of struvite precipitation (nutrient recovery)	Water Research (Ronteltap et al., 2007)
Lamichhane, 2007	Cost comparison: On-site (Urine diversion) versus central sewer system	Water Sci. Technol(Lamichhane, 2007)
Mels et al., 2007	Comparative performance of source separated systems	Water Sci. Technol (Mels et al., 2007)
Lienert et al., 2006	Young users acceptability survey of nomix toilets	Water Sci. Technol.(Lienert et al., 2006)
Escher et al., 2006	Removal of hormones and pharmaceuticals	Env. Sci. Technol.(Escher et al., 2006)
Berndtsson, J. C, 2006	Experiences from urine separation systems	Build. Environ.(Berndtsson, 2006)
Udert et al., 2006	Fate of nutrients and pathogens	Water Sci. Technol.(Udert et al., 2006)
Langergraber & Muellegger, 2005	Nutrient recycling	Env. International(Langergraber and Muellegger, 2005)
Larsen et al., 2004	Containment of pharmaceuticals and other micropollutants	J. of Biotechnology(Larsen et al., 2004)

Author	Main focus area	Source/Journal
Randall, C.W., 2003	Socioeconomic impacts of nutrient removal from wastewater	Water Sci. & Technol.(Randall, 2003)
Hellström, D., 2003	Nutrient recovery, energy analysis	Water Sci. & Technol.(Hellstrom, 2003)
Maurer et al., 2003	Nutrient recovery, energy analysis	Water Sci. & Technol.(Maurer et al., 2003)
Lienert et al., 2003	Farmers acceptability study of urine derived fertilizer	Water Sci. & Technol.(Lienert et al., 2003)
Hoglund et al., 2002	Microbial risk of using separated urine in agriculture	Waste Manag Res(Hoglund et al., 2002)
Jonsson et al., 1997	Nutrients and water conservation	Water Sci. & Technol.(Jönsson et al., 1997)

Name and address of main organization/agencies working on urine diverting (Nomix) sanitation technologies

Agency name	Country	Internet address
EcoSanRes program	Sweden	http://www.ecosanres.org
GIZ (formerly GTZ)	Germany	www.giz.de/ecosan
Swiss Federal Institute of Aquatic Science and Technology (Eawag)	Switzerland	http://www.eawag.ch/index
Sustainable Sanitation Alliance (SuSanA)	Germany	http://www.susana.org/

Projects and case studies related to urine diverting toilet (ecosan) technologies worldwide can be found at

http://www.giz.de/Themen/en/dokumente/giz2011-en-worldwide-ecosan-project-list.pdf, http://www.susana.org/index.php/lang-en/case-studies

UD toilets are similar to normal dual flush WCs in terms of use and flushing. It is expected that users would have no problem in adapting to UD toilets but they should be made aware of the periodic chemical cleaning necessary for UDTs. Local and mass media have been very effective tools to create public awareness and pro-environmental behaviors(Chan, 1998b). A manual for maintenance should also accompany each UD toilet to educate consumers.

2.3.1 Urine quantity and characteristics

Urine excretion by adults ranges from 0.8 to 1.5 L/p-d (WHO, 2006b) and a volume of 1.5 L/p-d (~550 L/p-y) is usually used for calculation purposes (Andersson et al., 2002; Hellström and Kärrman, 1996; Jönsson et al., 1997). The majority of ammonia (60-90%), phosphorus (40-70%), and potassium (55-90%) in municipal WW originates from urine (Almeida et al., 1999b; Kirchmann and Petersson, 1995; Larsen and Gujer, 1996b; Otterpohl, 2000). There should not be any pathogens in urine if urinary tract infection is absent. The total daily toilet visits and visits for urination are taken as 6.5 times and 5.1 times respectively (Jönsson et al., 2005; Jönsson et al., 1997 ; Norin, 1996; Verstraete et al., 2009b). UD toilets consume 4 and 0.15 liters per flush (lpf) for flushing the fecal and urine bowls, respectively (Lienert and Larsen, 2006a) versus 1.6 gallons (~6.0 L) per flush by conventional US toilets. A saving of 5.85 liter during urine flushing and 2 liter saving during feces flushing can be expected from a UD. It is assumed that 100% of urine can be collected if UD toilets are used.

Collected urine has a typical pH of 9 and TS of 20 g/p-d consisting of 19.24 g/p-d total dissolved solids (TDS) and 0.76g/p-d total suspended solids (TSS) (Jönsson et al., 2005).

Based on the quantity of flush water used, the liquid mixture that would be collected from a UD toilet would be a mixture of 1.5 L urine and 1 L flush water. The collected urine would thus have a TS, TSS and TDS concentration of 8,000 mg/L (20g/2.5 L), 304 mg/L and 2,397 mg/L respectively. Liu et al. (2009)(Liu et al., 2009) reported average urinary excretion (natural estrogen) rates of 10.73 µg E1, 4.71µg E2 and 8.12 µg E3 from a typical woman of reproductive age and 3.9 µg E1, 1.5 µg E2 and 1.5 µg E3 from a typical man. Using these values, Table 13 shows calculated concentrations of estrogens in sewage (assuming 300 L per individual equivalence, IE) and in urine.

Table 13: Daily human estrogen excretion, concentration and estrogenic potentials (EP) in source separated urine and sewage before and after treatment

	Female (µg/day)[Ω]			Male (µg/day)			Male and Female total (µg/d)	Average (µg/day)	Estrogen Concentration (ng/L)		Urine after ED+O_3 (99% removal) (ng/L)	Effluent estrogen concentration (ng/L)[π]		
Estrogens	Urine	Feces	total	Urine	Feces	total			Urine	Sewage		100% urine back to sewer	40% urine back to sewer	After CAS (90% removal)
E1	10.73	0.56	11.29	3.90	0.21	4.11	15.40	**7.70**	3080	25.7	30.8	0.10	0.025	2.57
E2	4.71	0.25	4.96	1.50	0.08	1.58	6.54	**3.27**	1307.4	10.9	13.1	0.04	0.010	1.09
E3	8.12	0.43	8.55	1.50	0.08	1.58	10.13	**5.06**	2025.3	16.9	20.3	0.07	0.016	1.69
EP equivalent[α]	6.41	0.34	6.74	1.86	0.10	1.96	8.70	**4.35**	1740.8	14.5	17.4	0.06	0.014	1.45

[Ω]Urinary excretion of estrogens adapted from Liu et al. (2009)(Liu et al., 2009), estrogens in feces assumed 5% of the total.

[π] Concentrations calculated based on a urine volume of 2.5 L/p-d (expected from a UD) and 1individual equivalence (IE) of 300 L/p-d

[α]Estrogenic potential (EP) is based on E2 arbitrarily fixed as unity (EP = 1), EPs of E1 is 1/40 and E3 is 1/5.7(Balaguer et al., 1999; Pillon et al., 2005), and EP equivalent is the sum of individual EPs of estrogens (E1, E2, and E3)

2.3.2 Urine treatment

Full scale urine treatment plants are not known to exist as of today but urine can be treated by various methods including storage, ozonation (O_3), electrodialysis (ED) plus ozonation, reverse osmosis (RO), or advanced oxidation processes (AOPs). A combination of two or more methods can be employed to achieve EDC removal, nutrient recovery, and pathogen destruction because no single treatment option can do all three (Maurer et al., 2006). Recovery of nutrients (and subsequent sale) should be taken in to account with UD systems as it can offset part of the cost for urine separation and treatment. It could be more energy efficient, economical and offer better process control to remove estrogenicity from a small volume (urine only) than to treat the chemicals at infinitesimal concentrations in bulk wastewater effluent. Some of the options for treating urine, though used only at the lab scale, are discussed below.

2.3.2.1 Storage

Urine from a healthy person is normally sterile (Schonning et al., 2002). Pathogens like *Schistosoma haematobium*, *Salmonella typhi*, and *Leptospira interrogans* that pose serious health risks are found in urine only from infected persons (Feachem, 1983). Pathogens in urine can be reduced to a level that is safe even for unrestricted irrigation if stored for 6 months at temperature 20˚C or higher (Schonning and Stenstrom, 2004) and the inactivation is linearly correlated with ammonia concentration (Vinneras et al., 2008). Storage generally does not destroy estrogens but is beneficial for pathogen destruction (hygienization). No full scale urine storage plants are recorded as of today but urine collection and storage at pilot scale and effect of storage on chemical and microbiological properties of urine is being studied in Sweden (Stintzing et al., 2007).

2.3.2.2 Ozone (O3) treatment

Ozone can oxidize organics including estrogens with a contact time of about 20-30 minutes(Huber et al., 2003) and can control odor and is also a virucide (EPA, 1999). The pH of 9 of collected (hydrolyzed) urine can be an added advantage for estrogen removal as the action of OH radicals, a byproduct of O_3 in water, is improved at higher pH (>8)(Byrns, 2001). Dodd et al. (2008)(Dodd et al., 2008) observed 99% estrogenicity elimination from urine at an absorbed ozone dose of 1.1 g/L (1.65 g O_3 for 1.5 L urine or 1.65 g/p-d) and energy expense of 26 kWh/p-y (70 Wh/p-d).

An ozone dose of 5-12 mg/L is normally used for treating CAS effluents. Only the most reactive estrogens can be fully eliminated at a dose of 5 mg/L (Nothe et al., 2009). Assuming 300 liters of water per individual equivalence (IE) per day, an O_3 dose of 1.5-3.6 g/p-d is required to achieve 99% estrogenicity removal from CAS effluent with an energy expense of 23 - 56 kWh per year. This is in addition to the 25 kWh per year per IE needed to operate CAS (Verstraete et al., 2009b). This amount is similar to that of ozonation of source separated urine. When treating CAS effluent, the estrogens in the sludge (5 to 10%) will remain untreated(Holbrook et al., 2002) making this option less favorable to ozonation of source separated urine. Dodd et al. (2008)(Dodd et al., 2008) were able to produce O_3 at an energy consumption of 13.1Wh per gram with a generator efficiency of 31% and these values are used in all calculations herein.

2.3.2.3 Electrodialysis (ED) and ozonation (O3)

ED is not considered efficient for treating highly concentrated salt solutions (Sagle and Freeman, 2010) but can be efficient in treating urine if the aim is also to recover nutrients because it is capable of removing ions like nitrate, nitrite, ammonium from other organic substances and estrogens present in water. Ninety percent of nitrogen (N), Phosphorus (P) and potassium (K) can be recovered (along with 10% of the EDCs) in the ED concentrate (0.3-0.35 m^3/ m^3 urine volume) (Maurer et al., 2006). Dodd et al. (2008)(Dodd et al., 2008) calculated the energy required to eliminate 99% of estrogens from two ED streams, the concentrate and diluate, followed by ozonation at absorbed doses of 1,050 mg/L and 250 mg/L, respectively. They reported total energy consumption of 12 kWh per year (32 Wh per day).

2.3.2.4 Reverse osmosis (RO)

RO can be used to produce drinking quality water from WWTP effluents (Radjenovic et al., 2008) and can achieve more than 90% estrogen rejection(Maurer et al., 2006). The energy required for RO is 3kWh per cubic meter of water (Cooley et al., 2006) which gives 296 kWh per year (810 Wh per day). The RO permeate can be directly reused for nonpotable uses as it should contain only a tiny fraction of estrogens. However, the estrogen -rich RO brine would require further treatment. Assuming a similar ozone dose (1.1 g/L) as that needed for direct urine treatment, the energy required would be 916 kWh per year. The total cost of treatment (CAS effluent by RO and ozonation of brine) would then be 1,212 kWh per year.

2.3.2.5 Advanced oxidation processes

Advanced oxidation processes (AOPs) make use of hydroxyl (OH) radicals to oxidize pollutants. Some of the AOP methods employed to produce hydroxyl radicals are Ozone/UV, Hydrogen Peroxide (H_2O_2)/UV, Ozone/H_2O_2, Catalytic oxidation, and Fenton type reactions. The H_2O_2/UV process is proven effective in treating various contaminants with more than 90% removal of VOCs like PCE, TCE, vinyl chloride (EPA, 1998). There is currently no literature on using AOPs to treat estrogens in high TDS, high-turbidity streams similar to urine.

2.4. Economics of urine separation

2.4.1 Cost for UD system installation

The costs involved to install a UD system include the cost of the toilet fixture, the pipes/fittings for urine diversion, and a urine holding tank. Buhot (Buhot, 2008) estimated that the total cost to install a UD toilet in Florida (inclusive of the fixture, all pipes and fittings and a 1,500 gallon urine holding tank) to be \$4,600. An average family of 3.14 (UCB, 2009) would produce approximately 760 gallon/y of urine flush liquid in one year if dual flush button UD is used making a 1,000 gallon tank big enough to collect and store the urine mixture for one year. The UD installation cost could decrease to approximately \$1,500 for multiple-toilet installations and using smaller storage tanks (~500 gallons) with semi-annual collection by pump truck. The \$1,500 cost includes \$600 for a UD unit and \$900 for piping and urine collection tank. Therefore the estimated total cost for a household with 2 UD units would be \$2,100. A 500-gallon tank will require a foot print of 30 ft^2 (3ft X 10 ft) which could be above ground, in a basement or buried. It is assumed that the fecal fraction from the UD goes into the existing sewer line.

2.4.2 UD system maintenance and urine transport

With UD systems there is a risk of pipe blockage due to urea [$CO(NH_2)_2$] degradation and subsequent calcium phosphate [$Ca_{10}(PO_4)_6(OH)_2$] and struvite ($MgNH_4PO_4$) precipitation. Kvarnstrom and her team (Kvarnström et al., 2006) suggest that one half liter of caustic soda (NaOH) or acetic acid (>24%) solution can be used for chemical cleaning of the urine pipe two times per year at an estimated cost of $25. Separated urine must be collected and transported to a treatment facility. Following treatment for 99% removal of estrogens, 40% would be returned to the wastewater and 60% could be recycled for nutrient recovery. The cost to pump and dispose of septage in Honolulu is $132.90 for 3,000 gallons (CCH, 2011). Therefore, the yearly O&M cost per household with a 500-gallon urine holding tank would be approximately $69.3

2.4.3 Economic and environmental benefits of UD systems

Publicly owned water and wastewater treatment systems consume 3% of the total energy generated in the US(EPRI, 1996). On-site residential aerobic treatment units (ATUs) consume 40kWh/IE of electricity and septic tanks release 20-40 m^3/IE of methane and nutrients to groundwater making them not environmentally sustainable (Verstraete et al., 2009b). The anticipated environmental and economic benefits that can be attributed to urine separation systems are recycling of nutrients, reduced greenhouse gas emissions, savings in energy for collection, conveyance and treatment of sewage and containment of most of the estrogens in a small volume for subsequent treatment. The environmental benefits of cost effectively treating estrogens depend on the retrofitting of existing toilets with UD toilets and it could take quite some time to accomplish even with incentives for homeowners.

2.4.4 Savings of energy and reduction of green house gas (GHG) emissions

An average individual excretes 30 kg COD, 4.5 kg N, 1 kg P, 1.5 kg K and numerous other micronutrients each year, mostly in urine (Almeida et al., 1999b; Jönsson et al., 1997 ; Larsen and Gujer, 1996b; Wilsenach and van Loosdrecht, 2004) (see Table 2.3). The electrical energy that would be used by processes to treat nutrients in separated urine

(60% of the total) is shown in Table 14 based on stoichiometric oxygen demand and power consumed by CAS aerators (1 kWh/kg COD). The average electricity cost in the US ranges from $0.062/kWh (Wyoming) to $0.251 per kWh (Hawaii) (EIA, 2012) with an average of about $0.10 per kWh. The average GHG emission attributed to electricity production in the USA is 0.601 kg per kWh (CDIAC; EIA, 2009).

Table 14: Electricity cost and GHG emission for wastewater treatment (per capita per year)

Organic matter and nutrients excreted$^{\Delta}$	Excretion (kg per capita per year)			COD demand (kg COD/kg)	COD for urine (kg)	Energy required for aerators to supply oxygen (kWh)	Electricity cost ($)	Associated GHG emissions (kg)
	Total	Urine♥	In 60% urine					
COD	30	3.6	2.16	1	2.16	2.16	0.22	1.30
Nitrogen (N)	4.5	4.05	2.43	4.58	11.13	11.13	1.11	6.69
Phosphorus (P)	1.0	0.5	0.30	Considered treated simultaneously with COD and N				
Potassium (K)	1.5	0.83	0.50	Considered treated simultaneously with COD and N				
Total					13.29	13.29	1.33	7.99

$^{\Delta}$Per capita per year average excretion

♥Calculated assuming urinary excretion of 12%, 90%, 50% and 55% of total excreted COD, N, P, and K respectively

The greenhouse gas emissions calculated in Table 3 (7.99 kg/p-y) are reductions that could be sold(UNFCCC). Developing countries are making money by earning certified emission reduction credits and selling them to companies in industrialized countries not meeting reduction targets imposed by the Kyoto protocol. These emission credits (one tonne of carbon dioxide or equivalent, CO_2 eq) may be worth about $16 (€10) per tonne on the world market (Åhman and Holmgren, 2007)

2.4.5 Cost recovery from water and nutrient recycling

Nutrients in urine that are not needed at the WWTP (in the separated urine), can be sold as fertilizer for crops or as a supplement for biological treatment of nutrient deficient industrial wastewaters. Values for chemical fertilizers are taken from USDA (2010) (USDA, 2010) and US ERS (2011) (ERS, 2011)**.** The average cost for water ($0.93/m^3) and sewer services ($1.01/m^3) is calculated based on the urban water pricing surveys for US cities(2010; Black and Vitch, 2009) for a block use of 12,000 gallons per month per family. The value of nutrients and water saved ($26.47/p-y) if urine is separated and recycled is shown in Table 15.

Table 15: Expected savings by recovering water and nutrients from urine

Organic matters and nutrients separated (kg)	Quantity (p.y)	Computed market rate ($) per unit	Total savings ($)	Associated environmental emissions avoided
Nitrogen (N)	2.43 kg	0.94/kg	2.28	Energy intensive
Phosphorus (P)	0.3 kg	1.353/kg	0.41	Toxic byproducts
Potassium (K)	0.5 kg	0.852/kg	0.43	
Total Nutrients:			3.12	
Drinking water volume reduction♣	11.91 m^3	0.93/m^3	11.08	
Wastewater volume reduction	11.91 m^3	1.03/m^3	12.27	
Total ($ p/y)			26.47	

♣ Individual daily urine bowl activation is taken as 5.1/d at 0.15 lpf and fecal bowl activation is 1.4/d at 4 lpf; daily saving of 5.85 liter during urine flushing and 2 liter during feces flushing per person can be expected.

2.4.6 Avoided environmental costs of chemical fertilizer

Nitrogen fertilizer is produced by the energy intensive Haber-Bosch process (Verstraete et al., 2009b) which consumes 15.18 kWh/kg N produced(Dodd et al., 2008 ; Maurer et al., 2006). Production of P requires 8.05 kWh per kg. K production requires 0.42 kWh per kg (Kongshaug, 1998). Energy consumed and GHG emissions associated with production of N, P and K fertilizers equivalent to the quantity of nutrients recoverable in 60% urine are presented in Table 16.

Table 16: Energy consumption and associated GHG emissions for chemical fertilizer production

Fertilizer	Nutrients in 60% urine (Kg)	Energy consumption (kWh/kg)	Total Energy (kWh)	Electricity cost ($)	GHG emission (kg)
N	2.43	15.18♠	36.89	3.69	22.17
P	0.3	8.05	2.41	0.24	1.45
K	0.5	0.42	0.21	0.02	0.13
Total			39.51	3.95	23.75

♠1 Kg N is equivalent to 1.214 kg NH_3; 1 MJ = 10^6 J, 1 Joule = 2.778×10^{-7} kWh.

P is a finite resource and should therefore be recovered and recycled wherever possible (Smil, 2000b; Tinker, 1977a). Production of 1 kg of phosphate fertilizer (P) produces about 2 kg of toxic byproduct, Gypsum, contaminated with heavy metals and radioactive elements (Driver et al., 1999) which is costly to dispose of in an environmentally acceptable manner. Cost for disposal of these byproducts is not included in the cost estimate.

2.4.7 Use of urine as natural fertilizer

Urine contains major nutrients N, P, K at approximately the same proportion (18:1:4) needed by plants (Jenssen et al., 2004) and in the form ideal for plant uptake (Esrey et al., 1998) so it is a good fertilizer for crops and contains less heavy metals than synthetic fertilizers (Richert et al., 2010). The fertilizer value of the nutrients in urine from a typical person in the US is $3.12/p-y (Table 2.4). There are guidelines for the application of urine as fertilizer on crops (WHO, 2006b). Field trials in Burkina Faso (Africa) showed no significant difference in yields of urine-fertilized crops and mineral-fertilized crops (Richert et al., 2010). Similarly, field trials conducted in barley crops in Sweden(Johansson et al., 2001) and in Germany (J. and J., 2003) revealed similar production. Similar responses were also observed on maize in India (Sridevi et al., 2009), on vegetables like cabbage, spinach and tomato in South Africa (Mkeni et al., 2006), in Finland (Pradhan et al., 2007), and in Mexico (Guadarrama et al., 2001).

Certain industrial wastewaters (dairy, fruits and vegetables, winery, paper and pulp, rag and rope) are deficient in nutrients N and P that must be supplemented(Broderick and Sherrard, 1985). Collected urine could possibly be sold for this purpose. Figure 14 below shows the layout of wastewater treatment plant for treating nutrient deficient industrial wastewater along with municipal (domestic) wastewater.

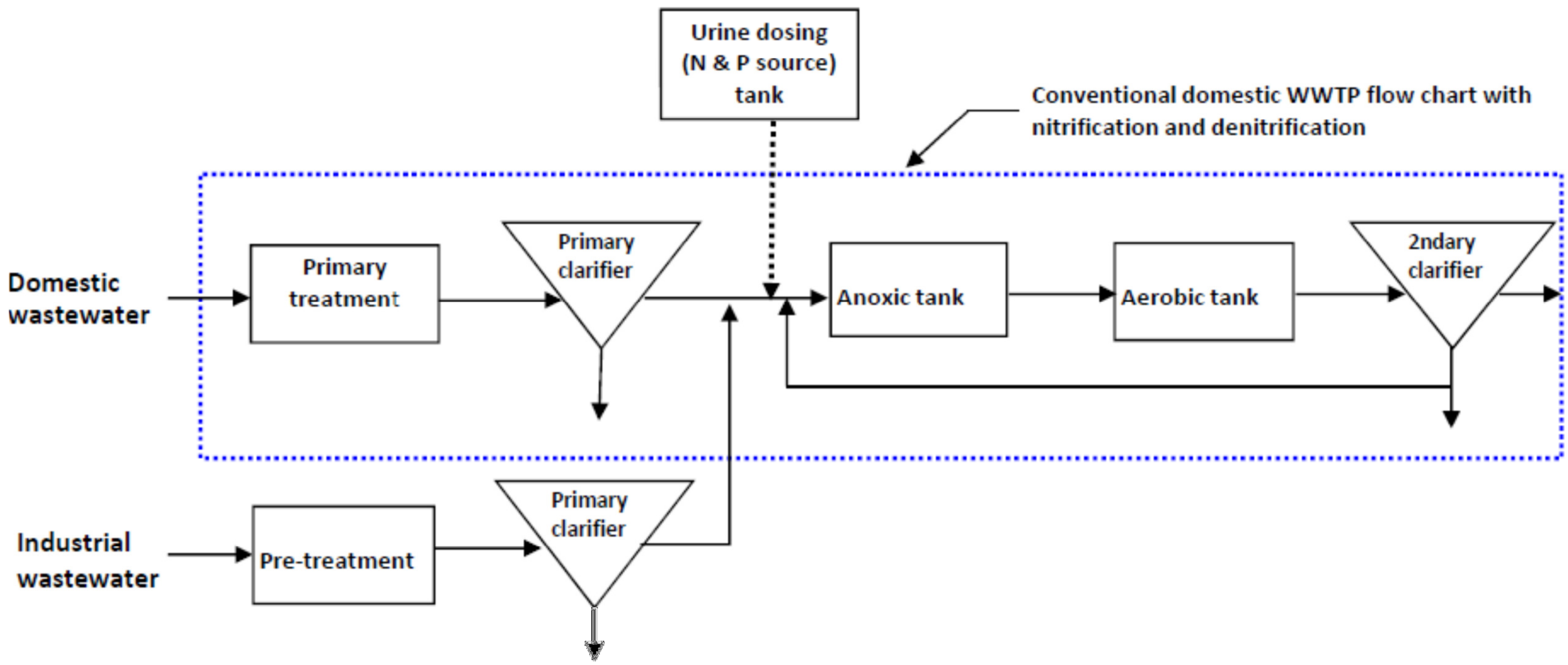

Figure 14: Proposed flowchart of biological treatment of nutrient deficient wastewaters in municipal wastewater treatment plant using urine as the nutrient (nitrogen and phosphorous) source.

2.5 Summary of the economic value of a UD system

UD systems can be considered more sustainable than conventional sanitation systems because they allow nutrient recycling, decrease water use, and reduce GHG emissions. A summary of total economic value of employing a UD system is presented in Table 17. As shown, each year a typical family in the USA can realize a savings of about $73 for water and wastewater, can recycle nutrients to farms worth about $10, help reduce community energy costs (for nutrient production and wastewater treatment) by about $17, and reduce GHG emissions by 100 kg (worth $1.59 in carbon credits).

Table 17: Summary of yearly savings by an average family in the USA (3.14/family) employing UD sanitation system

S. No.	Savings on	Quantity	Cost $	Total savings
1	Drinking water volume reduction	37.4 m^3	0.93/m3	$34.78
2	Wastewater volume reduction	37.4 m3	1.03/m3	$38.52
3	Nutrient recycling	10.14 kg		$9.78
	Nitrogen (N)	7.63 kg	0.94/kg	($7.17)
	Phosphorus (P)	0.94 kg	1.353/kg	($1.27)
	Potassium (K)	1.57 kg	0.852/kg	($1.34)
4	Energy conservation	166.04 kWh	0.10/kWh	$16.60
6	GHG emissions (Carbon credits)$^{\theta}$	99.66 kg	16/1000 kg	$1.59
	Total			$101.27

$^{\theta}$Calculated based on $16 per tonne CO_2 eq (Åhman and Holmgren, 2007)

2.6 Conclusions

Inclusion of natural and synthetic estrogens in EPA CCL3 (2008) indicates their possible regulation in the future. Existing municipal WWTPs generally remove about 50% of estrogens and can be optimized to remove somewhat more; however, addition of costly advanced treatment processes will be required in order to meet future regulations such as 99% estrogenicity removal. Alternatively, a source reduction methodology like UD system could be used to economically control estrogen discharges. Treatment of source separated urine with ED and O_3 is a more economical treatment method requiring per capita energy of only 12 kWh per year compared to 23 kWh per year for addition of O_3 process to treat CAS effluent at existing municipal WWTPs. A typical family in the US can contribute to a total annual environmental benefit of $101 with a capital expense of $2,100 while at the same time helping alleviate global warming by reducing GHG emissions by 100 kg. If UD systems are broadly applied, the unit capital and installation costs will surely decrease.

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CHAPTER 3. SURVEY OF ATTITUDES AND PERCEPTIONS OF URINE-DIVERTING TOILETS AND HUMAN WASTE RECYCLING IN HAWAII

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Survey of attitudes and perceptions of urine-diverting toilets and human waste recycling in Hawaii

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Abstract

Urine constitutes only about 1% of domestic sewage but contains 50% or more of the excreted nutrients and chemicals like hormones and pharmaceutical residues. Urine diverting toilet (UDT) systems can be considered a more sustainable alternative to wastewater management because they allow nutrient recycling, reduce water use, and allow source-separation of hormones and chemicals that can harm the environment. An online survey was conducted to determine whether UDTs are acceptable to the general public in Hawaii and if attitudes and perceptions towards it and human waste (HW) recycling vary with age, sex, level of education, religious affiliation, ethnicity, and employment status. The survey was also intended to detect possible drivers and barriers for the UDTs. Variations on variables were tested at 5% significance (p=0.05) level (Chi-squared test/ or ANOVA) and considered significantly different if the p-value was less than 0.05. The results were encouraging as more than 60% are willing to pay extra for the UDT, while only 22% knew that such systems existed. No statistically significant difference was found between males and females on all survey questions at the 5% level. However, females had higher willingness to pay (WTP) than males and WTP increased with age and income. The WTP of Caucasians was higher than Asians and differed significantly. Some respondents expressed concern about the legal provisions for recycling of HW. The survey results indicate that with a public education program, it is possible that most people would be willing to adopt UDTs and HW recycling with incurred societal benefits of reduced water and fertilizer use, reduced greenhouse gas emissions, and collection of micropollutants at the source to prevent their entry into waterways. Because of the small sample size (N=132, 13% response rate) the survey is not representative but may be indicative of the general attitude of Hawaiian people.
Keywords: Urine diverting toilet, nutrient recycling, attitude and perceptions, survey

3.1 Introduction

Urine constitutes only about 1% of domestic sewage. Major fractions of nutrients 80% Nitrogen (N), 50% Phosphorus (P), and 60% potassium (K) (Almeida et al., 1999a; Jönsson et al., 1997; Larsen et al., 2009; Larsen and Gujer, 1996a), more than 70% estrogens and more than 60% pharmaceutical residues (PhaR) (Lienert et al., 2007) are excreted in urine. The source separation of urine potentially offers an energy-efficient method to contain/recycle/treat these nutrients and harmful chemicals. The urine diverting toilet (UDT) that is being introduced in many countries, though mostly in pilot projects, is largely unfamiliar in the USA. Though there are not any coordinated or sponsored urine separating projects in the USA, urine reuse is accepted in certain social groups and the practice of urine application in backyard gardens is reported by some individuals (Allen and Conant, 2010; McCreary, 2010). The books “Solviva” (Edey, 1997) and “The liquid gold” (Steinfeld, 2004) are helping educate people about urine separation and nutrient recycling. A wealth of information available on the internet may also be partly responsible for the development of pro-environmental behaviors like urine recycling and reuse. An online survey was conducted to gauge perceptions and attitudes of people in Hawaii towards UDT, human waste recycling, and willingness to pay (WTP) for UDT and whether the attitude varied with age, sex, education level, occupation and social, cultural, and religious norms. UDTs do not exist in Hawaii nor do known or documented cases of urine application to crops for fertilizer.

