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A study of water and sanitation in rural villages of Lamjung District, Nepal: challenges and sustainable solutions

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Abstract

Many people throughout the world still lack safe and affordable access to drinking water and basic sanitation. As of this year, only 83.3% and 53.1% of the population in Nepal will have ‘improved’ water resources and sanitation facilities, respectively. Improvements in water and sanitation infrastructure results in benefits to health, education and livelihoods. During March 2016, an investigation of the existing water and sanitation situation in Lamjung District was undertaken to understand the key issues facing the region. In total, 50 surveys were carried out in four different Village Development Committees (VDCs) across the district, working with the aid of four Peace Corps Volunteers (PCVs) and two Nepali interpreters. Simple Correspondence Analysis was conducted on all significant correlations to describe relationships between different variables. The results from our study were compared with findings from the 2011 National Population and Health Census, as well as other similar studies in Nepal, and this showed that Lamjung District generally has a better situation than other rural districts in Nepal with regard to access to water and sanitation. However, there were a range of issues found including insufficient quantity of water for domestic and agricultural use, poor accessibility and reliability of water sources, prevalence of waterborne diseases, a lack of protection and maintenance of water supply sources, low production of biogas, over-reliance on chemical fertilizers and inequality of access to water and sanitation between different socio-economic groups. Some of these issues were found to disproportionately affect marginalised groups such as the poor and members of lower castes, while some issues are more dependent on location and impact all groups regardless of their socio-economic status. By analysing the results and researching relevant literature, this thesis proposes sustainable solutions to all issues discovered. Concrete measures that could be implemented in Lamjung District are proposed, including implementation of sustainable low-cost technology to improve the quantity, quality, reliability and accessibility of water, and ecological sanitation systems which will have benefits both in reducing the spread of diseases and in improving crop yields through increased access to organic fertilizer made from human excreta and urine. These systems should be accompanied by better education, management and funding practices, which are also discussed.

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Acronyms

ADB	Asian Development Bank
BSP	Biogas Support Program
EcoSan	ecological sanitation
ENPHO	Environment and Public Health Organization
ha	hectare (10,000 m^2)
ICIMOD	International Centre for Integrated Mountain Development
LPCD	litre per capita per day
m.a.s.l.	Metres above sea level
MDGs	Millennium Development Goals
NGO	non-governmental organisation
NPR	Nepalese Rupees
NTU	Nephelometric Turbidity Units
PCV	Peace Corps Volunteer
SODIS	solar water disinfection
VDC	Village Development Committee
WASH	water, sanitation and hygiene
WHO	World Health Organization

1. Introduction

1.1. General introduction

In rural communities across the world, many people face issues around having insufficient or unsafe water supplies, poor access to improved sanitation facilities, and low agricultural yields due to lack of water and fertilizer. In rural Nepal, these issues are particularly prevalent, due to poverty and lack of education of the population, political upheaval, remote locations of villages, challenging topography and the vulnerability of these areas to natural disasters such as earthquakes and landslides. For this reason, a district in rural Nepal was selected for research into issues relating to water and sanitation, with an aim to find sustainable solutions that could improve the situation.

During March 2016, a survey was given to 50 households in Lamjung District, with questions concerning their present situation with regard to water, sanitation and agriculture, and from the surveys' results, in combination with a detailed literature study, key issues were identified and possible sustainable solutions have been proposed. Lamjung District was selected because it is located in the mid-hills, which is a particularly interesting region from a water and sanitation point of view, due to the steep topography, varied socio-economic status in the population and a heavy reliance on spring sources for water supply.

Our study focused on the demographics of participants, the quantity, quality, reliability and accessibility of their domestic water supply, their agricultural water supply, the coverage and functionality of their sanitation technology, and some of their agricultural practices. Most questions sought to understand the current practices, but some questions also investigated the participants' opinions towards various sustainable solutions. Statistical analysis was undertaken in order to help answer the research questions. Correlation analysis was performed between key variables, to investigate whether or not socio-economic factors influenced the situation of the households surveyed and to better understand the issues as well as their causes in order to develop possible sustainable solutions.

1.2. Objectives and research questions

1.2.1. Main objective

To investigate the existing water and sanitation situation in Lamjung District in order to understand the key issues facing the region and to propose sustainable solutions.

1.2.2. Objectives and Research questions

- To investigate the current status of water and sanitation in Lamjung District.
  - How does the study area compare to the rest of the region and Nepal as a whole, in terms of access to 'improved' water and sanitation infrastructure?
  - Do households have an acceptable level of water quality for drinking purposes?
  - Do the participants have technical problems with their sanitation systems?
- To identify the main water and sanitation related issues facing Lamjung District.
  - Do households have sufficient amounts of water to meet both domestic and agricultural water requirements?
  - Are farmers overly reliant on chemical fertilizer and, if so, could it be replaced by recycling human urine and treated human excreta into organic fertilizer?
  - Do socio-economic factors influence households' access to sustainable water and sanitation systems?
- To develop sustainable solutions to key issues, based on the results of our study and a detailed literature review.

1.3. Rationale for study

1.3.1. Water and sanitation worldwide and in Nepal

World leaders gathered at the United Nations at the beginning of the millennium to develop the Millennium Development Goals (MDGs), which outlined how to work together to reduce poverty by 2015. This included the target to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation (UN 2015). The progression made towards these goals, with respect to 'improved' drinking water sources and sanitation in Nepal, the South-East Asia region and globally, is summarised in Table 1. Generally, an improved water supply is one that "adequately protects the source from outside contamination, particularly faecal matter" and improved sanitation involves "hygienically separat[ing] human excreta from human contact" (JMP 2016). More detailed definitions of 'improved' and 'unimproved' water and sanitation technologies are given in Table 2.

Table 1 - World health statistics of percentages of populations using improved drinking water sources and sanitation (WHO 2015)

	Percentage of the populations using improved drinking water sources			Percentage of the population using improved sanitation		
	1990	2000	2012	1990	2000	2012
Nepal	66	77	88	6	21	37
South-East Asia Region	70	80	91	25	35	45
Global	76	82	89	47	56	64

Despite increases in the percentage of the population using 'improved' technology, as shown in Table 1, access to drinking water services, sanitation facilities and general hygiene standards remains low in Nepal, with an estimated 77% of the population having access to improved drinking water sources and 46% using improved latrines (Shah 2008).

Table 2 - Improved and unimproved water supply and sanitation technologies (JMP 2016)

	Improved technologies	Unimproved technologies
Water supply	Household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection	Unprotected well, unprotected spring, vendor-provided water, bottled water, tanker truck provision of water
Sanitation	Connection to a public sewer, connection to a septic system, pour-flush latrine, simple pit latrine, ventilated improved pit latrine	Service or bucket latrines, public latrines, open latrine

As the MDGs came to a conclusion at the end of the year 2015, Nepal met the MDGs to improve the percentage of the population with access to ‘improved’ sanitation facilities and water sources, however there is still much progress to be made, as the 2015 targets set for improved water resources and sanitation facilities were only 83.3 and 53.1%, respectively (ECONOMICS 2016). Beyond the MDGs, the Sustainable Development Goals have been introduced and *Goal 6: Ensure availability and sustainable management of water and sanitation for all* (UN 2016a) provides a platform to continue to ensure that access to water and sanitation across the globe remains a priority. By 2030, the new goals aim to improve access to water and sanitation, while paying attention to the needs of vulnerable populations, through international cooperation in developing countries and increasing water sanitation and hygiene (WASH) management support in local communities (UN 2016b) .

1.3.2. Improving community livelihoods and health

Improvements in water and sanitation infrastructure result in a range of benefits to people’s health, education and livelihoods. Construction of household latrines and better access to water leads to improvements in personal hygiene and cleanliness of toilets, which in turn leads to reduced water and sanitation related diseases (Red Cross 2013). Similarly, improving the quality of the household water supply through treatment systems also reduces the frequency of these diseases (LSHTM/WEDC 1998). When less time is required for water collection, children can attend school more frequently and adults (especially the female members of the household) have more time to spend on income generating activities (Nichols 2015). Furthermore, ensuring an adequate supply of water for agricultural activities is an important aspect of poverty alleviation among households who rely on agriculture for the bulk of their income (Howard and Bartram 2003). Constructing toilets using ecological sanitation technologies, which will be discussed below, has the added benefit of increasing access to organic fertilizers, which also improves the livelihoods of farming communities.

1.3.3. Nutrient recycling

Phosphorus plays a vital role in soil fertility, plant growth and food security, and is mainly sourced from phosphate rock, which is a non-renewable resource and is expected to peak “this century, possibly as early as the next few decades” (Neset and Cordell 2012; Scholz et al. 2013). As such, finding alternative sources of phosphorus is an important issue that needs to be addressed by the global community. Fortunately, phosphorus is also found in human urine and faeces, with the largest fraction found in urine.

Human urine contains the major proportion of nitrogen, phosphorus and potassium in black-water (the fractions are shown in Figure 1). If the nutrients in urine were recycled as fertilizer, this would decrease the world's reliance on non-renewable resources for chemical fertilizers, as well as energy usage for production (Spångberg et al. 2014).

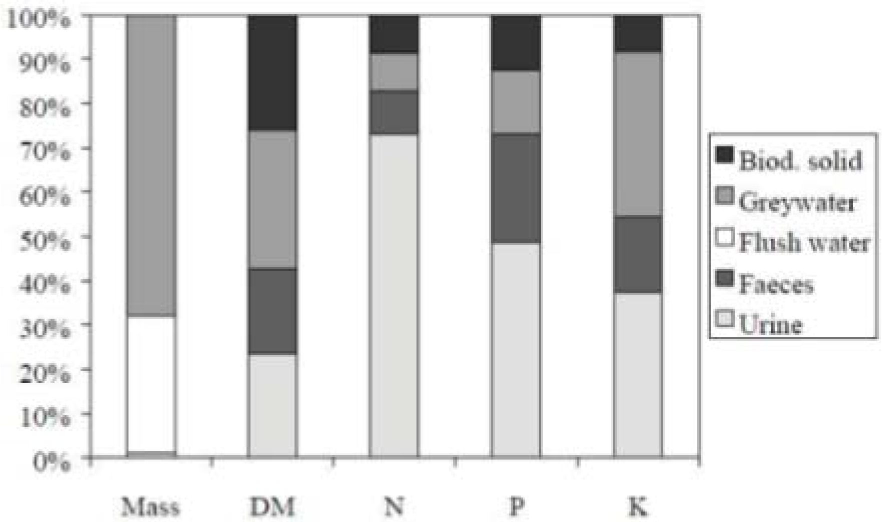


Figure 1 - Distribution of nutrients and organic matter among domestic wastewater fractions (Vinnerås 2001)

EcoSan is an abbreviation of ecological sanitation, which involve systems that use less water for toilet flushing, separate urine and faeces at the source and, with some systems, human excreta is composted and can be used as soil conditioner or toilets can be connected to a biogas reactor (Nienhuys 2012). These systems recycle nutrients such as nitrogen, phosphorus and potassium, which are critical in perpetuating soil fertility and plant growth. The nutrient cycle is depicted in detail in Figure 2. However, due to uneven geopolitical distribution of phosphate rock resources, people are often unable to afford phosphorus in developing countries, but with the utilisation of EcoSan technologies, dependence on this non-renewable commodity can be reduced (Scholz et al. 2013).

In addition, EcoSan toilets are often decentralised and do not require "a complete city sewerage system" (Nienhuys 2012). Toilets connected to centralized sewage systems often have a tendency to empty directly into rivers, which can lead to increased algal growth that can deplete levels of oxygen, causing eutrophication of surface water (WaterAid 2008a). Unimproved decentralised toilets such as pit toilets can also cause pollution, as the pit contents can leach into the groundwater, increasing the risk of disease (WaterAid 2008a). EcoSan has the potential to solve these problems, as long as human urine and excreta are properly managed and stored long enough for hygienization to occur to ensure that pathogens die off.

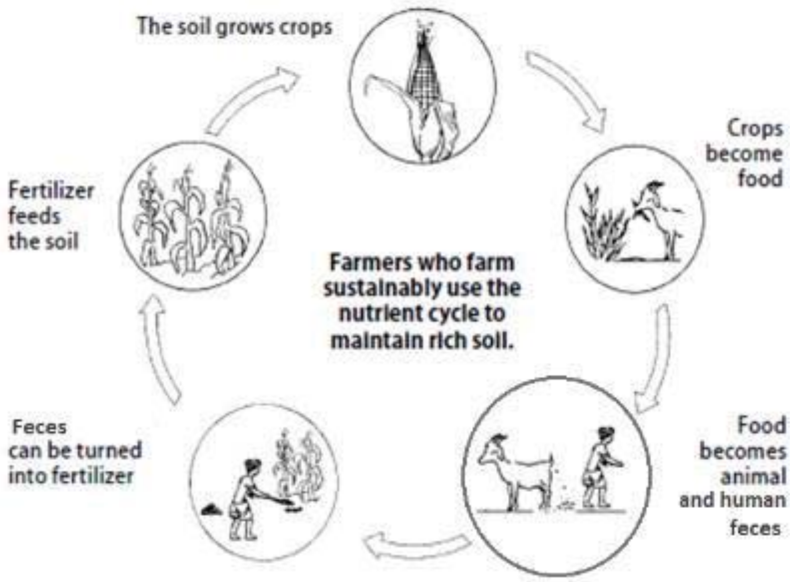


Figure 2 - How farmers use the nutrient cycle to maintain soil fertility (Edited from Conant and Fadem 2008)

2. Background Information

2.1. Geography, geology and hydrogeology

Nepal is a land-locked country located in South Asia, bordered by India to the west, east and south, and China to the north (Karan 2016). The total land area is 147,181 km^2, which is divided into three main agro-ecological regions, as shown in Figure 3: the low lands of the Terai in the south, the mid-hills in the centre of the country and the high northern mountains towards the northern border, comprising 23%, 42% and 35% of the country's land area respectively (Singh 2014). Nepal consists of five development regions, which are divided into 14 zones and 75 districts. Each of these districts are further divided into Village Development Committees (VDCs) and municipalities, which are, in turn, divided into wards (ICIMOD 2003). Lamjung District is located in the Western Development region, in the Gandaki zone.

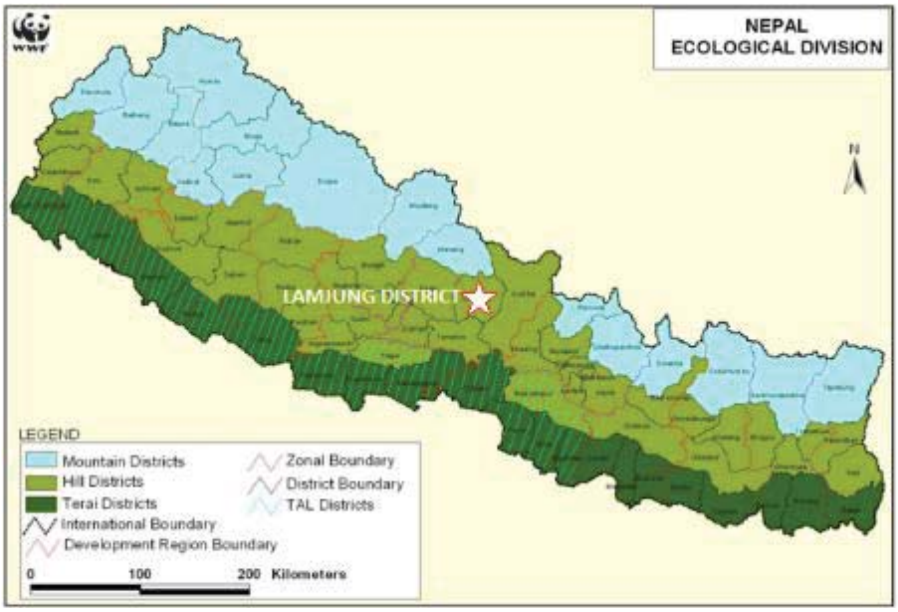


Figure 3 - Ecological regions of Nepal (Modified from WWF 2006)

Nepal can also be divided into five physiographic regions, which have similar elevation ranges: below 500 m are the Terai flatlands, between 500–1,000 m is the Siwalik region, 1,000–3,000 m are the Middle Mountains, 3,000–5,000 m are the High Mountains, and above 5,000 m is the High Himalaya region (Singh 2014).

Lamjung District, which has a total land area of 1,692 km^2 (NPHC 2011), is located in the mid-hills region of Nepal, and spans the Middle Mountains, the High Mountains and the High Himalaya physiographic zones (MoSTE 2014), as shown in Figure 4.

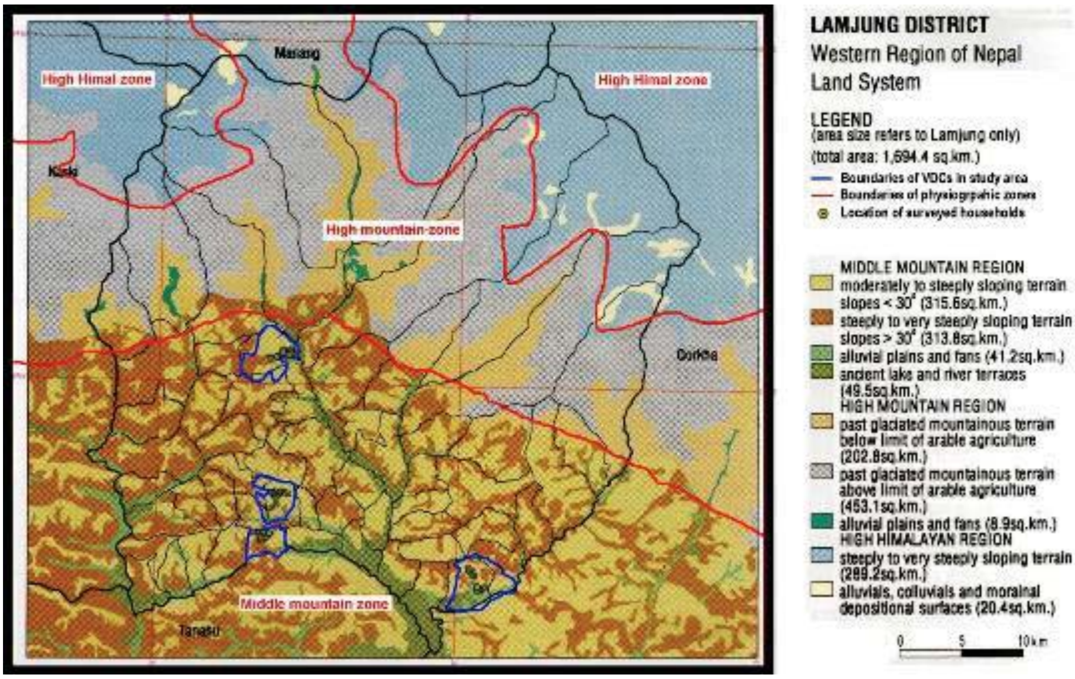


Figure 4 - Land type and physiographic zones of study area, (Modified from ICIMOD 1996) to include more recent VDC boundaries for the four areas surveyed in the study and the physiographic zones from (MoSTE 2014)

The four VDCs in the study area are all located in the Middle Mountain zone, although some households in both Charkratirtha and Simpani lie at lower elevations between 500-1,000 metres above sea level (m.a.s.l.), which is more typical of the Siwalik region. Land types are also shown in Figure 4, and it can be seen that most of the households surveyed in Chandreshwor, Chakratirtha, Kunchha and Simpani are located either in the 'moderate to steeply sloping' terrain (light yellow), or 'steeply to very steeply sloping' terrain zones (orange). However, houses in Saatbise bazaar, in Chakratirtha, are located in the alluvial plains and fans zone (light green).

In terms of geology, five major tectonic zones form bands running east to west across Nepal, as shown in Figure 5. These are: the Terai zone, the Siwaliks zone, the Lesser Himalaya zone, the Higher Himalaya zone, and the Tibetan-Tethys-zone (Dahal 2010).

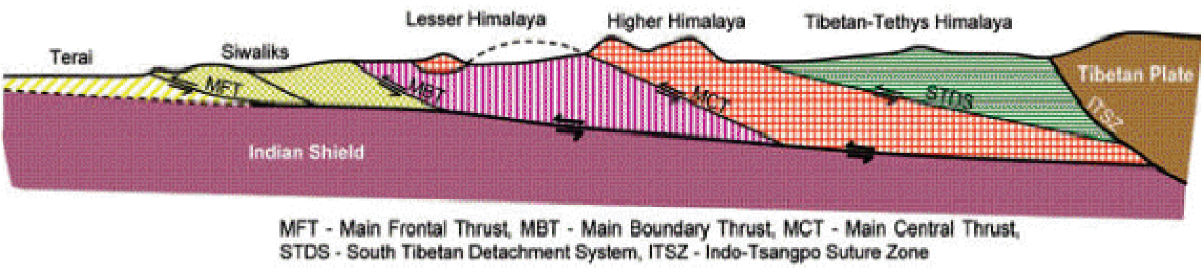


Figure 5 - Tectonic zones of Nepal (Dahal 2006)

Our study area, Lamjung District, is located in the Lesser Himalaya tectonic zone (Upadhyaya 2011). The geology consists mainly of sedimentary and meta-sedimentary rocks including limestone, schist, phyllite, dolomite slate and quartzite, with some granitic intrusions (Dahal 2010). Based on Figure 6, these indicate that the hydrogeology of this area consists mainly of Consolidated Sedimentary Aquifers (CSA), with some Weathered Crystalline Basement (WCB) aquifers, meaning that the ground water storage capacity ranges from medium to very large, and the groundwater flow potential varies from minor to major.

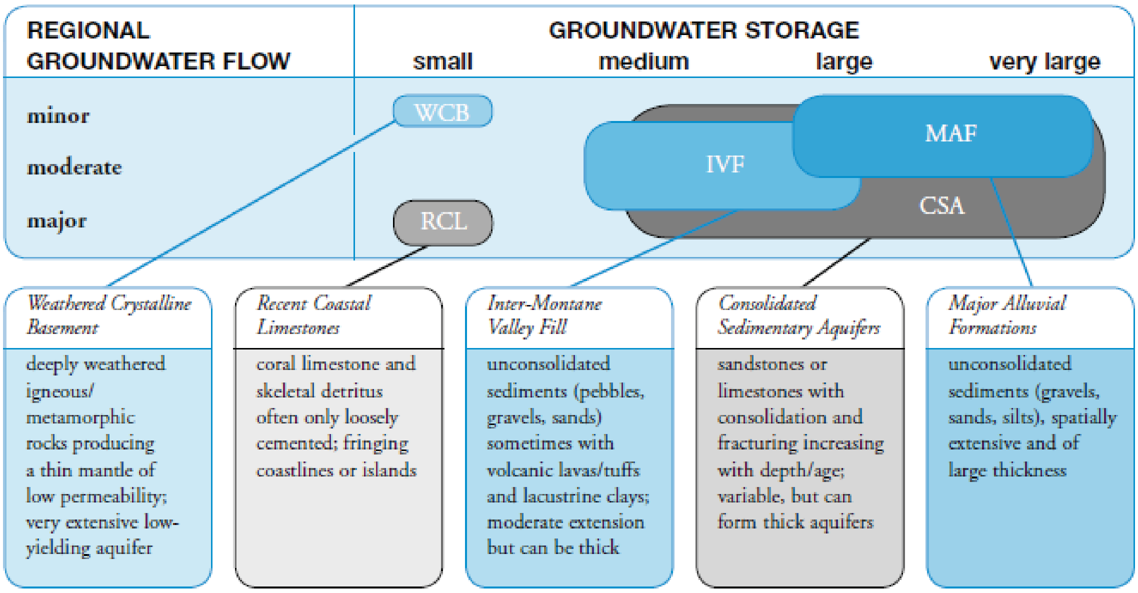


Figure 6 - Summary of key properties of the most widely-occurring aquifer types (Tuinhof et al. 2003)

This large variation in groundwater storage capacity and flow potential across the region is one of the factors which explains the varying discharges of the shallow groundwater aquifer-fed springs in the mid-hills, which are the main source of water for this region (ICIMOD 2015b). However, the size of the aquifer, and the location in the aquifer's watershed at which the spring emerges and is tapped also has a large influence on its discharge. Furthermore, the water level in these shallow aquifers fluctuates throughout the year due to the monsoonal nature of the climate. This means that some springs are located above the water table during the dry season and hence do not flow at all (ICIMOD 2015b). An example of the fluctuating groundwater level throughout the year is depicted in Figure 7. Ultimately, the flow of a spring is governed by the catchment area, rate of percolation through the ground, thickness of the ground above the aquifer and the storage capacity of the soil (Jordan 1984). Characteristics of the soil, in combination with the slope, provide information on infiltration, drainage, soil moisture retention capacity, organic matter content and stability (Pariyar 2008).

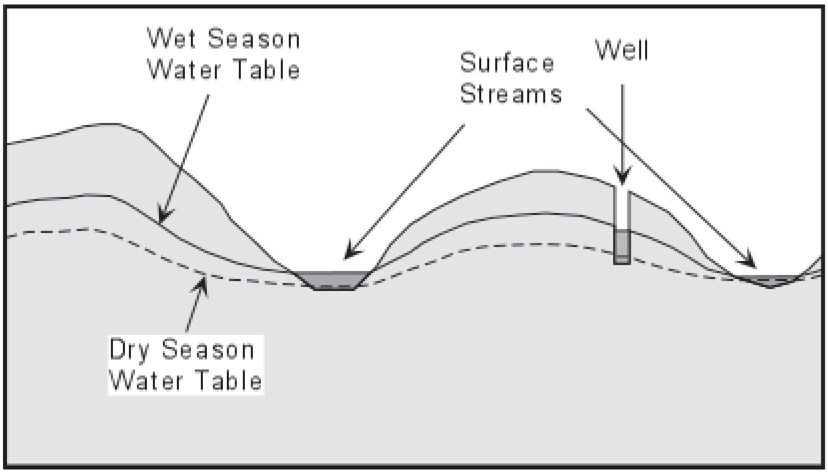


Figure 7 - Water table fluctuation during the wet and dry seasons (Nelson 2015)

Springs and small spring-fed streams are the most common water sources in the mid-hills, but they are not the only source of water in Nepal. Rivers are plentiful (Worldmark 2007), and as a result, surface water is also used as a drinking water source. However, the discharge of rivers fluctuates drastically from the monsoon to the dry season. This causes flooding and landslides during one part of the year, and water scarcity during another (ADB and ICIMOD 2006). In the middle mountains and the Siwalik region, where Lamjung District is located, an excess of water from monsoon-fed rivers and springs, combined with steep topography and the geology, commonly causes landslides and erosion of agricultural land during the wet season (Shah 2008). The risk varies depending on the type of rock and the slope of the hills (Dahal 2010). On the other hand, there is insufficient water for irrigation in the dry season (Singh 2014).

2.2. Caste system

Although the caste system was abolished in 1963 and discrimination based on caste is now illegal in Nepal (Jodhka 2008), there are still clear social distinctions between the various castes, which have implications for their socio-economic status (DFID and World Bank 2006). The castes can be broadly grouped into the categories in Table 3 below. Figure 8 shows how the various ethnic groups fit into the four traditional caste groups in descending order of their social status.

Table 3 – Caste or ethnic groupings (Modified from DFID and World Bank 2006)

% Total population	GSEA/NLSS (10 groups)	2001 National Census (103 groups)
Hindu caste groups (57.5%)	1. BC (Hill)	Brahman, Chhetri, Thakuri, Sanyasi
	2. BC (Tarai)	Kayashta, Rajput, Baniya, Marwadi, Jaine, Nurang, Bengali
	3. Tarai Middle Castes	Yadev,Teli, Kalwar, Sudi, Sonar, Lohar, Koiri, Kurmi, Kanu, Haluwai, Hajam/Thakur, Badhe, Rajbhar, Kewat Mallah, Numhar, Kahar, Lodha, Bing/Banda, Bhediyar, Mali, Kamar Dhunia
	4. Dalits (Hill)	Damai, Sarki, Gaine, Badi, Kami
	5. Dalits (Tarai)	Chamar, Musahar, Tatma, Bantar, Dhusadadh/Paswan, Khatway, Dom, Chidimar, Dhobi, Halkhor, Unidentified Dalit
Janajatis (37.2%)	6. Newar	All Newari Castes
	7. Janajatis (Hill)	Magar,Tamang, Rai, Gurung, Limbu, Sherpa, Bhote, Walung, Buansi, Hyolmo, Gharti/Bhujel, Kumal, Sunuwar, Baramu, Pahari, Adivasi Janajati, Yakkha, Shantal, Jirel, Darai, Dura, Majhi, Dunuwar, Thami, Lepcha, Chepang, Bote, Raji, Hayu, Raute, Kasunda
	8. Janajatis (Tarai)	Tharu, Dhanuk, Rajbanshi, Tajpuriya, Gangai, Dhimal, Meche, Kisan, Munda, Santhal/Satar/Dhangad/Jhangad, Koche, Pattarkatta/Kusbadiya
Muslims (4.3%)	9. Muslims	Muslim, Churoute
Others (1%)	10. Others	

Note 1: Table modified from (DFID and World Bank 2006) and simplified for clarity
Note 2: Janajatis is a word describing the indigenous people of Nepal (Jha 2004)

Figure 8 – Caste or ethnic grouping pyramid for Nepal (DFID and World Bank 2006)

The lowest caste on the pyramid, the Dalit population, have been historically marginalised and vulnerable, as have the very poor and women. Especially in the hills and mountain regions, there is a clear trend that Dalit and indigenous (Janajati) people are more at risk of poverty than the rest of the population (Gentle et al. 2014).

2.3. Health

The spread of disease in developing countries could be reduced through better access to safe water supply, adequate sanitation facilities for the safe management of human excreta, and better hygiene practices (Shah 2008). Water-related diseases are among the top ten leading diseases in Nepal (Shah 2008). Different types of water-related diseases fall into the following categories: faecal-oral diseases, strictly water-washed diseases, water-based diseases, water-related insect vector diseases and chemical contamination (LSHTM/WEDC 1998). The transmission routes, as well as the appropriate placement of barriers to prevent transmission of faecal-oral diseases are shown in Figure 9. In developing countries, “hindering the transmission of communicable diseases” results in benefits to health (LSHTM/WEDC 1998). This is important, as waterborne diseases such as diarrhoea, dysentery, cholera, and typhoid caused by the consumption of contaminated water, and water-washed diseases such as worm infestation and skin diseases caused by poor sanitation, account for 18% and 27%, respectively of the total outpatient department visits in Nepal (Shah 2008).

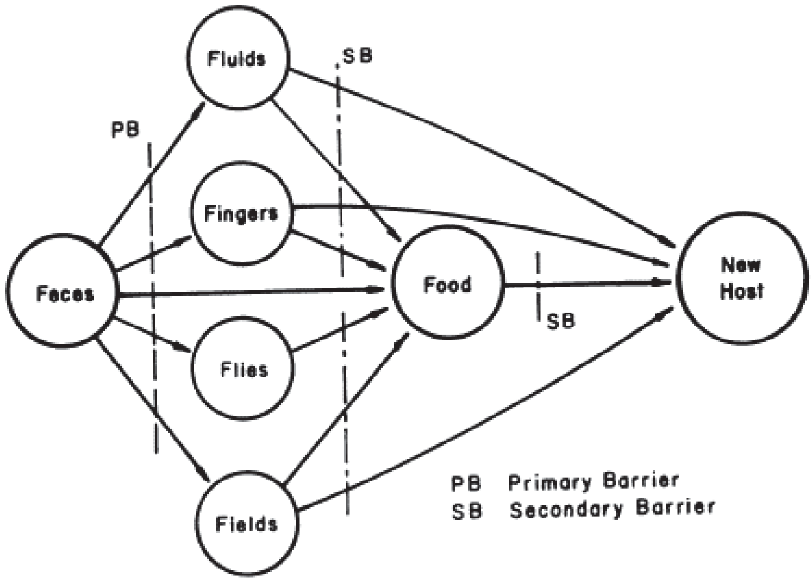


Figure 9 - Transmission routes for disease from faeces (Kawata 1978)

In general, children are the most vulnerable group to faecal-oral diseases and are the main reservoirs of infection, meaning that they are likely to carry disease-causing organisms (LSHTM/WEDC 1998). The Department of Health Services in Nepal and the Environment and Public Health Organization (ENPHO) found that “about one third of deaths of children below the age of five in the rural regions of Nepal were due to waterborne diseases such as cholera, typhoid fever, dysentery and gastro-enteritis” (Pradhan et al. 2005). This is reflected in Table 4, showing the overall life expectancy and mortality of infants, as well as estimates of the number of deaths among children under five years old for Nepal, South-East Asia and the world. According to a 2008 report that looked at WASH capacity by mapping zones of Nepal, the zone including Lamjung District has 51.45% infant mortality rate and 15.6% incidence of diarrhoeal disease per child under five per year (Shah 2008).