3.1.1 Urine diverting toilets (UDTs) and human waste recycling

Sustainable wastewater management warrants an integrated consideration of water, minerals, and energy (Wilsenach et al., 2003). The conventional sanitation system is based on using large volumes of clean water to dilute and transport small volumes of human waste (Niemczynowics, 1997) and consume about 15,000 liters of drinking water per person per year to flush toilets (Drangert et al., 1997). Recovery of nutrients is difficult and expensive because of the diluted nature of wastewater and conventional systems are thus unsustainable (Verstraete et al., 2009a). One of the options to make wastewater management more sustainable would be to separate urine at the source and then deal with the much smaller volume of wastewater to recover nutrients. UDTs or no-mix toilets can be used to separate urine from fecal matter at the source.

Dual flush WCs are currently in use in the US but UDTs are largely unfamiliar to US residents. There are not many UD toilets deployed currently but their use is starting to increase all over the world. The German Agency for International Cooperation (GIZ, formerly GTZ) estimates that there are about 2.81 million users of UDTs worldwide as of September 2011 (GIZ) and most of the users are from developing countries with dry UDTs (rather than the flush type anticipated for USA use). However, there are no large planned projects for UDTs and human waste recycling documented in the US as of today.

3.1.2 Water shortages and need for paradigm shift on sanitation and wastewater treatment systems

Water scarcity and quality problems are a worldwide phenomenon (Clarke, 1993). Declining river flows, collapse of water-based ecological systems and large scale ground water depletion are occurring in many parts of the world (UNDP, 2006) and a similar trend of dwindling fresh water resources is also the reality in parts of the USA (Maurer et al., 2006; USGS). Water conservation and reuse efforts are important also to the state of Hawaii as droughts are common (CWRM, 2008). The average daily indoor per capita water use in the US is 263 liters and the largest proportion (more than 25%) of water supplied is used for toilet flushing (AWWA 2010. Water information, 2012). Modification of toilet technologies has the potential to save large amounts of water and separate nutrients and chemicals from mainstream wastewater flows which can subsequently reduce wastewater treatment costs.

Because of the perception that on-site or decentralized systems are inferior and not safe, many communities demand centralized wastewater treatment systems (USEPA, 2002). Centralized systems are expensive to construct and maintain (Grau, 1994). Engineers and ecologists have proposed UDT systems also known as ecological sanitation (ecosan) as a sustainable alternative to conventional wastewater systems. The degree of investment required for a UDT system is much less compared to conventional systems and can function both on centralized and decentralized modes and can also be utilized as a transition to decentralized wastewater management (Larsen et al., 2001). Urine separation allows treatment methods tailored to the treatment needs of the waste fractions. Urine separation is beneficial also because phosphorus is finite (Cordell et al., 2009; Smil, 2000a; Tinker, 1977b) and should be recovered whenever possible.

Estrone, E1; 17β-estradiol, E2; and synthetic estrogen 17α ethynylestradiol, EE2, a main constituent of oral contraceptive pills are responsible for up to 90% of the endocrine disrupting effects observed in the aquatic environment (Korner et al., 2001a; Snyder et al., 2001a). EPA (USEPA, 2008) has included these chemicals on the contaminant candidate list (CCL3) indicating their possible future regulation. The major fraction of estrogens (>70%), and pharmaceuticals (>60%) from humans are excreted in urine. A source reduction methodology like UDT system can be used to economically control and remove these chemicals from source separated urine requiring per capita energy of only 12 kWh per year compared to 23 kWh per year required for removing these chemicals from conventional WWTPs effluents (Lamichhane and Babcock, 2012,). They also reported that a family in the US employing UDT system would save about 100 kg of greenhouse gas emissions and contribute to about $100 in environmental benefits annually. Major fraction (>94%) of X-ray contrast agents is excreted in urine (Lienert et al., 2007). Urine separation is also beneficial to capture chemicals like X-ray contrast agents which are not easily degraded in the conventional wastewater treatment plants.

3.1.3 Attitude, perception, and behaviors

The practices that have evolved in relation to waste and wastewater management in one place cannot be readily transferred to other places and warrants a thorough assessment (acceptability study) of the local sociocultural context of the specific community before introducing new technology (Wegelin-Schuringa, 2000a; WHO, 2006a). Social attitudes and perceptions towards excreta vary with age, sex, religion, education, employment, region and physical capacity (Mariwah and Drangert, 2011; WRC, 2007). In the same way, people's behavior towards a UDT and in utilizing human excreta as fertilizer is guided by their perception towards it. In a resource-poor community, it is often acceptable to use human excreta for food production (Furedy, 1990). Recycling nutrients in affluent communities, for example in America, may not have the same priority because chemical fertilizers are readily available and affordable. The possibility of containing endocrine disrupting chemicals (EDCs) like hormones and PhaRs, and pro-environmental behaviors like water and energy conservation and having a small carbon footprint can be some of the motivating factors for using UDTs in affluent environmentally-conscious communities.

3.1.4 Social acceptability of UDTs and human waste recycling

The acceptance of a new system by users is a key to the success of the system and a user/consumer acceptability survey is a must before introducing a new technology. Consumer attitudes and perceptions towards UDTs in various countries have been investigated by conducting user surveys. A survey of Swiss farmers revealed that urine based fertilizer was accepted by 57% and 42% were willing to purchase urine fertilized products (Lienert et al., 2003). The survey conducted in various focus groups in Switzerland showed that the acceptance for UDTs without additional financial burdens was more than 80% while more than 60% expressed the willingness to purchase urine-fertilized products but were concerned about the effects of micropollutants to human and ecosystem health (Pahl-Wostl et al., 2003). UDT projects are also being introduced in Nepal and most of the projects currently launched are in communities with long-standing traditions of using HW on crops and UDT acceptance is reported as 71% (WaterAid, 2008).

Similar results were also found in a review of surveys about urine diversion in 7 European countries: 80% liked the idea of urine separation (UDT), 85% regarded urine as a good fertilizer, and 70% would buy food/products grown using urine-based fertilizer (Lienert and Larsen, 2010b). Another survey conducted in one Swiss school and in one Swiss research institute also revealed the high acceptance of UDTs among users: 72% liking the idea of urine diversion and 86% were willing to move in to the apartments with UD toilets (Lienert and Larsen, 2006b). In contrast to responses in Switzerland, users in a village of Masiyarwa in Zimbabwe showed a generally negative perception towards the use of HW in root, leaf and stem crops (Manyanhaire and Sandra, 2009). A study conducted in 4 villages (Muslim communities) in the North West Frontier Province in Pakistan revealed that people consider urine less offensive than fecal matter and farmers, no matter how poor they are, usually avoid direct handling and use of excreta in crops but opt to channelize sewage in farms (Drangert and Nawab, 2011). Another study conducted in peri-urban farming community of Efutu (Ghana) revealed, in general, negative attitudes towards the handling and use of human waste (Mariwah and Drangert, 2011). People practicing backyard urine-harvesting projects in the USA are small in number but are happy to use it as fertilizer (Allen and Conant, 2010). The user survey (a very small group, N=7) revealed that water conservation was the main motivating factor whereas the fertilizer value was the second. They also reported that the interest and acceptance among their friends and colleagues is also growing. It is reported that 80% of the farmers in a village of Indonesia are willing to use urine and feces-based fertilizer to crops but only 40% would inform their customers about the type of the fertilizer used (WSP, 2010). Using human excreta in agriculture is an age-old tradition in China and is still practiced in some parts of the country and urine separating toilets are also being introduced on a large scale (EcoSanRes). The survey described in this paper was conducted to determine whether people in Hawaii have similar or different attitudes and perceptions.

3.2 Materials and methods

The University of Hawaii (UH) population (students, faculty and staff) was selected for the online survey because we could access them via e-mail. An online survey was chosen because subjects might consider it more private and anonymous than a paper based survey (Evan and Miller, 2006). E-mail invitations were sent to approximately 1,000 people on the Water Resources Research Center (WRRC) mailing list (wrrc-l), the East West Center Participants Association (EWCPA) list serve (ewcpa-l), and to undergraduate Civil Engineering majors. The survey results, therefore, do not completely represent the residents of Hawaii’s view on acceptance or rejection of UDTs but gives an indication as to how the relatively younger and educated population in Hawaii (USA) would perceive it. The participants had the choice to respond to questions through e-mail reply (questions embedded in the message) or through a link (blog) (http://ecologicalsanitation.blogspot.com/) which directed them to a new window to register their responses. E-mail responses received during October 5 to December 1, 2011 were used in the analyses. The survey program was developed using Google doc which is capable of collecting anonymous responses in real time and everyone who took part in the survey was able to see the summary of total responses after completing the survey. The sampling method used was mostly random (email lists) and partly snowballing (asking friends and acquaintances to take the survey). The survey instrument (CHS # 19508/2011) was reviewed and approved by the UH Committee on Human Studies (CHS).

The survey package contained three sections; very basic information about UDTs and human waste recycling as well as information related to informed consent was in the first section, the second section collected socio-demographic information, and the third section consisted of 10 questions/statements regarding UDTs. The basic background information provided in the first section was: "Conventional flush toilets are used worldwide. Human waste (urine and feces) contains many important nutrients. These same nutrients are necessary for agricultural plant growth. Most of the nutrients as well as non-metabolized medicines are excreted in the urine. Treatment of these wastes requires large amounts of energy. In order to reduce energy use and recycle nutrients for agriculture, engineers and ecologists have proposed ecological sanitation (ecosan) that employs urine diverting toilets (UDTs). UDTs use less water for flushing and separate urine and fecal matter at the source. This allows the urine to be collected, treated and recycled for agriculture. The purpose of this survey is to gauge public opinion on UDTs and Urine Recycling". Perceptions and attitudes towards UDTs and human waste (nutrients) recycling were gauged through the responses on the 10 questions in the third section of the survey questionnaires. Of the 10 questions, 8 were binary (Yes or No) type and the remaining two were closed questions in a multiple-choice format. The survey questions and the number of answer choices the participants had are presented in Table 18.

Table 18: Questionnaires (Statements) circulated to subjects and number of answer choices

No	Survey statements	Answer choices
1	Do you know what happens and where the toilet (Human) wastes go when you flush it down the drain?	2 (Yes or No)
2	Have you heard of Urine Diversion (UD) toilet systems before?	2 (Yes or No)
3	Would you allow a UD toilet to be installed at your home for free?	2 (Yes or No)
4	Would you be willing to pay about $50 extra for a UD toilet?	2 (Yes or No)
5	What could motivate you to install a UD system (Please select all that apply)? (a) Want to be green, (b) Conserve water, (c) Recycles nutrients, (d) Want to try new technology, (e) Not applicable (NA), and (f) Other (Respondents were allowed to write their opinions on this section)	6 (Multiple choice)
6	What factors would discourage you from installing a UD system? (a) Technology not tested, (b) Complicated, (c) Expensive, (d) Not much information, (e) Not applicable (NA), and (f) Other (Respondents were allowed to write their opinions on this section)	6 (Multiple choice)
7	Are you aware of the nutrient value of human waste (urine and feces)?	2 (Yes or No)
8	Human waste cannot safely be recycled so is suitable only for disposal	2 (Yes or No)
9	Both urine and fecal matter pose similar health risks	2 (Yes or No)
10	Sanitized (treated) human waste can be used as fertilizer	2 (Yes or No)

In order to minimize dropout, the survey did not demand any writing or typing from the participants. However, they were given the opportunity to add their opinions under the heading “other” for the two multiple-choice questions. An original plan of presenting sample statements using 3 to 5- point Likert items was abandoned in order to eliminate central tendency bias thinking that respondents may avoid using extreme responses on subject matters little known to them. The introduction part of the survey consisted of very general and limited information about UD toilet and nutrient recycling to avoid social desirability bias as well as acquiescence biases that are common to questions with ordinal scales. No neutral option in answer choices was therefore given as it was desired that people make decisions based on their knowledge on water, wastewater treatment, the environment, and sustainability.

3.3 Results

3.3.1 Socio-demography of the sample

A total of 132 responses (N= 132) were recorded within the survey period (13% response rate). Survey responses were evaluated and no duplicates were found. Among 132 respondents, 74 (56%) were male and 57 (43%) were female and one participant did not indicate. The survey was designed to collect responses from 6 age categories (18-29, 30-39, 40-49, 50-59, 60-69 and above 70 years and 3 educational categories (High school, undergraduate and graduate or higher) and responses to each question were recorded automatically according to age category, education level, religious affiliation, and ethnicity. The demographic characteristics of the sample are presented in Table 19.

Table 19: Demographic characteristics of the sample

Demographic information	Total (N)	% of total[Ω]	Female Number	Female % of total	Male Number	Male % of total
Age						
18-29	62	47	28	21	34	26
30-39	25	19	10	8	15	11
40-49	21	16	8	6	13	10
50-59	14	10	7	5	7	5
60-69	9	7	4	3	5	4
Sex						
Female	57	43	57	43		
Male	74	56			74	56
Other	1	1				
Education						
High school	4	3	3	2	1	1
Undergraduate	49	37	19	14	30	23
Graduate and higher	79	60	35	27	43	33
Occupation						
Student	68	52	29	22	39	30
Office employee	41	31	18	14	23	17
Instructor	10	7	3	2	7	5
Self employed	2	2	0	0	2	2
Others	**11**	8	5	4	5	4
Religious affiliation						
Christian	46	35	21	16	25	19
Buddhist	11	8	5	4	6	5
Hindu	9	7	4	3	5	4
Islam	1	1	0	0	1	1
Do not want to mention	19	14	7	5	12	9
Other	46	35	21	16	25	19
Ethnicity						
African American	2	2	1	1	1	1
Asian	54	41	20	15	34	26
Caucasian	52	39	23	17	29	22
Hawaiian	8	6	7	5	1	1
Other	**16**	12	6	5	9	7

[Ω] % may add up to more than 100 due to rounding

Most of the responses received (62%) were from relatively the younger population (18-29 years) and subjects from age categories 30-39 years and 40-49 years had similar representations (19% and 17%). Age groups 50-59 and 60-69 years were 11% and 7%

respectively while the above 70 years category had no responses. The Caucasian (39%) and Asian (41%) communities comprised the majority of the responses. The sample represented more than 30 university disciplines and the education level was skewed to graduate or higher level studies comprising 60% of the sample. This implies that a majority of the respondents were relatively highly educated. Half of the respondents were students (51%) and faculty and employees comprised about 40%. The sample is composed of 35% Christian, 8% Buddhist, 7% Hindus and about 50% of the sample either was from other religious beliefs or did not indicate.

3.3.2 Attitude and perception towards UDT system

A majority of the participants (80%) were aware of wastewater generation and treatment but 78% did not know that UDTs existed. It was interesting to find that 80% of respondents would be willing to install a UDT at their home if available for free even though only 22% ever heard of it before. The willingness to install decreased somewhat to 61% if they had to pay $50 for the UDT installation which indicates that most but not all (76%, 61/80) are willing to pay a small extra cost for this environmentally friendly product. This effect is typically limited by the price difference between the conventional technology and the environmentally-friendly product as indicated by Lant (Lant, 1993). This is also an indication of people's attitude favoring pro-environmental behavior if services offered are equivalent to their existing system and the costs are similar (Figure 15). It is likely that few respondents would have shown interest in an unknown technology if the actual cost of installation (currently at least $1,000) was used in the survey.

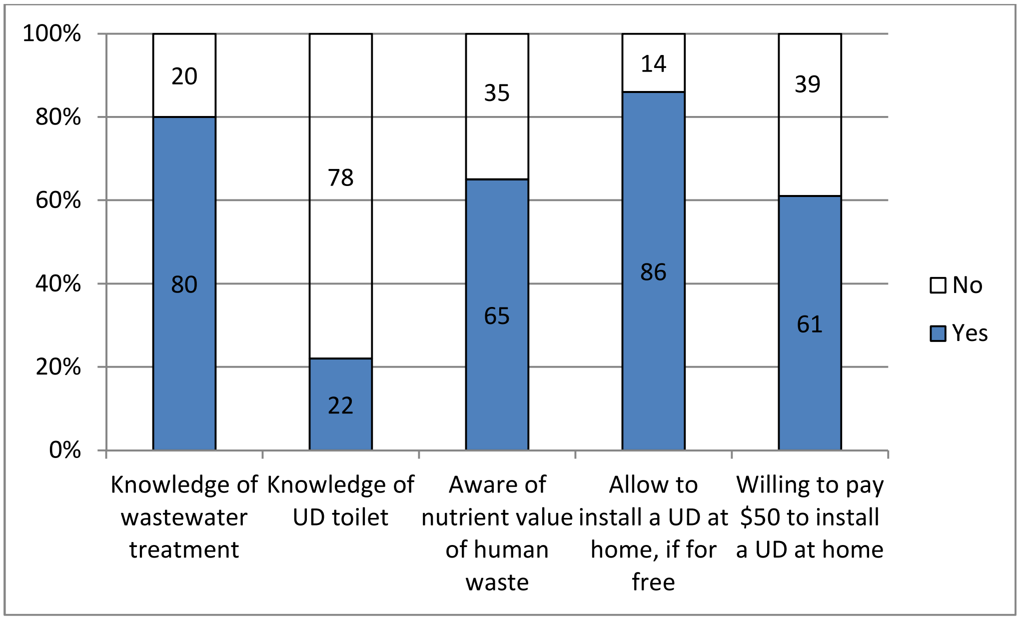

Figure 15: Participant's knowledge of wastewater treatment and UDT and willingness to install a UDT at home

The two survey statements with multiple choices were designed to acquire information as to which factors motivate or discourage respondents regarding installing a UDT. Water conservation was considered the main advantage of installing a UDT by 80% followed by nutrients recycling for farming (70%) and "want to be green" (61%) (Figure 16).

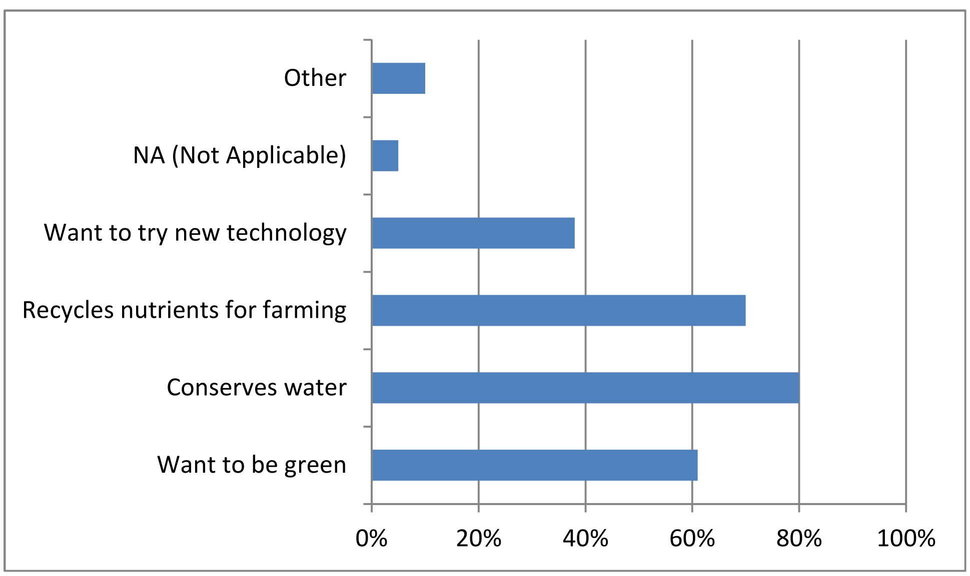

Figure 16: Motivating factors for installing a UDT

Some of the people who strongly liked the idea of using UDT to separate two waste fractions and recycle and reuse human waste (HW) emphasized that they would install a UDT at their home and would recycle HW if appropriate sanitary systems were in place. Others were worried about additional effort like emptying of collection units, pumping, etc. that might be required on their part reflecting the need for appropriate service providers in the community. The main discouraging factors for a UDT installation are limited information (55%), expensive (46%) followed by complicated (33%) and technology not tested (32%) (Figure 17).

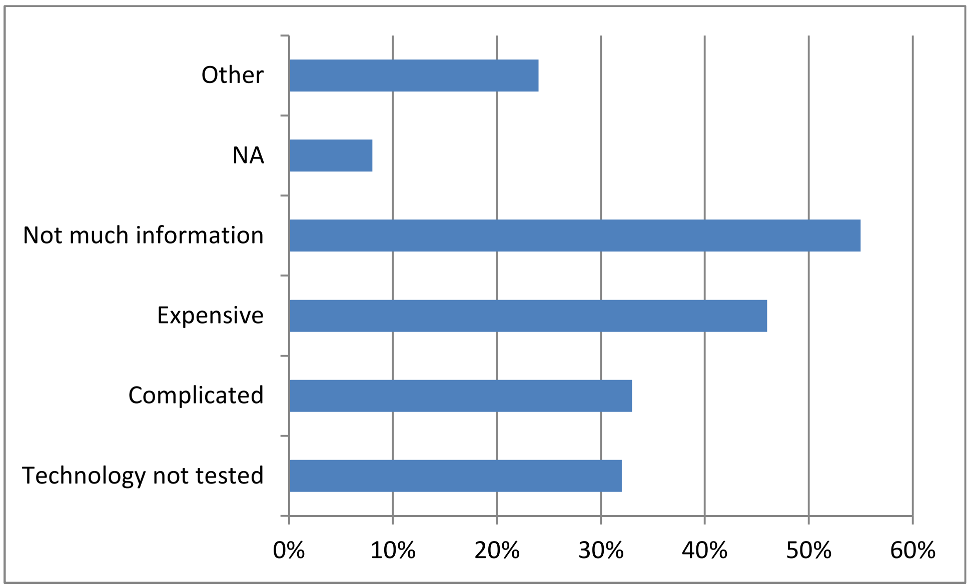

Figure 17: Factors that would discourage people from installing a UDT

It was interesting to find that though only 65% of the subjects were aware of the nutrient value of HW, 83% opined that HW should not be disposed of because it can be safely recycled and 92% supported the idea of using treated waste as crop fertilizer. Public acceptance of new technology can be increased if related information (advantages, disadvantages and associated risks) are made widely available to the public (Hills et al., 2002; Lienert et al., 2003 ; Mariwah and Drangert, 2011). Accordingly, use of UDTs and recycling of HW could be increased if the advantages of UDTs are widely made common knowledge. Participants were also asked if fecal matter and urine pose similar health risks, and 73% believed that they were different in terms of health risks. We interpret this to mean that respondents understand that fecal matter has high health risk, that urine has lower health risk, and therefore urine might safely be used to irrigate crops.

Concerns were volunteered that existing sewer piping systems might not allow for a UDT to be installed in multi-unit dwellings (apartments and condominiums) and that rental unit owners would not want to pay for UDTs unless it would equate to increased value (rent). The other volunteered concerns were about government regulations: people do not know whether regulations restrict them using urine in their yards. Concerns were also raised about whether all age groups of people like children and elderly could use the same toilet seat on a UDT. It appears that they perceive of a UD seat as very complicated and completely different from the conventional one. The role of media (Radio, TV, newspapers) can be instrumental in overcoming these knowledge gaps.

3.3.3 Attitudes and perceptions and willingness to pay for environmental technology

Numeric values "1" for disagreement (or No) to the statement presented or "2" for agreement (or Yes) were assigned to responses for the purpose of analyzing data. The responses were processed to determine if the perception and attitude towards UDTs and HW recycling differed by sex (Table 20), age, educational level, ethnicity and religious affiliations. Statistical software SAS (SAS Institute Inc., Cary, USA) was used for all statistical analyses. Chi-squared (χ^2) test was used to evaluate variations in the variables with only two categories and one- way analysis of variance (ANOVA) for variables with more than 3 categories and difference in mean values of the variables in questions are tested at 5% significance ($p = 0.05$) level and considered significantly different if the p-value was less than 0.05.

It can be seen that people are very positive towards UDTs and HW recycling though it is new to Hawaii and the USA (Table 20). No statistically significant difference in mean values is found between male and female populations on all 10 statements/questions including attitude and perceptions towards urine diversion and human waste recycling at 5% significance (p=0.05) level but the male population seemed to be more aware of the current practice of wastewater treatment ($p = 0.064$) and nutrient value of HW ($p = 0.074$) and are significantly different at 10% ($p = 0.10$) level (Table 20).

Table 20: Gender based perceptions and attitudes towards UD toilet and human waste (HW) recycling.

SNo	Questions/statements	Sex	Yes	No	Mean	SD	Test statistic	*P*-value
1	Do you know what happens and where the toilet (human) wastes go when you flush it down the drain?	Female	41	16	1.719	0.453	χ^2-test	0.064
		Male	63	11	1.85	0.358		
2	Have you heard of urine diversion (UD) toilet systems before?	Female	12	45	1.891	0.368	χ^2-test	0.937
		Male	16	58	1.842	0.312		
3	Would you allow a UD toilet to be installed at your home for free?	Female	48	9	1.21	0.411	χ^2-test	0.55
		Male	65	9	1.22	0.414		
4	Would you be willing to pay about $50 extra for a UD toilet?	Female	37	20	1.667	0.476	χ^2-test	0.344
		Male	42	32	1.567	0.499		
5	Are you aware of the nutrient value of human waste (urine and feces)?	Female	32	25	1.561	0.500	χ^2-test	0.074
		Male	52	21	1.716	0.453		
6	Human waste cannot safely be recycled so is suitable only for disposal	Female	10	47	1.175	0.383	χ^2-test	0.997
		Male	13	61	1.324	0.471		
7	Both urine and fecal matter pose similar health risks	Female	16	41	1.280	0.453	χ^2-test	0.759
		Male	19	55	1.256	0.439		
8	Sanitized (treated) human waste can be used as fertilizer	Female	52	5	1.912	0.285	χ^2-test	0.667
		Male	69	5	1.932	0.252		

SD: Standard Deviation

The responses were also analyzed to see if the perceptions and attitudes differed when a $50 payment was required for a UD toilet. This was intended to discover how many people are willing to pay a modest extra amount for environmentally friendly technologies over conventional ones. No statistically significant difference was found based on age, sex, occupation and religious affiliations though the female population had relatively higher WTP for a UDT than males. The WTP extra for Asian ethnic population significantly dwindled (mean 1.852 for free to mean 1.444 to pay extra) and was significantly different ($p = 0.025$) from Caucasian and "other" categories: Caucasians and “others” in this sample were more willing to bear extra costs. As mentioned earlier, because of the small sample size, the analyses may not represent the respective ethnic composition of UH population but this information can be used as a basis for future research on UDT or no-mix toilet and HW recycling and reuse on crops. Though statistically not significant, the respondent’s occupation also played an important role for the pro-environmental behavior; instructors/faculty (mean 1.9) had higher WTP compared to students (mean 1.573) (Table 21). This indicates that people who earn more are willing to spend a little extra for the environmental cause.

Table 21: Perceptions and attitudes (agreement and disagreement) to UDT, human waste (HW) recycling and health risks associated with HW

Demographic information	Agree to pay $50 for a UDT at home				Human waste can be recycled				Treated human waste can be used as fertilizer				Fecal matter and urine pose similar health risks			
	No	Yes	mean	test statistic, *p* value	No	Yes	mean	test statistic, *p* value	No	Yes	mean	test statistic, *p* value	No	Yes	mean	test statistic, *p* value
Sex																
Female	20	37	1.649	t-test, *p*=0.252	10	47	1.83	t-test, *p*=0.997	5	52	1.91	t-test, *p*=0.669	41	16	1.28	t-test, *p*=0.76
Male	32	42	1.567		13	61	1.82		5	69	1.93		55	19	1.26	
Education																
High School	2	2	1.5	Anova, *p*=0.757	1	3	1.75	Anova, *p*=0.721	1	3	1.75	Anova, *p*=0.240	2	2	1.5	Anova, ***p*=0.003**
Graduate	29	50	1.632		12	67	1.848		4	75	1.949		68	11	1.44	
Under grad.	21	28	1.58		10	39	1.8		5	44	1.9		27	22	1.13	
Age																
18-29	30	32	1.516	Anova, *p*=0.266	9	53	1.85	Anova, *p*=0.363	6	56	1.9	Anova, *p*=0.657	39	23	1.354	Anova, ***p*=0.0012**
30-39	10	15	1.6		6	19	1.76		2	23	1.92		17	8	1.32	
40-49	6	15	1.714		6	15	1.714		2	19	1.904		17	4	1.19	
50-59	4	11	1.733		1	14	1.933		0	15	2		15	0	1.732	
60-69	2	7	1.778		1	8	1.888		0	9	2		0	9	1.778	
Religion																
Christian	23	23	1.5	Anova, *p*=0.708	11	35	1.76	Anova, *p*=0.504	6	40	1.869	Anova, *p*=0.443	14	32	**1.695**	Anova, ***p*=0.001**
Buddhist	6	5	1.454		2	9	1.818		0	11	2		5	6	1.545	
Hindu	3	6	1.666		4	5	1.555		0	9	2		7	2	1.222	
Islam	1	0	1		0	1	2		0	1	2		1	0	1	
Do not want to share	7	12	1.631		3	16	1.842		1	18	1.947		15	4	1.21	
Others	21	25	1.543		15	31	1.673		2	44	1.956		12	34	**1.739**	
Ethnicity																
Caucasian	14	38	1.738	Anova, ***p*=0.025**	6	46	1.884	Anova, *p*=0.282	3	49	1.942	Anova, *p*=0.922	45	7	1.134	Anova, ***p*=0.009**
Asian	30	24	1.444		12	42	1.777		5	49	1.907		30	24	1.444	
Hawaiian	4	4	1.5		3	5	1.625		1	7	1.875		5	3	1.375	
African American	0	2	2		0	2	2		0	2	2		2	0	1	
Others	2	14	1.875		2	14	1.875		1	15	1.937		15	1	1.063	
Occupation																
Student	29	39	1.573	Anova, *p*=0.182	13	55	1.808	Anova, *p*=0.877	6	62	1.911	Anova, *p*=0.687	45	23	1.338	Anova, *p*=0.452
Faculty/ Instructor	1	9	1.9		1	9	1.9		0	10	2		8	2	1.2	
Employee	16	25	1.609		9	32	1.78		4	37	1.902		33	8	1.195	
Self employed	0	2	2		0	2	2		0	2	2		2	0	1	
Others	6	5	1.454		2	9	1.818		0	11	2		8	3	1.272	

UDT: Urine diverting toilet

The mean values of perceptions and attitudes towards HW recycling, health risks associated with fecal matter and urine, and fertilizer value of HW were compared to determine if they differed among age groups, religious affiliations, ethnicities, occupation, and educational levels. No statistically significant difference was found except for the health risks associated with the two waste fractions. Among religious affiliations, Christians (mean 1.695) and people in the “other” category (mean 1.739) behaved significantly different (p=0.001) from other religious beliefs (means 1.545 for Buddhists and 1.222 for Hindus) by believing that both urine and feces pose similar health risks (Table 21). Because American societies are mostly Christian and these groups were strongly in favor of HW recycling and its fertilizer value, use of mass media and information dissemination workshops and focus group discussions to educate people about the different health risks associated with urine (low) and fecal matter (high) are suggested before any UDTs and urine recycling schemes are put in place. It is surprising to note that some of the people (who label themselves as environmental consultant and organic Hawaiian plant growers) have been recycling nutrients from urine in their yard but did not mention whether they use urine to grow foods they consume or just fertilize other plants and flowers. It could be that these groups of people were motivated from the international ecological sanitation movement like people in San Francisco California, Massachusetts (Allen and Conant, 2010) and Portland Oregon (McCreary, 2010).