Table 4 – Life expectancy and mortality, and estimates of the number of deaths among children under five years old (WHO 2015)

	Infant mortality rate (probability of dying by age 1 per 1000 live births)			Under-five mortality rate (probability of dying by age 5 per 1000 live births)			Distribution of deaths caused by diarrhoea among children aged <5 years (%)	
	1990	2000	2013	1990	2000	2013	2000	2013
Nepal	98.8	60.4	32.2	142.3	81.9	39.7	10	7
South-East Asia Region	83.6	61.3	37.3	118.3	83.4	46.9	14	10
Global	62.7	53.0	33.6	90.2	75.8	45.6	13	9

2.4. Climate

In recent years, Nepal has been experiencing impacts of climate change with "increasing temperatures, erratic rainfall and the unpredictable onset of monsoon seasons, which has led to an increasing vulnerability to glacial lakes outburst floods, and experiences of droughts, floods and landslides" (Gentle et al. 2014). The climate in Nepal varies dramatically with elevation, and as such it spans eight ecological zones: lower tropical, upper tropical, sub-tropical, temperate, sub-alpine, alpine, Trans-Himalayan, and Nival/arctic (Singh 2014). Similarly, precipitation varies with elevation, as well as with the seasons (ICIMOD 2003).

Around 80% of the yearly precipitation falls during the monsoon season, between June and September, resulting in a long dry season for the rest of the year (ICIMOD 2003; Worldmark 2007). The Department of Hydrology and Meteorology provided the authors with the average monthly rainfall over the span of 12 years for Kunchha and Simpani, as shown in Table 5. There was no data available for Chandreshwor and Chakratirtha. From this, it can clearly be seen that the monsoon season takes place between June and September, and this uneven temporal distribution results in water scarcity for half of the year and flooding during the other half.

Table 5 - Average monthly rainfall from 2001 to 2012 in mm (Nepal)

VDC	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Kunchha	16,6	38,4	53,1	126,5	276,3	499,7	655,6	555,0	364,0	85,1	8,8	5,8
Simpani	28,6	46,2	67,8	139,6	213,3	576,4	896,3	761,2	446,2	109,2	5,1	5,8

Based on maps from a study by the International Centre for Integrated Mountain Development (ICIMOD), while Lamjung District spans the subtropical, warm temperature, cool temperate, alpine and arctic zones, the VDCs within our study area are located in the subtropical and cool temperate zones (1996). The average temperatures for the study area, presented in Table 6, were obtained from the Department of Hydrology and Meteorology's *Agro-climatic Atlas of Nepal (2014)*. Temperature is important when considering the optimisation and use of biogas reactors, as will be discussed further in section 6.3.1.

Table 6 - Seasonal temperatures in the study area: (Modified from MoSTE 2014)

Season	Months	Average temperature range (ºC)
Pre-monsoon	March to May	20-24
Monsoon	June to September	24-28
Post-monsoon	October to November	16-24
Winter	December to February	12-16

3. Lamjung District

3.1. Location

The study area includes four VDCs in Lamjung District of Nepal, which is located in the mid-hills region (see Section 2.1). The VDCs visited were Kunchha, Chandreshwor, Chakratirtha and Simpani, and multiple wards were surveyed within each of these. The distribution of the households surveyed across Lamjung District is shown in Figure 10.

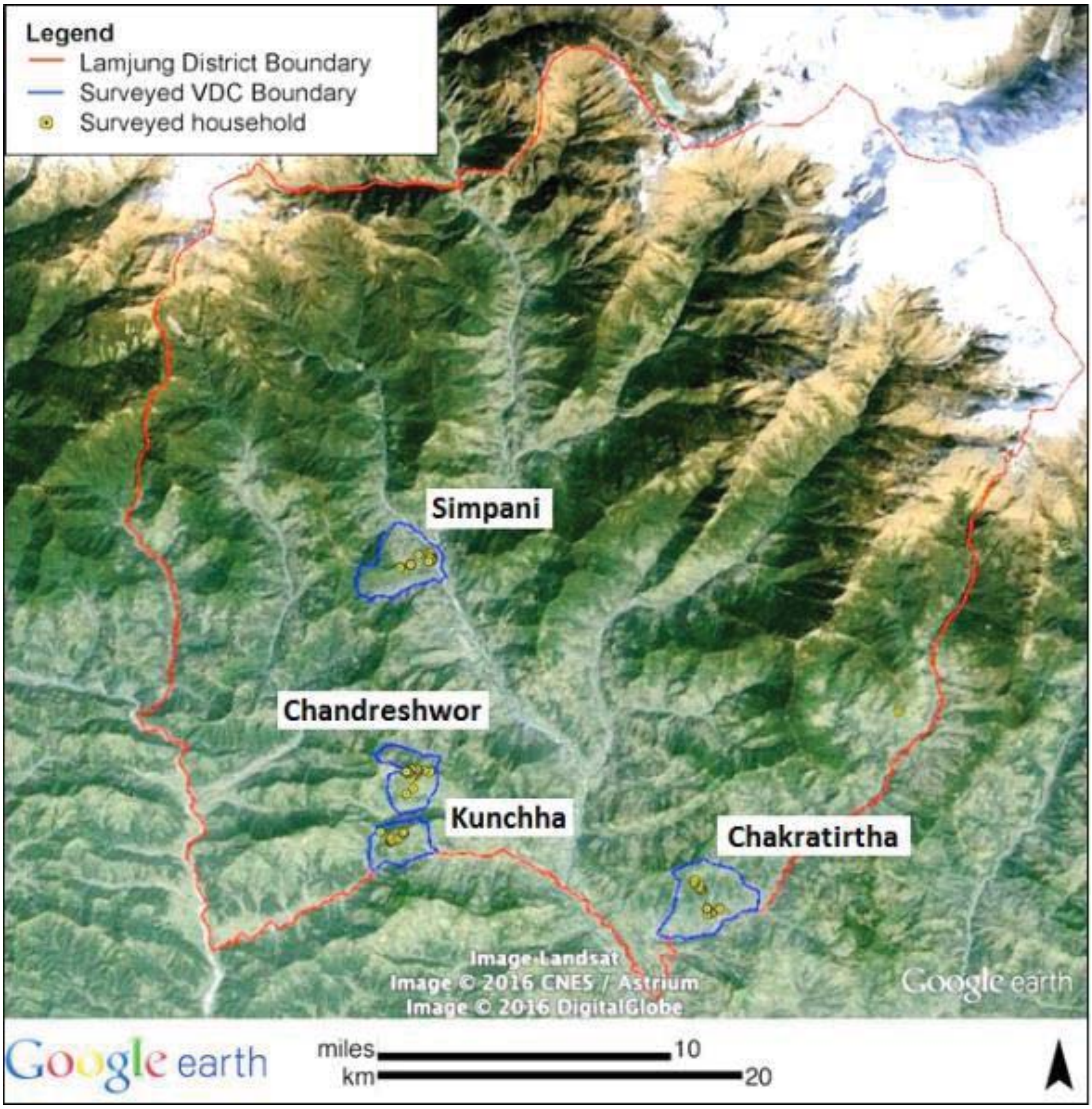


Figure 10 – Map of GPS coordinates of surveyed households (created in Google Earth by the authors)

3.2. Demographics

The Central Bureau of Statistics of Nepal reported the population of Nepal to be 26,494,504 and the population of Lamjung District to be 167,724 in 2011. The number of households in Nepal in 2011 was 5,423,297 with 4.88 people per household and the number of households in Lamjung District was 42,048 with 3.99 people per household (Nepal 2014; NPHC 2011). Table 7 shows the demographics of all VDCs surveyed as per the 2011 Census. Of the total population in Nepal, 50% live in the Terai districts, 43% in the hill districts and 7% in the mountain districts (NPHC 2011). Only 17% of the total population live in urban areas, hence 83% live in rural areas (NPHC 2011). Wealth is unevenly distributed geographically, with poverty rates above 40% in the far western and mid-western regions and the mountain districts (ADB 2015b). With approximately a quarter of its population living below the poverty line, Nepal is ranked as one of the poorest countries in the world (CIA 2013).

Table 7 - Demographics of each VDC surveyed according to the 2011 Census (Nepal 2014; NPHC 2011)

VDC	Population	Households
Kunchha	1855	514
Chandreshwor	1958	546
Chakratirtha	5011	1253
Simpani	3289	820
Total	12113	3133

Agriculture, including farming, fishing, and forestry, contributes 31.7% of the national GDP, and employs 69% of the labour force. Industry, which includes mining, manufacturing, energy production, and construction, contributes 15.1% and employs 12% of the workforce. The services sector, which includes government activities, communications, transportation, finance, and “all other private economic activities that do not produce material goods” is the largest contributor to GDP, contributing 53.2% of GDP (information from 2010 data) and employing 19% of the labour force (CIA 2013). However, the services sector also includes remittance from overseas work, which makes up close to 29% of the national GDP (CIA 2013).

4. Research Methods

4.1. Survey

4.1.1. Design and validation

This study focused on investigating the current water and sanitation situation in Lamjung District and the main issues facing the region from a local perspective, in order to suggest possible solutions to these issues based on our research and relevant literature. The survey used in this study was a result of five months of research, trial and error. The survey was designed with reference to *Designing household survey questionnaires for developing countries: lessons learned from 15 years of the Living Standards Measurements Study: Volume three*, a book compiling 15 years of experience designing household surveys in developing countries by The World Bank, and a report for household surveys by the World Health Organization (WHO) and UNICEF. The draft was reviewed by the project coordinator of the Environmental program at the Institute of Engineering at Tribhuvan University and three members of a village in Dhading District before it was altered and translated into Nepalese.

A pre-test of this survey was undertaken in a village in Dhading District where it was administered in three face-to-face individual interviews, a focus group with 13 men and a focus group with 14 women. After the administration of the pre-test, a condensed survey was developed for validation. This survey was validated by our supervisors and before a class of 13 Master's program students in their first year at the Environmental Institute of Engineering at Tribhuvan University: 12 male and one female. Their contribution provided constructive criticism with respect to cultural sensitivities and the local perspectives, and ensured proper understanding of the questions amongst local people in rural regions.

After validation, a final version of the survey was generated, consisting of 30 close-ended questions that were divided into five sections: General, Water, Sanitation, Agriculture and Opinionated Response. This final survey was translated into Nepalese and administered in four different VDCs in Lamjung District. The full survey is attached in Appendix D.

4.1.2. Implementation

The implementation of the final survey took place in Lamjung District over the course of ten days, on two separate trips, with visits to Kunchha and Chandreshwor from March 1-5, 2016 and to Chakratirtha and Simpani from March 10-14, 2016. Surveys were administered by the authors, while working in collaboration with four Peace Corps Volunteers (PCVs) and two native Nepali speakers, who were used as interpreters throughout the course of this study, with one accompanying us on each trip. A photo of the administration of a survey is shown in Figure 11.

Figure 11 - Giving a survey in Kunchha with the help of one of our interpreters (photo taken by a PCV)

In total, 50 surveys were carried out: 11 in Kunchha, 15 in Chandreshwor, 14 in Chakratirtha and 10 in Simpani. Each survey consisted of an individual face-to-face interview with one member of a randomly selected household. The interviews were both structured and semi-structured, depending on the questions. All of the questions were read aloud by one of the interpreters from a translated script and diagrams were used as aids to describe some of the technology explained in the Opinionated Response section, such as rainwater harvesting, EcoSan toilets and biogas systems.

4.1.3. Data analysis

Answers from the survey were first entered into Microsoft Excel. Mean values were calculated for numerical data variables, and they were also grouped into ranges so that they could be analysed with the categorical data. The original categorical variables were coded into variables with fewer categories, to facilitate statistical analysis. See Appendix A for a detailed description of the coding used. Descriptive statistics for key variables were produced, which are presented as bar graphs, pie charts and a scatter plot in the body of this thesis.

Minitab 16 was used for a more detailed statistical analysis of the data. The relevant data was exported into Minitab, and response variables were cross-tabulated against possible predictor variables. The Likelihood ratio Chi Squared Test was used to identify statistically significant correlations in the data, which were defined as those with a 90% confidence interval (p-value > 0.1), as in most cases the aim was to look for key trends rather than direct linear correlations between data sets. Based on the census data there were a total of 3,133 households in the four surveyed VDCs in 2011 (NPHC 2011), and our study surveyed 50 of these households. With a confidence level or level of certainty of 95%, and a prevalence of 0.5 (i.e. assuming that for questions with two answers, half of the population would chose each answer, which is the worst case in terms of sample size), our sample size of 50/3,133 gives a confidence interval of 86% for all our correlations (CUHK 2015). This means that there would be, at most, a 14% chance that any correlation found was simply due to random chance, which must be considered when drawing conclusions from the correlations found between variables. This confidence interval will not be repeated throughout the document, but is implicit in the definition of a correlation within this study.

As many of the relationships between variables were not linear, Simple Correspondence Analysis was conducted on all significant correlations and presented as asymmetrical plots and graphs to describe the relationships, with missing data excluded from the analysis. Simple Correspondence Analysis was selected as it is a simple way to visualise the associations between categorical variables with multiple categories. It is a method used to show which combinations of categorical groups most strongly disprove that there is no correlation between the two variables (the null hypothesis), and hence contribute the highest value to the total Chi-Square value. The method and theory behind the interpretation of these asymmetric plots and graphs, as well as a detailed analysis and the asymmetric plots and graphs from correlations performed in this study are included in Appendix B. The summaries of what was found is presented in Section 6, Further Results and Discussion.

4.1.4. Research ethics

To ensure that participants understood the study before consenting to participate and did not experience any negative consequences, each interpreter was instructed to introduce themselves, the nature of the study and to explain what each participant was volunteering for prior to involvement in the survey. In addition, the interpreters were instructed to ask the participants for their consent to take part in the study.

4.2. Field Investigation

4.2.1. Observations

Aside from administering the survey, observations were also documented with respect to the housing material of each household and the level of hygiene. For every household, photographs were taken of the house and toilet structure. These photos were examined to determine the composition of the building, foundation, roof, windows, number of storeys, balcony, whether or not the house was painted and features of the toilet. However, the roof material was excluded, as it was not a good indicator of wealth when compared to the other indicators.

These records were used to rank households in order of wealth. This method was considered more accurate than using occupation or land ownership as a measure of income due to the following example: a shopkeeper may not own any land for cultivation, but could make more money than a small-scale farmer, while on the other hand, a successful farmer may earn more than a shopkeeper. The coding used is described in Appendix A.

On the second research trip, to Chakratirtha and Simpani, hygiene observations were documented to determine if participants had a handwashing station, had soap available for handwashing and kept the storage container for their water supply covered.

4.2.2. GPS coordinate data and elevations

A handheld Garmin E-trex 10 was used to take coordinates at each surveyed household. As it only has an accuracy of 15 metres (Garmin 2005), the locations of the households were adjusted based on the satellite image after being imported to Google Earth, to improve accuracy. Elevations were taken from Google Earth after the household locations were adjusted.