The mean values among 5 age groups and 3 educational levels for all 8 binary type statements were also compared to see if attitudes and perceptions differed with age. Though mean values are not significantly different, it is interesting to note that the WTP for a UDT gradually increased with age: minimum mean value (1.516) for the youngest group (18-29) and the maximum mean value (1.778) for the oldest age group (60-69). The other interesting finding again with the age group is that the youngest group consider urine and feces similar in terms of health risks whereas the oldest group consider two waste fractions completely different and also significantly different even at 0.1% level (p=0.001). Similarly, health risks associated with two waste fractions differed significantly (p=0.003) with educational status: people with lower education level considered urine and fecal matters similar in terms of health risks whereas people with higher education considered them different. The perception did not differ significantly with occupation. The results are presented in Table 21.

3.4 Discussion

The results of the survey prove that very useful information can be collected by employing a simple survey method and simple questions. The results show that the surveyed population is highly positive towards UDTs. More than 60% of the people were willing to pay extra for the UDT installation at their homes though only 22% knew that such systems existed. No statistically significant difference was found between males and females regarding UDT installation and HW recycling at the 5% (p=0.05) level. However, females were willing to pay more than males, and WTP and UDT acceptability increased with age and income. The WTP of the Caucasian and “other” groups were greater than the Asian population and differed significantly (p=0.025). The perceived health risks with urine and feces also differed significantly at 1% level (p=0.001) with age and religious affiliation: younger groups and Christians considered both waste fractions the same risk compared to relatively older groups and people with other religions who believe the risks are not the same.

It seems that pro-environmental attitudes are growing and the relatively older and working populations are more positive about green behaviors. One of the reasons for the positive perceptions of participants towards new technologies like UDTs and pro-environmental behaviors like HW recycling and reuse could be because of knowledge acquired through online sources and mass communication media, because according to (Chan, 1998a), attitude is the major factor predicting behavioral intention and mass communication is one of the major sources of establishing subjective norms. People are willing to accept the new UDTs if service providers are available and the system is legally endorsed by the concerned regulatory authorities. Some respondents were also concerned about the technicalities of the dual piping system necessary for a UD system. It is clear that cultural and social norms play an important role in deciding which type of sanitation system to use regardless of financial status. UDT systems and HW recycling are accepted in some communities not because people are poor as envisioned by (Furedy,

1990) but because of the long traditions of using HW in crops. Though resource poor, people from Zimbabwe, Ghana, and Pakistan had negative perceptions towards UDTs and HW recycling whereas the communities with similar economic status in China, Vietnam and Nepal are accepting of these systems. Though resource rich, people in Hawaii show very positive attitudes towards UDTs and HW recycling similar to those found in European countries. The similar perception of Americans and Europeans can be attributed to their similar life styles, same level of education, and the attention they give to curbing environmental pollution and greenhouse gas emissions. Overall, the survey results are encouraging for a proposed effort to employ UDTs to reduce water use, reduce chemical fertilizer use, reduce greenhouse gas emissions, and capture and treat micropollutants such as estrogenic endocrine disruptors at the source rather than at centralized wastewater plants (Lamichhane and Babcock, 2012).

3.5 Conclusion

The results from the Hawaii survey are similar to previous surveys in that they indicate that large majorities of people have favorable opinions of the new UDT technology (based on a small amount of factual information), they are willing to pay something for it, and they also feel that HW recycling is safe and a good idea. It is important to involve all stakeholders concerned (government authorities, general public, organic food growers, consumers, UDT practitioners and service providers) before decisions are made because the adoption and success of any new system is dependent on perceptions (like behavior) which are influenced by knowledge, beliefs and societal norms (Mariwah and Drangert, 2011). As Chan (Chan, 1998a) stated, behaviors and perceptions of the people can be improved to more environmentally responsible (pro-environmental) behavior through education and mass communication campaigns. People will chose the toilet/sanitation system that they think would be appropriate for them considering economic, social and environmental concerns. It is therefore suggested that information regarding pollution and related environmental consequences are disseminated through mass media and environmental groups.

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CHAPTER 4. ECOLOGICAL SANITATION: SOIL FERTILITY TO FOOD SECURITY

This part of the dissertation is a submitted manuscript to the journal "*Waste Management & Research*"

Ecological sanitation: soil fertility to food security

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Abstract

High rate of population growth and rapid urbanization has exerted huge pressures on natural resources including agriculture (soil), air, water, and sanitation facilities. In many countries agricultural production is decreasing because of nutrient mining and water bodies are extremely polluted because of direct disposal of domestic wastewater. There are 41 countries in the world with an undernourishment rate of 20% or higher. Making fertilizer available to small landholders and providing adequate sanitation facilities are the most effective means to reduce the number of hungry people and to reduce water pollution. The data related to per capita income, average fertilization application rate, rate of agricultural production and average dietary intake including protein for 170 countries were collected and analyzed. The average nutrient excretion rate was calculated based on dietary energy supply or intake (DES) data. The regression analysis shows that the increase in agricultural growth with fertilizer application was very highly significant ($p < 0.001$) but also showed a negative relationship with per capita arable land holdings. The DES is on a continuous rise and its increase with income (GDP) is very highly significant ($p < 0.001$) but the intake increase rate decreased when GDP reached around \$5000. The annual human excretion of nutrients only in urine is more than the average fertilizer application rates in 22 countries and is valued at about \$10 per year. Agricultural production would substantially increase if the nutrients excreted from humans only in urine, if not all, could be recycled to crops. Urine can be separated at the source by employing urine diverting toilets (UDTs). UDTs can be one of the sustainable alternatives of wastewater management as the level of investment and O&M costs are much less than central sewer/treatment systems. This is known as ecological sanitation. Coordinated and simultaneous intervention on water and sanitation and agriculture would reduce program costs, water pollution problems, and the increased production would also contribute to local food security.

***Key words**: Urine separation, urine diverting toilet, water conservation, nutrient recycling, food security*

4.1 Introduction

The world population is expected to reach 8 billion in 2020, a 35 % increase from 1995 (UN 1996). Urbanization continues to increase with more than half of the world's population currently living in urban areas requiring food that is more energy, land, water and greenhouse gas emission-intensive (Satterthwaite, 2011; McGranahan et al., 2010). As a consequence, more wastes (wastewater, solid waste, smoke and soot) are released in to the environment than ever before.

Approximately 40-60% of crop yields are produced using commercial (inorganic) fertilizer (Stewart et al., 2005). The population growth rate in many developing countries is higher than the agricultural growth rate. These countries need to apply more nutrients to increase production (FAO, 2003). However, chemical fertilizer application rates in developing countries are not keeping pace with population growth either because fertilizers are not readily available locally or are too expensive. Subsistence farmers (smallholders) and the urban poor, who spend more than 50% of their income on food, are the ones to suffer the most from insufficient production (Esrey, 2000). These groups cannot afford imported food, and dietary intake rates are therefore restricted and insufficient (lack of food security). Making fertilizer available to smallholders at affordable prices to increase production and reduce the number of hungry people is a major challenge in developing countries.

Concomitant to population growth and urbanization, the demand for adequate water and sanitation facilities is also increasing at an alarming rate (Hinrichsen et al., 2002). Water use and wastewater generation has increased at more than twice the rate of the population growth for the past century. And domestic (municipal) wastewater is considered to be one of the main causes of poor water and environmental quality in developing countries (UNEP, 2010). There are estimated to be more than 780 million people in the world without access to improved sources of drinking water and over 2.4 billion people without access to adequate sanitation (UNICEF/WHO, 2012). It is believed that approximately 2.8 billion people live in river basins with some form of water scarcity (UN, 2008). It is urgent to develop sustainable water and sanitation technologies to provide services to those billions of people who are not getting adequate services. These systems should be affordable to low income people and at the same time conserve water and facilitate nutrient recycling for food production (ecological sanitation).

4.2 Materials and methods

This study is based on the analysis of secondary data with the main focus on population growth and its impact on humans and the environment especially on water and sanitation (watsan) services and agriculture (land). Attempts are made to establish correlation among income, dietary intake (and changing food habits), agricultural production, and fertilizer application rate. Regression analysis was performed to determine whether there are any relationships between variables significant at 5% (p = 0.05) level and considered significant if the p-value are less than 0.05 and highly and very highly significant if the p values are less than 0.01 and 0.001, respectively. Statistical software SAS (SAS Institute Inc., Cary, USA) was used for all analyses.

The data were collected for more than 170 countries from various online and published sources including government web sites. The data related to income (GDP), average agricultural land holding, and average fertilizer application rate were mostly gathered from the World Bank web site. The data related to energy supply including average dietary (including protein) intake, dietary energy supply (DES), and dietary energy requirement (DER) were gathered from FAO. Water and sanitation related data were mostly collected from UNICEF and WHO.

4.3 Population growth and impact on environment

Population growth is one of the main causes of a myriad of complex problems the world is facing. These problems range from poverty, food insecurity, water scarcity, resource depletion and climate change. Urbanization is considered one of the main drivers of unsustainable resources demand. The demand has surpassed local government capacity (in many Asian and African countries) to provide services for a large proportion of the urban population living without basic services like water, sanitation and healthcare (Satterthwaite, 2011). Urbanization increases environmental impacts because of population density and increased per capita demand for resources both from industry and people (UN Habitat 1996; Hardoy et al. 2001). Although the nature of the treats is different, developing and developed countries both pose threats to environmental sustainability: the poverty-driven depletion of resources in the developing world and the consumption-driven pollution in the developed world, respectively (WCED, 1987). Holdren and Ehrlich (1974) established a simple relation between population size and environmental deterioration widely known later as the IPAT equation ($I = P*A*T$), where I is the environmental disruption or impact (I) caused by the variables population size (P), affluence or consumption per person (A), and damage per person or technology (T). The environmental impact will continue to grow in the future as all three variables in the IPAT equation show an increasing trend. Lands and water resources will be under immense pressure to satisfy the growing demand for food and water and sanitation services.

4.3.1 Water demand increase

Water use has increased at more than twice the rate of population growth for the past century (FAO water, 2013). Per capita demand has risen due to increased awareness of the benefits of improved water and sanitation services due to better education, higher income and improved standards of living. The increasing demand for various water uses (commercial, industrial, and residential) will compete each other for available quantities and consumers will have to pay higher prices in the future for the same amount of water. The per capita demand of water varies as according to the living standard, cultural practices, climatic conditions, income level, food habits, availability and proximity to water sources and personal habits. Increased calorie intake and the preference for a meat and milk products based diet also increases water demand because about 1 liter of water is needed to produce 1 calorie of these types of foods (IWMI, 2006).

4.3.2 Food demand and supply

World food production increased substantially in the past century (Nellemann et al., 2009). However, much of the production increase has utilized unsustainable agricultural practices that include cropping in new lands by clearing forests or other low productivity lands and intensive farming by excessive nutrient mining that destroys the soil resource base (Scherr, 1999). In many countries, soil fertility is depleting at a continuous rate as farmers cannot afford imported fertilizers and crops yields decline. The world food stock is sufficient to feed the entire world population (Figure 18), however, more than 800 million people suffer from hunger (FAO, 2012).

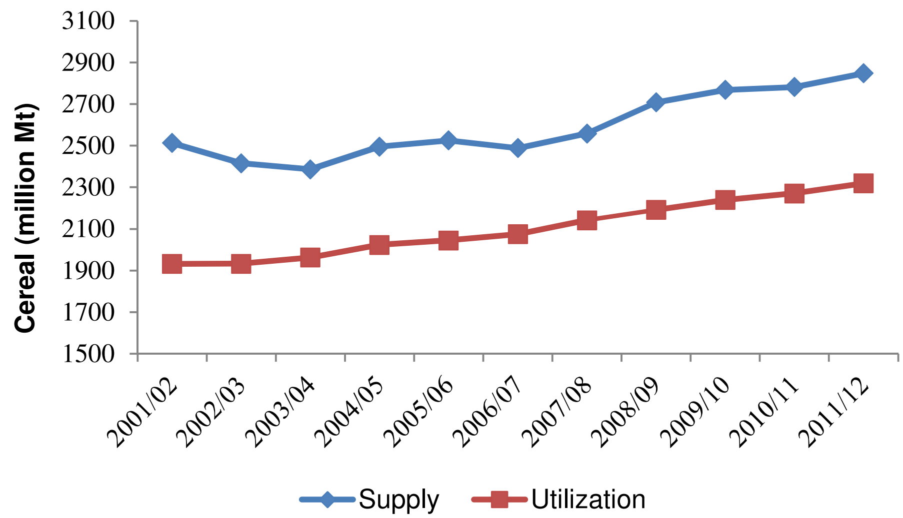

Figure 18: World food (cereal) demand and utilization scenario (data from FAO, 2011)

Hunger is the result of unequal income distribution rather than food shortages as the hungry are simply too poor to buy food. The majority of the hungry are small farmers who produce much of what they eat but not enough to avoid hunger. They cannot even protect the long-term productive capacity of their natural resources due to lack of inexpensive fertilizer (Hazell and Wood, 2008). Food security is avoidance of hunger due to availability, accessibility, affordability and stability of the supply of adequate amounts of quality food. The food security challenge is, therefore, to increase production either by making long hauled inorganic fertilizers affordable to subsistence farmers (smallholders) and food affordable to the impoverished or to produce fertilizers locally.

4.3.2.1 Changing food consumption pattern and increased dietary intake

The demand for food will continue to increase at a rate greater than the population growth rate as a result of rising incomes, urbanization, and changes in food habits and cultural changes (Huang and Bouis, 1996). The per capita calorie intake has been increasing steadily on a worldwide basis (Figure 19). The current daily average per capita calorie intake is 2,831 kcal/d up from 2,400 kcal/d in 1975 (FAO STAT, 2011). However, this increase is not constant throughout the world and per capita consumption in 20 countries is less than 2,200 kcal/d. By 2020, more than 80% of the world population of 8 billion will be in developing countries (UN, 1995, 1996) and will account for the major part of the food intake increase: 80% cereals and 90% meat and root tubers.

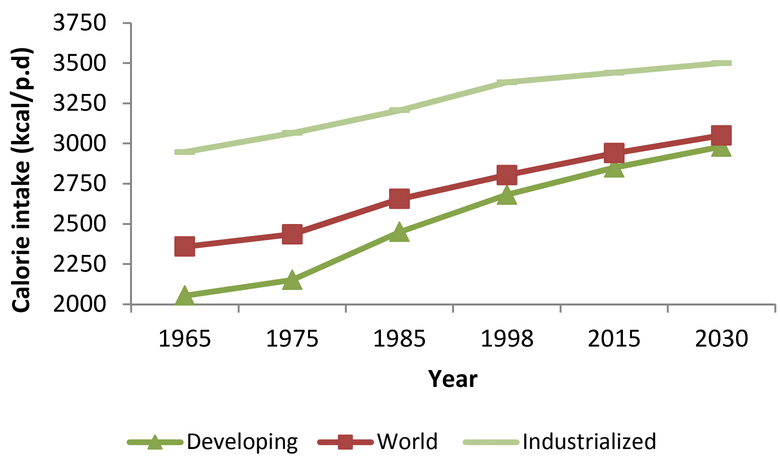

Figure 19: Global food consumption (dietary intake) trend (Data from FAO STAT)

Food habits in developing countries are also changing toward more animal protein and milk based diets. FAO estimates that, by 2015, the average calorie intake in developing countries will be 2,850 kcal/p-d but there will still be 41 countries with average food intakes of 2,500 kcal/p-d or less. There are about 878 million people from 41 countries with an undernourishment rate of 20% or more. A regression analysis shows that dietary intake differs very highly significantly with income ($p < 0.001$). In other words, income has a direct effect on dietary intake. Figure 20 shows sharp a rise in calorie intake with GDP increase approximately up to \$5,000 and a leveling off at larger GDPs. This is the GDP level around which some of the environmental pollutants that follow inverted U-shaped pattern (Environmental Kuznets Curve) start to show a decreasing trend (Grossman and Krueger, 1995; Hilton et al., 1998; Kauppi et al., 2006). There are 98 countries in the world (~ 4.8 billion people) with per capita GDP less than \$5,000. This implies that the environment in many countries will continue to deteriorate further as GDPs and calorie intakes increase.

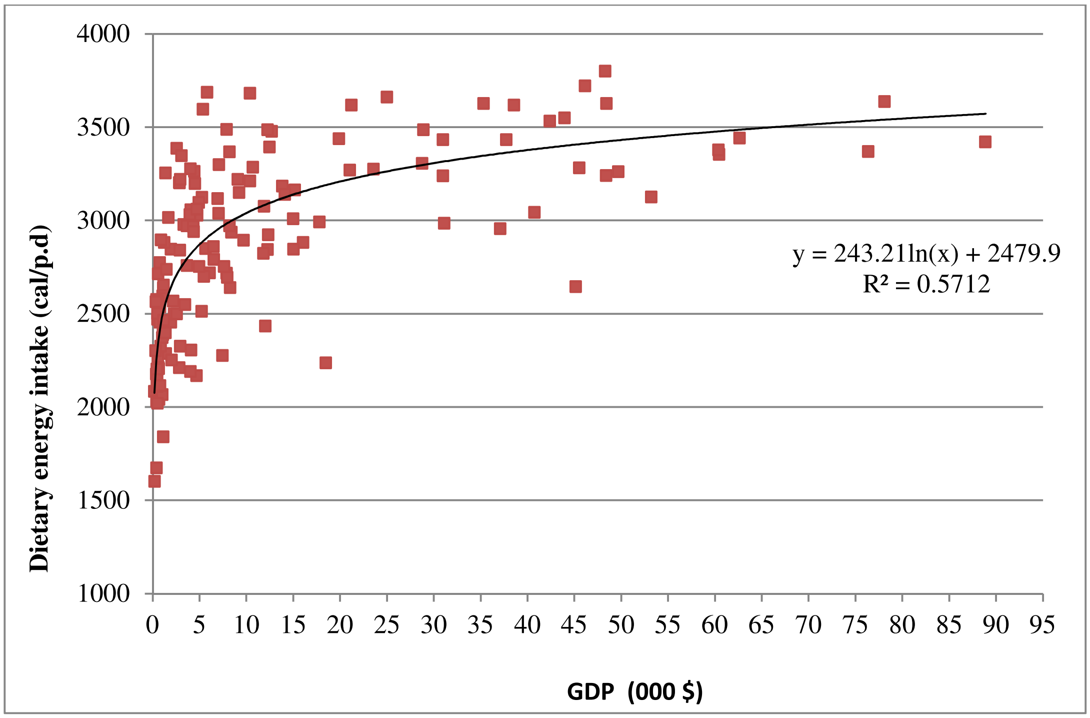

Figure 20: Calorie intake as a function of GDP (diet and GDP data are from FAO and WB, respectively). Significance $p < 0.001$ (very highly significant)

Projections indicate that meat consumption will continue to rise (FAO, 2006) and that more than 50% of total cereal production will be utilized for meat production by the year 2050 (Keyzer et al., 2005).

4.3.3 Pressure on agricultural land

Arable land comprises 10% of the total world land mass and most arable land is already under cultivation. Decline in the global stock of humic substances has been observed since farming began (UNEP, 1986). About 99.7% of human food comes from cropland which is, on average, losing soil at a rate 10 to 40 times faster than it is replenished (Pimentel, 2006). Agriculture is the main source of income and employment for the 70% of the world's poor living in rural areas (WB, 2011). The agricultural sector absorbs more than 50% of the total labor force in 48 countries with a total population of 3.5 billion.

World food demand is also increasing at a higher pace than population growth so that more food needs to be produced from the existing cropland to meet the demand for food that is more nutrient, water and energy intensive. The poor will be further marginalized and suffer from hunger if more food grain is used for producing meat and other intensive resource consuming food products that are mostly out of reach to poor. It is urgent to work on conserving soil fertility not only to feed the growing population but also to keep people retained (or employed) in that sector.

Large increases in yield (per hectare) have been achieved through the introduction of high yield crop varieties with high environmental costs (UMICH). In spite of this, per capita food production declined in 51 developing countries (FAO, 2008) and will decrease further in the future as some of the cropland will be used for non-food production such as biofuels (Nellemann et al., 2009; Pimentel et al., 2009) and more resource intensive food products like meat and milk products. The yield will be 5-25% short of demand by 2050 if current trends continue. The challenge of feeding the increased population can be made possible by raising production from current levels, modernizing farming practices (new breeds and technologies), reducing the costs of inputs (better marketing), promoting information dissemination, by intensive farming in a more sustainable way, and rehabilitating degraded soils (Scherr, 1999). Development of new cultivars with higher yield potential and greater yield stability with integrated nutrient and pest management are thus imperative to meet the demand.

4.3.3.1 Soil productivity loss and fertilizer application rate

Demand for basic food crops, high value crops, and animal products in recent years have led to increased production and correspondingly greater fertilizer consumption (FAO, 2008). There is a large variation in the world in applying inorganic fertilizers in crops depending on cost, availability, and affordability. It is general practice to apply 60 to 200 kg of N in addition to P and K fertilizers depending on the crop type. In addition to N, P, and K, several other micronutrients are depleted over time (Agarwal, 2000; Jonsson et al., 2005) either because of the soil degradation or due to crop harvest. Despite huge surpluses in synthetic fertilizer production and stocks (Figure 21), millions of hectares of land in the world do not receive sufficient amounts of fertilizer to sustain crop yields. The carrying capacity of soils has been exceeded because of large population pressures (Hrabovszky and Miyan, 1987) combined with low fertilizer application. Agricultural production in most developing countries is unsustainable (Lal, 1990; UNCED 1992).

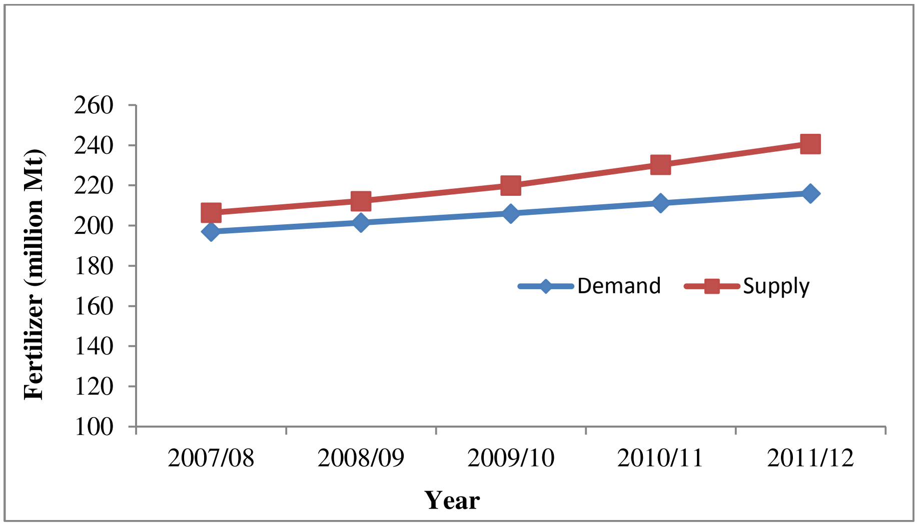

Figure 21: World fertilizer balance (Data from FAO STAT, 2011)

For example, the estimated annual soil fertility depletion rate in Sub-Saharan Africa is 22 kg N, 3 kg P, and 15 kg K per ha (kg/ha), respectively (Stoorvogel et al., 1993). African Union member states agreed in June 2006 (known as Abuja declaration) to increase the current level of fertilizer use to an average of at least 50 kilograms per hectare by 2015 in an aim to alleviate poverty and hunger by increasing production. In 2003 the Comprehensive Africa Agriculture Development Program (CAADP) was adopted and countries committed to spend at least 10 percent of their GDP on agriculture. However, only 8 countries (including Burkina Faso, Ethiopia, Malawi) allocated the committed budget and not much progress on agriculture growth has been realized in these countries. In South Asia, the annual economic loss is estimated at US$1.2 billion from soil fertility depletion (Stocking, 1986; UNEP, 1994). In Nepal, annual productions in hills and mountains are decreasing by more than 40 kg/ha/yr (Ghimire and Upreti, 1997).
There are about 45 countries (with approximately one billion people) using fertilizer at less than 20 kg/ha. In Sub-Saharan Africa, current fertilizer application rate is only about

8 kg/ha (N, P, and K total) (IFAD, 2006) compared to the world average of 101 kg/ha. In some countries in Western and Central Africa the application rate is as low as 1kg/ha (Camara and Heinemaan, 2006; FAOSTAT, 2009). Poverty (high cost of fertilizer), unavailability, and lack of transportation and distribution facilities are contribute to the low fertilizer use. Sanchez (2002) has reported a great disparity in the price of urea fertilizer. In 2002, one tone of urea was sold for \$90 in Europe, \$120 in the harbor of Mombasa, \$400 in Western Kenya and \$770 in Malawi. There are almost a billion people in the world with GDP less than \$800/y. Productions are thus compromised as it is impossible for people in these countries to spend their entire annual income to purchase a bag of fertilizer. Because nutrient mining (low fertilizer application) the crop yield in more than 40 countries is less than 1,500 kg/ha compared to more than 4,000 kg/ha in many countries (WB, 2011). Most of the countries with low crop yield are from Africa: Cape Verde has the lowest yield of 222 kg/ha and Namibia (373 kg/ha), Sudan (452 kg/ha), and Niger (490 kg/ha) are second, third and fourth on the list, respectively. Belgium is on the top of the list with an average yield of 9,231 kg/ha and The Netherlands is the second with a yield of more than 8,500 kg/ha.

The average per capita arable land in African countries with lowest yield (Cape Verde: 0.12 ha, Namibia: 0.36 ha, Sudan: 0.47 ha, and Niger: 1.0 ha) is much more than per capita arable land in countries with maximum average yield (Belgium: 0.08 ha, Netherlands: 0.06 ha). Regression analysis shows that the difference in production (crop yield) was very highly significant ($p < 0.001$) with fertilizer application but was poorly correlated ($R^2 = 0.028$) with per capita arable land. This shows that land resources are underutilized in many countries and the production can be substantially increased with better agricultural practices like introduction of new cultivars, and increased fertilizer use. Billions of dollars are needed to increase the level of mineral fertilizer application to increase the soil fertility/productivity, especially in Africa. However, these countries are unable to afford such huge investment. Holistic approaches to soil fertility management have to be introduced that would include integration of mineral and locally available organic sources of nutrients and maximize their use efficiency (TSBF-CIAT, 2006). This approach would also reduce dependency on oil-based commercial fertilizers.

4.3.3.2 Environmental consequences of fertilizer application and fertilizer alternatives

Among nutrients, nitrogen has a crucial impact on the yield of a crop as it is, most often, the limiting nutrient. N fertilizer has great economic and environmental significance not only because its production is an energy intensive process but also because approximately 30-75% of N applied to farmland is easily lost polluting water systems and the atmosphere (Smil 2000; Goulding et al. 2008). The leaching loss can be as high as 45% (Javris, 1996) and the denitrification loss can be 10-30% (Parker, 1972). The application of ammonium fertilizers (N-source) also acidifies the soil. The world's phosphorus (P) reserve is finite and should be recycled whenever possible (Cordell et al., 2009; Tinker, 1997; Smil, 2000). These facts show the urgency for sustainable alternatives to energy intensive and costly inorganic fertilizers which would be inexpensive and locally available. These fertilizers would also maintain soil fertility and be retained in the soil for a long time subsequently reducing the pollution load to receiving water bodies and the atmosphere.

Disposal of human waste (urine and feces) is a major activity that leads to widespread water quality problems (Genius et al., 2005; Carr and Neary, 2008; UNEP, 2010). Human excrement contains almost all of the macro/micro nutrients necessary for plant growth and could be the good source of plant nutrients. As fertilizer supplements, urine and feces complement each other: urine is rich in N and is quickly available whereas feces are rich in P, K and organics but are released slowly. Fecal matters, unlike chemical fertilizers, improve soil structure, water retention, pH, and buffering capacity (Jönsson et al., 2004) and nutrient losses are minimal. Human excrement is also a source of nutrients in remote areas where inorganic fertilizers are scarce and expensive. Proper management of human excreta and reuse of nutrients in agriculture after proper treatment could be the sustainable alternative to expensive inorganic fertilizers which would also help reduce pollution problems and meet goal one of MDG (reduce extreme poverty and hunger).