4.2.3. Water sampling

Coliform presence/absence test vials based on the 'Manja et al. hydrogen sulphide principle' were used as an on-site method for detecting the presence or absence of coliform contamination in drinking water sources. These vials work by observing "an iron sulfide precipitate on a paper strip (or in the water sample liquid) in a bottle or test tube, as a result of the reaction of H_2S with iron" (Sobsey and Pfaender 2002). Advantages of this test include: low-cost, materials found locally, no refrigeration required, incubation occurs at room temperature and ease of use (Mosley and Sharp 2005). Disadvantages of this test include: false positives coming from sulphides of a non-faecal bacteria origin as some coliforms are naturally occurring in the soil, meaning that only an indication of the risk of the water containing pathological bacteria and not the actual degree of risk is found.

The test vials were purchased in Kathmandu from ENPHO, a service-oriented, scientific, national non-governmental organisation (ENPHO 2014). Samples were kept at room temperature for at least 48 hours prior to examination. In the samples where the water turned black after 48 hours, this indicated the presence of coliforms.

A total of 22 coliform presence/absence tests were performed including a single control that was taken from bottled water in Kathmandu that underwent UV treatment, 20 samples gathered from tap stands in Chakratirtha and Simpani and one sample was taken from the original spring source with distribution to four of the tap stands sampled.

4.3. Limitations

4.3.1. Survey

A significant limitation is that the fieldwork was conducted by two foreign students who do not speak the local language in Nepal, potentially leading to misinterpretation and the inability to ask questions for clarity. The use of two interpreters instead of one for all four VDCs resulted in slight inconsistencies of translations, as their backgrounds differed. Due to logistical limitations with the number of researchers available, remoteness of VDCs, local bus schedules, and timeline for fieldwork, the number of households surveyed was lower than the desired sample size. The level of education of the participants involved could have had an impact on their ability to understand some of the questions, leading to misinterpretation. This is likely, as the average literacy rate for males and females is 43% and 57%, respectively (NPHC 2011). In addition, participants' answers may have been influenced due to the researchers being female and foreign, the caste and/or gender of the interpreters and other factors that may have not been evident to foreigners. The researchers were informed by the local PCVs that foreign NGOs have undertaken projects and surveys in this region in the past and that, understandably, as a results participants may have exaggerated the issues they were facing in order to maximise the chance of receiving foreign aid, despite being informed that this was only a study for a Master's thesis.

4.3.2. Data analysis

The limitations involved in the statistical analysis related to various constraints with the chosen statistical method and with having a small sample size. As outlined in section 4.1.3, the sample size of 50 households out of 3,133 in the study area results in a (worst case) confidence interval of 86% for our correlations, meaning that that there would be, at most, a 14% chance that any correlation found was simply due to random chance (CUHK 2015). However, as this study aimed to find general trends of issues in the region and possible solutions to them, this is considered a sufficient level of certainty to warrant reporting. Furthermore, our research was both qualitative and quantitative in nature. In qualitative research there are "no rules" about sample size, as it is considered more important to collect rich and accurate data than the statistically significant sample size of responses (Hardon et al. 2004).

Furthermore, the nature of Simple Correspondence Analysis means that a relationship is considered statistically significant when any two or more categories (answers) from the two variables (questions) being compared have a statistically significant correlation. This does not necessarily mean that the two variables themselves are directly correlated, for example one or more income categories may be strongly associated with a certain water service level, while other income categories in the same analysis are not strongly associated with any particular water service level. As long as one category has a strong enough association with another, the correlation is considered statistically significant. To overcome this, the detailed interpretation of the asymmetric graphs and bar charts, presented in Appendix B, was undertaken to fully understand and describe each of the relationships that were found with confidence intervals greater than 90%. As the Simple Correspondence Analysis is used for categorical data, and cannot be used when the variables contain more than 3 or 4 categories, answers to the survey questions were simplified as described in Appendix A, leading to a loss of information and accuracy.

4.3.3. Water sampling

The use of the hydrogen sulphide principle has limitations in itself, as some coliforms naturally occur in the soil and this test only indicates a presence or absence of coliforms and no distinction as to whether those coliforms are naturally occurring or of a faecal origin. Meaning, the test kits used can give false positives coming from sulphides of a non-faecal bacteria origin (Mosley and Sharp 2005). Despite the limitations of this method, it was selected because site visits took place for more than 24 hours, with no refrigeration facilities available, meaning samples could not be preserved long enough to be analysed in a laboratory.

Limitations within the scope of the water sampling also include the fact that water samples were not taken in all of the VDCs. Some of the samples were taken at night, with limited visibility which made it difficult to be sure the sample was sealed without contamination. Due to lack of indoor heating, the length of bus rides and the general temperature of the day, there was no guarantee that the samples were kept at a constant room temperature, as recommended on the test kit instructions.

5. Results

5.1. Survey demographics

The total number of households surveyed was 50, with an average of 4.6 people per household and an average participant age of 44.4 years old. The full survey demographics are shown in Table 8.

Table 8 – Survey demographics

VDC	No. households surveyed	Average no. people per household	Average age
Kunchha	11	5.2	43.0
Chandreshwor	15	4.5	38.7
Chakratirtha	14	4.8	47.1
Simpani	10	3.9	48.8
Total/Average	**50**	**4.6**	**44.4**

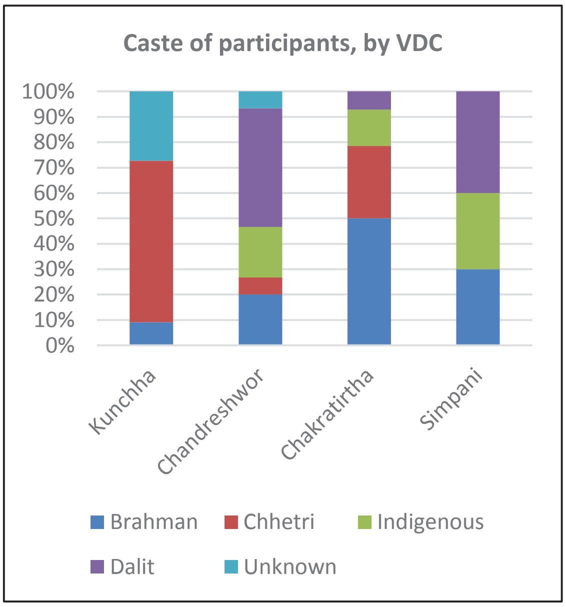


Figure 12 - Caste of participants in all VDCs surveyed

Members of several different castes were interviewed, including Brahman, Chhetri, Indigenous, Dalit and some that were unknown. As previously explained, the caste system is a hierarchy that creates distinctions for each caste that includes their socio-economic status. The results showed more members of the Brahman and Dalit, the ‘high’ and ‘low’ castes, respectively, across all VDCs surveyed. Figure 12 shows the proportion of members of each caste living in all surveyed VDCs.

All households surveyed reported farming as an occupation, except one that was solely a small business owner. Farming was the sole occupation for 32% of the households, while 60% also listed occupations or income sources as remittance, pension, owning a small business, retirement, hosting a PCV, government employment, and health volunteer.

5.2. Statistical analysis

Results from the correlation analysis are presented in the matrix below in Figure 13, and are discussed in Section 6.

	Demographics				Water															Sanitation	Agriculture			Opinion			
	Caste	Location	Land ownership	Gender of respondent	Water Service Level	Daily water consumption	Primary water collection method	Water collection method (all sources)	Primary water distribution method	Original water source	Water quality (rainy)(all sources)	Used for drinking	Level of treatment (all sources)	Level of treatment (primary)	Presence of waterborne diseases	Source continuity (all sources)	Time to source 1-way (all sources)	Time to collect water (all	Water supply responsibility	Biogas ownership	Irrigation method	Chemical fertiliser usage	Animal ownership	Opinion of rainwater harvesting	Opinion of biogas	Opinion of urine as fertiliser	Opinion of human excreta as fertiliser
Income	0.001	x	x	.	0.033	x	0.020	x	0.005	x	x	.	0.030	0.028	.	x	x	x	x	x	x	.	.	x	x	x	x
Caste		0.000	x	.	0.041	x	x	x	0.009	x	x	.	x	x	.	x	x	x	x	x	.	.	.	0.066	x	x	0.068
Location			x	.	0.005	x	x	x	0.003	x	0.000	.	0.020	x	0.000	x	0.038	x	x	0.061	0.007	.	.	0.000	0.053	x	0.000
Land ownership				.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	0.025	x	.	.	x	x	x	x
Gender of respondent					.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	0.020	x	0.014
Water Service Level						x	x	.	x	x	.	.	.	0.033	.	.	.	.	x	.	.	.	.	0.069	.	.	.
Daily water consumption							0.041	x	0.006	x	.	.	.	x	.	x	x	x	.	.	.	.	x	x	.	.	.
Primary water collection method								.	0.000	x	x	x	x	x	.	x	.	.	.	.	.	.	.	.	.	.	.
Water collection method (all sources)									.	x	x	x	0.084	.	.	x	.	.	.	.	.	.	.	.	.	.	.
Primary water distribution method										x	x	x	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.
Original water source											x	x	x	x	.	x	.	x	.	.	.	.	.	.	.	.	.
Water quality (rainy)(all sources)												0.049	0.007	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Used for drinking													0.093	0.094	.	x	.	x	.	.	.	.	.	.	.	.	.
Level of treatment (all sources)														.	.	x	x	.	.	.	.	.	.	.	.	.	.
Level of treatment (primary)															.	x	.	.	.	.	.	.	.	.	.	.	.
Presence of diseases																x	.	.	.	.	.	.	.	.	.	.	.
Source continuity (all sources)																	.	.	x	.	.	.	.	.	.	.	.
Time to source 1-way (all sources)																		.	.	.	.	.	.	.	.	.	.
Time to collect water																			.	.	.	.	.	.	.	.	.
Water supply responsibility																				.	.	.	.	.	.	.	.
Biogas ownership																					.	x	x	.	0.000	.	x
Irrigation method																						.	.	0.052	.	.	.
Chemical fertiliser usage																							.	.	x	x	x
Animal ownership																								x	x	x	x

.	The correlation was not investigated
x	No significant correlation found
0.08	Signficant correlation: 90% Confidence Interval
0	Signficant correlation: 95% Confidence Interval

Figure 13 - Correlation matrix

5.3. Field investigations

In addition to administering the survey, observations of housing material and level of hygiene were also documented. This section will outline the results for all of these observations.

5.3.1. Observations

The housing materials that were observed included the composition of the building, foundation, windows, number of storeys, balcony, whether or not the house was painted and features of the toilet. Based on the housing materials mentioned above, the participants were grouped into three categories of wealth: highest income, medium income and lowest income (as described in Appendix A). Figure 14 shows the distribution of these income categories amongst the VDCs. Features of the toilet structures were also observed including the type of pan, flushing mechanism as well as the presence of windows, drains, bins and ventilation pipes. Photos showing examples of the observed housing features are shown in Figure 15.

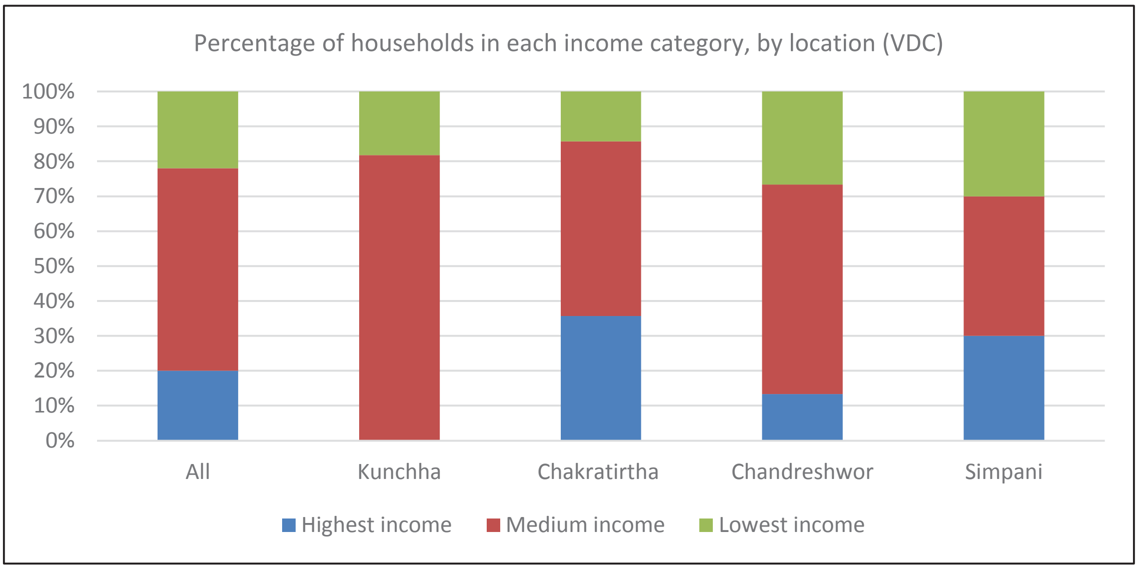


Figure 14 - Income categories of all VDCs surveyed

Foundation: the foundation was made of either concrete or stone and mud	
Windows: made of either glass, metal or wood; the metal was sometimes decorative	
Number of storeys	
Balcony: made of either metal, metal sheeting, wood, with carvings or not and was painted or not or a household did not have a balcony	

Features of the toilet: the superstructure was either inside a household or not and was made concrete, metal sheeting, stone, mud, bamboo or a combination of any of the materials listed

Figure 15 - Housing materials and different features of the toilets observed (photos taken by the authors)

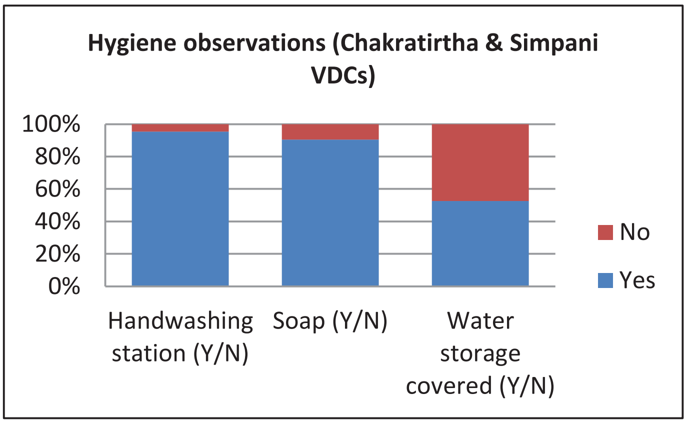


Figure 16 - Hygiene observations

In half of the VDCs in our study, hygiene observations were documented to determine if participants had a handwashing station, had soap readily available for handwashing and kept the storage container for their water supply covered. The results of these observations are shown in Figure 16.

5.3.2. GPS coordinate data and elevations

GPS coordinates were obtained from a handheld GPS and Google Earth (see Section 4.2.2). Locations of the households based on their coordinates can be seen in Section 3.1. The elevation of VDCs affects the climate, distance from services, geology, soil type, farming practices and demographics. Hence, based on the coordinates, the elevations were also recorded. Table 9 shows the proportion of households in each elevation range, by VDC.

Table 9 - Elevations of the study area

	500-750 m.a.s.l.	750-1000 m.a.s.l.	1000-1250 m.a.s.l.	1250-1500 m.a.s.l.
Chakratirtha	43%	29%	29%	0%
Kunchha	0%	55%	45%	0%
Simpani	0%	60%	10%	30%
Chandreshwor	0%	0%	27%	73%

5.3.3. Water sampling

A total of 22 coliform presence/absence tests were performed, shown in Figure 17, with all photos taken by the authors. The control has visibly clear and colourless water, indicating an absence of coliforms and hence that the test kits function as intended, as the control water was taken from bottled water known to be free of contamination. Of the 20 samples gathered from tap stands in Chakratirtha and Simpani, only two showed an absence of coliforms/faecal contamination. The single sample taken from an original spring (which fed a spring box that then fed the community water supply) also detected the presence of coliforms/faecal contamination.