4.3.4 Sanitation coverage and wastewater management alternatives

The demand for drinking water and wastewater facilities is increasing at a rate faster than population growth. The issues of water scarcity and quality are worldwide phenomena

(Clarke, 1993). Declining river flows, collapse of water-based ecological systems and large scale ground water depletion are common problems all over the world (UNDP, 2006). There are approximately 1.1 billion in the world without access to improved water and 2.4 billion people without access to improved sanitation facilities (JMR, 2010). The wastewater volume to be treated would be enormous if these populations were served with proper water and sanitation (conventional flush type) facilities. Lack of financial resources and lack of sustainability of water supply and sanitation services are considered the main reasons for this low coverage. Water conservation and reuse programs have to be introduced at all levels for the sustainability of water resources.

Various toilet systems are in practice in the world based on culture, social and economic status and technology available in the locality. Conventional systems include water based (flush type) systems with centralized sewer and treatment plants and several on-site disposal systems (OSDS) such as pit latrines, cesspools, septic tanks, and aerobic treatment units (ATUs). Niemczynowics (1997) estimated that about 95% of all the wastewater produced in the world is released to the environment without any treatment. The average daily indoor per capita water use in the USA is 263 liters and the largest proportion (more than 25% or 66 l) of water supplied is used for toilet flushing (AWWA, 2010). Modification in toilet technologies has the potential to save a large amount of water. These kinds of toilet technologies might also not be appropriate in places with water scarcity and low income.

Investment to improve drinking water, sanitation and hygiene and water resource management systems makes strong economic sense: every dollar invested in the watsan sector leads to benefits of $3 to $34 (Hutton and Haller, 2004; Hutton et al., 2007). Though watsan services have great effects on environment and public health, billions of people still lack appropriate services. In order to increase the rate of progress, the watsan sector has been selected as a part (Target 3) of Environmental Sustainability (Goal 7), one of the eight Millennium Development Goals (MDGs), in the UN Millennium Summit of 2000. The target was set at reducing by half the proportion of people, between 1990 and 2015, without sustainable access to safe drinking water and sanitation. The investment required (based on 2005 dollars) for meeting the MDG target only on water and sanitation during the period 2005-2014 is $42 billion and 142 billion, respectively (Hutton and Bartram, 2008). This is equivalent to per capita annual investment of $8 for water and $28 for sanitation. Based on low-cost and sustainable technologies an estimated investment of at least $11.3 billion/yr over and above current investment should be made just for closing the MDG gap. The cost up to $136.5 billion/yr is needed if in-house piped water supply and in-house sewer connection with partial sewage treatment is desired (Hutton and Haller, 2004; UN 2008). There is a need for a sustainable alternative to the current practice of sanitation that is economically and socially feasible and decentralized eco-technologies can serve the purpose (UNEP 2004). Investment in the watsan sector also helps to achieve MDG goals 4 (reduce child mortality), and 5 (improve maternal health).

4.3.4.1 Conventional toilet system

The water borne sanitation (conventional central sewer) system is currently the most preferred sanitation system in the world. This requires approximately 15,000 l/p.y of drinking water to flush the toilets (Drangert et al., 1997) making the wastewater volume to be treated enormous. The discharge of wastewater with nutrients excreted from the human body causes a linear flow of nutrients from farm to wastewater receiving watercourses. Conventional OSDSs are inexpensive and easy to operate but can have negative environmental consequences like release of all or partially treated sewage, nutrients, and methane (Verstraete et al., 2009) to underground aquifers and/or nearby surface waters. Because of the perception that on-site or decentralized systems are inferior and not safe, many communities demand centralized wastewater treatment systems (USEPA, 2002). Central sewer systems with proper wastewater treatment facilities offer high levels of service. However, these systems need huge capital and operation and maintenance (O&M) costs (Grau, 1994) and are very costly even for rich and developed countries. The average cost of networked sanitation ranges from $300 - $800/capita depending on the level of service desired (UNEP, 2004). The dilution of wastewater in these systems makes it difficult and expensive to recover nutrients and is thus unsustainable in terms of water conservation and nutrient recycling (Verstraete et al., 2009). Dilution also lowers the degradation efficiency of certain chemicals like estrogens and pharmaceuticals (many of them with endocrine disrupting capability) during wastewater treatment (Joss et al., 2006).

The sanitation coverage in more than 40 countries (with total population of 2.2 billion) still less than 50% and providing networked sanitation to this same population would need an investment of $660 – 1,760 billion depending on the service type. Developing and poor countries are vying for such systems that are not easily affordable even to affluent societies in developed countries like in the USA (Lens et al., 2001). There are billions of people in the world with per capita income less than $1,000 (WB data) and countries with GDP less than $1,000 could not even maintain the system if it was constructed for free (Grau, 1994; 2005). Countries generally spend 1-1.5% of their GDP in constructing sewers and wastewater treatment plants. With this level of investment people in developing countries would have to save for 25-80 years in order to generate enough money ($300-$800 per capita) to construct networked wastewater management system in addition to large O&M and recurrent costs. According to UNICEF (2012) the median government spending on watsan sector was only 0.38% of GDP (0.04 – 2.8% for water and 0.01 – 0.46% for sanitation) much less than needed as reported by Grau (1994). The sanitation coverage growth in the future will be so slow that about 5.5 billion people will be without sanitation by 2035 if current rates of investment and demands for central sewer systems continue (Niemczynowics, 1997).

4.3.4.2 Urine diverting toilet (UDT) system and potential for nutrient capture

Sanitation concepts based on flush toilets are neither an ecological nor economical solution in either developed or developing countries (Langergraber and Muellegger, 2005). The level of investment as well as O&M costs can be drastically reduced if eco-technologies can be implemented. Ecological sanitation in urine diverting mode (urine diverting toilet or UDT) can be one of the sustainable alternatives to current sanitation system because of lower construction (~$160-175 per capita) and O&M costs compared to conventional sewer systems ($300-800 per capita) (UNEP, 2004). Urine, which constitutes only about 1% of domestic sewage, contains nearly all of the human excreted nutrients and is the main source of ammonia (60-90%), phosphorus (40-70%), and potassium (55-90%) in municipal wastewater (Kirchmann and Petersson, 1995; Larsen and Gujer, 1996, Almeida et al, 1999). Urine from a healthy person is relatively sterile and UDTs can be employed to collect two waste fractions (urine and feces) separately at the source (Jonsson et al., 2005). The services offered by UDT systems are no better than conventional flush systems but offer several ecological benefits. Recovery of nutrients only from urine can have a great impact on food security, water conservation and pollution reduction and also on the cost of wastewater treatment. UDTs collect relatively concentrated waste that makes nutrient recovery easier. Collection and reuse of nutrients helps to close the nutrient flow (Figure 22).

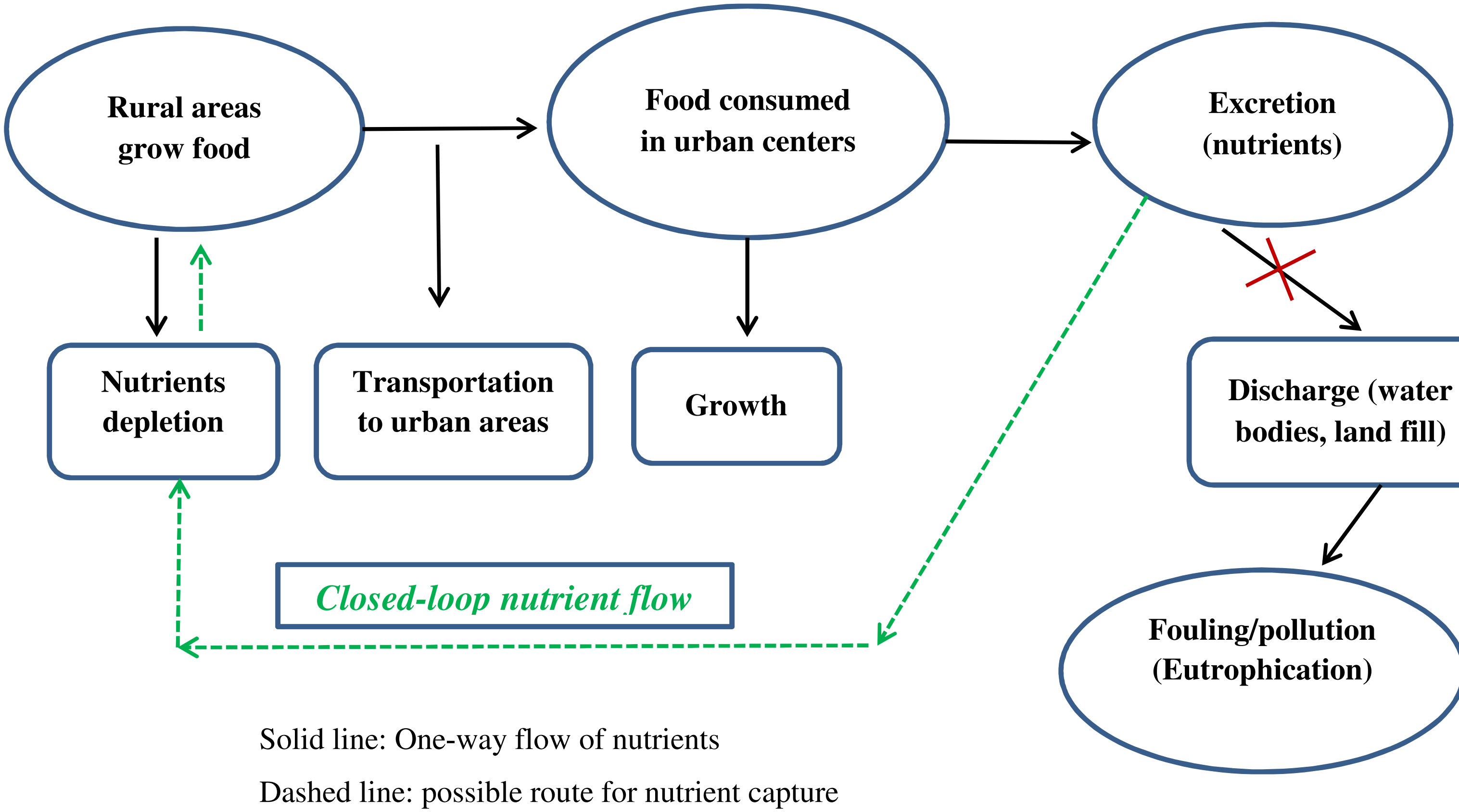

Figure 22: Schematic of nutrient flow (modified from Lamichhane, 2007)

In many societies it is considered a taboo to handle/touch feces (due to cultural, religious or social norms) (Manyanhaire and Sandra, 2005; 2009; Drangert and Nawab, 2011; Mariwah and Drangert, 2011). However, various studies (such as Lienert et al., 2003; Drangert and Nawab, 2011; Lamichhane and Babcock, 2012) have reported that people consider urine much safer than fecal matter and may not be opposed to recycling nutrients in urine. Subsistence farmers can make use of nutrients only in urine, if they do not want to handle/recycle feces, to increase yield, preserve soil fertility and food security. Urine separation also allows using treatment methods tailored to specific requirements of the waste fractions. Because of separate collection and use of urine, nutrients loads to receiving water bodies can be drastically reduced. In developing countries financing of decentralized and ecotechnologies like UDTs to each and every household could be much cheaper than constructing central wastewater treatment plants (WWTPs) to receive and treat wastewater from the same population (Lamichhane, 2007). People could make use of nutrients (human waste) to increase production which would otherwise pollute the environment.

4.4 Human excretion of nutrients

Once the skeleton and muscles in humans reach their full size almost all plant nutrients consumed leave the human body as wastes. A study in Sweden revealed that only about 2% N, 6% P, and 0.6% K of the total intakes are retained in the (growing) body during the age 2-17 years (Becker, 1994; 1999). The quantity of nutrients excreted from the human body depends on the quality and type of food an individual eats. A typical man excretes approximately 4.5 kg N, 1 kg P and 1.5 kg potassium (K) and several other micronutrients (Ottorpohl, 2002). Collection and reuse of these nutrients could not only enhances the agricultural growth but also help prevent environmental pollution. Jonsson and Vinneras (2004) have developed empirical equations (Equations 1 and 2) to estimate nutrients (N and P) in excrement from human body as a function of consumed protein (food intake).

$$N = 0.13 \times (\text{Total food protein}) \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

$$P = 0.011 \times (\text{Total food protein} + \text{vegetable food protein}) \quad \dots \quad (2)$$

These equations can be used to estimate the average nutrients (N and P) that can be collected from a population knowing the food intake (food intake data by country are available from FAO STAT).

4.4.1 Fertilizing potential of human excreted nutrients

In many developing countries, agricultural productivity growth is the strongest driver of income growth (USDA) and is also a key to sustainable management for subsistence farmers (Kibblewhite et al., 2008). There are 54 countries applying inorganic (synthetic) fertilizers at rates of less than 20 kg per hectare arable land (kg/ha) and 39 countries applying less than 10 kg/ha (WB, 2011). The average fertilization rate for heavily indebted poor countries is only 6.5 kg/ha.

The country specific average food (calorie) intake (also known as dietary energy supply, DES) data were collected from FAOSTAT (2011). The average nutrients (N and P) excreted by a typical man from a particular country were calculated based on the average food (protein) consumption and using Equations 1 and 2. The data indicate (not shown) that Burundi has the lowest average per capita calorie intake of 1,604 kcal/d and Eritrea comes the second with 1,674 cal/d compared to the world average of 2,831 kcal/d (FAO STAT, 2012). Maldives has the medium average intake (2,720 kcal/d). Based on the DES data, the average per capita yearly nutrient excretion (equivalent to urea and phosphate fertilizers) was calculated (calculation not shown). It was found that per capita nutrient (N and P) excretion equivalent to urea and phosphorus oxide (P_2O_5) was the highest in Iceland (total - 15.2 kg, in urine - 13.04 kg) and the lowest in Congo, DPR (total – 2.93 kg, in urine – 2.47 kg). The calculations indicate that there are about 30 countries in the world with fertilizer application rate less than the people from those countries excrete (urine and feces together) and in 22 countries the nutrients excreted only in urine are more than the fertilizer application rate. The average nutrient excretion in some of the countries with DES in the lower end (Burundi, Burkina Faso, DR Congo, and Malawi) (FAOSTAT, 2011) and average fertilizer application rate (WB, 2011) is shown in table 22. The data show that the amount of nutrients excreted from a typical man only in urine in these countries is much more than the average fertilizer application rate (Table 22).

Table 22: : Daily DES and yearly total and urinary nutrient excretion of nutrients from a typical man

Country	Arable land (ha/p)	Fertilizer application (kg/ha)	Daily dietary energy (calorie) supply (kcal/p.d)[1]		Total nutrient[2] excretion (kg/p.y)		Urine nutrient excretion[3] (kg)		Total (and urine) fertilizer equivalent (kg/p.y)[4]
			DES	Protein	N	P	N	P	
Burundi	0.11	1.6	1,604	43.2	2.2	0.2	1.98	0.18	5.5 (4.63)
Burkina Faso	0.37	3.9	2,647	79.6	3.8	0.6	3.42	0.30	9.59 (8.07)
Congo	0.1	0.5	2,084	24.4	1.2	0.2	1.08	0.09	2.93 (2.47)
Malawi	0.25	1.7	2,318	62	2.7	0.4	2.43	0.22	6.84 (5.75)
Maldives	0.01	5.25	2,720	99.4	4.7	0.6	4.23	0.28	12.83 (9.85)

[1]DES: Dietary energy supply; DES data were obtained from FAO (FAOSTAT, 2011)

[2]Total nutrient excretion was calculated based on DES data (FAOSTAT) using equations 1 and 2 developed by Jonsson and Vinneras (2004).

[3]Urinary excretion of N, P, and K is assumed as 90%, 50% and 55% of total excretion, respectively

[4] The fertilizer equivalent was calculated based on nutrient content in inorganic fertilizers (urea with 46% N and P_2O_5 with 44% P) and the values in the parenthesis are fertilizer equivalent nutrients excreted only in urine

Per capita arable land (hectare per person) and fertilizer application rate (kilogram per hectare) data were obtained from The World Bank (2009)

Human nutrient excretion will grow in the future along with increased food (dietary calorie) intake. There could be a strong motivation to install UDTs and recycle nutrients to crops if the nutrient potential of urine and its relatively sterile state (almost pathogen free) could be made widely known to people.

4.5 Economic and environmental benefits of introducing UDT system

Lack of adequate sanitation causes contamination of water courses worldwide and is one of the most significant forms of water pollution. Improving water, sanitation and hygiene has the potential to reduce 3.7 percent of DALYs (Disability adjusted life years) globally (UNICEF/ WHO 2008) and prevent at least 9.1% of the disease burden DALYs (Prüss-Üstün et al., 2008). As mentioned above, billions of people cannot afford central sewer systems and will be without sanitation services if countries continue dreaming for central sewer systems and the current rate of investment continues. Many more people would get the sanitation services if UDTs were employed which would subsequently reduce associated disease burdens or DALYs. Proper use of UDTS and recycling/reuse of nutrients will drastically reduce pollution loads to receiving water bodies and increase agricultural production which would help alleviate poverty and hunger.

UDTs can be used in centralized as well as decentralized mode but can also be used as a transition to decentralized mode (Larsen et al., 2001). UD system saves water, wastewater and reduces energy consumption. A properly used UDT can save up to 32 l/p.d of drinking water used for flushing toilets leading to a yearly savings of \$23.35 in drinking water/wastewater charges in the US (Lamichhane and Babcock, 2012). They also estimated that recovering nutrients (N, P, and K) from human waste (feces and urine) from a typical man in one year can save approximately 88 kWh of energy (and 52.89 kg of associated green house gas emissions) that is required to remove these same nutrients from wastewater and needed to produce equivalent inorganic fertilizer for crops. The annual value of the recovered nutrients on the US market is approximately \$6.86 and more than \$10 in Burkina Faso (Africa) (Richert et al., 2010). The launching of watsan and agricultural programs/projects simultaneously will be more economical, environmentally friendly and relatively easier to manage than separate programs.

4.6 Conclusion

The dietary energy supply (DES) or intake in developing countries, continues to rise placing increasing pressure on farmlands. The regression analysis shows that the increase in dietary intake with income (GDP) is very highly significant ($p < 0.001$) and the intake increase slowed down when GDP exceeded \$5000. Agricultural production in many countries has been stagnant. The regression analysis shows that the increase in agricultural yield with fertilization application was very highly significant ($p < 0.001$) and showed, though poorly correlated ($R^2 = 0.028$), a negative relationship with per capita arable land holdings. There is a huge potential of increasing yield by managing soil fertility as most of the lands in poor countries yield 20-25 times less (underutilized) than the lands in countries with better agricultural and fertilizing practices. However, the average fertilizer application rate in many countries is less than 1 kg/ha because inorganic fertilizers are not affordable to poor people. A major challenge is to find ways of making long hauled (or imported) fertilizers available and affordable to smallholders or to produce them locally.

Proper management of human waste (HW) or municipal wastewater can bring life to water bodies and can also partly supplement nutrients for local farms that are removed from soil in the form of crop harvests. Nutrients excreted in HW by a typical man in 30 countries is more than the average fertilizer application rate (kg/ha) and urinary excretion of nutrients alone is more than the fertilizer application rate in 22 countries. Though common to all nations, the economic and environmental benefit of HW recycling will have more pronounced effects in poor developing countries as they can immediately realize the benefit of increased agriculture production (fertilizer value of approximately $10) and lower disease incidence. A coordinated governmental intervention is imperative to economically provide watsan services and increase food production as the current level of investment in these sectors individually in most of the developing countries are not sufficient. The investment and O&M costs for UD systems are much lower than for central sewer systems and WWTPs and yet offer all the benefits of a good sanitation system. Introduction of UDTs and reuse of nutrients in agriculture is, thus, an environmental as well as economic gain as this would contribute to reducing water pollution, water use, sanitation and hygiene based DALYs and enhances food security.

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CHAPTER 5. CASE STUDY ANALYSIS OF WATER AND SANITATION CONDITIONS, FERTILIZATION APPLICATION RATE, AGRICULTURAL PRODUCTIVITY AND POSSIBILITY OF INTEGRATING SANITATION SERVISES TO REDUCE UNDERNOURISMENT AND POVERTY

5.1 Introduction

The essential needs like food, clothing, shelter, and jobs for the vast majority of people in the developing world are still to be met. Sustainable development requires that societies meet human needs both by increasing productive potential and by ensuring equitable opportunities for all (Bruntland Commission Report). Poverty is a major cause of environmental degradation (pollution of water courses and unsustainable fishing, soil nutrient mining, forest depletion and biodiversity loss) and alleviation of poverty is essential for environmental programs to be effective. UNEP (2007) estimates that about 20% of the disease burden in developing countries is associated with environmental risks and wise investments in wastewater management can generate significant returns by sustaining ecosystem services. Instead of being a source of problems, well-managed wastewater will be a positive addition to the environment which in turn will lead to improved food security, health and therefore economy (UNEP/UNHABITAT, 2010). For poverty reduction to be effective and development activities to be sustainable, the poverty reduction strategy should be integrated along with wastewater management (water and nutrient reuse) and agricultural production growth. This integration will be one of the most economically viable and technically feasible alternatives to poverty reduction through environmental conservation and agricultural growth increase. Urine diverting toilet (UDT) is proposed as one of the best alternatives for sanitation as they are relatively cheap and are appropriate for both centralized and onsite modes. The status of water and sanitation (watsan) services, agricultural productivity, food security and economic benefits of human waste recycling for two African countries (Burkina Faso, and Malawai) and one Asian country (Nepal) will be discussed. Though not covered in detail, similar information to these three countries is also provided for China, India and the USA for comparison.

The costs required for providing sanitation services are predicted based on the cost of ecological sanitation, UDT in this case. Costs are estimated for providing sanitation services only to people currently practicing open defecation (OD). Nutrients saving calculations are also made based only on the number of people practicing OD. The average cost of UDTs is assumed to be the same for both Asian and African countries as these countries have similar economic and social conditions. The economic value of nutrients that would be collected using UDTs is calculated based on the price of the inorganic fertilizer in the specific countries. The savings due to nutrient recycling and the costs necessary to offer sanitation services for all OD people with UDTs are calculated.

5.2 Sanitation practice in developing countries

Many people believe that onsite sanitation disposal systems (OSDSs) like septic tanks, cesspools, and pit latrines cannot be the final step in managing wastewater (EPA, 2000) and there is also thinking that these systems are good only for developing countries (Ottorpohl, 1997). OSDS serve up to 60% of the houses in many megacities of Asia like Manila, Bangkok and Jakarta and more than 80% of houses in the large cities in Sub-Saharan Africa (Strauss et al., 2000). OSDS will remain predominant over water-borne sewered systems in the coming years in developing countries because of costs, the growing water scarcity, and intermittent water supply (Eawag, 2006). The flow in a sewer system would not be sufficient enough to transport fecal sludge to wastewater treatment plants even if sewer systems were built. The introduction of sanitation systems was effective in reducing water and sanitation related disease burdens in developing countries. However, wastewater management systems were built without thoroughly anticipating the need of managing the waste afterwards (fecal sludge in case of OSDSs and sludge in case of networked systems). In many developing countries people did not even know that septic tanks need to be de-sludged periodically. Systems were built without any plan and are now facing the problem of fecal sludge management. For example, 76,600 m3 of fecal sludge produced from septic tanks in Kathmandu (the capital city of Nepal) is disposed without any treatment and the majority of that goes into the river systems of the city that the septic tanks were meant to help protect (HPCIDBC, 2011). There is also a general tendency to dump non useable things in toilets. These foreign objects (like sanitary pads, cloths, card boards, chemicals, medicines, oil and grease) in the toilet system hinder both networked and OSDS system performance. If the sanitation system is designed for recovering resources, not only the volume of the waste but also the entry of foreign objects in the toilet system will be drastically reduced and will ease subsequent treatment.

5.2.1 Networked sewer systems and central WWTPs are costly

Conventional sanitation (water-borne) system with central sewerage networks and wastewater treatment plants (WWTPs) is still the most preferred sanitation system in the world but are capital and O&M cost intensive. Sanitation improvement has not yet been the priority for many countries. Only 12% of the money invested in water supply and sanitation sector went specifically to fund sanitation in Africa (WHO/UNICEF (2000), and was only 15% in Asia (WSSCC and WHO 2005). It is urgent to put in place wastewater management systems because the disease burden of watsan in many developing countries is very high (JMP, 2012). With the current rate of investment (about1.5% of GDP) construction of sewer systems in these countries seems unrealistic because these countries need longer periods than the economic life time of WWTPs (20–30 years) and sewers (50–60 years) (Grau, 1994, 2005; Gijzen and Ikramullah, 1999; Keraita et al., 2009). Based on the current pace of investment and development Kenya would need 1,034 years and India would require 746 years to providing sanitation services to all.

5.2.2 Poor sanitation systems cost more

OD is a widely practiced method of excreta management in many developing countries in Asia and Africa. OD costs more per person than any other type of unimproved sanitation. Each person without access to a toilet can spend up to 2.5 days a year finding a private location to defecate, resulting in losses totaling almost US$500 million in access time worldwide annually due to OD (WSP, 2012). Women have a larger share of the cost than men because they spend additional time accompanying young children or sick or elderly relatives to relieve themselves, as well as time spent finding a safe place for urination. These losses do not include the costs of epidemic outbreaks; losses in trade and tourism revenue; impact of unsafe excreta disposal on water resources; and the long-term effects of poor sanitation on early childhood development.

5.2.2.1 Urine diverting toilets in open defecating areas

Though appropriate water and sanitation services are necessary for all people, the open defecators (people who practice OD) are the ones to be targeted first to increase the sanitation coverage and reduce water pollution as ODs normally prefer river banks. Using calorific data and nutrient excretion rate, the quantity of nutrients that can be collected only from ODs is calculated. An economic analysis is made and payback period is calculated considering the nutrient value of excreta. Other environmental costs of OD like mortality and morbidity are not considered. Calculations for nutrients are made both for total nutrients and only nutrients in urine. Table 23 shows data related to dietary energy supply, nutrient excretion and average fertilizer application rate. It is assumed that 100% of the nutrients can be collected from urine diverting toilets (UDTs). The cost of sanitation alternatives, VIP and UDT, are estimated based on the UNEP (2004) sanitation cost ladder. The per capita cost of $180 (UNEP, 2004) for a UDT and around $900 for a family, considering a family size of 5, seems quite high for these countries. Table 24 shows the data related to food security (import, export), cost of providing sanitation facilities (UDT) to OD population and also shows the payback period. Though OD exists everywhere, it is more prevalent in rural and semi-urban areas. People would be happy to have one toilet in a family as even well off people in these areas use one toilet for the whole family. The cost calculations are based on per capita investment of $180 but the capital cost drastically reduces if a family uses one UDT. The payback period thus seems quite large (21+ years). If the UDT cost is reduced by one fifth (one UDT per family) the payback periods would be reduced by a factor of 5 also.

Table 23: Food habit and nutrient excretion in human excreta

Country	Arable land (ha/p)[α]	Fertilizer application (kg/ha)[♠]	Undernourishment	Daily dietary energy supply (DES) (kcal/p.d)[♣]		Total nutrient excretion (kg/p.y)[μ]		Urine nutrient excretion[θ] (kg)		Total (and urine) fertilizer equivalent (kg/p.y)[Ω]
				DES	Protein	N	P	N	P	
Burundi	0.11	1.6	73.4	1,604	43.2	2.2	0.2	1.98	0.18	5.5 (4.63)
Burkina Faso	0.37	3.9	25.9	2,647	79.6	3.8	0.6	3.42	0.30	9.59 (8.07)
Congo	0.1	0.5	75	2084	24.4	1.2	0.2	1.08	0.09	2.93 (2.47)
Malawi	0.25	1.7	23.1	2,318	62	2.7	0.4	2.43	0.22	6.84 (5.75)
Maldives	0.01	5.25	5.6	2,720	99.4	4.7	0.6	4.23	0.28	12.83 (9.85)
Nepal	0.08	17.7	18	2,470	60.3	2.9	0.4	2.61	0.2	7.17 (6.11)
China	0.08	503.0	11.5	3,096	88.9	4.2	0.6	3.78	0.3	10.5 (8.87)
India	0.13	167.0	17.5	2,397	57.4	2.7	0.4	2.43	0.2	6.9 (2.63)
USA	0.53	109.4	-	3,626	112.9	5.4	0.6	4.86	0.3	13.0 (11.22)

α From WB (2011)
♠ From WB (2011)
♣ From FAOSTAT (2012)
μ Calculated using equations (Jonssosn and Vinneras, 2004)
θ Estimated assuming approximately 90% N and 50 % p are excreted in urine (Janssen et al., 1997)
Ω Calculated based on urea (N) fertilizer with 46% N and Phosphorus pentooxide (P) fertilizer with 44% P

Table 24: Average dietary intake, nutrient excretion and fertilizing potential of human excreted nutrients and estimated cost and payback period to introduce UDTs

	Population (millions)	Sanitation coverage (improved) (%)	Open defecation (OD) (%)	Open defecation (OD) number (million)	Average Arable land (ha/p)	Average fertilizer application (kg/ha)	Average food intake (kcla/d)	Equivalent N fertilizer excretion (kg/p.y)	Total fertilizer excretion (N & P, kg/p.y)	Total fertilizer collection from OD only (1000 t/y)	Expected increase in cereal production (kg/p.y)	Average Cereal yield t/ha (2010)	Food balance (million tons)		Average fertilizer (urea) cost (US $/t)	Total fertilizer value (million $/y)	Cost (in billion $) to providing sanitation services only for OD population			Payback period (only due to fertilizer benefit if UD was introduced), years
													Import	Export			VIP@ $65/p	UDT@ $180/p	Networked sewer @$350/p	
World Av.		63		1100		101	2829		9.3			3.56				-				
DR Congo	66	15.8	9	5.94	0.1	1	1605	2.52	2.93	17	24	0.77	0.236	0.001	830	14.4	$0.39	$1	$2.1	66
Maldives	0.32	0.31	0	0	0.01	5.25	2685	5.28	12.83	-	103	2	0.052	0		-	$0.00	$0	$0.0	
Burkina Faso	16.5	17	58	9.7	0.37	3.9	2647	3.78	9.59	93	77	1.05	0.31	0.02	800	74.4	$0.63	$2	$3.4	21
Malawi	13.2	51	8	1.06	0.25	1.7	2172	2.69	6.84	7	55	2.21	0.15	0.44	1090	7.9	$0.07	$0.19	$0.4	21
Nepal	30	37	49	15	0.08	7.7	2360	6.3	7.21	108	58	2.3	0.32	0.086	402	43.4	$0.98	$2.7	$5.3	55
USA	316.7		0		0.53	142	3748	11.74	13.1	-		6.99	9.09	105.67	362	-	$0.00	$0	$0.0	
China	1341	64	1.04	14	0.08	504	2981	9.13	10.5	147	84	5.52	8.99	11.71	332	48.8	$0.91	$2.52	$4.9	46
India	1241	34	50.4	626	0.13	153.5	2352	5.9	6.8	4,257	54.4	2.54	2.74	9.94	102	433	$40.69	$112.7	$219.1	231

Data source:

- Population data from UN (2013) and partly from CIA Fact Book (2013); Fertilizer related data from WB (2013), and Africa Fertilizer dot Org, USAID (2010), and US Department of Agriculture (2013); typical fertilizer response rate data from FAO (1989)
- Water and sanitation related data including open defecation information: JMP (2012), http://www.who.int/water_sanitation_health/monitoring/jmp2012/fast_facts/en/index.html
  Sanitation alternatives and average per capita cost: UNEP Cost Ladder (UNEP, 2004); Average nutrient excretions were calculated based on dietary energy (intake) supply (DES) data from FAO STAT (2013) and using equations (Jonssosn and Vinneras, 2004)

5.3 Poverty alleviation, sanitation services, and agricultural production growth

Poverty alleviation has been a top priority in many countries mainly after UNCED (1992) but the possible contribution of the sanitation sector to poverty reduction has not been realized. Sanitation coverage would greatly improve if resource recovery from excreta is incorporated in to the country's poverty reduction strategy. Simultaneous intervention on sanitation and agriculture will be a good alternative for ensuring environmental sustainability and poverty/hunger reduction through agricultural growth increase due to nutrient recycling. The sanitation system in urine diversion mode is one of the alternatives of excreta management that reduces waste volume, discourages entry of foreign objects in the system and also makes resource recovery easier. Nutrient recovery will help reduce water pollution and also help reduce hunger and malnutrition. People in developing countries migrate to urban centers normally to seek employment and it would be easy to retain the rural population if employment opportunities could be generated in rural areas. The development of marketing mechanisms with appropriate and sufficient agricultural inputs and extension programs would surely boost the yield. This yield increase will also help reduce migration to urban centers.