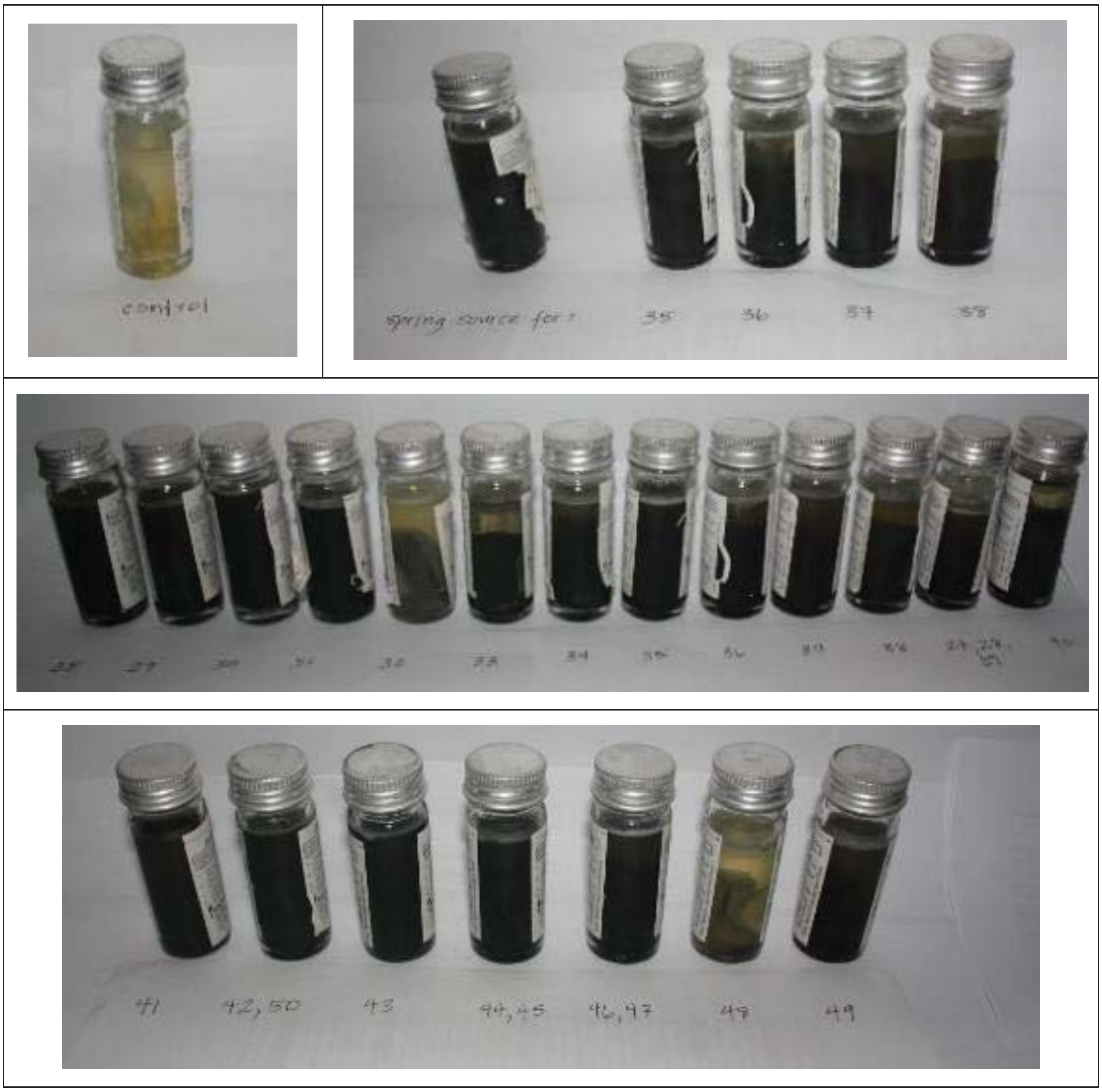


Figure 17 - Control water sample (top left), water sample from original spring source (top right), water samples from tap stands 28 through 40 (middle), water samples from tap stands 41 through 49 (bottom)

6. Further Results and Discussion

The first objective of this thesis to investigate the current status of water and sanitation in Lamjung District. As such, the survey results and observations are presented in this section. Data regarding the agricultural situation is also presented, as this is closely linked to water and sanitation. The second objective is to identify the main water and sanitation related issues facing Lamjung District. Correlations between variables were investigated using the Chi-squared Likelihood ratio in order to determine the factors that make households more vulnerable to these issues, and to better understand the issues in order to find appropriate and sustainable solutions, which is the third objective.

In general, the results from our study have been assumed to be representative of Lamjung District, but it must be noted that the water and sanitation situation in the four VDCs studied may be slightly better than in the overall district. In our study, 98% of houses used an improved water source, that is, they either had water piped to their house or collected it from a communal tap stand, which is 10% higher than the overall percentage of 88% in the district (NPHC 2011). Similarly, 98% of houses in our study had a toilet, while the National Census found that only 81% of households in Lamjung District own toilets (NPHC 2011). However, the census was undertaken 5 years before our study, and in that time the district has been declared ‘Open Defecation Free’ (NWA 2015) and new community water systems have been built, so it is assumed that if a new census was undertaken in 2016 it would likely show improvements in all areas of Lamjung District, including the VDCs in our study area.

6.1. Domestic Water Supply

In our survey, a number of questions were designed to obtain information about the household’s water sources, specifically, about the quality and quantity of water, types of water treatment, activities water was used for, how much time was spent collecting water, and questions about the operation, maintenance and reliability of the source. It was found that many households had alternative sources in addition to their primary water sources, which were used particularly frequently in the dry season when many of the primary water sources do not supply any or enough water. These are referred to as secondary sources, when there was only one additional source, and tertiary sources when the households had three water supply sources.

When researching households' primary water supply sources, it was found that 50% of households have water piped directly to their house from the community water supply, 20% pipe water to their house from a communal tap stand through a hose which they have to connect each time they use it, 28% collect water directly from a communal tap stand, and the remaining 2% request water from their neighbours. Aside from the household which collects water from neighbours, these are all 'improved' water sources as defined in Table 2. Secondary and tertiary sources were mostly 'unimproved' sources such as springs and streams, with a traditional collection system such as a stone spout or *kuwa* (collection tank/pond/shallow well), but not necessarily a pipe or tap or spring protection measures. Examples of these different types of water sources are shown in Figure 18.

Tap stand in Chandreshwor (note the hose/pipe currently connected to a house)	Piped to house – Kuncchha household tap	*Kuwa*/spring source in Kunchha	Stone spout in Chandreshwor
			

Figure 18 - Water source types in Nepal (photos taken by the authors)

Community water supply systems were installed in all VDCs in the study area. These consist of a tank at a high elevation, filled either by spring water or by water pumped from a river at a lower elevation.

Based on the data gathered about water collection and usage, households were divided into service levels, as defined in the joint project between the Governments of Nepal and Finland, the *Rural Village Water Resources Management Project* (RVWRMP 2011). Criteria defining water service level (shown in Table 10) include the quality, quantity, reliability, continuity and location of the household's primary water source. The primary water supply of the households in our survey was categorised as having 'good', 'moderate', 'poor' or 'very poor' service level based on Table 10.

Table 10 - Water service levels (RVWRMP 2011)

Service Level	Average Fetching Time (minutes)*	Quantity (LPCD)	Quality of Water	Reliability (month/year)*	Continuity (hr/day)*
Good (Level-1)	≤ 15	≥ 45	Good, no possibility of contamination	12	≥ 6
Acceptable or Moderate (Level-2)	>15 ≤ 30	≥25 < 45	Moderate,likely to be contaminated	≥ 11 <12	≥ 5 <6
Poor (Level-3)	> 30 ≤ 45	≥ 15 <25	Poor, high chances of contamination	≥ 10 <11	≥ 4 <5
Very Poor (Level-4)	> 45	< 15	Very poor, contaminated and intolerable	< 10	< 4

Note: Fetching time is defined as the total time incurred to go to water collection point, queue, collect water and return back home. Reliability is defined as the amount of months the source runs in a year. Continuity is defined as the amount of hours the source runs per day.

The water service level was used to determine if there are inequalities in access to improved water supply between different socio-economic groups, and the criteria in Table 10 were used as the basis for grouping participant’s answers to the various questions about their water supply.

6.1.1. Issues

A recurring issue for households surveyed in Lamjung District was the accessibility, quantity and reliability of their water supplies. Research by ICIMOD (2015b) confirms that spring sources are the “life-blood” of people living in the mid-hills of Nepal, as their villages are generally located too far above the large streams and rivers that supply water to populations in the low-lands. Spring sources produce a limited supply of water, which varies in discharge throughout the dry and rainy seasons, and are vulnerable to disruption by natural disasters and poor management. In some areas, such as Kunchha, community water supply systems have been installed to pump this water up to tanks which can then become a reliable water source, but for households located in poorer wards the cost of pumping the water uphill is “prohibitively high” (ICIMOD 2015b).

This section discusses the issues households are facing regarding their water supply, which factors influence how much water households use, how much time participants use for water collection, and how reliable and sustainable their water sources are.

Insufficient quantity

Many rural households experience acute water shortages during the dry season, as 85% of the precipitation occurs during the monsoon season, resulting in many consecutive months with little to no rainfall (Merz et al. 2003). In Nepal, the minimum essential amount of water for personal and domestic use per person per day is usually taken as the WHO standard of 45 litres per capita per day (NEWAH 2004; WaterLex 2014).

In our study, each participant was asked to estimate their daily household water usage, which was then divided by the reported number of household members to calculate the per capita daily water usage (excluding water used for irrigation of crops). It is assumed that the answers that were given are for water consumption during the dry season, as this was the season when the survey was carried out and as in the rainy season there is so much water available that it would be hard for the participants to estimate the volume.

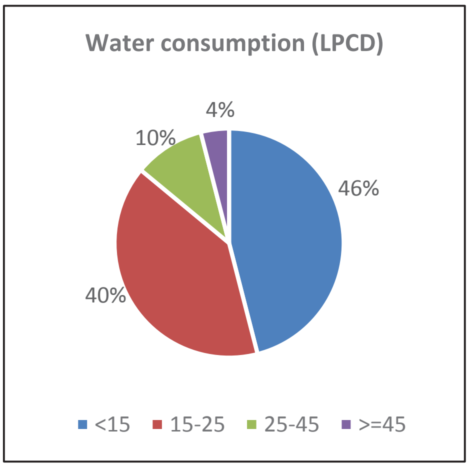


Figure 19 - Daily per capita water consumption in litres

As shown in Figure 19, only 4% of participants reported using more than 45 litres per capita per day, while 86% use under 25 L/day, which is classified as a poor or very poor quantity of water as per Table 10. As many participants reported insufficient water for activities such as flushing the toilets and watering crops, it is assumed that this minimal water usage is due to insufficient water quantity rather than simply being due to the households deciding to use less than 45 litres per person.

Research has shown that the distribution method of the water supply (e.g. collecting and carrying water from a source or having a piped connection) effects the water consumption of the household (LSHTM/WEDC 1998). The research undertaken in our study confirmed this relationship, as the water distribution method of the primary water source had a significant correlation with the household daily water usage (p-value 0.006). The various water distribution methods analysed were: private pipeline connections, households which connect a hose to a public source, and those which carry water from a communal source or from neighbours' houses. In addition, household water consumption was sorted into different groups: less than 100 L/day, 100-200 L/day, 200-300 L/day and over 300 L/day. Out of these groups, households consuming less than 100 L/day were the most likely to carry water from a public source, although it should be noted that 37.5% of households in this group had a private pipeline connection. Similarly, households consuming over 200 L/day were more likely to use a piped connection (either private or piped from a communal tap stand) than households consuming less than 200 L/day.

This is as expected, as households with a piped connection can fill up many or large containers, rather than having to fill containers at the source and carry them home. However, for the 68% of households who had water piped to the house, whether it was piped through a private connection or through a pipe connected to a public source had no significant effect on the household's water consumption. Although it was encouraging to see so many households with piped water connections, it was also observed that households with piped supplies were less careful with their water usage, often wasting water by leaving the tap flowing, which in areas facing water scarcity issues could be an argument against installing more piped systems.

Having established that the water distribution method of the household's primary water source affects the quantity of water consumed, the contributing factors to why households used different distribution methods were analysed. Possible contributing factors were identified as household income, caste and location; these were investigated in order to understand whether socio-economic factors influence the quantity of water households have access to. Water distribution methods showed significant statistical correlations with both income (p-value 0.005) and caste (p-value 0.009). However, these were not simple linear correlations, where the highest income and caste families had piped connection, and the poorest carried water from a public source. The relationship between carrying water from a public source was as expected, with households from lower castes and lower income households being more likely to carry water. However, the proportion of households with private connections did not follow any particular pattern. This could be explained by government bodies and external non-governmental organizations (NGOs), who are responsible for the installation of community water supply systems, setting targets to reach disadvantaged members of the community.

This is further confirmed by looking at the statistically significant correlation (p-value 0.003) between location (based on VDC) and the primary water distribution method. This correlation was stronger than water distribution method by caste or income, demonstrating that the best predictor for a household's water distribution method is its location. Simpani, where all water is distributed from the community tank to communal tap stands, has no houses with private pipelines. On the other hand, over 50% of households in the other three VDCs have a private pipeline to their house, where the community water supply systems include private connections to households, often with water meters to monitor water usage.

In our study, the fact that some VDCs have better community water supply systems installed than others could explain why location is a more important factor than income or caste when determining if users have to carry water, have water piped to their house or pipe it themselves from a public source and, accordingly, the amount of water they consume. Encouragingly, this indicates that, in Lamjung, households from all income levels and castes have access to similar infrastructure when an external body such as the government or an NGO installs a high quality community water supply system. The location also influences the elevation of the households, and hence the number of spring or stream sources they have access to, however households were surveyed at varying elevations across each VDC so it is assumed that this is less likely to be the explanation for the correlation found.

Poor accessibility

An important criterion when assessing the water service level of a household is accessibility or the distance to the source. Our study found that the total water collection time (based on households' primary water sources) was greater than 25 minutes for approximately one quarter of all households surveyed, which can be categorised as 'poor' or 'very poor' based on the RVWRMP water service level criteria (2011). However, compared to other areas of rural Nepal, where women and girls often spend up to 4-5 hours per day collecting water (ADB 2015a), it can be concluded that households in Lamjung have relatively good water accessibility.

A 2005 study in Kathmandu Valley determined that, as the distance between a household and their water source increases, their daily water consumption decreases, which in turn increases the possibility of contamination of the water supply and hence, increases the health risk from waterborne diseases (Pradhan et al. 2005). The WHO Report *Domestic Water Quantity, Service Level and Health* cites a review of several studies in different countries, which concluded that there is a clear relationship between the volume of water used by a household and the accessibility of their source (Howard and Bartram 2003). Findings from our study were generally consistent with this trend, as shown in Figure 20, with comparisons to the total water collection time from the primary source with the household's daily water consumption, under the assumption that all water is collected from the primary source. However the relationship is not statistically significant, and households in our study do sometimes collect water from secondary and tertiary sources as well, so no clear conclusions can be drawn on whether this relationship applies in Lamjung District.