5.3.1 Fertilizer subsidized for boosting production

Fertilizers are heavily subsidized in all of these countries discussed herein. Subsidies are justified on equity grounds as they serve as an income transfer to poor smallholder households (Crawford et al., 2006). However, fertilizer use should accompany improved seeds, appropriate market conditions, extension services, and technical knowledge transfer to farmers for effective production increase (Minot and Benson, 2010). People would start recycling if they are made aware of the nutrient value of excreta and the negative environmental consequence if released untreated to the environment or water bodies. Organic (manure) and inorganic fertilizers act as complements rather than substitutes. Manure, in combination with inorganic fertilizer, plays a crucial role in improving fertilizer use efficiency and soil moisture conservation (Vanlauwe et al., 2011). If people knew these facts, the overuse of inorganic fertilizer (in many cases also in developing countries) and subsequent water pollution would be substantially reduced. The sanitation coverage, prevalence of poverty, hunger and the poverty alleviation possibilities due to introduction of UDT system are evaluated here for three countries (Burkina Faso, Malawi and Nepal) as case study sites.

The data related to average dietary intake, average agricultural production (yield, kg/ha) and average fertilization applications rate (kg/ha) were collected from FAOSTAT and WB (2012). Expected human excretion of nutrients was calculated using equations (Jonsson and Vinneras, 2004) based on calorific intake data (FAOSTAT, 2012). The fertilizer value (in dollars) of excreted nutrients was calculated based on the market price of urea fertilizer in the respective countries. The anticipated cereal production increase due to nutrients recycling (additional nutrients to nutrient limited condition) was calculated based on the typical fertilizer response rate of 8 kg cereal per kg fertilizer applied. The typical fertilizer response rate (kg food produced/kg fertilizer applied) is 8 to 12 for cereals, 4 to 8 for oil crops and 30 to 50 for roots and tubers (FAO, 1989).

5. 4 Case study: Nepal

Nepal is one of the poorest countries of the world with a total population of 30.4 million and per capita GDP of $540. The annual population growth rate is about 1.4% whereas urban areas are growing by about 5% (World Bank, 2007; CBS, 2012). Agriculture is the mainstay of the people of Nepal and the agricultural sector absorbs 75% of the labor force (WB, 2011). Nepal has very low average per capita arable land holding (0.08 ha) (WB, 2011). About 22.5 % of the population has dietary energy intake below the minimum requirement (2,183 kcla/d) (NPC/UNDP, 2010) and 18% of the population is undernourished (FAOSTAT, 2012).

5.4.1 Water and sanitation status

Eighty percent of people in Nepal get drinking water from improved sources whereas only 31% people have access to improved sanitation services (NAWSFA, 1017). About 42% of rural water supply systems are functioning poorly needing maintenance in the near future and 15 million people defecate in open causing loss of 4% GDP (WaterAid, 2006). There are reports that about 13,000 children aged less than five years die of diarrheal disease annually which can be partly attributed to poor hygiene and sanitation (IRIN, 2009). Nepal's government has set an ambitious national goal of open defecation free Nepal (universal toilet coverage) by 2017. It is estimated that the plan needs an investment of at least one billion rupees per year to meet its target; this is a 14-fold increase in investment over the current allocation (WaterAid, 2009). Annual expenditures on water and sanitation as % of GDP was 0.80% on 2008, 0.70% on 2009, and 0.79% on 2010 (WaterAid, 2011).

5.4.2 Food security

Food insecurity is a major problem for many Nepalese. Nepal has been food-deficient since the 1990s (NPC/UNDP, 2010). Even the food sufficiency at the national level in Nepal does not guarantee food security at the household level because of poor infrastructure, lack of functioning markets, and lack of reliable transport networks. High dependence on traditional agriculture, low productivity, small landholdings, and no or limited access to new technology have been cited as the reasons for low productivity. Currently 27 of Nepal's 75 districts are labeled as "food deficit" and about 3.5 million people are not getting sufficient calories IRIN (2012). It is believed that 18% of the population is undernourished (FAOSTAT, 2012). The government provides subsidies on chemical fertilizers and transport subsidies on food to remote districts. The country has not been able to secure enough food for its people because supplying enough fertilizer to farmers has always been a challenge for the government of Nepal and the food security situation is getting worse rather than improving.

5.4.3 Agricultural production

Nepal does not produce inorganic fertilizers and fertilizers are highly subsidized. It is very likely that subsidized fertilizers are smuggled across borders and sold in the black markets. Fertilizer subsidies amount to 25% of the overall government budget allocated to the agricultural sector and thus presents a heavy burden on the national treasury (Goletti, 2001). Nepal's market structure is not well developed and is heavily dependent on the Indian markets as these countries share about 1,000 km of open border. Inorganic fertilizers in Nepal are up to three times as expensive as in India due to differences in government subsidies. Most of the subsistence farmers are not able to buy costly inorganic fertilizers (even subsidized) and agricultural production is thus compromised. Smuggled fertilizer costs $390/t even in city centers bordering India - the same price as government-subsidized fertilizer but of a low quality (IRIN, 2012), and do not meet the advertized quality. In rural areas with no road connection the cost goes very high and is not affordable to farmers. Public spending in agriculture as a percent of agricultural GDP is less than 3 % in Nepal. Over the past 3 decades, the percentage of government expenditure on agriculture steadily fell from around 30 percent in the 1980s, to below 20 percent in the 1990s, to 5 percent in 2008. During this period, Nepal has been witnessing frequent food deficits (MOAC, WFP, FAO, 2009). Great disparity in agricultural production exists between geographical regions (UNDP, 2008): very low production in the mountains and Himalayan region and high production in Terai (low land) region.

In order to maintain the food security of the country, the government has endorsed a twenty-year Agriculture Perspective Plan (APP) that went into effect in 1997. APP (1995) had identified inorganic fertilizers as the main engine for agricultural growth increase and expected that fertilizer application rate would increase to 131 kg nutrients/ha by 2017 and contribute to 64% to 75 % of the targeted food production growth. The production of cereals is increasing by only 2 % per annum (CIP, 2010) and fertilizer application rates have not increased at a pace as envisioned by APP.

5.4.4 Introduction of urine diversion (UD) toilets and growth increase

Large investment is needed to cover all people if a conventional networked sewer system is intended; appropriate and sustainable sanitation services are thus needed. In Nepal, about 15 million people defecate in open (OD) and about $2.7 billion is needed to construct 15 million UDTs. As mentioned above, ODs are mostly in rural areas where one toilet would provide adequate services for a family. Table 5.1 shows total nutrients than can be collected from excreta (total and in urine). The estimated cost of nutrients recovered is only $14.4 million per year giving a payback period of more than 60 years (table 5.2). However, if UDTs were only provided for every 5 persons, the payback period would be reduced to about 12 years. Because average dietary energy intake in developing countries continues to increase, more nutrients can be collected in the future.

Because fertilizer application is still low, there is the potential to increase yield with increased fertilizer application. With UDT installed and nutrients recovered, people in Nepal can realize an estimated cereal growth increase of about 58 kg per year. This would greatly help increase food security of the country.

5.5 Africa

A combination of large soil nutrient deficits and very low fertilizer use (3% of global fertilizer consumption [7 kg/ha] in Africa compared to more than 150 kg/ha in Asia) are cited as the main reasons for low production/yield in Sub-Saharan Africa (SSA) (Druilhe and Barreiro-Hurlé, 2012, Minot and Benson, 2009). In order to increase national agricultural production for food security purposes, inorganic fertilizers are subsidized in Africa. Some of the governments, mostly West African countries, have practiced universal subsidies (Burkina Faso, Senegal, Mali, Nigeria, Ghana) whereas some governments from East and Southern Africa employ targeted subsidies (Kenya, Malawi, Rwanda, Tanzania, Zambia). Though costly (US$ 100–160 million/year in these 10 countries), the subsidy programs have been effective in raising fertilizer use, average yields and agricultural production. The high cost of fertilizer in Africa is also due to poor infrastructure and road networks. For example, the shipping of 1 ton of maize from Iowa to Mombasa (13,600 km) is $50 and shipping same amount from Mombasa to Kampala (Uganda), a 900 km distance, costs $100 (Denning et al., 2006).

5.5.1 Water and sanitation

In most SSA countries, current investments in sanitation are less than 0.1% of GDP well below the eThekwini commitments of at least 0.5% (eThekwini Declaration, 2008). A survey conducted in 18 countries (including Burkina Faso) revealed that only five countries invest more than 0.1% of GDP in sanitation (WSP, 2012). This study also revealed that they are losing about US$5.5 billion every year due to poor sanitation. SSA countries should spend at least 1% of GDP on sanitation and at least a further of 2.5% of GDP on water supply (Wateraid, 2011). Overall, the water and sanitation spending need is 3.53% of GDP in Africa (WB, 2012). The poor are suffering more from poor water and sanitation practices as government subsidies (or support) either do not reach the real poor or they cannot voice their concerns. In African countries poor people end up paying a lot more than rich people for similar or even lower level of services. Table 25 below shows the average price of drinking water in Africa.

Table 25: Africa water price $/m3 (Source: WB, 2012)

Water price ($)	Household (HH) connection	Small piped network	HH reseller	Standpipe or kiosk	Water vendor	Water tanker
Average	0.39	1.04	1.63	1.52	3.38	4.67
Max	1.45	2.11	3.38	5.51	6.89	9.67
Min	0.04	0.47	0.98	0.48	1.67	2.4

Because the poor people cannot afford in-house or piped connections, they have to depend on water vendors which charge a lot more than public utilities companies. This situation is common to many cities in developing countries where utility companies cannot meet the demand. These groups also suffer the most from polluted environments.

5.5.2 Food security

The value of lost nutrients in Africa is US$4 billion/year FAO (2006). SSA (excluding South Africa) imported almost 20 million tons of cereal in 2004, at a cost of $4.4 billion. By 2020 SSA is projected to import more than 34 million tons yearly, at a cost of $8.5 billion (IFDC.org). Malnutrition is widespread and there are 20% more stunted children today than in 1990. Fertilizers and other external inputs are relatively expensive. For example the price of urea in 1997 was US$ 100/t in India but US$ 350/t in Burkina Faso (IFDC-A). Similarly, the inland transportation cost is also very high in Africa, for example it costs $100/t for transporting 1000 km in Africa whereas it costs only $30/t in India and only $20/t in the USA for transporting the same distance (Denning et al., 2006).

Africa has witnessed an agricultural growth increase in recent years (about 4%) but most of the increase is attributed to agricultural land/area expansion. The land is scarce and there are limits to further expansion and most of the countries have surpassed that limit (World Bank fact Sheet). And because of the higher population growth rate, the agricultural growth rate has not been able to meet the ever increasing food demand.

African farm yields are among the lowest in the world. The yield must increase to sustain the livelihood of most of the people because this sector absorbs 65% of the labor force and contributes to 32% of gross domestic product. The low productivity in Africa is mainly attributed to very low fertilizer use (8 kg/ha) and it was agreed to increase to an average of at least 50 kg/ha by 2015 (Abuja declaration, 2006).

5.6 Burkina Faso

Burkina Faso (BF) is one of the poorest countries in the world. It has a population of 16.3 million, and has a very high population growth rate of 3.1% per annum. It has a low literacy rate of 26% (2009) and high infant mortality rate of 91.7 per 1,000 and life expectancy rate of 56.7 years (2010) (USDOS, 2012). Agriculture absorbs about 78% of the work force and contributes 34% to the GDP (2009). About 80% of the population relies on subsistence agriculture. The average per capita arable land holding is 0.37 ha (WB, 2011). The real GDP growth rate as of 2010 is 7.9% (USDOS, 2012) and has a per capita GDP of $570.

5.6.1 Water and sanitation

The drinking water coverage rose to 83% and passed the MDG target (82%) but sanitation coverage is only 17% which is off track to MDG target of 53% coverage (JMP UNICEF/WHO 2012). The spending on watsan sector in BF is continuously increasing from 0.86% of GDP in 2008 to 1.85% in 2010 (WaterAid, 2011). USAID (2012) estimated that sanitation facilities required an annual investment of $28.25 million to meet the MDG goal on sanitation but the public budget for 2007 on sanitation improvements amounted to only $3.96 million. In Burkina Faso, the annual cost of poor sanitation to national economy is estimated to be 171 million (2% of GDP) and annual cost of open defecation is estimated to be 124 million (WSP, 2012). WSP (2012) also estimates that 2,000,000 toilets have to be constructed to eliminate open defecation. The country needs at least $ 1 billion spending on sanitation to meet the MDG target and even if the target is met there will be 48% of rural and 34% urban population without sanitation (SWA).

Incorporation of sanitation services with agricultural development is slowly beginning with two agriculture funded sanitation projects in rural Niger and Burkina Faso. The projects have introduced urine diversion toilets (UDTs) and sanitized urine and feces are used as fertilizers for enhancing local nutrient management, food security and health (Dagerskog and Bonzi, 2010). The villagers were given a subsidy of US$ 180 for constructing a UDT and are happy using UDTs and recycling nutrients to agriculture. The estimated cost for providing UDT to 9.7 million ODs comes out to be $2 billion. The fertilizer economic value is $74.4 million. It seems that UDTs in Burkina Faso pay back the cost during their life time, around 20 years (Table 5.2). If one UDT per provided for every 5 persons, the payback period would be reduced to 4 years.

5.6.2 Food security

In Burkina Faso, a deficit of 154,462 tons of cereal production has been reported representing a 19.6% decrease compared to the last agricultural season (OCHA, 2012). The government has declared 2,800,000 people at risk of food insecurity in 2012. And there are estimates that more than 100,000 children under-five will suffer from severe acute malnutrition. Average dietary intake (2,647 kcal/d) is higher than the average dietary requirement (2,196 kcal/p.d). However, approximately 26% of the population is undernourished (FAOSTAT, 2012).

5.6.3 Agriculture

Heavy subsidy in fertilizers started since 2000 under Malawi StarterPack 1998 (untargeted) and then under Sasakawa Global since 2008 (FAO, 2012). The first phase was free fertilizer in small quantities (physical distribution), the second phase was targeted and covered more than 50% of price subsidy in the form of vouchers and the third phase (since 2008) has subsidies less than or equal to 50% (FAO, 2012). Subsidy enhanced production in Burkina Faso with 1227 ka/ha cotton produced (12% increase) during the subsidy period from 1097 kg/ha during pre subsidy period (FAOSTAT). There is huge potential for production increase with UDT nutrient recovery and people from Burkina Faso can realize an estimated cereal growth increase of about 77 kg/y. This would greatly help increase food security of the country.

5.7 Malawi

Malawi is one of the poorest countries in the world with a per capita GDP of $340. It has a population of 15 million and approximately 90% percent of households are farming households (WB, 2006). The average per capita arable land holding is 0.25 ha (WB, 2011). Poverty reduction programs have not been very successful and the Human Development Index (HDI) has stagnated since the mid1990s (WB, 2006).

5.7.1 Water and sanitation

Eighty three percent of the people get water from improved sources and more than 51% people have access to improved sanitation facilities. Approximately 33% of the people share toilets, and unimproved sanitations and open defecation share 8% each (JMP UNICEF/WHO, 2012). Sanitation is not on track to meet MDG target of 87% by a large margin of 36%. Malawi is one of the 6 countries with HDI of achieving significant progress (20%) on providing improved sanitation in contrast to an average of 12% growth in Sub Saharan Africa (JMP UNICEF/WHO, 2012). Urbanization is very rapid with 7.9% growth from 1980-2000 (Manda, 2009) and urban water and sanitation facilities are stressed. The average investment on watsan sector was 0.46% of GDP in 2008, 0.69% on 2009 (WaterAid, 2011) and around 1.15% in 2012 (WSP, 2012).

5.7.2 Food security

The dietary energy supply (DES) in Malawi (2,318 kcal/d) is higher than the average dietary energy requirement (2124 kcal/d) (FAOSTAT, 2012). However, around 35 percent of Malawians consume insufficient amount of calories, with significant disparities between urban and rural dwellers (WB, 2006). Chronic malnutrition is endemic and approximately 23% people are undernourished (FAOSTAT, 2012). Food import is three times larger than exports.

5.7.3 Agriculture

Average agricultural production (yield) in Malawi is 2.21 t/ha (Table 5.2). In order to boost agricultural production, fertilizers are heavily subsidized. With the introduction of StarterPack (1998) program, families got 100% (universal or untargeted) subsidies on 0.1 ha. An additional 1.5 metric tons of produce per hectare was expected with an investment of $75/household ($15-20/person) under 5- years of Sasakawa Global, 2000 (Denning et al., 2006).

Other subsidy programs like TIP (Targeted Input Programme) started in 2003-04 and, AISP (Agricultural Input Subsidy Programme) started in 2005 also subsidize fertilizers. AISP targeted poor farmers and the subsidy ranged from 64-91% on 1 acre or for 2 bags (FAO-Druilhe) covering 1.5 million beneficiaries or 65% of farm households. The objectives of the Malawian schemes evolved from social protection for vulnerable households with the first program (Starter Pack), to kick-starting agricultural production with the second (Targeted Input Program), to national food production and self-sufficiency objectives in the third and so far final phase (AISP). The total program costs grew continuously from 2005 to 2008 from over 60% of the national agricultural budget in 2005 to 74% in 2008 (the peak) representing 2.1% and 6.6% of GDP, respectively (Dorward and Chirwa, 2011). The AISP had very positive impacts on input use, agricultural output and national food security. From the time of subsidy (AISP, 2005 on) the yield in Malawi increased to 1,853 kg/ha (post-subsidy period) from 1,331 kg/ha (pre-subsidy period), a 24% increase compared to production in other countries in Africa with similar geophysical conditions but without subsidies where growth was only 4% from 1243 kg/ha to 1299 kg/ha. The estimated cereal production increase due to nutrient recycling from human waste is approximately 55 kg/y (Table 5.2).

5.8 Conclusion

Agricultural production/yield increases are vital to poverty reduction. The fertility of agricultural land in most of the developing countries is decreasing and increased use of fertilizer has shown to substantially increase production. Because inorganic fertilizers are expensive, rural poor cannot afford to purchase these mineral fertilizers, and production is compromised. And subsidy is not always good in terms of sustainability because it makes people dependent and can have several negative consequences like over application and misuse. A mechanism should be developed to safely reuse and recycle locally produced organic and nutrient wastes not only to increase production but also to improve environmental and public health. Recycling/reuse of domestic wastewater/human excreta in agriculture, thus, can be one of the sustainable alternatives of soil fertility increase.

Projections show that 3.5 billion (48%) of the world population will live in river basins considered to be water stressed by 2025. The use of domestic wastewater in agriculture is getting increasing attention from scientists, policy makers and the general public. The main drivers for wastewater irrigation are global water scarcity, increased agricultural production from nutrients in wastewater and environmental protection (Hamilton et al. 2007). However, human excreta (urine and feces) use has not been widely considered. UDT systems are slowly becoming established all over the world and people have started recycling treated human waste in crops in certain communities/geographical regions. The sanitation coverage will grow fast if it could be made a part of government poverty reduction agendas and integrated into poverty reduction and environmental sustainability programs. Simultaneous intervention on sanitation and fertility management (food production) will also reduce program implementation cost. Calculations show that the cost of UDT system can be recovered in around 20 years only by considering the nutrient value in excreta. If other intangible benefits (like reduction in morbidity and mortality, and time savings due to improved services) were considered, the cost of installing UDT can be recovered well within the acceptable life time of sanitation systems (Table 5.2).

The average dietary intake in developing countries is in continuous rise and is directed towards more meat and milk product based diets and away from vegetable based diets. The nutrient excretion, especially nitrogen (N), will also increase subsequently increasing the value of the nutrients in human excrement. This will reduce the payback period to within the lifetime of the toilet system (within 20-25 years), UDT in this case. For example, average dietary intake (DES) and also protein intake in countries like Burundi, Congo and India is very low compared to other countries (Table 5.1) which makes the payback period very long (Table 2).

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CHAPTER 6. ANALYSIS OF PUBLIC AND ENVIRONMENTAL HEALTH VULNERABILITY ISSUES DUE TO POOR WATER AND SANITATION SERVICES IN KATHMANDU BASED ON DPSIR MODEL

Abstract

Kathmandu valley is experiencing various environmental problems. The most serious are inadequate and poor quality water supply, air pollution, raw wastewater disposal to rivers, squatter settlements, and haphazard solid waste disposal. With rapidly growing water use due to population growth and subsequent (untreated) wastewater disposal, both surface as well as ground water sources in the city are heavily polluted and are likely to deteriorate further as there seems to be no effective plans from the government to address the issue of wastewater management for the foreseeable future. It is necessary and important to have studies which identify major causes and their share of water pollution to help formulate appropriate policies and effective mitigation programs. A few studies mainly focused on measuring the quality of surface and ground water sources and sanitation coverage in the valley have already been completed. These existing studies mostly conclude that domestic wastewater is one of the main causes of water pollution in the valley but do not quantify the share of various pollution sources.

This research delves into the causes of water pollution (and their share), compares alternatives of wastewater management and proposes a best alternative to alleviate the pollution load to water (river) systems of Kathmandu Valley. For this purpose, the history of urban development processes, land use change and population growth and urbanization and their effects on water resources (river systems and ground water) will be briefly discussed first. Second, the major environmental problems facing Kathmandu valley will be described. Third, the focus will be narrowed to identify problems associated with water resources (mainly the causes of water pollution) and the history of sanitation/wastewater management practices and behavioral changes over time. Fourth, different scenarios to address those issues/problems will be developed. Fifth, the factors

affecting/hindering implementation of the mitigation measures will be identified and the costs involved will be discussed. Alternatives for wastewater management systems are compared based on social, cultural, religious practices and economic status of people, knowledge, technology, and infrastructure available and the trend of urbanization and associated vulnerabilities.

For this purpose, the nature of stressors have been identified and causal links among various activities have been established starting from driving forces, D (social, political, and economic activities); pressures, P (emissions); states, S (physical, chemical and biological); impacts, I (river water quality, ecosystems, public and environmental health); and responses, R (policies, laws and regulations, prioritization, target settings). Widely known as DPSIR framework, it demands integrated assessment of environmental pollution. The trend of population growth and urbanization and subsequent pressure on water resources mainly on drinking water supply and wastewater management services are the main focus area of discussion of this paper. The future direction for the development of sustainable management of wastewater is also proposed.

6.1 Introduction

A bowl-shaped Kathmandu valley, once a fertile land is now the major economic and political hub of Nepal. The valley makes up an area of about 665 square kilometers (km^2) that includes five municipalities (Kathmandu metro, Lalitpur Sub-metro, Bhaktapur, Kirtipur and Thimi) from three districts Kathmandu, Lalitpur and Bhaktapur (ICIMOD/UNEP/NP, 2007). The main three cities Kathmandu Metro, Lalitpur Sub-Metro, and Bhaktpur Municipal form the core urban area of the valley. The valley is facing severe socio economic and environmental problems like many other cities in the developing world. High population growth rate coupled with unplanned development/urbanization has exerted huge pressure on natural resources. Open spaces in the valley are disappearing quickly and agricultural lands are rapidly turning in to built-up areas. The environmental quality of the valley is very poor and people lack even basic amenities like potable drinking water and safe sanitation facilities. Ambient air total suspended particulates (TSPs) concentrations regularly exceed World Health Organization (WHO) guidelines (Giri et al., 2006). Drinking water sources routinely exceed WHO guideline values on BOD, nutrients and microbiological parameters (Warner et al., 2008; Prasai et al., 2007). River systems of the valley are so polluted that most parts of the rivers in the city core are biologically ‘dead’ (Tachamo et al., 2009; KAPRIMO, 2007; ICIMOD, 2005). These same rivers are the major source of drinking water in the valley. There is an urgent need to act immediately to mitigate/alleviate pollution load and restore life in surface water bodies including Bagmati River for them to be able to perform their natural, religious, cultural and other functions. No change in water quality can be expected without investments in infrastructure and changes in wastewater management practices, which are slow in coming due to the lack of institutional awareness of the complexity of the problem. Interaction and cooperation amongst various stakeholders to influence waste disposal practices and reuse of wastewater is imperative for the effective implementation of remedial programs and to restore life in the rivers.

The Bagmati River system is extremely polluted and remedial measures are urgent. In order to tackle the serious pollution problems facing the valley, a strategy of integrated environmental assessment is a must. A DPSIR framework has been established to develop a strategy for integrated environmental assessment (Figure 23).

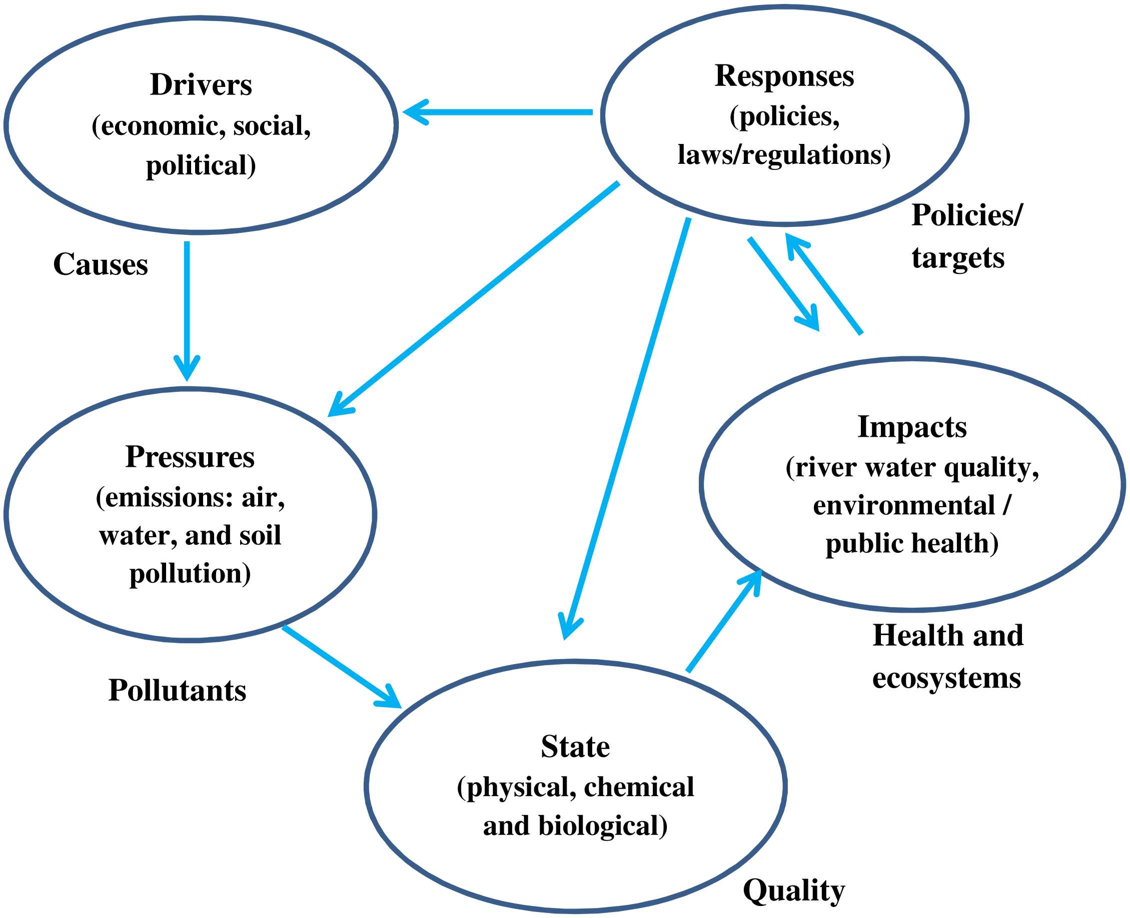

Figure 23: DPSIR assessment framework for Bagmati River system

The following paragraphs identify the drivers (D), environmental pressures (P), state of the environment (S), impacts on human and public health (I) and responses from the government (R) (and also from communities). The main pressure (P) (waste, emissions) is due to population explosion (and rapid urbanization) in the valley and the drivers (D) being bounty of social, economic, political, education, employment, health (prevention and cure) related opportunities concentrated in the valley.

6.2 Problem identification

The environmental health of the Kathmandu valley is so bad that comfort and well-being of the people are compromised in many respects. Many factors contribute to this poor environmental quality. Well planned and coordinated remedial measures are needed to tackle severe environmental problems facing the valley. The major contributors of water pollution in the valley are: rapid population growth, water supply system not meeting demand, inadequate management of city expansion (haphazard growth), infrastructure development not paced with population growth, poor solid waste management/disposal practices, squatter settlements (and associated environmental problems including open defecation), insufficient/inefficient wastewater treatment facilities, discharges not regulated, excessive accumulation of pollutants in the rivers (especially during dry months due to low flow) and imprudent use of agrochemicals including fertilizers.

6.3 Driving forces (D)

As mentioned above, opportunities for employment and also educational institutions are concentrated in Kathmandu. The centralized nature of administrative structure and fragile security situation in other parts of Nepal are also some of the reasons that force people to migrate to city centers.

6.4 Pressures (P)

Rapid Population growth and urbanization are the main agents for deteriorating environmental quality though land use change, change in life style and eating habits also contribute to deterioration of the environment. The per capita emission release (waste production like wastewater, solid waste, and green house gas) in urban areas is much higher than per capita emission in rural areas as per capita resources use (like water, energy, food) in urban centers is much higher than people use in rural areas.

6.4.1 Population growth

Out of total area of 656 km^2 of the valley, the urban Kathmandu that comprises 5 cities (Kathmandu Metro, Lalitpur Sub-Metro, Bhaktapur, Kirtipur and Thimi Municipals) cover an area of 97 km^2 (UNEP) up from 82.53 km^2 in 2006 (Khadka and Shrestha, 2008; ICIMOD, 2007). Kathmandu valley has experienced a high population growth rate (>4%) for many years (CBS 2011) and saw a 500% increase of its population from 1955 to 2008

(Bhattarai and Conway, 2010). The recent census (CBS, 2011) revealed that Kathmandu Valley has witnessed the highest population growth rate (>5.5% per annum) in the country and the population of about 1.6 million in 2001 (CBS, 2003) has increased to about 2.51 million (Figure 24) in 2011(CBS, 2011).

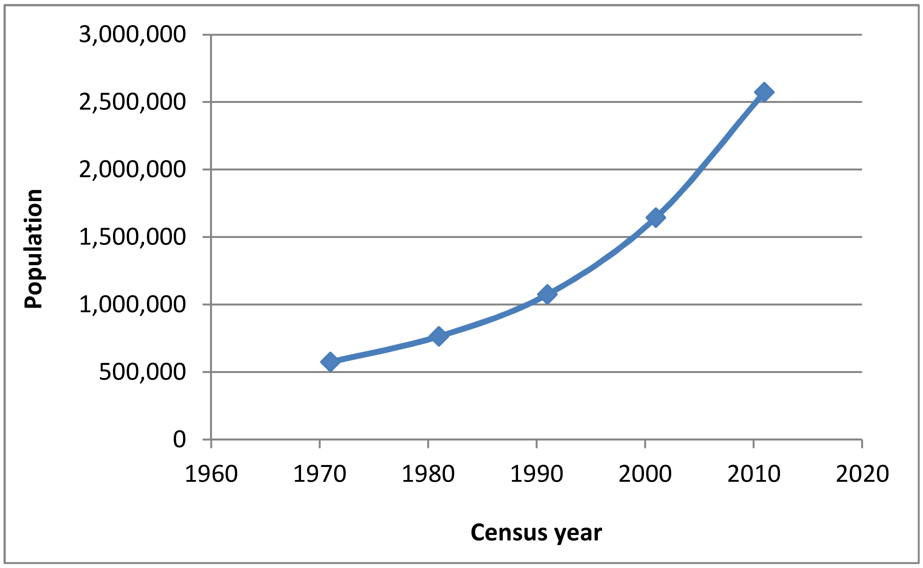

Figure 24: Population growth trend of Kathmandu Valley

The urban population of about 1 million in 2001 increased to about 1.6 million in 2011 (CBS, 2011).The population density of the valley which was 1,830 persons per square kilometers (p/ km^2) in 2001 is now 2,781 p/ km^2 (Figure 25). Because of poor planning and management and the high cost of land, construction of small-sized and substandard housings is common.

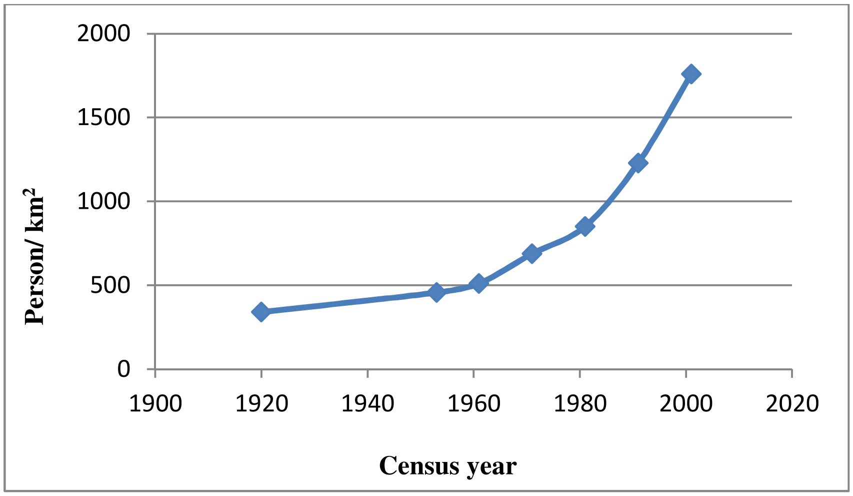

Figure 25: Population density of the Kathmandu Valley

The Kathmandu Metro with an area of 48.29 km^2 in 2006 grew to 50.67 km^2 in 2011 (KMC, 2011). The population of about 672,000 of the metro city in 2001 increased to more than 1 million in 2011 (CBS, 2011). There is a sharp increase in density from the valley boundary towards urban core of the valley (Figure 26). The population density of the urban area is around 10,200/km^2 whereas the density in the Kathmandu Metro core is around 21,000/km^2. There still exist many traditional houses in the urban core that are like urban slums with poor light and ventilation, dampness, and without adequate wastewater management and solid waste disposal services (Shrestha, 2010). One-third of the population of Kathmandu Valley lives in slum dwellings (PDC, 2005) and the slum type development is increasing in the last 10 years (KMC- EMI, 2010). It is difficult, if not impossible, to install/upgrade services like sewer lines and road accesses in such densely packed areas.

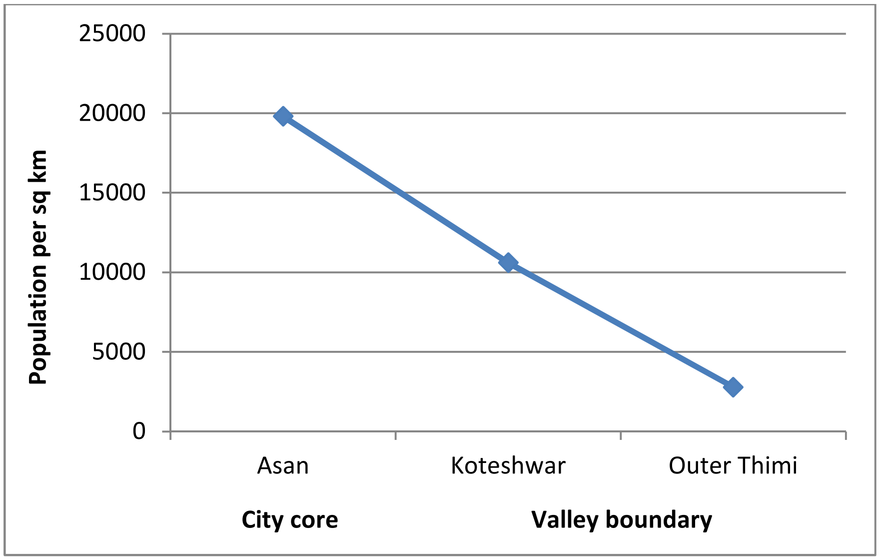

Figure 26: Kathmandu Valley population density profile

6.4.2 Inadequate management of city expansion and infrastructure development not paced with population growth

The fast and continuous but unplanned urban sprawl of Kathmandu Valley is exerting huge pressure on natural resources especially to fertile agricultural land, forest areas, air and water resources. The urban area of the valley has witnessed an area increase of 7% over the period 1984 and 1990 (Halcrow Fox and Associates, 1991) and concomitant to this urban sprawl, agricultural area decreased by about the same amount (IUCN, 1995). The influx of immigrants is continuous. The proportion of migrant population was only about 6% in between 1961-1971 but grew to about 42% in between 1971-1981 and to over 64% in between 1981 and 1991 (MOPE, 1999). Migration to the valley was exacerbated further in the past decade (1995-2005) because of armed conflict. Total built up area of the valley had grown up to 134% during that period (1989- 2006) (Bhandari, 2010). Between 1984 and 2000, the proportion agricultural land in the valley decreased from 62% to 42% and if this trend continues there will be no agricultural fields left in the valley by 2025 (ICIMOD, 2007). Because of rapid population growth, the demand for housing, physical infrastructure and utilities (like road, electricity, water supply, sewerage systems and others) has increased exponentially. The government has neither been able to manage the large influx of people nor been able to respond to the demands for infrastructure development and city expansion.

6.5 The state of environment (S) and impacts (I)

The impact of poor water and sanitation hygiene has been very high in Nepal in terms of environmental and public health. The rivers in the valley are 'dead' and cannot perform environmental functions. Approximately 14,000 deaths are attributed to diarrheal diseases annually. Approximately 63,300 deaths are caused by poor environmental conditions (WHO, 2009) and cost 71 years of DALYs per thousand people. The negative correlation of water and sanitation facilities and incidence of diarrhea and water and sanitation facilities complement each other. In a study on Nepal, Aryal et al. (2012) reported just drinking water from improved sources does not necessarily reduce diarrheal incidence (204.89 cases per thousand) compared to people using toilets and improved drinking water sources (46.05 cases per thousand).

6.5.1 Urban vulnerability

The rules and regulations for constructing houses are more liberal in rural areas compared to urban areas. The land is also very expensive in areas closer to urban areas (Adhikary, 1998), and most of the time not affordable to people with average income and to the majority of migrants. People are reluctant to go for the cheap alternative of buying plots in the hinterlands (mostly raw agricultural land) with no provision of basic infrastructures and construct substandard housings (Bhattarai and Conway, 2009). More than 4,000 buildings are constructed every year in the valley; most of them without any knowledge of engineering (UNEP, 2007). Kathmandu Valley Town Development Plan (KVTDC), under the Local Self-governance Act (LSGA, 1999) has fixed the minimum size of the plot as 80 square meter (m^2), and a frontage of 6 m. Irrespective of these guidelines houses are built on plot sizes of 15-45 m^2 (Bhattarai and Conway, 2009) even without the provision for road access and sewage outlets and three to four people share a room of 12-15 m^2. According to New York State Legislature Tenement Housing Act of 1867, every sleeping room should be connected to outside air or if not should have a 3 foot square window and should have a toilet connected to an approved disposal systems (cited from

Claghorn, 1901). Many housing units in Kathmandu do not even meet these century old standards of New York.

People are more vulnerable to disasters as rescue operations in such settings are difficult. The haphazard urban sprawls exert more pressure to the environment than does planned growth. This type of urban development makes infrastructure service provision (like sewer services) very difficult and expensive, if not impossible. Local governments lack the financial and technical capabilities to address these demands for basic services. Some of the most prominent and visible environmental consequences of the unplanned urbanization are release of raw sewage to street drains and nearby rivers/streams, increased and random dumping of solid waste, and squatting on open spaces and river banks. In order to discourage the haphazard construction of substandard single family homes in small plots and without basic amenities, the national government has to introduce and enforce laws and codes that encourage construction of multi storied apartment buildings affordable to middle class people. This vertical expansion of urban areas would minimize horizontal expansion of built-up areas and help conserve open spaces and fertile agricultural lands from further encroachment.

6.5.2 Inadequate and poor quality water supply

Kathmandu Valley has been suffering a shortage of drinking water since the 1980s, and the situation is getting worse day by day. The water supply system in the valley is intermittent and with limited quantity. People in most of the areas hardly get 1 hour of supply every fourth day (KUKL, 2011). Yoden and Chettry (2010) reported that only 67% of the urban houses in the KUKL service areas were connected to the supply network as of 2009. Brown and Watkins (1994) reported that almost 20% of the population of the valley relied on stone spouts during much of their year, which are prone to contamination. Water quality enforcement and surveillance mechanisms are not well developed in Nepal and this is the case for water supply systems in Kathmandu Valley. Water quality testing, monitoring and control of physical, chemical and microbiological parameters and immediate response from the service provider (for instance KUKL in Kathmandu) to curb the pollution/contamination seems to be a distant dream. Several studies including studies by the water utility company itself (KUKL, 2008) have reported the poor quality of water in the valley.

Surface water has been the main source of drinking water for the valley population for decades. The river Bagmati, and its tributaries Bishnumati and Manohara are the main source of water for meeting drinking, irrigation and industrial water demands. During the 1980s, Bagmati River used to meet about 92% of the drinking water demand in wet months and 60% in the dry months (CBS, 1998). Due to rapid population growth and urbanization, the demand of water increased tremendously and surface water sources have no longer been able to meet the demand of water even for drinking purposes. Several conflicts/competitions over water use among various water users (mainly drinking water service providers, farmers and industries) have been reported (Sada, 2010).

The valley's total water demand is 320 MLD to serve an estimated 2.51 million people within its service area. Only 100 MLD in dry season and 155 MLD in the wet season is met by surface water sources (KUKL, 2011; KVWSMB, 2010). KUKL is producing only 88.8 MLD (32% by ground water and 67% by surface) in the dry season and 118.4 MLD (29% by ground water and 71% by surface water) in the wet season (Subedi, 2010). Moreover, the leakage loss of over 40% of water in Kathmandu water supply system (ADB, 2006) is making the situation even worse. The demand gap is met mostly by unregulated pumping of ground water sources (shallow and deep) by industries (hotels etc.) and private vendors. Due to lack of strong institutional, regulatory, enforcement, and monitoring mechanisms, ground water is severely abused. The ground water withdrawal of about 7 MLD before 1980 rose to 46 MLD during 1980-1990, 58 MLD in 1999 and to more than 70 MLD as of 2009 and is expected to increase further. There are no records on exact number, location, and capacity of pumping wells (except for KUKL), or the amount of GW withdrawal. GW extraction exceeds about 6 times the natural recharge rate and as a result, the ground water table is lowered by approximately 2.5 meters per year (MPPW, 2002). KVWSMB (2010) has also reported that the static ground water level in some areas has gone down by 30 meters. Various studies report that the ground water reserve would be emptied in less than 100 years if the rate of withdrawal continues at the same rate as in 2001 (i.e. 21.56 Million m3/year equivalent to 59 MLD) (Pandey and Kazama, 2009; Cresswell et al. 2001). The current rate of withdrawal is more than 71 MLD (KVWSDB, 2010 dhakal), much more than 2001 withdrawal rate decreasing the estimated time to complete depletion. The KUKL has tapped all possible sources of surface water (rivers/streams) and the flow in the river is only the sewerage (KVWSDB, 2010).

ADB (2012) estimated that around 80% of the Bagmati River flow is diverted for domestic use during dry season leaving very little flow for irrigation and other sectors including environmental. To tackle the water shortage in the valley, the Melamchi Water Supply Project (MWSP) was conceived more than 20 years ago (first proposed in 1988 and full feasibility study completed in 1992). Melamchi Water Supply Development Board (MWSDB) was constituted to handle the project which aims for an inter-basin transfer of 510 MLD water in three phases from rivers located about 40 km north-east of Kathmandu. Each phase plans to bring about 170 MLD of water in the valley from Melamchi, Yangri and Larke rivers (MWSDB, 1998). The construction of project components of MWSDP is not proceeding smoothly and is already delayed by many years. At the beginning it was expected to complete the project by September 2006 but the completion deadline was revised later on. To bring in 170 MLD water in the valley in the first phase by 2008/09 was also not met due to various reasons. Another completion deadline of June 2013 (MWSP online) was also shattered when the contract was terminated again in October 2012. The government has set new completion dead line of March 2016 but people of Kathmandu do not believe that the project will be completed within the re-scheduled date as claimed by the government. Even if construction went as planned the water demand of the valley would be already 390 MLD by the time first phase of Melamchi project (170 MLD) would be completed (ADB, 2004).

6.5.3 Surface water quality deterioration

The Bagmati river was in potable condition in the 1970s (Erlend, 2002) but is severely polluted presently. The Bagmati River is considered sacred and serves many religious and cultural functions but these functions are severely impaired. In addition to reduced river flows, the quality of water also deteriorated and is continuously deteriorating. The primary river functions are thus shifting towards managing waste and wastewater. Pollution levels increase as the rivers flow down from the source to the city core. The main cause for the deteriorating water quality of the valley's rivers are the discharge of untreated domestic and industrial sewage, septic tank failures, leaching from landfill sites, pit latrines and open defecation. Though perennial, Bagmati, Bishnumati and Manohara rivers, the main river systems of the valley, do not originate from glacier or Himalayas and thus the flows fluctuate according to seasonal rains.

The quality of water sources (both surface and ground water) is not satisfactory as they do not meet WHO water quality guideline values for E-coli, BOD/COD, ammonia nitrogen and other parameters. The river water fails the test for all three water quality classifications to be a source of drinking water: Bacterial Water Quality (BWQ) (Kannel et al., 2007), Chemical Water Quality (CWQ), and Saprobic Water Quality Classification (ICIMOD, 2007). ENPHO (2009) and Pradhan et al. (2005) reported the presence of *E-coli* in nearly all sources crossing the limit set for drinking water sources.
The water quality of rivers near the source is still good (DO >7.5 mg/L, BOD <4 mg/l) (KAPRIMO, 2007) but quality deteriorates very quickly as the rivers flow downstream through the city core. People inhabit the source area of these rivers and open defecation is still prevalent: MWSP (2000) reported *Coliform* counts of 10 per ml at Sundarijal (near the source) and 1000 per ml at Khokna downstream after the city core. Many direct untreated sewage disposal outlets to Bagmati and other rivers can be easily observed (ICIMOD, 2005). The same is the case for Bishnumati river regarding untreated sewage and solid waste dumping. Manohara Khola is relatively better in terms of solidwaste dumping but direct sewage discharge is also a common phenomenon (KVEO, 2007; ICIMOD, 2005).

The water quality parameters of the Bagmati River change significantly according to climatic conditions. The seasonal variation in water quality parameters (like BOD, COD, DO, TSS, NH4, *E-coli*) is very prominent in Nepalese rivers, especially those flowing through urban centers. BOD as high as 250 mg/l and COD as high as 625 have been reported at low flow conditions (Jan-May) in the river stretch closest to the main city core (KPRIMO, 2007). The average BOD and COD concentration at the city core seldom go below 40 mg/l and 80 mg/l, respectively even during monsoon season (after first couple of flushes and in high flow situations in between July-Sept and remains low only for a couple of days) but BOD and COD remain above 150 mg/l and 275 mg/l, respectively for most of the year during low flow conditions. Figure 27 elucidates the average BOD profile of the Bagmati River (reproduced from NTNC, 2008) clearly indicating the high level of pollution throughout its length in the valley.

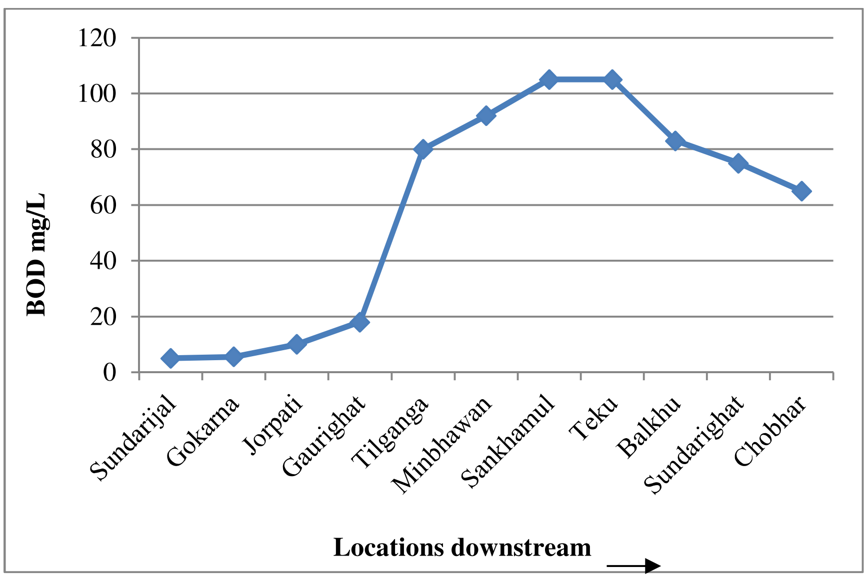

Figure 27: BOD profile along the Bagmati River (the river flows through highly dense urban areas starting from Gaurighat to Sundarighat approximately 15 km river stretch) during medium flow conditions

Most of the rainfall events (more than 60-80% of the rain) occur during four months (June-September) during which rivers get swollen and wash away the accumulated pollution load. When the flow rate decreases (low rain months), the rivers of the valley turn into filthy sewers with a pungent smell. The natural purification of the rivers is also hindered along the city core because of flat topography. For instance, the gradient of

128.6m/km (12.86%) in Shivapuri (near the source) of Bagmati River comes down to 0.27% (Shah-Newaz and Magumdar, 2011) within the 15 km stretch in the valley drastically reducing the turbulence and subsequent reoxygenation capacity of the river.

The discharge of untreated sewage from the urban areas of Kathmandu is the main source of organics in the river (KUKL/ADB, 2011). Paudel et al. (1995) estimated that 42 metric tons (MT) BOD_5 generated in the valley was discharged to Bagmati River daily. The Bagmati River could drain only 40% of the BOD_5 and 60% is retained in the valley (mostly on river bed) and is a major source of water pollution. Discharge records for the last 25 years (1975-1999) at Sundarijal station revealed an overall decreasing trend in water discharge (DHM, 1999) of the river. Sharma and Shakya (2005) also reported changing patterns in magnitude, frequency and duration of floods and reduced flow (water volume) of Bagmati River. The river has not been able to wash away the waste it receives during most part of the year due to ever increasing waste load and decreased flow.

6.5.4 Ground water quality deterioration

Similar to surface water, the quality of ground water of the valley is also deteriorating. The main causes of the contamination are leaking sewers (Brunke and Gonser 1997; Santos et al. 2002), septic tank failures, pit latrines (Jha et al. 1997), and leaching from landfills and contaminated rivers (Khadka 1993; Karn and Harada 2001, Pathak et al., 2011). Diwakar et al. (2008) reported that 82.76% of water samples from Bhaktapur municipality (ground water is the main source of drinking water in Bhaktapur) were positive in *total coliform* bacteria tests. They also found increasing incidence and prevalence of water-borne diseases such as typhoid and intestinal worms. Chapagain and Kazama (2009) reported that most of the samples exceed WHO guideline values for drinking water for $NH4^{+}N$, Fe, Pb, and Cd. In another study (N = 87) WHO recommended values for bacteriological quality were far exceeded by 92% of the samples and all samples exceeded recommended values for electrical conductivity and turbidity (Pant, 2011; Keiles, S., 2011). Tanaka et al. (2012) reported that in addition to fecal microbes all ground water samples tested (N=6) contained opportunistic microbes of genus *Acinetobacter*. They further reported that two of the samples contained multi-drug resistant *Acinetobacter* that are currently spreading in the world. Nitrate was common in samples from shallow aquifers (Andrew 2000; BGS, 2001). Several other studies such as JICA (1990), JICA/ENPHO (2005), Warner et al. (2008), Sakamoto et al. (2009) also reported that almost all waters from rivers and wells were not suitable for using as drinking water source.

6.6 Inadequate wastewater treatment

A large volume of wastewater is generated in the valley due to rapid population growth and urbanization. One of the major consequences of rapid population growth is the pollution of the river system due to production and discharge of untreated domestic and industrial wastewater. As a result, not only the river ecosystem has been degraded, displacing or diminishing its aquatic organisms, but also the health condition of the general public and overall urban environment quality have been affected.

Metcalf and Eddy/CEMAT (2000) reported that 62 million liter per day (MLD) of WW was generated in 2000. Darnal (2002) reported the volume as 120 MLD in 2002. The recent estimate of WW generation in the valley is 176 MLD (KUKL, 2011). The average water consumption in the valley is 73 liters per person per day (lpcd) (NGO Forum, 2003). Approximately 58 lpcd of WW (assuming 80% of drinking water supplied) is generated in the valley and this estimate is similar to the value (60 lpcd) estimated by KVEO (ICIMOD, 2007). The KUKL (2011) estimate of 176 MLD of WW in the valley seems a bit in the higher end for per capita drinking water supply of 73 lpcd. Calculations and estimates for the BOD budget herein will be based on 58 lpcd of WW generation (73 lpcd of water supply) generating approximately 156 MLD of wastewater (includes industrial contribution of 7%) produced by 2.51 million valley dwellers.

Various sanitation systems (wastewater management technologies) exist in the valley from open defecation (OD) and pit latrines to modern networked systems with wastewater treatment plants (WWTPs). A majority of the people use pour flush latrines connected either to septic tanks or a sewer line. Ecological sanitation in urine diverting

(UD) mode has recently been introduced in peri-urban areas on a pilot project basis. Irrespective of the sanitation system employed, wastewaters from houses mostly end up in nearby rivers and streams without proper treatment. Most of these sewer lines end up in the Kathmandu Valley's river system and a very small proportion of wastewater generated in the valley gets treated. HPCIDBC (2011) estimated that approximately 70% of the households dispose their wastewater directly into the sewer line while 30% of the households use on-site systems.

6.6.1 Onsite sanitation

Pit latrines and pour flush latrines connected to septic tanks are most popular on-site sanitation systems in the valley. The squatter population mostly defecates in open and in river banks. On-site systems both low-cost options like various forms of pit latrine (PL) and high-cost options like septic tanks (ST) provide a similar level of service to sewerage (Howard et al., 2002). Onsite/decentralized wastewater treatment systems could protect the public health and environment and could lower capital and maintenance costs in low density developments, and provide long term manageable solutions (US EPA, 2002). However leachate from PL is one of the major sources of water pollution in developing countries (WHO, 2002; Howard et al., 2002). There are estimates that 4% people use pit latrines, and 1% defecate in open. The water can easily pass in and out of the unlined pits causing pits to fill up earlier than expected. This phenomenon is common in places with high ground water table and during monsoon season (Chaggu, 2004). Sludge from PLs does not get completely stabilized and still has the potential to contribute BOD/COD and bacteria/pathogens (Mgana, 2003).

Estimates of number of STs and the population served in the valley vary ranging from 21% of the valleys' population (~527,100 people) (HPCIDBC, 2006) to 40% of the urban population (~640,000 people) (Rutkowski et al., 2007). According to HPCIDBC (2006) there are about 68,000-77,000 STs in the valley that generate approximately 76,600 m3 of septage annually. Many STs are not associated with soak pits and treatment is compromised. The new policy endorsed by Kathmnadu Valley Town Development Committee made it mandatory from May 2007 to have a soak pit associated with a ST for any new house to be built (KVTDC, 2007). However, because of the weak institutional set-up and monitoring and evaluation programs, STs are being built without soak pits or not meeting prescribed standards. As on-site sanitation systems in Kathmandu (pit latrines and septic tanks) are not designed properly and have not been able to protect water sources from pollution, appropriate improvement/design modifications are warranted for the safe management of wastewater.

6.6.2 Central sewer systems and wastewater treatment plants

People in the valley prefer central sewer systems but are practicing on-site systems because sewer line either does not exist in the area or connection to sewer line is technically not feasible (HPCIDBC, 2006). Wastewater even from households in urban areas that are connected to networked sewer systems is discharged in to rivers either directly or indirectly via septic tanks. All wastewater treatment plants (WWTPs) if rehabilitated to their full capacity can offer service equivalent to only 170,000 people (ADB, 2006). The history of modern sewage collection and treatment systems in Nepal dates back to 1978 when World Bank funded Kodku and Dhobighat wastewater treatment plants (WWTPs) were completed. As of today, there are five centrally controlled WWTPs of simple lagoon and oxidation ditch types in the Kathmandu Valley: Guheshwori (17.3 MLD), Kodku (1.1 MLD), Dhobighat (15.4 MLD), Sallaghari (2 MLD), and Hanumanghat (0.5 MLD) WWTP. However, they have not been effective in treating wastewaters. Of the five WWTPS, only Guheshwori WWTP is working smoothly in its full capacity (Arata, 2003; Green et al., 2003; Poh, 2003; WaterAid, 2008). Lack of financial capability, poor operation and maintenance (O&M), and lack of expertise are cited as the main reasons for the failure of centralized WWTPs (Poh, 2003; Green et al., 2003; WaterAid, 2008; WASH, 2011). Figure 28 below shows the location of WWTPs in the valley.