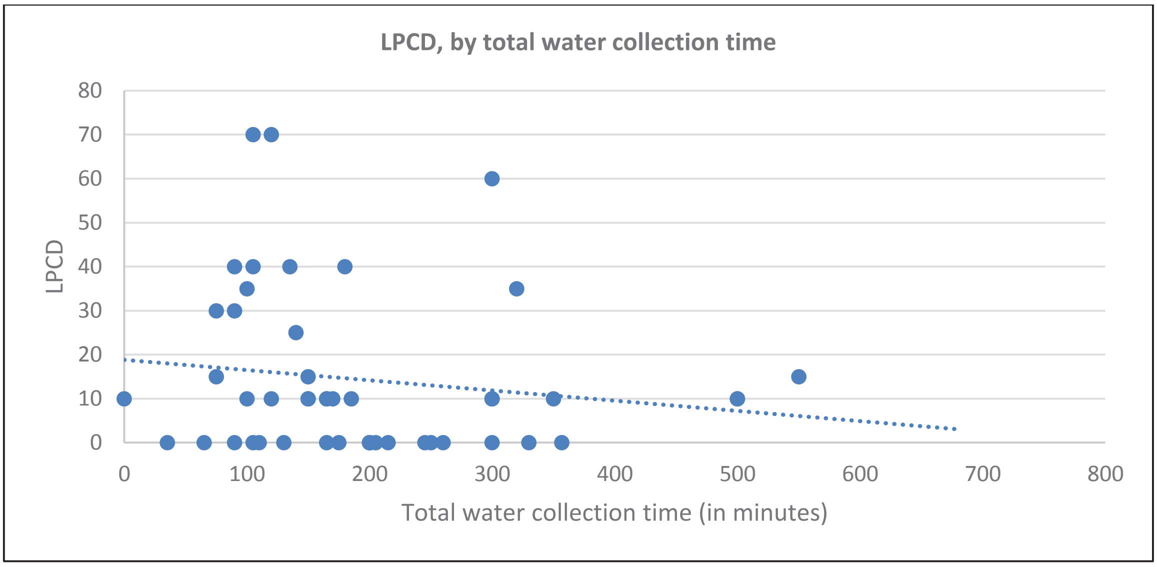


Figure 20 – Daily per capita water consumption in litres per capita per day compared to total time to collect water from a household's primary source
Note: queuing time for houses with a piped connection (public and private) assumed to be zero.

As shown in Figure 21, over 50% of households took less than 5 minutes to walk to their primary water source. However, 70% of households also use secondary and tertiary sources, as their primary sources often ran dry for part of the year towards the end of the dry season.

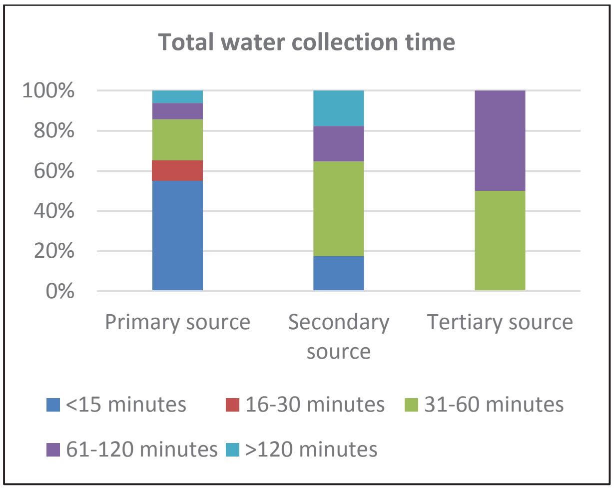


Figure 21 - Total water collection time, by source

Figure 21 shows that these sources are far less accessible than the primary sources, indicating that during these months many households face even greater accessibility issues than usual, as they are forced to use sources that are further away from their houses to collect sufficient water.

Poor reliability

A 2012 report by the Water Integrity Network reported that supply of water through improved sources in Nepal is "unreliable, and in many places infrequent" due to the "lack of system maintenance, minimal community ownership and irregularities inside the water supply schemes" (WIN 2012). In the RVWRMP water service level system, reliability is defined as how many months of the year the source is functional, and continuity is defined as how many hours water is supplied each day. In our study, these questions were combined into one, which will be referred to as reliability from this point on.

Our study investigated both the reliability of water supply and to what extent each community was involved in the maintenance of their water sources. Correlations between water source characteristics and the frequency of the sources going dry (our reliability indicator) were investigated to determine which types of sources were most at risk, but no statistically significant correlations were found, indicating that measures to improve reliability of sources should be applied to all types of water sources.

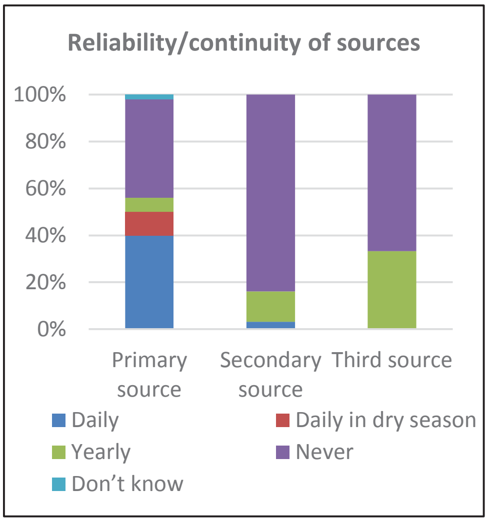


Figure 22 - Frequency of a source going dry

As shown in Figure 22, there were reports from 40% of the participants that their primary water supply only runs for a few hours each day in the morning, evening or both. Many households reported that during the dry season their primary source had significantly reduced flow, 50% said it went dry daily and 6% said it stopped flowing all together. As a result, many households rely on a secondary and even tertiary source for at least part of the year, which are more reliable.

If houses do not have access to a satisfactory alternate water source in the dry season, then they are at risk of not having enough water to meet their daily needs. Furthermore, if an unexpected event disrupts their supply, households with no access to a secondary source are in a danger of having limited or no water supply. An example of this is the earthquakes of April 2015, and the resulting landslides, when many community water supply systems were damaged and people were forced to seek alternative sources or to walk long distances to the original source of water until emergency repairs could be made (OSOCC 2015). The monsoon season is another frequent cause of landslides, as well as flash floods, which also threaten the sustainability of water sources (Shah 2008; WaterAid 2008b). One participant in Simpani described how their water source is damaged multiple times each rainy season and does not function properly until the mudslides are cleared and the pipes are repaired by an appointed maintenance technician in their village.

A second example was witnessed during the survey – in Chakratirtha a group of people were gathered in a field digging furiously. They explained that there was an obstruction in the main pipe, blocking the flow to their tap stands downstream. They were trying to locate the pipeline and the source of the blockage. This was an example of a community sharing the responsibility for the operation and maintenance of the system. In addition to having a properly designed water supply system, clearly defining who holds responsibility for operation and maintenance and ensuring they have the proper training is important for the reliability and continuity of a community water supply system (WaterAid 2008b).

Figure 23 shows that all the primary water sources had someone responsible for their operation and maintenance, although many of the secondary and tertiary sources did not. Participants reported that the whole community shared responsibility for operation and maintenance of the primary water source in 31% of interviews, and that there was an appointed person in the community responsible in 56% of interviews. In most cases, people using the water supply system paid a small fee and the appointed person had a salary, but one participant in Chandreshwor reported that the appointed person was not paid but instead had first priority to take water from the source.

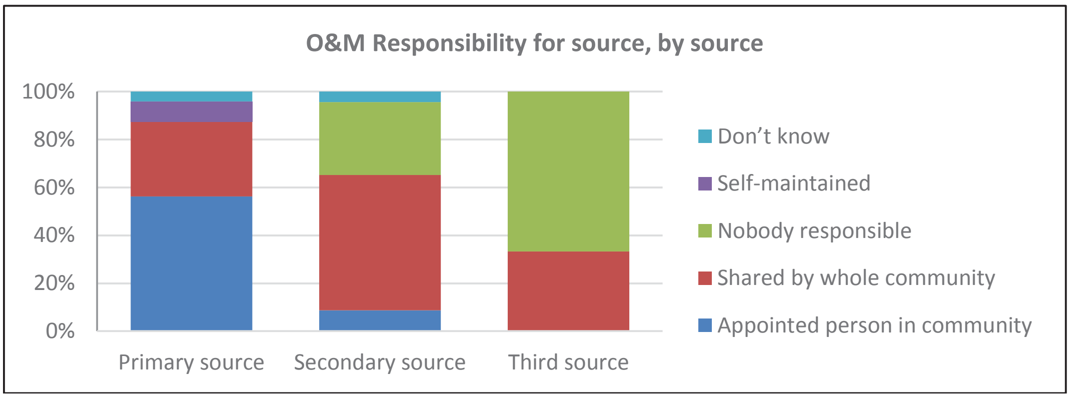


Figure 23 - Responsibility for operation and maintenance of the sources

Aside from the risk of a community’s water source being damaged in an earthquake or landslide, there is a growing risk that springs currently supplying community water supply systems will simply dry up (ICIMOD 2015b). ICIMOD (2015b) believes this is primarily due to “poor management and technical and socio-economic factors”. Further risks to community water sources are “poorly understood hydrology, fragile geology, erosion, pollution, and deforestation” (WaterAid 2008b).

From these examples it can be seen that there are a variety of factors contributing to the poor reliability of the water sources in the study. Their vulnerability means that it is important to find sustainable solutions to protect the existing sources, and to find and develop other sources in order to reduce reliance on one source.

6.1.2. Solutions

The results from this study highlight issues people in the Lamjung District are facing regarding water scarcity and unreliability of sources. Potential solutions to augment their domestic water supply and to provide better water security will be discussed in this section.

Measures should be taken to protect and augment existing sources. A report by WaterAid suggests that structural options can be used to protect the supply, including "erosion control barriers, construction of drainage channels, plantation surrounding the sources, and pipeline protection" (WaterAid 2008b). These protection methods will be discussed further in Section 6.2.2. In the past ponds for buffalo to bathe in acted as recharge ponds for the springs, however less and less people now own buffalo which is contributing to the springs drying up (ICIMOD 2015b). Options such as building as small recharge ponds and dams above springs and along streams could be considered to remediate this and to augment the water supply. Better management of greywater and runoff water from tap stands and other communal sources is also important. This will be discussed further in section 6.4.2, which considers solutions for augmenting the quantity of water available for irrigation.

Installing or upgrading community water supplies is another option that can be considered. It was found that the quantity of water consumed was influenced by whether a household had water piped to their house or had to carry it from a water source. When factors affecting these water distribution methods were investigated, it was found that the strongest correlation was not with income or caste, but rather with location. This is most likely explained by the fact that community water supply systems were constructed for all households in entire VDCs or wards, no matter their socio-economic status, by the government and by NGOs such as NEWAH and HELVETAS Swiss Interco operation (HELVETAS 2016; NEWAH and WaterAid 2002).

The fact that households with such systems are more likely to have access to the WHO standard of 45 litres per person per day is an argument for their continued installation, however, it was observed that having a piped supply meant that households used their water less efficiently and carefully. Research by ICIMOD cites over-pumping and wastage of water due to piped and pumped water supply as one of the management issues causing traditional spring sources to dry up (2015b). Hence, for VDCs whose water supply is unreliable due to water scarcity, perhaps it would be better to spend this money on augmenting the water supply to the community tank and increasing the number of communal tap stands instead of constructing a piped system, increasing the accessibility of the water supply while still ensuring its reliability and sustainability. Where piped systems are constructed, they should be combined with education on how to use them sustainably, and/or with technology to limit water usage such as flow meters in each household.

For areas where there are insufficient reliable spring and stream sources to supply a community water tank sized to service all households, or where the cost of installing a water pump is too high, alternative household-based solutions must be found. A commonly used technology in this situation is rainwater harvesting (Domènech et al. 2012).

Figure 24 - Simple household rainwater system (Modified from Worm and Hattum 2006 to include first flush system)

Domènech et al. estimated that in 2008 rainwater harvesting systems had been installed in 160 communities in Nepal (2012). A standard Nepalese rainwater harvesting system is shown in Figure 24, and consists of (1) a corrugated iron sheet roof, (2) metal or bamboo gutters, (3) a 2 to 6.5m^3 ferrous cement rainwater jar and (4) a first flush system to flush away the contaminated water that first runs off a dirty roof (Domènech et al. 2012).

Domènech et al. undertook a survey of 120 households who had owned rainwater systems for over two years. Although these systems are relatively simple to build and maintain, there is a high initial installation cost and as result, it was found that for most of these households 70-80% of the construction cost was supported by international aid (Domènech et al. 2012). This same study found that most users (78%) reported that they were fully satisfied with their system, 11% mostly satisfied, 10% neither satisfied or not satisfied and 1% not satisfied (Domènech et al. 2012). It is evident from Domènech's survey that, once installed, rainwater harvesting is a good solution for water-scarce areas, but relying so heavily on international aid is not sustainable. Furthermore, it was found that the 20-30% of the cost which is borne by households is in the form of materials and labour, so poorer households unable to contribute materials were more likely to be given smaller systems (Domènech et al. 2009). Subsidies and micro-loan schemes, where households receive a small loan to cover the high initial installation cost, may be a good solution, and as more rainwater systems are constructed in Nepal the cost of the infrastructure should decrease due to economies of scale. This occurred in Thailand, where prices decreased as the demand for rainwater jars and the availability of low-cost local cement and skilled artisans increased (Luong 2002).

As well as improving the quantity of water available to households, rainwater harvesting technology improves its accessibility and reliability. In Domènech et al.'s survey, users reported that "convenience due to the on-site availability of water is the most salient feature of rainwater harvesting" (2012). Time and energy previously spent collecting water was saved and could be used on education or income-generating activities (Domènech et al. 2009). The monsoonal nature of Nepal's climate means that rainwater tanks are most important during the long dry season, when nearby spring sources of water dry up. Rainwater tanks can be used as an emergency water source, with some households reporting that they lock the tap at the end of the rainy season in order to ensure that they have water available in the driest period of the year (Domènech et al. 2009). While this improves water security, people must be made aware that this water should be treated prior to consumption, as the quality will deteriorate during storage (Worm and Hattum 2006). Possible household treatment methods are discussed in section 6.2.2.

As shown by Domènech et al.'s survey, the majority of rainwater harvesting users are satisfied with their systems, however research and education should be carried out into potential users' opinions before construction of a system. For systems that had been operating for over 6 years they found that 15% were performing poorly, indicating that better training in maintenance of the systems was required (Domènech et al. 2012). Furthermore, cultural factors such as the belief of some Nepalese people that stored water standing overnight is impure (ICIMOD 2015b) or that drinking warm water will cause a common cold (Domènech et al. 2009) must be taken into account.

In our study, a diagram of a simple rainwater harvesting system was explained to the participants and they were asked if they would be interested in installing such a system. The results showed that 6% of participants already used rainwater harvesting or had used it in the past, 68% said they would be willing to install a system, 6% did not want to install a system, and 20% said they were positive to the technology but would not install a system because they already had sufficient water. Multiple households said that they would like to use rainwater harvesting, but that they could not afford it or did not have the right roof material. Unsurprisingly, analysis of the correlation between opinion on rainwater harvesting and water service level (p-value 0.069), and the correlation between opinion on rainwater harvesting and caste (p-value 0.066) reveals that households with ‘poor’ water service level and those from lower castes were most likely to be positive towards the technology, as they are the households facing the greatest water insecurity.

The size of tank required to meet certain amount of per capita water consumption per day was calculated for the two VDCs for which accurate rainfall data was found. The average roof area was assumed to be 40 m^2, based on recommendations for the standard size of a traditional rural Nepalese house from a leading Nepalese architecture firm, Wonaw & Associates. The average household size in Lamjung District from the 2011 census of four people was used, and a runoff coefficient of 0.85 was selected to take into account water lost in the first flush and from evaporation and splashing. The results are presented in Table 11, and the full calculation can be found in Appendix C.

Table 11 - Comparison of rainwater harvesting potential, for various litre per capita per day (LPCD) demands

	Required tank size (m3) to meet demand all year		
VDC	15 LPCD	20 LPCD	45 LPCD
Kunchha	5	8	27
Simpani	4.5	7	24.5

The results show that the standard 6.5 m^3 rainwater tank that has been used in Nepal thus far would not be sufficient to supply the WHO recommended daily volume of 45 L per capita. However, as harvested rainwater is generally of high quality, the standard sized tank could be used to collect sufficient water for drinking and cooking purposes, in conjunction with appropriate treatment methods. Alternatively, this water could be used as an irrigation source.

Another water harvesting technology is fog water harvesting, which NEWAH has been successfully implementing in Nepal since the mid-1990s (NEWAH 2005). These are normally community-managed systems, where large polypropylene mesh nets are built on ridgelines to collect water from fog that is blown into them by the wind. According to NEWAH field trials, small-community based systems can harvest 2000-5000 L/day during the wet season, which can be stored for use in the dry season (2005). They are suitable for communities living between 1,500 and 3,500 m.a.s.l. (NEWAH 2005), which means they are feasible for some of the more northern VDCs in Lamjung, but not for the VDCs that were surveyed in our study.