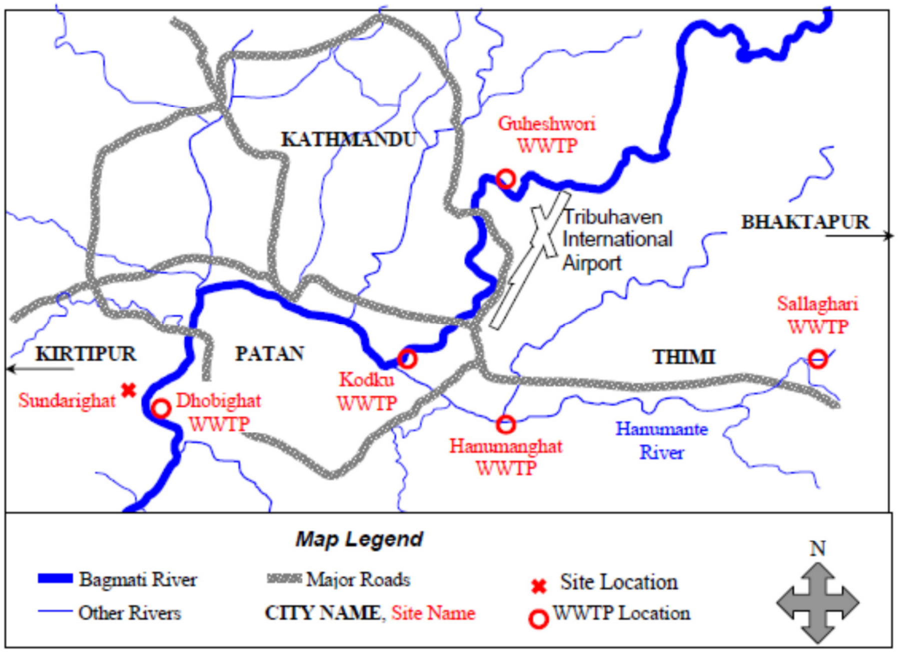

Figure 28: Location of wastewater treatment plants in urban Kathmandu (Source: ADB, 2000)

6.6.3 Poor performance of wastewater treatment plants

Networked sewer systems offer best services if operated appropriately. Centralized WWTPs are capital intensive (Grau, 1995; Montgomery, 2007), need uninterrupted power supply, produce green house gases concomitant to the quantity of energy use (Bruch et al., 2011; Kivaisi, 2001; Korkusuz et al., 2004; Singh et al., 2009). Rapidly growing, unplanned peri-urban areas are also not effectively served by centralized systems (Langergraber and Muellegger 2005). For a large number of communities modern sewerage systems are neither feasible nor desirable particularly in communities where large quantities of water for flushing are not available (Bolt, 2000). Requirement for a constant energy supply for networked sewers and WWTPs can also be one of the major problems in countries like Nepal as electricity supply is never regular. Moreover, central sewer systems with WWTPs are also not feasible in places where laying and maintenance of sewer pipes is not possible due to narrow roads and congested housing. The other pertinent issues are easy unavailability of spare parts and lack of trained operators to monitor the system and react to changes immediately. According to WB (2013), the track record of activated sludge plants in the developing world has been very poor as only few operate as designed or intended. The same is true for WWTPs in

Kathmandu. Moreover, adequate attentions have not been paid by the government (authorities) on monitoring and management of existing centralized treatment plants in Kathmandu Valley. Large investment in construction and major works are needed to make existing WWTPs work. Only 37 MLD of WW generated is treated and the rest ends up in the Bagmati River without any treatment (HPCIDBC, 2011).

6.6.4 Constructed wetland systems

Constructed wetland (CW) system is one of the relatively inexpensive and easy to handle wastewater management technologies applicable to poor countries like Nepal. CWs, started in 1998, are getting popular for treating wastewaters from small conglomerate in semi urban areas of the valley. According to Gurung and Oh (2012), approximately 345.5 m^3/d (~0.34 MLD) of wastewater is being treated with CWs. CWs need relatively large areas and are not feasible in core city centers in the valley due to space limitations (HPCIDBC, 2011) but can be a good options in peri-urban agglomerate where land availability would not be an issue.

6.6.5 Ecological sanitation

Networked and centralized sewer system and WWTPs in countries like Nepal are not feasible, currently if not always, because of poverty, scarce skilled personnel, expensive but discontinuous power (electricity) supply (less than 12 hours per day almost throughout the year). It will be very expensive and difficult, if not impossible, to connect houses to the central sewer system in densely packed areas of Kathmandu City core with narrow roads. Household based sanitation technologies and decentralized wastewater treatment approaches can be a viable alternative to central sewer systems in less affluent communities (Elimelech, 2006; Mintz et al., 2001; Wilderer, 2005). On-site sanitation systems currently practiced are not well designed and thus do not offer services to the extent desired. It is, therefore, necessary to adopt simple, ecologically sound, efficient and cost-effective treatment technologies that are appropriate for both affluent and poor communities and even in congested cities (densely packed housings). There is a need for developing a system of sanitation in decentralized mode appropriate for places where building sewer lines are difficult and very expensive, water supply is inadequate (not enough water for flushing toilets) and the waste can be collected and economically transferred to processing/treatment unit for nutrients and organic matters recovery. Ecological sanitation in urine diverting toilet (UDT) system can be one of the alternatives.

6.6.5.1 Urine diversion (UD) sanitation system

As the performance of central sewer systems and WWTPs has not been very positive and current practice of on-site systems are polluting the environment (poorly constructed and maintained and are liable to contaminate water bodies), on-site systems on UD mode can be the most feasible alternative. Such decentralized sanitation and reuse options (DESAR-concepts) of human waste are the only possible sustainable concepts (Otthorpohl, 2000). The on-site sanitation systems in urine diverting (UD) mode also seems to be one of the most appropriate and sustainable solution for wastewater management in places like the Kathmandu Valley with congested housings with inadequate water supply, narrow roads and with no networked sewer systems already in place.

UD toilets (UDTs) separate relatively pathogen free, nutrient rich liquid waste (urine) at the source from highly contagious fecal matters which can also be converted in to useful agricultural input (organic matter) after proper treatment. Major fraction of micropollutants including hormones, and pharmaceutical residues are also excreted in urine and they get separated in a small volume if urine is separately collected. UDTs help conserve water as volume reduction would be one of the motivating factors for users as they would try to minimize the cost for collection and final disposal. As UDTs are relatively new wastewater management technologies, careful attention must be paid to social and cultural sensitivity of the system. The nearly sterile urine can be immediately used for crop fertigation and the fecal matter can be recycled to fields as organic supplement after pathogens removal which could be achieved through die-off, desiccation, and predation by microorganisms (Langergraber and Muellegger, 2005). This separation also enables us to devise/use treatment methods tailored to the treatment needs of the waste fractions i.e. different treatment processes to urine and feces.

UDTs on small scale (pilot basis) were introduced in Nepal in 2002. Both government bodies and NGOs are involved in promoting UDTs in Nepal and as of 2011, about 2,000 UDTs have been constructed (Khatri, 2012). The interest towards UDTs is slowly growing in peri-urban Kathamndu and the motivating factors being reduced water use and fertilizer recovery. Reduced greenhouse energy consumption for collection and treatment and reduction of green house gas emissions (compared to central WWTPs), and containment of micropollutants at the source to prevent their entry into waterways would be some of the other motivational factors for adapting to urine separated systems in the future. As most of the people in Nepal are 'washers' separate provision of collecting cleansing water has to be made which makes UDTs in Nepal a bit different from UDTs in western (wipers) world.

6.6.5.2 Urine diversion dry and twin pit pour flush latrines

In Nepal, UDTs are made of twin pit type in an aim to collect fecal matters alternatively so as to give sufficient time for the fecal matter to digest. All UDTs use squatting type (Chinese style) pan. In Kathmandu, UDTs have two lined pits (most of the time raised structure) and use of water is made very minimal (only for rinsing the bowl) and wash water and urine both are collected separately. These UDTs are considered 'dry ecosan' in Nepal. The wash water is normally directed to soak pit or constructed wetland and urine is collected in a plastic container placed outside the toilet. In Terai, the low land region of Nepal, UDTs are of pour flush type and two pits made of concrete rings are provided for collecting feces and wastewater. Urine is collected in a plastic container outside the toilet.

6.6.5.3 Biogas attached latrine

The biogas attached latrine recycles human excreta, along with other types of waste such as cattle dung, to produce biogas. The biogas produced is used for cooking and lighting and the slurry is used as fertilizer after composting. Currently there are about 100,000 latrine attached biogas plants in Nepal. Almost all of these are fixed dome type plants with capacities of 4, 6, 8 or 10 m^3. A slight modification (replacing the normal pan with UD pan) can be made so that urine is separated and fecal matter along with wash water and flush water is directed to the digester for producing biogas. This concept has not been introduced yet.

6.7 Municipal solid waste management/disposal not regulated

The five municipalities in the valley generate approximately 435 tonnes per day (tpd) of municipal solid waste (MSW) of which more than 70% comes from the Kathmandu Metropolitan City alone. The final disposal sites have always been controversial as local people keep on complaining about the site and also block disposals during many occasions. The daily solid (domestic) waste generation in Kathmandu is 0.25 kg per person per day (UNESCAP, 2012). Studies have revealed that the composition of solid waste in Kathmandu is mainly organic (60-75%) followed by plastic (9%) and paper (8.5%) (Alam et al., 2008). They also reported that approximately 13.5 t of waste remains uncollected daily. Part of the uncollected waste litters the streets of Kathmandu and part of it gets washed away with the urban runoff polluting water bodies. There exist a few designated landfill sites but because of lower collection efficiency and lack of stringent legislation MSWs are also dumped in river banks. The reported leachate BOD and COD values from one of the landfill site located on a river bank ranged from 3,500 to 5,003 mg/l and 7,148 to 45,500 mg/l, respectively (NESS, 1996). These reported BOD and COD values are very high compared to values (<1,500 mg/l) reported for Florida MSW leachate (Reinhart and Grosh, 1998). The warm temperatures (50 – 85 °F) and dilution by heavy rainfall (yearly average 1,400 mm) have been cited for the low BOD, COD values compared to values reported in literatures. The higher BOD and COD values of the leachate for the city of Kathmandu with similar climatic conditions to Florida (average annual rainfall 1,400 mm and temperature range of 45 to 90 °F) implies the larger proportion of organic matters in the municipal waste of Kathmandu. There is, thus, a large potential to have self-sustainable plants installed to recover fertilizer (composting) or heat/electricity generation from the waste if appropriate policies/programs are put in place. As the quantity (and also quality) of leachate entering the river system and leaking to ground water has not been well documented, the total pollution load (BOD, COD, ammonia, heavy metals and others) to river system and ground water by such river bank dumping is not known. However, there are estimates of about 3,000 m3 of solid waste that accumulate in the Bagmati River during dry season months (WECS, 2008). With the raw density of 225 kg/m3 (Alam et al., 2008) and assuming 6 months of low flow period, the mass of MSW accumulated in the Bagmati River is approximately 4 t/d. The biodegradable fraction paper, garden and food waste accounts for 53% of waste composition of MSW with 70% organic compounds (Kayhanian, 1995). According to Themelis and Kim (2002), excluding minor components including N, biodegradable fraction of MSW can be represented by the molecular formula $C_6H_{10}O_4$. And this biodegradable fraction of MSW contains about 15%-70% water (Verma, 2002). Assuming 75% organics in the MSW of the valley and 53% biodegradable organics the total BOD load of 1.6 t/d can be expected to Bagmati River system from direct dumping of MSW in rivers. The accumulated solids (BOD, MSW) putrefy over time and release obnoxious gases making urban environment, especially places in the vicinity of river system, very unpleasant. The pollution load of the river reach maximum during a couple of rain events in the beginning of the monsoon season as the flow washes away the accumulated waste.

6.7.1 Squatter settlements

One in six people in the world is a squatter (Neuwirth, 2006). In Nepal, the proportion of squatters does not seem to be that high as envisioned by Neuwirth. Most of the squatters in Nepal occupy the river banks and public areas close to city centers/urban areas and same is true for the squatters in the Kathmandu Valley. Rabenau (1990) reported that 60% of the squatter settlements in the valley are on public lands (like river banks) and 40% are in public buildings such as temples. Thapa (1994) recorded 33 squatter settlements with a total population of 15,000 in the valley as of 1994. A survey conducted on 24 squatter settlements revealed that 46% of the settlements were on river banks and 54% in urban areas (ICIMOD, 2007). Of the total households surveyed, 52% were without tap water and 66% had no toilet facilities. KUKL (2008) recorded 8,846 households in 39 squatter settlements and 137 slums in the valley a population of 40,237 as of 2008. Of the total houses more than 80% had access to piped water supply (an average increase of about 30% from 52% in 2006) but none had adequate sanitation facilities. The population of squatters in the valley must be more than 55,000 as of today if they are growing at 12-13% per year as estimated by Shrestha (2010). Such a huge population mostly defecating in open in the river banks has great potential to pollute surface as well as ground water sources.

6.7.2 Industrial wastewater

Domestic wastewater (146 MLD) makes up approximately 93% of the total wastewater generation in the cities, and the remaining 7% (~10 MLD) is industrial wastewater (ICIMOD, 2007). The main water polluting carpet industries are either closed or moved to other parts of the country. The pollution load (BOD) from industries is approximated to 5 t/d.

6.7.3 Quarrying of sand from river beds

Sand mining in river beds is still the main income generating activity for some group of people. Sand extraction from the river is much higher than natural deposition rate (IUCN, 1995). Approximately 60% (3,103 m3) of the total annual sand demand of the valley was extracted from the river in 2007 (Sayami 2007). The rivers get deepened Due to rapid population growth and urbanization, the demand for construction materials like sand, cement, and bricks are continuously increasing. Though sand mining is made illegal recently, it still continues and seems that it is not going to stop unless alternative employment opportunities to the people involved are put on place. Sand mining increases the turbidity of water by resuspending solids and other detritus materials deposited in the bed. This causes the river deeper and polluted river water more easily percolates down and contaminates the ground water reserve. The deepening also leads to river beds scouring, bank erosion, and landslides. The net BOD load to river might be negative as part of the BOD can be taken away with sands, and part of the BOD can percolate down to ground water but these effects are neglected.

6.7.4 Other stressors

In addition to the above mentioned causes of water pollution, there exist some other stressors but are less significant. Some of them are agricultural runoff, cremation sites, washing and bathing (Tachamo et al., 2009). There is also a practice of slaughtering animals, especially buffaloes, in the river banks and remains like bones are left on the banks or are thrown away in to the rivers. There are very few public toilets in the city of Kathmandu and people with no toilet facilities at their homes and visitors are compelled to release their pressures in drains, streets or in river banks. Kantipur online (2012) reported that there were only 68 public toilets in the valley of which only 61 are usable and only 43 have running water. The organic load from these sources being small compared to the load from major causes, are not included in the BOD budget.

6.8 BOD Sinks

Concomitant to rapid population growth, tremendous increase in wastewater volume has been observed in the valley during past few years. ICIMOD (2001) analyzed domestic wastewater (grey and black water) based on Tebbut (1992) method and estimated an average of 50g BOD/p-d produced in the Kathmandu Valley. Similar estimates were also made by Karn and Harada (2001). They also reported that the Bagmati River has been the repository of waste generated in the valley and the average BOD load remains almost stable to 31 mg/l per person per day since many years. The BOD budget (mass balance) is prepared for 2.51 million valley dwellers based on 50 g BOD/p.d generation and 31 g/p.d directed to river system (Karna and Harada, 2001). The total domestic BOD generation of the valley population of 2.51 million is estimated to be 125.5 t/d and the contribution to river system is approximately 77.81 t/d (at 31 g/p.d) from domestic sources and about 5 t/d from industrial sources making total river BOD of 83 t/d. The following paragraphs list the potential BOD sinks and the proportion of BOD that they absorb.

6.8.1 Pit latrines and open defecation

In the valley approximately 4% of the households (~100,000 people) use pit latrines (PL) and about 1% (~25,100 people) practice open defecation (OD) (HPCIDBC, 2011). With a total BOD generation of 50 g/p.d, PLs and OLs handle 5 t/d, and 1.26 t/d, respectively. The ODs and PLs are handling waste equivalent to about 1.5 MLD and 6 MLD of wastewater, respectively. Haskoning and M-Konsult (1989) reported that 50% of the domestic COD ends up in PLs and 33% of the original COD, Total-N and Total-P infiltrate to ground water (for high ground water table <10 m), and equal amount ends up in surface water. Toilet Pits in Nepal are never lined and most of them get flooded during rainy season (for about 4 months). In Kathmandu Valley the ground water table (GWT) is high (<10 m). Shimura et al. (2012) and Nakamura et al. (2011) reported that high level of nitrate concentration in the ground water samples of the valley correlated with *Escherichia coli* concentration which is an indication of sewage as a possible source of contamination of the groundwater. An individual using PL contributes to about 16.5 g BOD per day (33% of total production of 50 g BOD/d) to the ground water (GW) and 16.5 g BOD per day to surface water (SW). Total BOD load to each GW and SW from PLs is approximately 1.65 t/d (16.5 g daily from 100,000 people). Assuming that out of remaining 17 g/d BOD 33% (0.56 t/d) would be lost due to flooding in rainy months and 67% (1.14 t/d) would get stabilized. As the city is congested, and people do not have enough space for having drain fields, the overflowed BOD load will drain to local streams/gullies/drains and finally to the river system making SW total BOD load of 2.21 t/d. Assuming that 10% BOD (0.13 t/d) from OD gets stabilized and neglecting the contribution to GW, the total BOD load to SW from OD users would be approximately 1.13 t/d.

6.8.2 Septic tanks (STs)

The septic tank (ST) is probably the single most important treatment unit in the small scale decentralized wastewater management system concept, and accomplishes approximately 50% of the ultimate treatment (BOD5: 50-60%; TSS: 60-80%, N; 10-30%) within the tank (Seabloom et al., 2005). The pollutants in septage get highly concentrated and the concentrations can go up to 10 to 100 times higher than in municipal wastewater (Koottatep et al., 2003). The average total solids content of the septage in the valley is 27 g/l (N=27) with total volatile solids of 65% (Sherpa, 2005). An average septage BOD of 15,000 mg/l is used herein for calculation purposes. The total BOD contribution of the septage (76,600 m^3/y) would be approximately 3.15 t/d. HPCIDBC (2006) reported that only 60% of the STs have cement plaster coating from inside to block leakage, while according to ADB (2006) only 35% of them have soak pits associated with them.

Estimates are made assuming that STs serve about 527,100 people (26.35 t/d BOD) and half of the incoming would be BOD stabilized in the tank. Sixty percent of the STs would perform good and stabilize 50% of BOD and 40% perform satisfactorily and would stabilize only 25% of the incoming BOD. The other assumption made is that 80% of the effluent BOD would be removed from good performing or first category STs and remaining 20% would be partitioned to SW and GW equally. The other assumption made is that only 20% of effluent BOD would get stabilized by the second category STs (40%) and remaining 80% would end up in SW (30%) and GW (50%). The remaining 20% effluent BOD from the first category STs would equally partition to GW and SW whereas remaining 80% effluent BOD from the second category STs is assumed to contribute 50% to GW and 30% to SW. The amount of BOD stabilized (not considering septage BOD and losses) in STs would be 10.55 t/d (in the tank) and effluent BOD stabilized by soak pits (leach fields) would be 7.38 t/d and the BOD released to GW and SW is 4.75 t/d and 3.67 t/d, respectively. Table 26 below shows the septic tank BOD budget.

Table 26: BOD mass balance for sedimentation tanks in the Kathmandu Valley (Nepal)

Septic tanks category	Total incoming BOD (t/d)	ST contribution (in the tank) BOD (t/d)			Effluent BOD (t/d)			Total (t/d)
		Stabilized	GW	SW	Stabilized	GW	SW	
Good performing (60% STs)	15.81	7.91	-	-	6.33	0.79	0.78	15.81
Poor performing (40%)	10.54	2.64	1.32	1.31	1.05	2.64	1.58	10.54
Total	26.35	10.55	1.32	1.31	7.38	3.43	2.36	26.35

ST: septic tank, GW: ground water, SW: surface water, t/d: ton per day

The septage from most of the STs is collected manually and partly (~34% households) by mechanical means. Only mechanically collected sepatage used to get directed to the only septage treatment plant in Kathmandu which has not been working since many years, thus, ends up in the Bagmati River without any treatment. Approximately 28% of the septage (from the farming community) goes to agricultural farm as soil conditioner (HPCIDBC, 2006). The farm application would thus take away 0.9 t/d and the rest (~2.25 t/d) would end up in rivers (BOD loss from farms neglected). The actual BOD removed in tanks would be 8.3 t/d and the organic load to SW would thus be 5.93 t/d (including septage contribution of 2.25 t/d). The GW portion of the BOD would either leach to GW or intercepted in subsurface soil. Similarly, part of the SW portion of BOD could be intercepted locally in gullies, ponds, streets and drains partly reducing the organic load to rivers. If 10% of the BOD is intercepted locally in gullies, ponds, streets and drains the total BOD load to river system (or SW) from STs would be approximately 5.33 t/d.

6.8.3 Central Wastewater treatment plants (WWTPs)

Among 5 major WWTPs (combined capacity 47 MLD) in the valley only one WWTP, Guheshwori, with the design capacity of 17 MLD is working in its full capacity. The wastewater either does not enter into the treatment processes (WWTPs) in other four WWTPs because of pumps and interceptors failure or if enters by gravity flow comes out untreated and drain in to rivers (Darnal, 2002; Arata, 2003). There are some other community based WWTPs mainly based on constructed wetland systems and all of these plants including Guheshwori WWTP together treat only about 18 MLD. The other 4 WWTPs (30 MLD combined capacity) is expected to remove about 20% of BOD equivalent to 6 MLD making total WWTP's contribution to 24 MLD. Using BOD removal efficiency of 85% with average incoming and effluent of BOD 363 mg/l and 45 mg/l, respectively as reported by Shah and Das (2002), approximately 7.63 t/d BOD would be stabilized releasing back daily 1.08 ton effluent BOD to SW. The population equivalent (PE) served by WWTPs can be approximated to 450,000.

6.8.4 Land fill

The practice of wastewater management by burying does not exist in the valley. People used to bury (land fill) septage in the past but because it is difficult to afford expensive land in the valley, the practice of burying has also declined to a level very negligible. All of the sepatge and WW is drained to rivers except a few farming communities who use it as soil conditioner. No contribution to BOD stabilization/digestion is expected from land filling.

6.8.5 Irrigation with sewage water

In terms of volume, irrigation use used to be the largest water user of surface (river) water (Dixit, 1996) but now because of urbanization and subsequent decrease in agricultural land diversion of the river for irrigation purposes has decreased (ASBSAS, 2008). Fifty nine percent of the valley comprises agricultural land: 20% is formally irrigated and the rest 80% depend on WW (irrigation water quality standards not met) for irrigation especially during dry months. Increasing water shortages coupled with poor wastewater infrastructure leading to contamination of otherwise clean irrigation water sources have created the conditions under which farmers consider wastewater as a reliable source of irrigation (Rutkowski et al., 2007). They also reported that some farmers pump WW directly from sewers whereas some use it indirectly by gravity flow from polluted rivers. They also observed that about 84% of the land is irrigated with water with *fecal coliform* level of 2.2 x 10^8 per 100 ml exceeding the WHO irrigation standard for unrestricted irrigation (10^3 *coliforms* per 100 ml). The BOD levels in the river increase at the start of the rainy season and followed by lower levels due to dilution resembling to those of weak and medium strength domestic sewage, respectively (McGhee, 1991).

NTNC (2008) estimates that the area of core settlement including built up areas and cultivated land in the valley is nearly equal and are about 89 km2. Due to rapid population growth, this proportion must have skewed to urban area as the agricultural land is shrinking and urban areas are increasing very fast. And also because of the other better economic opportunities, farming practices in and around the city core is decreasing very fast. The land used for active agricultural practices can be approximated to 60% (~53 km^2) of the estimate of NTNC (2008). The frequency of irrigation is dependent on the rainfall pattern: farmers normally irrigate four to five times more in winter (in dry season) than in monsoon season. These are the times with the highest pollution levels in the water sources used. There are no reports of frequency and depth of irrigation, the farmers in the valley practice. The soil in the valley is mostly sandy and silty alluvial and dark clay / silty clay (FAO, 2012a). The farmers close to urban areas mostly grow cash crops/vegetables like spinach, tomatoes, radish, beans (Rutkowski et al., 2007). The net irrigation (d net) water need for vegetable crops (say tomatoes) based on the soil type and temperature in Kathmandu valley is 718 mm (FAO, 2012b). The gross depth of water (d gross) needed for the crops, with a field application efficiency (ea) of 0.6 (60%) for surface irrigation would be approximately 1,200 mm for the entire season of the crop (3-5 months). Farmers in Nepal normally irrigate crops continuously as long as the water is available as most of the farmers are not aware of good agricultural practices and extension services are also poor. The volume of water used for irrigation would be approximately 64 million m^3/y (176 MLD). Assuming 80% of the water used is wastewater, the average volume of wastewater withdrawn would be 51 million m^3/y (140 MLD). Assuming 60% irrigation efficiency (40% water applied is lost and returns to river system) and with average BOD of 125 mg/l (Figure 6.4), amount of BOD removed from the river system is 10.5 t/d. The volume of WW that is taken out of the system for irrigation with 60% irrigation efficiency would be equivalent to 6 MLD.

6.8.6 Leakage of sewer to ground water and soil

The sewers in the core area of Kathmandu, Lalitpur and Bhaktapur were built in the 18th century for the conveyance of surface drainage and domestic sewage (ADB, 2006). A total of 60 km sanitary sewer and two WWTPs were constructed during 1976-1990. Frequent sewer blockage and overflowing of sewers can be witnessed in Kathmandu. It is believed that sewer systems are leaky as routine maintenance are lacking. Estimates are made assuming the leakage of about 20% of the wastewater that enters into sewer lines. Wastewater equivalent to 26% is taken care of by STs, PL and OD, approximately 74% of total wastewater produced (~12 MLD) is directed to sewer lines. The BOD load to GW and soil corresponding to 23 MLD wastewater is approximately 8.42 t/d.

6.8.7 Surface water (rivers and streams) BOD

The Bagmati River and its tributaries have several functions to carry. Though considered sacred, Bagmati River has become the main victim of rapid population growth and subsequent disposal wastes in to the river. Estimates to pollution load to Bagmati River are made based on the reports of quantity of wastewater generation and average BOD in the river water. Subjective judgments were also made if relevant data were not available. Figure 29 presents a schematic of BOD absorption/stabilization by various sectors.

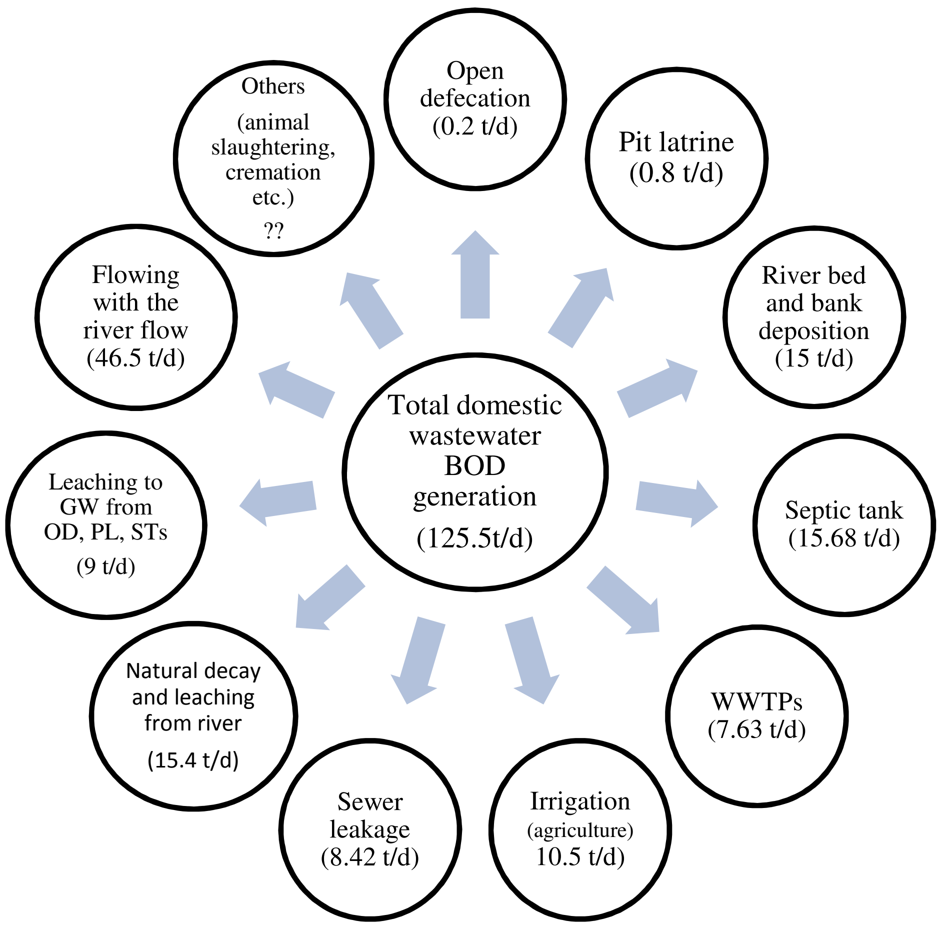

Figure 29: Quantity of BOD stabilized or partitioned by different compartments (BOD sinks); GW: ground water

The contribution of industrial WW in the valley is around 7% (CEMAT, 2000) with the daily BOD load of about 5 ton. The total WW volume equivalent that passes through some sort of treatment or taken out of the river system comes out to be 68.5 MLD (ODs - 1.5 MLD, PLs - 6 MLD, STs - 31 MLD, WWTPs - 24 MLD, irrigation – 6 MLD). Assuming sewer leakage of 20% (~24 MLD) the wastewater that is taken out of the system comes out to be approximately 93 MLD leaving behind approximately 65 MLD of raw wastewater equivalent entering in to the Bagmati River system (Table 27).

The table below (Table 27) shows that about 73% of the BOD (equivalent to 68.2 MLD wastewater or approximately 1,000,000 PE equivalent is completely stabilized and part of the remaining BOD reenters the river system (16 t/d or equivalent to 320,000 PE) giving total raw sewage load of approximately 75.5 t/d from municipal wastewater from about 1.5 million people. The river system would also receive an additional 1.6 t/d from MSW dumps. The combined BOD load of 77 t/d of BOD would partition to bed and bank deposition, suspension (flow with river water), ground water (leaching from bed and banks), decay (stabilized/consumed by natural processes) and a small fraction would be taken away with bed sand used for construction works. Assuming 20% BOD is stabilized (or taken away from the system) by natural decay and by leaching to ground water (15.4 t/d) in the river stretch of about 15 km in the urban core and 31 g/p.d flowing with the river (46.5 t/d), approximately 15 t/d of (organic load) BOD would get deposited in river bed and banks. The river system must receive organic loads from other sources like urban and agricultural runoffs, other activities in the river but due to lack of information their effects are considered minor compared to the organics in domestic wastewater from millions of people.