In summary, existing water sources should be protected and augmented as a first priority, and simple methods to re-use and/or store greywater and runoff water should be implemented wherever possible. Community water systems should continue to be installed where there is sufficient water and money to sustain them. If not, money would be better invested in subsidising the construction of household rainwater or fog harvesting systems.

6.2. Domestic Water Quality

This section discusses the results and many of the major issues found with respect to health, water quality, treatment of drinking water, the prevalence of waterborne disease in communities and the protection and maintenance of water supply sources. At the end of this section, solutions for the issues identified are suggested.

6.2.1. Issues

The quality of drinking water is a major issue in rural areas of Nepal (Pradhan et al. 2005). In our survey, participants were asked to classify the quality of their water in first the dry season, then in the rainy season, according to a list of multi-choice answers. Based on their answers, the quality of the water was grouped into ‘Good’, ‘Moderate’, ‘Poor’ or ‘Very poor’. In Figure 25, the percentages of these groupings of water quality for all sources are shown in the dry and rainy seasons for all VDCs surveyed. In the dry season, over 90% of the water sources were classified as having ‘Good’ or ‘Moderate’ water quality, as opposed to only 50% during the rainy season. As a result, the reported quality during the rainy season was used for the correlation analysis of water quality with location and whether or not water was used for drinking.

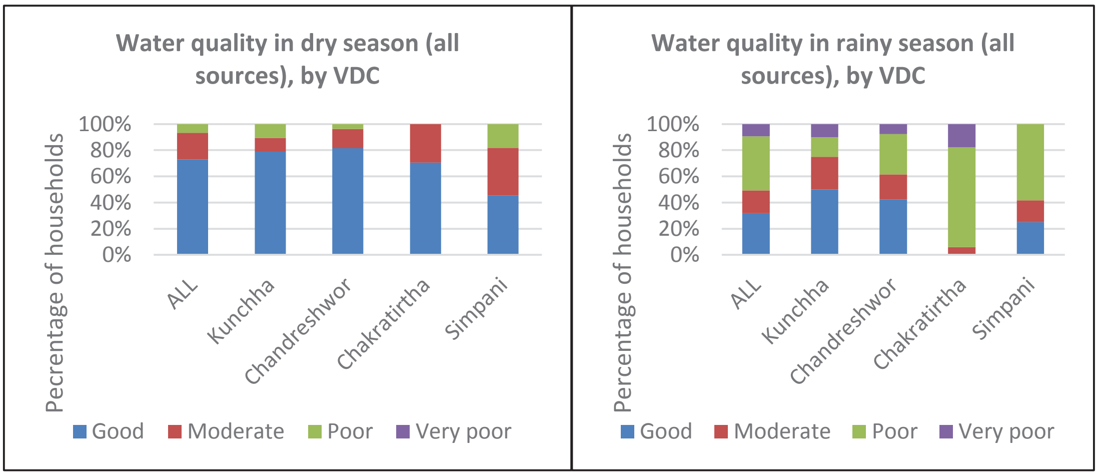


Figure 25 – Water quality in the dry season (left) and rainy season (right) of primary, secondary and tertiary sources for all VDCs

In terms of treatment, participants were asked whether they treat their households' drinking water or not and, if so, which methods they use to do so. It should be noted that a participant only reported whether or not their communal water supply was treated if they were aware of it. It was found that some households perform one or a combination of treatment methods that involve allowing water to stand and settle, straining water through a cloth, using ceramic water filters, boiling, using water purification tablets and treating the community collection tank. From this the frequency of treatment was grouped by 'Always treat', 'Sometimes treat' or 'Do not treat'.

The results showed that water quality of all water sources had a statistically significant correlation (p-value 0.000) with location of all VDCs. Participants in Chandreshwor in particular, reported 'Good' water quality and were most likely to not treat their drinking water. Meaning, households that put trust in their water supply, are less likely to treat their drinking water as a result. One correlation (p-value 0.084) between the level of treatment for drinking water and the water collection point corroborates this assumption. It was found that 55% of households that carry their water supply from a distant source never treat their drinking water, while only 31% of households that pipe their water supply directly to their homes never treat their drinking water. This may seem contradictory, but based on conversations, participants expressed that despite sources being further away, they would rather use distant sources because they have been used and trusted for generations, while newer communal water sources were built by the municipal government or NGOs. Meaning, those that carry their water, are more familiar with and have faith in the quality of the source to not treat their drinking water. However, the likelihood for households to always treat their drinking water is generally low, irrespective of how they collect their water.

Participants were asked about the activities they associate with each of their water sources in the rainy season, and from this, household activities were categorised into being either 'Used for drinking' or 'Not used for drinking'. Figure 26 shows the full list of activities that participants were asked about in the survey. The results revealed a correlation (p-value 0.049) between water quality of all water sources and whether or not they were used for drinking. Not surprisingly, more than half of all sources with 'Very poor' water quality were not used for drinking. However, it was surprising to find that 90% of the sources with 'Poor' water quality, were still used by households for drinking. This might be due to the fact that "rural people use the most convenient sources of water in their areas, irrespective of quality, due to lack of piped water". However, this also conflicts with some households in the survey claiming to walk further to a secondary source that they believe to be safer and more suitable for drinking.

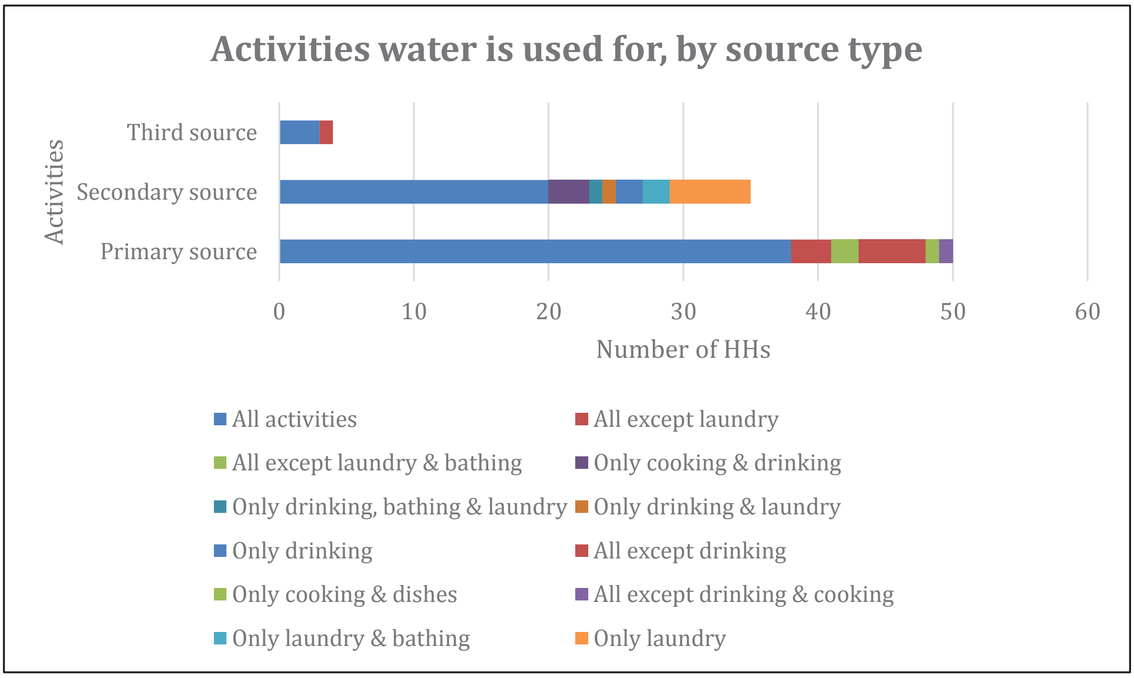


Figure 26 - Activities participants reported to associate with primary, secondary and tertiary water sources

The results displayed a correlation (p-value 0.007) between the level of treatment for drinking water and the water quality of all water sources. Surprisingly, 86% of households with 'Very poor' water quality were least likely to treat their drinking water, (though it is important to note that they might not have been using water from this source for drinking), while households with 'Poor' water quality were most likely to treat their drinking water some of the time. It was generally difficult to interpret correlations between some of the variables including 'water quality', 'treatment of drinking water', and 'water used for drinking or not', as there were many interdependencies between them, which were sometimes contradictory. An example of one of these contradictions was the finding that out of the water quality groups, 22% of households with 'Good' water quality, the highest of all households in other groups, are most likely to always treat their drinking water. This affirms the correlation (p-value 0.033) that households with a good service level will either always treat or sometimes treat their drinking water. The reason for this might be that participants with good service levels are also in higher income categories with higher levels of education, which would explain why they always treat their water, even if it's of visibly good water quality. However, this contradicts one correlation (p-value 0.020) between the level of treatment for drinking water and location (based on VDC) that found that 66% of households in Chandreshwor, which also have the best water quality, never treat their drinking water.

The results showed that the level of treatment for drinking water has a statistically significant correlation (p-value 0.030) with a household's level of income. It was found that only 5% of households with a low level of income and 36% with a high level of income always treat their drinking water. In addition, households with a high level of income are least likely to never treat their drinking water. One report that aims to understand Nepal's diversity, shows that members of the Dalit caste are not as well off economically as the Brahman and Chhetri castes, and this same report found that "nearly 85% of Dalit women are not educated". This confirms our finding that people of a lower socio-economic status do not recognise the importance of treating their drinking water. The opposite is likely to be true, that people of a higher income and a higher level of education understand the importance of treating their drinking water.

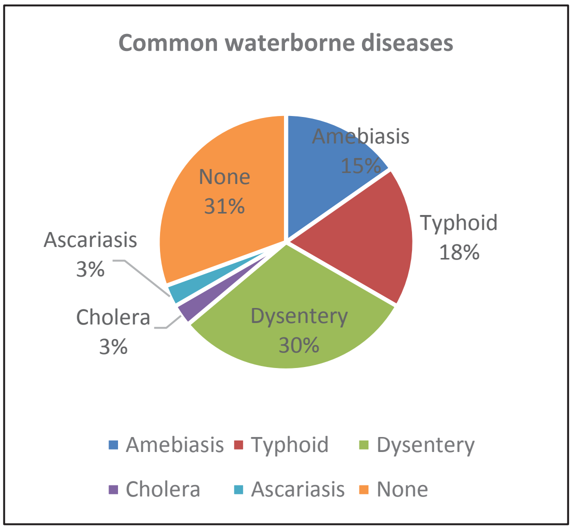


Figure 27 - Common waterborne diseases in all VDCs

In our survey, participants were asked to select from a list of waterborne diseases common in their community. Figure 27 shows the waterborne diseases reported across all VDCs. From this, the frequency of occurrence of these diseases in each community was divided into 'No diseases', '1 disease', '2 diseases' or '3 diseases'. The results revealed a correlation (p-value 0.000) between the prevalence of waterborne diseases with each VDC. It was found that 25% of households in Chakratirtha had a combination of '3 diseases' and '2 diseases', while 27% and 17% of households in Chandreshwor and Kunchha respectively had 'No diseases'. These results are consistent with the correlation found between water quality of all water sources and all VDCs, with Chakratirtha having the worst water quality and Chandreshwor and Kunchha having the best water quality. The coliform presence/absence tests performed in Chakratirtha and

Simpani substantiate this, because only 1% of the water samples collected detected an absence of coliforms/faecal contamination.

It is interesting to note that some participants insisted that the diseases most common in the community were either caused by food or were airborne, instead of being waterborne. Another study in Nepal also found that people believe that eating too much food was an important cause of diarrhoea, followed by eating stale food and eating in restaurants (Pradhan et al. 2005). Incidence of waterborne diseases caused by other factors including lack of protection and maintenance of water supply sources will be further discussed.

As previously mentioned, only 50% of the water sources in our study were classified as having ‘Good’ or ‘Moderate’ water quality during the rainy season and as such were more vulnerable to contamination by pathogenic bacteria. This may have been due to multiple circumstances including an unprotected water supply source, lack of proper treatment of water, poor surrounding environment, leakages in the distribution system, intermittent water supply and poor drainage system (Pradhan et al. 2005). Figure 28 comes from a study that investigated the drinking water quality in rural Kathmandu Valley that found the highest incidence of diarrhoeal disease in the month of June. This is a common case in the hills because it is the beginning of the monsoon season. Thus, an unprotected water supply would be most vulnerable to contamination due to flooding in the monsoon season.

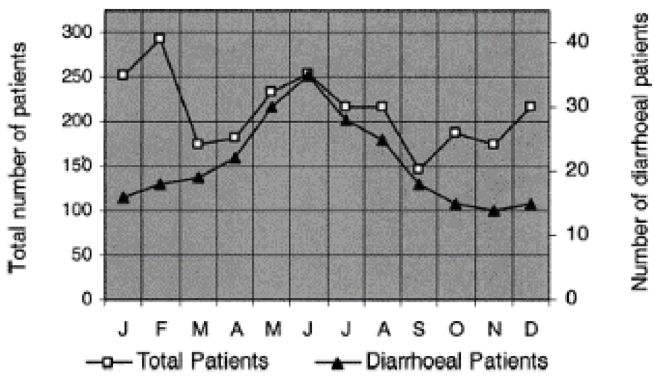


Figure 28 - Number of patients for diarrhoeal related visits to health posts (Pradhan et al. 2005)

The proper maintenance of a water supply source and its distribution system are equally important as protection of the source. The primary and secondary water sources across all VDCs had high percentages of either an appointed person in the community being responsible or sharing responsibility in the community for operation and maintenance. Despite responsibility being shared by the community or by a single appointed person, multiple participants gave an account of crabs or rodents blocking tanks or eating into the walls, which caused mud to leak in. This was also found in another study where "locals tampering with the drainage, as well as crabs, rodents and other animals getting into the tanks, reflect[ed] the importance of proper design, maintenance and community caretaker training in achieving sustainability" (WaterAid 2008b).

6.2.2. Solutions

Improving access to a safe water supply can result in benefits to health (Conant and Fadem 2008). Strategies to increase water quality involve empowering local stakeholders, including public and local health authorities and individual consumers, as well as actions, such as surveillance and quality control, water resource management and community management distribution networks. In this section, solutions to the issues previously outlined will be suggested, based on the results from our study and research into literature from previous studies, Lamjung District, the mid-hills and Nepal as a whole. Technical solutions, hardware, as well as behaviour-changing methods, software, will be introduced.

With respect to water supply, having multiple hygienic barriers increases safety and involves "protection of water sources, proper selection and operation of a series of treatment steps and management of distribution systems (piped or otherwise) to maintain and protect treated water supply" (WaterAid 2011). Most springs are free of pathogens due to ground percolation and filtration, however, springs flowing through limestone or geologic cracks and fissures in the rocks have minimal filtration and may still contain pathogens and cause disease (Jordan 1984). As the geology in this region includes limestone, it is important to protect water sources and the area around a spring to prevent contamination. This is accomplished by fencing the area, having a proper drainage system, planting native trees near the spring to prevent erosion and building a spring box. Figure 29 depicts how the outlet of a spring can be protected. There are also problems around collection points with water accumulating in puddles becoming a "breeding ground for mosquitoes" that carry illnesses (Conant and Fadem 2008), to avoid this, a proper drainage system around outlets from storage tanks, tap stands and other water collection areas is important. An example of such system for water spillage is a soakaway pit that allows drainage into the ground and is illustrated in Figure 30.