Table 27: BOD budget for the valley of Kathmandu for different wastewater management practices

Sanitation practice	BOD budget (t/d)				Total PE[µ] served	Equivalent wastewater volume handled, MLD[♣]
	Total	Stabilized	Ground water	Surface water		
Open defecation (OD)	1.26	0.13	-	1.13	25,000	1.5
Pit latrines (PL)	5	1.14	1.65	2.21	100,000	6
Septic tanks (STs)	26.35	15.68	4.76	5.92	530,000	31
WWTPs	8.71	7.63	-	1.08	450,000	24
Irrigation use[Ω]	10.5	10.5	-	-	210,000	6
Sewer leakage[θ]	8.42		2.53	5.9		24
Total	60	35	9	16	1,310,000	93

[µ] PE: Population equivalent
[♣] Calculated based on 58 lpcd wastewater generation
[Ω] Calculations are based on irrigation efficiency of 60%
[θ] Leakage assumed 20% and is considered partitioned to GW and SW in the proportion of 70% and 30% , respectively

6.9 Responses (R)

As explained above, the Bagmati River system is extremely polluted and coordinated remedial measures are urgent. In order to tackle the serious pollution problems facing the valley, a strategy of integrated environmental assessment is a most. The state of water resources (S) like water availability, water quality, use type, demand and supply; causes of water quality deterioration (or pressures, P) like disposal of domestic and industrial wastewater, squatter settlements; and the impact of pollution to human and environmental health (I) like impairment of river function, disease burdens; and the driving forces (D) like economic sectors, human activities have been explained above. The responses (R) from the government (policies and regulations, pollution limits like maximum contaminant level, MCL) and the society (awareness raising, pressure to government and polluting firms/organizations) will be discussed herein.

6.9.1 Social responses

The river systems in Nepal carry special religious and cultural significance and river systems of the Kathmandu Valley are no exceptions. Bagmati River, the biggest river in the valley, is considered one of Nepal's most important water body as it carries large religious and cultural significance for both Hindus and Buddhists. Because of rapid population growth and people having no other alternatives for waste/wastewater disposal/management, Bagmati River has been the repository of all sorts of waste.

There are tens of community groups, local clubs, NGOs, and INGOs working on Bagmati cleanup campaigns some of them working on the issues since 1980s. The outcomes are very positive but not enough as the degree of pollution is very intense. Mass protests against severe abuse of the environment against the abusers (some industries, persons) are also frequently seen in Kathmandu. The appendix 6 A lists the names of some of the organizations working for Bagmati River pollution prevention activities. These groups lack sufficient funds to tackle severe environmental problems and thus warrant major remedial programs from the government. The role of nongovernmental organizations along with governmental agencies is important in establishing an effective monitoring program in conjunction with a financial system that uses both local and government resources to pay for ongoing improvement programs. This management would help people to use resources wisely (not wasteful) as higher pollution production/release may need to pay higher prices.

6.9.2 Government responses: policies, laws, regulations, and programs

The policy initiations from the government are a must to tackle environmental problems. Appropriate plans and programs should be developed with active consultation and participation of all stake holders for preventive and remedial programs to be effective.

The government has assigned high priority to the Bagmati River cleaning agenda and had devised several short term and long term plans not only because of its environmental functions but also because of its cultural and religious importance. The names of government agencies working to restore Bagmati are included in appendix 6 B. Appropriate laws and regulations are also needed to support pollution prevention and or mitigation programs. Stringent regulations are necessary for protecting the environment and to discourage environmentally unfriendly activities. However, formulating and introducing new rules and regulations would not do any better if the implementation part is weak. For example, there are several laws/rules/regulations already in place in Nepal (appendix 6 C) since many years but they have not been successful in conserving the environment.

In developing countries like Nepal, there are several instances that intended results are not achieved for pollution prevention and control not because there are no laws addressing those issues but because laws are violated due to lack of strong institutional set up and enforcing and monitoring mechanism. Laws and regulations therefore should assign clear responsibilities to individuals and or organizations for setting water quality standards, monitoring water quality, and impose penalties to violators.

There are several conservation programs already introduced by the government for restoring Bagmati River but no tangible outcomes have shown up yet because of limited funding for the programs. However, WWTP plant established in Guheshwari area in order to clean a small stretch of Bagmati River in an area close to Pashupati Temple (one of the most sacred temples in Nepal) has shown very positive effect but the functioning of the project has since been questioned on the ground of sustainability because of very high O&M cost. Government has recently (March 2013) introduced large penalties (~US$1,150) for unlawful dumping of municipal solid waste and construction materials in the river banks. This penalty would certainly help to reduce pollution load but would not at all be effective as intended as no clear monitoring institutions/mechanisms are put in place yet. One of main reasons for not getting intended outcome from the cleaning campaigns/projects is because of poor community participation and ignorance about government's plans and programs. This demands more awareness raising programs in communities and imposition of pollution levies based not only on quantity of emissions but also based on the quality of emission/waste (toxicity, concentration etc.) released based on polluters pays principle (PPP).

6.9.3 Participatory approach for pollution prevention/treatment

People are becoming increasingly aware of the environmental pollution and have come forward to press the government to start cleanup efforts and to bring strong legislation to punish violators. The remedial programs to be effective there must be close coordination among communities, local bodies of the government (municipalities), and federal authorities. One of the main remedial measures would be to control pollution at source (preventive actions) which can be achieved by employing water and sanitation projects involving communities from planning, design to implementation phase.

The funding increase is a most for cleaning measures to be effective but increasing funding alone is not the solution without an emphasis to implementing demand-based rather than supply-based systems. In demand-driven systems communities commit to partnering in the development of preventive and control programs that are appropriate to local conditions (Montgomery and Elimelech, 2007). After establishing local partnerships and management structures, effective evaluation and monitoring programs are necessary to ensure that the programs/projects in place are effective. Waste recycling and reuse programs should be included in the plan for the preventive/treatment programs to be effective.

6.9.4 Incentives for environmentally friendly activities

Incentives are useful in promoting good behaviors. People will not feel comfortable in trying the technology/system that has not proved successful or very little information is available. Government's policy initiation and support towards resource recovery friendly sanitation systems would be instrumental to help promote appropriate sanitation systems in the communities. This would help promotes UDTs in the valley and in other parts of the country. The support could be in the form of tax credits, cash or construction materials subsidy.

6.9.5 Introduction of appropriate sanitation technologies

The obstacles to providing water and sanitation for all should be dealt by appropriate policies and investments that address the interrelated nature of water, sanitation, and health (Montgomery and Elimelech, 2007). Policies and funding initiatives that focus on either one of water and sanitation, environmental pollution management/mitigation or disease treatment should be replaced by a holistic approach where all activities go simultaneously. Investment on watsan interventions is economically beneficial and a return in the range of US$5 to US$28 can be realized on a US$1 investment in developing countries (Hutton, 2004). However, employing networked and high tech sanitation systems are not economically feasible for many developing countries no matter how cost beneficial the interventions are. Similarly, some existing sanitation systems might be more preferable over the other depending on the local conditions (weather, ground water table, cultural and religious preferences). Most of the water and sanitation projects in developing countries fail because of the supply driven nature rather than demand based projects. As domestic wastewater has been the main culprit for water quality deterioration in many developing countries including Nepal, improvement is needed in the current sanitation technologies or new sanitation system should be put in place with the holistic management of water, wastewater and waste based on reduce, recycle and reuse concept. Realizing the importance of sanitation system, many developing countries encouraged people for constructing toilets. The benefits of toilets use was realized but because there were no plans in place needed to manage waste (collection and final disposal) afterwards many cities like Kathmandu (Nepal), Dar es Salaam (Tanzania), are now facing serious difficulties in handling fecal sludge from septic tanks and VIPs and as a result they end up in receiving water bodies.

6.9.5.1 Ecological sanitation in urine diverting mode

It would be much easier for people to manage waste had they been told it in the beginning that they should also manage the waste after few years. They would also have used it wisely and the system could last longer as intended. The sanitation concepts based on reduce, recycle and reuse concepts are inevitable as waste volumes are becoming large and government’s sole effort to manage the issue has been a distant dream for many developing countries. This concept would also reduce and ultimately eliminate entry of foreign objects in to toilets (like medicine, chemicals, sanitary pads) if the stabilized waste was to be used either by the producer or sold in the market. The foreign objects in the toilet not only reduces the capacity of toilet (shortens desludging time) but also reduces the economic value of the resources that would be recovered and used/sold later on.

The ecological sanitation in urine diverting mode seems to be one of the alternatives to current sanitation technologies as it reduces water use, reduces waste volume and makes resources recovery easier (Lamichhane and Babcock, 2012). Source separation or urine diversion (UD) and collection of urine enables the collection of majority of human excreted nutrients relatively easily. In many cultures in the world urine is considered relatively safe (also has medicinal value in many cultures) and people comfortably handle it. Urine diverting toilet (UDT) seems to be the most appropriate sanitation technology for peri-urban and rural areas of the Kathmandu Valley. The fecal sludge that is produced in the valley (~76,600 m3) from septic tanks and VIPs end up in the Bagmati River (HPCIDBC, 2011). This fecal sludge could be easily recycled had there been a plan for collection, treatment and disposal in place. Neither religious nor cultural practices hinder urine handling/touching for the people of Kathmandu. UDTs are much cheaper than networked sewer systems but are relatively expensive in terms of capital investment compared to VIPs and pour flush latrines.

6.9.5.2 Economic consideration for UDT

Ecological sanitation in UD mode has been recognized as an appropriate technology for waste management (UNEP, 2004). UNEP (2004) has also given the medium range of cost for different sanitation options and UDT ($140/p) is assumed to be cheaper than ST system ($160). The estimated cost of an elevated double box UDT, "ecotoilet" in Nepal was approximately $250 (not to be confused with per capita cost) with an annual maintenance cost of $15 (Lamichhane, 2007). WaterAid (2008) estimated $230 for a double vault UDT in dry mode in Kathmandu much cheaper than the toilet with septic tank, and flush toilet with reed bed treatment facilities. The fertilizer value of urine and feces was also estimated and was approximately equivalent to $30 (NRs 2100) in 2008 exchange rate.

The land in the valley is very expensive and it would be difficult for medium income people to buy land that can accommodate both ST and soak pit (soak pit with ST is now mandatory by law). It would be much cheaper for the government in developing countries for providing UDTs to all houses than only to treat collected wastewater (cost of sewer construction and conveyance cost not included) from the same number of houses from the same catchment (Lamichhane, 2007). Government should therefore try to generate UDT demands by offering subsidies and should also discourage polluters by imposing increased pollution levies. There is also a possibility of developing UD system under clean development mechanism (CDM) from which users can earn green house gas credits which could be sold to international markets.

6.10 Remedial measures for water quality restoration

The most important step of reducing pollution is to start reducing from the source. Domestic wastewater being one of the major causes of pollution of the Bagmati River system, wastewater management should be targeted first. There is a huge potential for introducing UDTs and reduce environmental pollution as drinking water is becoming scarce day by day. Urbanization and rapid population growth being the main reason for the increased pollution in Bagmati River systems, government has to put programs to retain people in rural and peri-urban areas or encourage reverse flow of migrants: from city centers to peri-urban areas and satellite towns. This may not be that easy, though and takes long time for results to come. The provision of adequate sanitation to squatters (possibly the potable mobile UDTs) and introduction of regulations requiring new house owners (about 4,000 houses are built in Kathmandu in one year) to have long term waste management and recycling plans. These activities would not reduce the BOD load but would not also contribute to additional organic load to rivers. There is a high chance of accepting UDTs also from the current users of on-site sanitation system (STs, VIPs and PLs) as they are having difficulties managing the sludge.

6.11 Cost involved for introducing appropriate sanitation alternatives

The wastewater volume treated in the valley is equivalent to 1.1 million PE (Table 6.2) in terms of BOD removal (or removal from the river system). It would be very expensive and not affordable for offering networked sewer systems and WWTPs for all people. As people have tendency to move towards flushing toilets and WWTPs, they would not stick to the cheaper and conventional style toilets like pit latrines and VIPs. It would be good to go through the middle and encourage people to use UDTs. Unimproved and improved pit type latrines are liable to contaminate surface as well as ground water sources so are not appropriate in valleys like Kathmandu with high ground water table. People would also hesitate to try new technology (like UDs) that was not in practice from before. The government should set up a strong institutional mechanism to provide technical support, and after completion management (like maintenance, waste collection and treatment, entrepreneurship development or service providers) to push people for more environmentally friendly sanitation technologies like UDTs.

Introduction of UDTs starting from rural and semi-urban areas to urban areas afterwards seems easier to implement as people in rural and semi-urban areas are more easily accessible than their urban counterparts. This seems to be the one of the most sustainable sanitation alternative and with the minimum investment. Table 28 shows the average per capita cost for providing sanitation service by various alternatives.

Table 28: Cost estimate for providing sanitation services (UDT) in Kathmandu for people practicing open defecation and or other onsite sanitation systems

Per capita cost ($)	Improved pit latrine	VIP	Pour flush	Septic tank	Networked sewer	Secondary and above	UDT
UNEP (2004) $^{\Omega}$	45	65	70	104	140-300	450-800	180^{μ}
WHO / UNICEF, (2000)	26	50	50	104	154		250^{α}

$^{\Omega}$ also includes O&M costs of 15%

$^{\mu}$ Cost for dual pit UD toilet (WaterAid, 2010)

$^{\alpha}$ Cost for an elevated double box UD toilet (Lamichhane, 2007)

It can be seen from the Table 6.2 that UDTs are slightly expensive than pit type toilets. The cost of UDT includes the cost of whole toilet assembly (not just a toilet) including collection system. The per capita cost of an elevated UDT can be approximated to $65 based on a family size of 4 (CBS, 2012). The difference of UDT system from the septic tank type toilet is that UDT is a single entity consisting of toilet structure and collection system (tanks). The cost is estimated based on a family size of 4 (CBS, 2012) and it is assumed that one UDT is used by a family, which is normally the case in rural, and peri-urban areas of Kathmandu.

6.13 Conclusion

The causal links starting from driving forces to pressures, state, and impacts can be effectively established by using DPSIR model. DPSIR model is an effective tool in identifying cause of pollution, their effects in the environment and responses needed from communities or authorities for restoring Bagnmati River system. There are many organizations working for Bagmati River restoration efforts but no concrete step has been taken yet. Only coordinated efforts can bring situation in control. The government has to take initiation and should address this issue by introducing policy directives, and appropriate plans and programs in consultation with all stakeholders. Wastewater management/treatment should be assigned top priority as domestic wastewater is the biggest contributor of organic load. The first priority for the government should be to treat/manage the sewage that is collected through networked sewer systems but comes out untreated because almost all existing WWTPs but one works. However, large investment on water and sanitation systems is needed even to make existing infrastructures work. It would be difficult for the government to spend huge amount (should look for donors!) on this sector at once and even if it could manage the fund it would takes years to complete the task based on the technology and expertise available in Nepal. The other pertinent issue is of fecal sludge (~76,600 m3/y) management from VIPs and septic tanks which ends up in to the Bagmati River system untreated. It would be easier, more economical and also sustainable to reduce pollution from such on-site systems in the beginning.

Introduction of appropriate and sustainable sanitation system is a must to control wastewater entering into river systems. UDT system can be one of the alternatives for managing human waste in Kathmandu as water is scarce and wastes are contained and allow better handling. The other factor that would help to introduce UDTs is the presence of some farming communities (Jyapu) who have been using fecal sludge, though a few in numbers these days, to grow vegetables. Government should subsidize part of the cost of UDT in the beginning to generate demand and role of Jyapu community can be instrumental in this regard. The cost of UDT seems a bit at the higher end compared to existing unimproved or onsite sanitation systems but still a cheaper alternative compared to networked systems and costs will surely decrease if used in large scale and waste (nutrient and organics) could be sold.

The other important pollution sources are municipal solid waste and industrial discharges. Though, managing solid waste would not be an easy task for the government because of several social and political reasons, but managing industrial discharges would be relatively easy. By introducing pollution prevention principles like P2 or PPP and strongly monitoring the discharges and severe punishment to violators would certainly bring results. However, government should give them sufficient time for process improvement activities and also need to provide technical support if needed. The scenario is different for municipal solid waste (MSW) management. There are hundreds of people in Kathmandu who make their living on collecting and selling recyclables from MSW/garbage. Most of these people live in river banks or on slums where MSW is dumped and are also the ones to suffer the most from the polluted environment that is created because of the dump. The government has recently introduced a system of imposing large fine (about $1,100) for dumping waste illegally in the river banks. There are no signs of improvement yet as it was declared without setting up appropriate institutional mechanism for monitoring. The illegal dumping can be very effectively controlled if these slum dwellers can be involved in governments efforts of discouraging illegal dumps in river banks.

Recently, the imprudent use of agrochemicals including fertilizers is also cited as one of reasons for water quality deterioration. The practice of overusing fertilizers would be substantially reduced if appropriate agricultural extension programs were put in place. The demand for chemical fertilizer would certainly decrease if other organic supplements were available and well composted/treated excreta can be one of the alternatives.

In order to tackle the serious water pollution problems of the valley, a strategy of integrated environmental assessment is a most setting up causal links of drivers of pollution to environmental impacts. The links developed for Bagmati River system based on DPSIR framework (Figures 6.6 and 6.7) will be useful for government bodies, policy makers and experts/organizations involved in the field of integrated environmental management. The appropriate responses (economically viable, technically feasible and socially acceptable) can be made from concerned authorities based on the degree and severity (such as organic load) of impacts.

Some of the major issues the government has to address for cleaning Bagmati River systems are:

- Decentralization of administrative authority, and devolution of power to district level bodies to minimize influx of migrants (decentralizing opportunities or drivers)
- Invest on existing water and sanitation infrastructure and ensure cost recovery to sustain the system (all water and sanitation systems related utility companies in Nepal are operated on government subsidies).
- Water and wastewater service charges should be revised, updated and also defragmented by imposing increased sanitation levies to large water users (industries, hotels) not just based on the proportion of water use on a flat basis
- Develop national municipal solid waste management plan promoting recycling and reuse, and acquire lands for sanitary landfill sites
- Introduce more stringent regulations regarding environmental pollution and enforce polluters pay principle (PPP)

- Introduce policy and associated rules, regulation and codes to encourage multistoried buildings accompanied with clear waste (solid waste and wastewater) management protocols
- Promote water conservation and recycling habits. Introduce appropriate policy and code and develop appropriate sanitation technologies
- Provide incentives for people/organization/industry with environmentally friendly activities like pollution prevention and control
- Ensure maximum community participation in all environment and development related activities
- Regulate industrial effluents and no license should be issued to any industry establishment in the valley that has potential negative environmental consequences (industries that consume a lot of water, produce very concentrated effluent).
- Polluting industries that have crossed or are on the verge of crossing their design period (useful life) should not be allowed to renew their license to continue operating in the valley.

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APPENDIX

Appendix 2 A: Urine composition (Source: Putnam, D. F. ; and Thomas, E. C. : Recovery of Potable Water from Human Urine, Douglas Paper no. 4277, Aerospace Medicine, July, 1969)

Item	Formula	Formula weight	Concentration range (mg/l)		Solubility limit in a binary solution g/100g H2O
			Min	Max	
Total solutes			36,700	46,700	---
Urea	H_2NCONH_2	60.1	9,300	23,300	119
Chloride	$C1^-$	35.5	1,870	8,400	---
Sodium	Na^+	23.0	1,170	4,390	---
Potassium	K^+	39.1	750	2,610	---
Creatinine	$C_4H_7N_3O$	113.1	670	2,150	8.7
Sulfur, Inorganic	S	32.1	163	1,800	---
Hippuric acid	$C_6H_5CO.NHCH_2.CO_2H$	179.2	50	1,670	0.367
Phosphorus Total	P	31.0	470	1,070	---
Citric Acid	$HOC(CH_2CO_2H)_2CO_2H$	192.1	90	930	208
Glucuronic Acid	$C_6H_{10}O_7$	194.1	70	880	S.
Ammonia	NH_3	17.0	200	730	---
Uric Acid	$C_5H_4O_3N_4$	168.1	40	670	0.00645
Uropepsin (as tyrosine)	$HOC_6H_4C_2H_3(NH_2)CO_2H$	181.2	70	560	0.04

Appendix 2 A Contd.

Item	Formula	Formula weight	Concentration range (mg/l) Min	Max	Solubility limit in a binary solution g/100g H2O
Bicarbonate	HCO_3^-	61.0	20	560	---
Creatine	$HN{:}C(NH_2)N(CH_3)CH_2CO_2H.H_2OS$	149.2	0	530	1.4
Sulfur, Organic	S	32.1	77	470	---
Phenols	C_6H_3OH	94.1	130	420	8.2
Glycine	$NH_2CH_2CO_2H$	75.1	90	450	23
Lactic Acid	$CH_3CHOHCO_2H$	90.1	30	400	∞
Calcium	Ca^{+2}	40.1	30	390	---
Histidine	$C_3H_3N_2CH_2CH(NH_2)CO_2H$	155.2	40	330	S.
Glutamic Acid	$HO_2CCHNH_2(CH_2)_2CO_2H$	147.1	< 7	320	1.5
Androsterone	$C_{19}H_3O_2$	290.5	2	280	1;S.
1-Methylhistidine	$C_3H_3N_2CH_2CH(NHCH_3)COOH$	169.2	30	260	
Magnesium	Mg	24.3	20	205	---
Imidazole Derivatives	$C_3H_4N_2$	68.1	90	200	S.
Glucose	$C_6H_7O_6(COCH_3)_5$	390.4	30	200	0.15

Appendix 2 A Contd.

Item	Formula	Formula weight	Concentration range (mg/l) Min	Max	Solubility limit in a binary solution g/100g H2O
Taurine	$NH_2CH_2CH_2S0_3H$	125.2	5	200	6.4
Aspartic Acid	$C_4H_7O_4N$	133.1	< 7	170	2.71
Carbonate	$CO3^{-2}$	60.0	100	150	---
Cyatine	(HO2CCH(NH2)CH2S)2	240.3	7	130	0.01
Citrulline	$NH_2CONH(CH_2)_3CH(NH_2)CO_2H$	175.2	0	130	S.
Threonine	$C_4H_9O_3N$	119.1	10	120	S.
Lysine	$(NH_2)_2C_3H_9CO_2H$	146.2	5	110	V.S.
Indoxylsulfuric Acid	$C_8H_7ONH_2SO_4$	231.2	3	110	
m-hydroxyhippuric Acid	$C_4H_4COHC(CONHCH_2COOH)$	195.2	1	100	
p-Hdroxyphenyl-Hydrocrylic Acid			1	100	

Appendix 6 A: List of government organizations, NGOs and private organizations working for Bagmati River cleaning work

1. Bagmati Area Sewerage Construction/Rehabilitation Project (BASP)
2. Bagmati Civilization Integrated Development Committee (BCIDC) (formerly Bagmati Area Sewage Project, BASP)
3. Bagmati River Conservation Project (BRCP)
4. Bagmati Sewa Samittee
5. Bishnumati Sarokar Samittee
6. Centre for Integrated Urban Development (CIUD)
7. Damaichaghat Puspalal Tole Sudhar Samiti
8. Department land survey- cadastral survey and registration
9. Department of National parks and wild life conservation (DNPWC)
10. Department of Roads
11. Department of soil conservation and watershed management (DSCWM)
12. Department of Urban Development and Building Construction (DUDBC)
13. Departments of mines and Geology (DoMG)
14. Development Centre (DC)- Nepal
15. Didi Bahini Family, Annamnagar
16. Environment and Public Health Organization (ENPHO)
17. Environmental Camps for Conservation Awareness (ECCA)
18. Forum for Protection of Public Interest (ProPublic)
19. Friends of Bagmati (FoB)
20. Guthi Sasthan
21. Indrabinayak Club
22. Irrigation Department (DoI)
23. Kathmandu Environmental Education Project (KEEP)
24. Kathmandu Metropolitan City (KMC)
25. Kathmandu Tole Sudhar Samaj
26. Kathmandu Upatakya Khanipani Limited (KUKL)
27. Kathmandu Valley River Monitoring (KAPRIMO)

28. Kathmandu Valley Town Development Committee (KVTDC)
29. Kathmandu, Bhakatapur, Lalitpur District development committees (DDCs)
30. Khadgi Sewa Samaj
31. Lions Club of Pashupatinath
32. Lumanti
33. Municipalities (Kathmandu, Bhakatapur , Madhyapur Thimi, Lalitpur , Kirtipur)
34. Narayan Pariwar Club
35. National Trust for Nature Conservation (NTNC)
36. Nepal Basobas Basti Sanrakchan Samaj
37. Nepal Forum for Environmental Journalists (NEFEJ)
38. Nepal Mahila Ekta Samaj
39. Nepal Pollution Control and Environment Management Centre (NEPCEMAC)
40. Nepal River Conservation Trust (NRCT)
41. Nepal Water Conservation Foundation
42. NGO Forum for Urban Water & Sanitation
43. Nodan Club
44. Pashupati Area Development Trust (PADT)
45. Rotary Club of Yala
46. Sagarmatha Environment Development Centre (SEDC)
47. Small Medium Enterprise (SME)
48. Solid Waste Management & Resource Mobilization Centre (SWMRMC)
49. UN Park Development Committee
50. Urban Environment Management Society
51. Village development committees VDCs) of Kathmandu, Bhakatapur and Lalitpur districts
52. Women Environment Group (WEG)
53. Women Environment Protection Committee (WEPCO)

APPENDIX 6 B: Institutional set up and government agencies responsible for policy formulation and implementation for Bagmati River system restoration related works

Policies, institutional set-up and legislations

1. Wastewater Management Policy 2006
2. National Urban Policy (2007)
3. Rural Water Supply and Sanitation Sector Strategy (2004)
4. National Guidelines for Hygiene and Sanitation Promotion (2005)
5. Urban Water Supply and Sanitation Policy (2009)

Government Agencies (policy level)

1. Parliament Natural Resources Committee
2. Ministry of Culture, Tourism and Civil Aviation
3. Ministry of Environment, Science and Technology
4. Ministry of Forest and Soil Conservation
5. Ministry of Land Reform and Management
6. Ministry of Local Development
7. Ministry of Physical Planning and Works
8. Ministry of Water Resources
9. National Planning Commission

Government Organizations (implementation level)

10. Bagmati Area Sewerage Project (BASP)
11. Bagmati Civilization Integrated Development Committee (BCIDC)
12. Department of Hydrology and Meteorology (DHM)
13. Department of Urban Development and Building Construction (DUDBC)
14. Department of Water Supply and Sewerage (DWSS)
15. Departments of mines and Geology (DoMG)
16. Kathamndu Valley Town Development Committee (KVTDC)
17. Kathmandu Upatakya Khanipani Limited (KUKL)
18. Solid Waste Management & Resource Mobilization Centre (SWMRMC)

APPENDIX 6 C: Environment related acts, rules, regulations in Nepal and conventions and treaties

Acts

1) Ancient Monuments Protection Act, 1956
2) Civil Aviation Act, 1958
3) Aquatic Animals Protection Act, 1960
4) Plant Protection Act, 1964
5) National Parks & Wild Life Conservation Act, 1987
6) Public Road Act, 1974
7) Trust Corporation Act, 1976
8) Tourism Act, 1978
9) King Mahendra Nature Conservation Trust Act, 1982
10) Soil & Watershed Conservation Act, 1982
11) Nepal Petroleum Act, 1983
12) Nepal Electricity Authority Act, 1984
13) Mines & Mineral Act, 1985
14) Pashupati Area Development Trust Act, 1987
15) Solid Waste (Management & Resource Mobilization) Act, 1987
16) Town Development Act, 1988
17) Kathmandu Valley Development Authority Act, 1988
18) Nepal Water Supply Corporation Act, 1989
19) The Constitution of the Kingdom of Nepal, 1990
20) Pesticides Act, 1991
21) Village Development Committee Act, 1991
22) District Development Committee Act, 1991
23) Municipality Act, 1991
24) Water Resources Act, 1992
25) Forest Act, 1992
26) Electricity Act, 1992
27) Motor Vehicle & Transportation Management Act, 1992
28) Labour Act, 1992
29) Industrial Enterprises Act, 1992
30) Nepal Tourism Board Act, 1996
31) Environment Protection Act, 1996
32. Soil and Watershed Conservation Act (1982)
33. Aquatic Animals' Protection Act (1965)

Rules

1) National Parks & Wild Life Conservation Rules, 1973
2) Plant Protection Rules, 1974
3) Wild Life Reserve Rules, 1977
4) Himalayan National Park Rules, 1979
5) Mountaineering Rules, 1979
6) King Mahendra Nature Conservation Trust Rules, 1984
7) Petroleum Rules, 1984
8) Khaptad National Park Rules, 1987
9) Ancient Monuments Protection Rules, 1989
10) Solid Waste (Management & Resource Mobilization) Rules, 1989
11) Water Resources Rules, 1993
12) Pesticides Rules, 1993
13) Labour Rules, 1993
14) Electricity Rules, 1993
15) Forest Rules, 1994
16) Buffer Zone Management Rules, 1995
17) Royal Bardiya National Park Rules, 1996
18) Conservation Area Management Rules, 1996
19) Vehicle & Transportation Management Rules, 1997
20) Environment Protection Rules, 1997

Conventions, treaties, and agreements related to water and sanitation and ecology

1) Convention on Wetlands (Ramsar Convention)
2) Convention on Biological Diversity (CBD)
3) UN Convention to Combat Desertification (CCD)
4) Basel Convention on Transboundary (international) shipments of waste
5) Rotterdam Convention – prior informed consent (PIC) for shipment of chemicals
6) Stockholm Convention – Persistent Organic Pollutants (POPs)