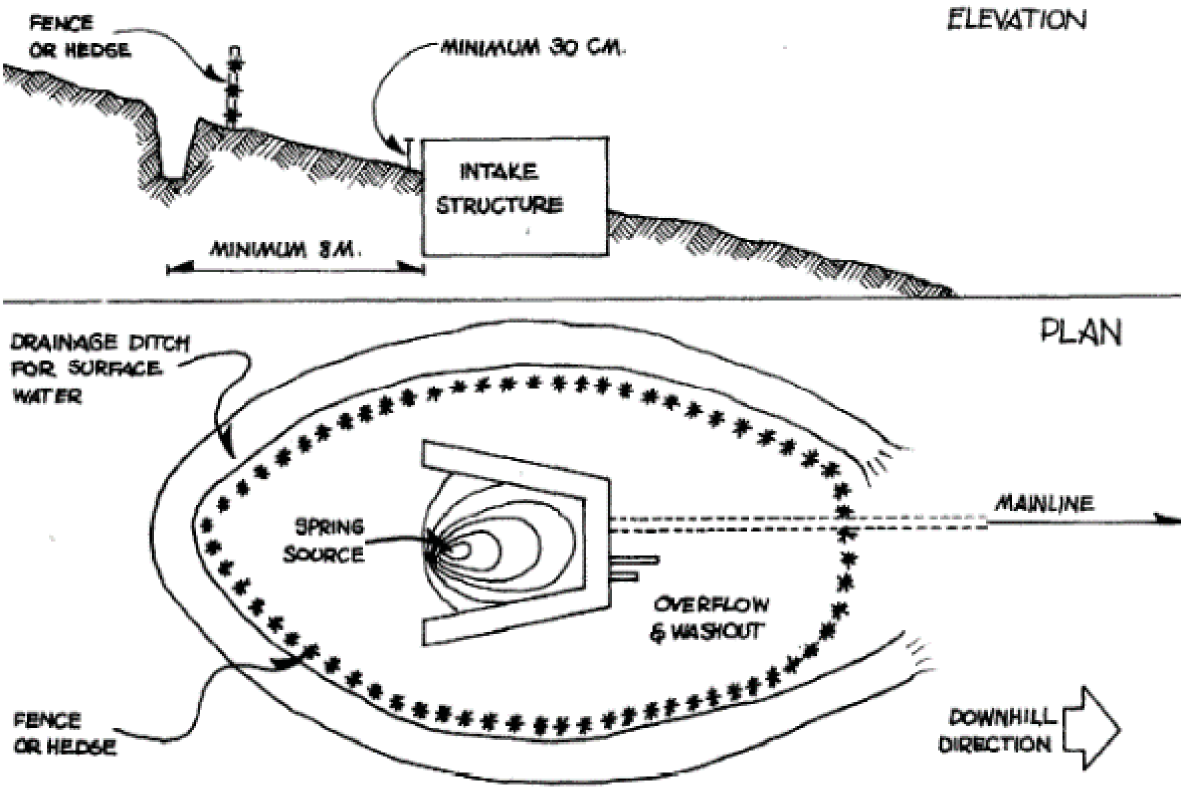


Figure 29 - Protection of a spring outlet (Jordan 1984)

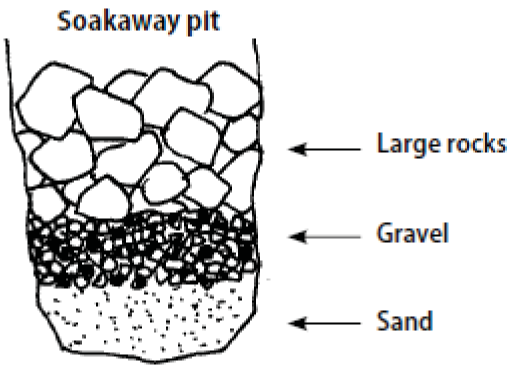


Figure 30 - A soakaway pit (Conant and Fadem 2008)

A series of simple, centralised treatment options for communal water supply systems could also act as hygienic barriers. If a stream, rather than a spring, is the original source for a communal water supply system, then sedimentation, prior to the communal tap stand, is important. According to the *Sustainable Sanitation and Water Management Toolbox*, sedimentation is the "gravity settling of particles in a liquid as they accumulate". In addition, slow sand filtration is a purification process which can be used to treat communal water supplies in which water flows through a "porous filter-bed" and considerably improves the water quality, with a reduction in the number of pathogens (Conradin et al. 2010). However, it should be noted that the required influent should have low turbidity (<10-20 NTU) and low algae contamination, meaning this process is most appropriate for spring sources (Bruni and Spuhler 2010). Slow sand filtration is especially effective if there are inhabitants upstream from the source, who may cause contamination. Treatment of communal water supply systems is beneficial, however household water treatment technology or point-of-use treatment technology, coupled with safe storage of treated water, is more relevant in a rural setting.

Individuals that "correctly and consistently use methods that make their water safe for drinking" will effectively create a "preventive health intervention" (WHO and UNICEF 2012). Drinking water safety involves safe storage to protect treated water collected in a container with a lid and preferably, "a tap to access the stored water and to prevent contact with hands, cups or dippers" (Murcott 2006). Hygiene behaviours were observed in half of the VDCs in our study and 47% of these households did not cover their water storage containers, indicating a lack of knowledge about the importance of safe water storage. Combining multiple hygienic barriers or treatment methods in a series of steps increases the quality of water. Some of these treatment options include sedimentation, filtration and disinfection, with the technologies that are potentially suitable for Lamjung District and the mid-hills, presented below.

Many households in our study reported that in the rainy season, their water was turbid and had some suspended particles. To remove particles on a household level, sedimentation can be utilised with the three-pot method. This method is the simplest water treatment system that can be easily adapted for sedimentation of turbid water. The method involves systematically pouring water from pots over the course of at least two days to promote settlement during storage (WEDC).

Filtration is "a mechanical separation process using a porous medium that captures particulate material" (Conradin et al. 2010). Our study showed that households across multiple VDCs use a cloth to strain water and ceramic filters for treating their primary and secondary water supply. Ceramic candle filters are used to remove pathogens and suspended material by physical processes including adsorption. According to the Centers for Disease Control and Prevention, in developing countries, commercially manufactured filters in conjunction with safe storage reduces diarrhoea by 60-70% (CDC and USAID 2008). However, for these filters to work efficiently, "turbidity levels greater than 50 NTU,…should first be strained through a cloth or sedimented before using the ceramic candle filter" (CAWST 2009).

Biosand filters are an adaption of the traditional slow sand filters, to be used on a household level and they can be made from local materials. Figure 31 depicts the materials required for a household biosand filter.

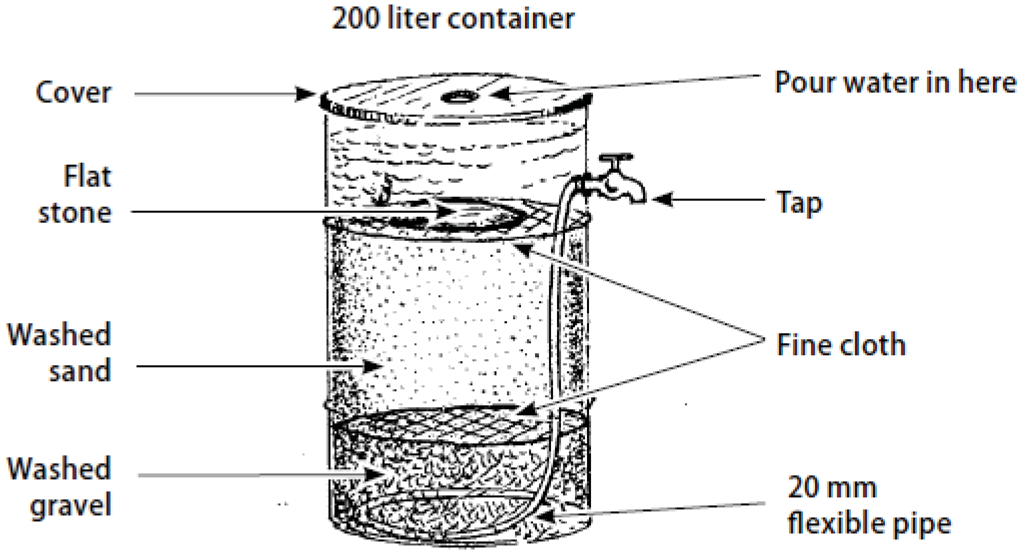


Figure 31 – A biosand filter (Conant and Fadem 2008)

Disinfection involves the removal of pathogens by inactivation or by physical separation processes (Conradin et al. 2010). Chemical disinfection, including chlorine-based technology, "is one of the popular methods for water disinfection in Nepal" (Pradhan et al. 2005). In Kunchha, some households reported that their communal collection tank for their primary water supply was treated, presumably with chlorine. As previously mentioned, our study also showed that 56% of all households surveyed appoint one member of their community to be responsible for the operation and maintenance of their water source, meaning that in many communities, there is already a person who could be responsible for chlorine dosing or chlorine dosing could be added to their maintenance routine. Together, these findings demonstrate that with proper dosing, as per the simple guidelines shown in Figure 32, chlorine would be a viable treatment option for both communal collection tanks and households. According to WHO guidelines, "recommendations are to dose with free chlorine at about 2 mg/l to clear water (<10 NTU) and twice that (4 mg/l) to turbid water (> 10 NTU)" (WHO 2011).

Water	Bleach 'Mother Solution'
For 1 liter or 1 quart	3 drops
For 1 gallon or 4 liters	12 drops
For 5 gallons or 20 liter	1 teaspoon
For a 200 liter barrel	10 teaspoons

Figure 32 - Guidelines for proper chlorine dosing (Conant and Fadem 2008)

Solar water disinfection (SODIS) is a method that "uses solar energy in the form of ultraviolet radiation and infrared heat to disinfect small quantities of contaminated water" (Rainey and Harding 2005). The method and steps involved can be seen in Figure 33. It should be noted that treated water must be safely stored if not immediately consumed, to avoid re-contamination. According to a study that examines the acceptability of SODIS in a village southeast of Kathmandu Valley, perceived barriers seem to outweigh the benefits of treating water to reduce stomach ailments. Perceived barriers include a heavy workload, availability of bottles, lack of space to expose bottles to the sun each day and the temperature and taste of the water after treatment. This same study suggested to change this perception by making drinking water treatment behaviours seen in the context of water quality, not just in terms of health and the high rates of diarrhoeal disease (Rainey and Harding 2005). This is possible with the aid of behaviour changing techniques, outlined in the next paragraph.

Figure 33 - Steps of the SODIS method (Luzi et al. 2016)

In combination with hardware solutions, software is important for the improvement of a safe water supply, resulting in health benefits. Education in the form of activities for learning and mobilising plays an important role in this. According to *A Community Guide to Environmental Health*, people must first understand what causes illness and that change takes time, before engaging in behaviour-changes such as using soap when washing hands after using the toilet and before handling food, using any of the above mentioned treatment technologies and keeping water storage containers clean and covered (2008).

6.3. Sanitation and hygiene

Environmental sanitation is defined in terms of “personal hygiene, toilet facilities and surrounding environment” and is essential to the promotion of health and the prevention of diseases (Pradhan et al. 2005). Our survey revealed that the environmental sanitation situation in the Lamjung region is better than in other areas of Nepal, as the national average sanitation coverage is 46% of households using improved latrines (Shah 2008), compared to the 98% found in our survey. Out of the 50 households that were interviewed, only one did not own a toilet, while two households owned two toilets and the rest owned one toilet. All of these toilets were pour-flush, water-sealed squat pans with a bucket of water nearby for anal-cleansing. water-sealed squat pans with a bucket of water nearby for anal-cleansing.

After each interview, the toilets were observed, and it was found that 56% of households had a window or small opening for ventilation, 19% of houses had a ventilation pipe on the septic tank/leach pit, and 4% had a drain. Although the toilet pans and flushing mechanisms were homogenous, the excreta disposal methods varied. Aside from the one house without a toilet (which accounted for 2% of the participants), 34% had a toilet connected to a biogas reactor and the remaining 64% had either a toilet with a septic tank or an offset soak-pit. Although many of these 64% of households claimed to have septic tanks, observations of the toilet systems and the participant's admission that the tanks had never been emptied despite many years of use led the researcher to believe that most of these were in fact unlined soak-pits which simply infiltrate into the surrounding soil, potentially contaminating the groundwater. However, some participants did have septic tanks and said that had a pipe outlet directly to the field. Figure 34 shows an example of one of the toilets connected to biogas reactor.

Figure 34 – A toilet (1) connected to biogas reactor including a grinder (2) for addition of manure and organic waste, a lid (3), and a gas pipe (4) connected to household stove in Chakratirtha (photo taken by the authors)

Figure 35 shows the difference between a pour-flush latrine with a soak-pit, a pour-flush latrine with an offset soak-pit, and a toilet connected to a biogas reactor. The difference between an unimproved pit latrine and an offset pit latrine is that the pit is located behind the super-structure of the toilet for ease of emptying when it is full.

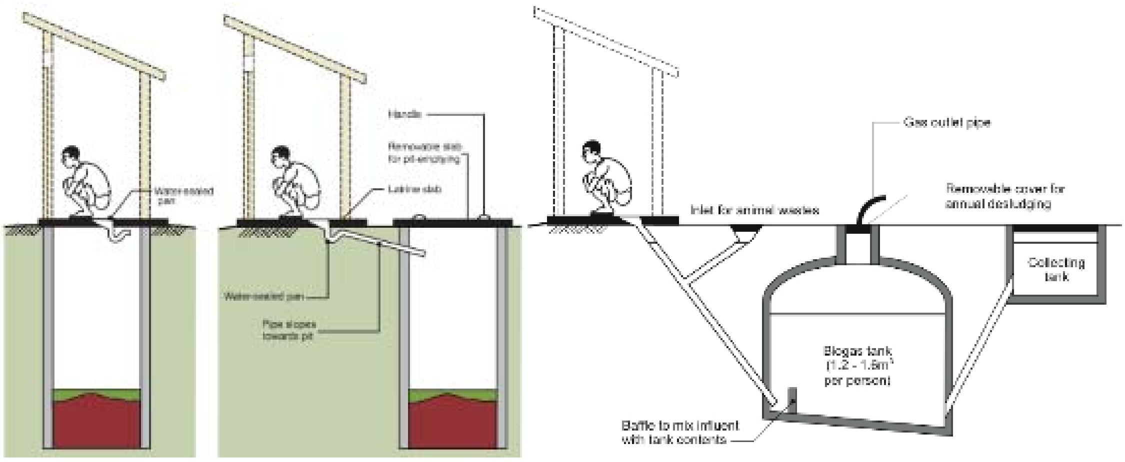


Figure 35 – Common types of toilets: (left) pour-flush latrine with a soak-pit, (middle) pour-flush latrine with an offset soak-pit (LSHTM/WEDC 1998) and (right) biogas reactor with toilet connected

The biogas reactor shown in Figure 35 shows a typical reactor with a toilet connected to the digester, as well as an inlet for manure and household organic waste (Forte 2011). The gas pressure pushes the digested sludge into the collecting tank on the right hand side of the figure, which can be used as a fertilizer after hygienizing (Forte 2011) shows a typical reactor with a toilet connected to the digester, as well as an inlet for manure and household organic waste (Forte 2011). The gas pressure pushes the digested sludge into the collecting tank on the right hand side of the figure, which can be used as a fertilizer after hygienization (Forte 2011). Ideally, the sludge will be fully hygienized in the biogas reactor, however, it was found that the design, construction and operation of the reactors was not perfect, and that the temperature in the reactor was likely to be less than optimal. As a result it is recommended that sludge drying beds are used to ensure complete die-off of pathogenic bacteria, as they can spread disease if the excreta is not properly treated before re-use (WHO 2006). Household biogas systems are a well-developed technology in Nepal, and are "almost universally" fixed dome, below-ground biogas plants such as the one shown in Figure 35 . The plants, which can be almost entirely constructed from "locally available materials such as clay, brick, cement, bamboo, wooden supports, etc.", come in a range of sizes from 4 to 20 m^3 (Gautam et al. 2009).

The entire Lamjung District has been declared Open-Defecation-Free since 2014 (NWA), and a number of participants reported that there were fines if anyone was found to be defecating in the open. When asked their opinion on why people in the community would open defecate, 66% of participants said there was no open defecation. However, some stated that there were some exceptions, as shown in Figure 36.

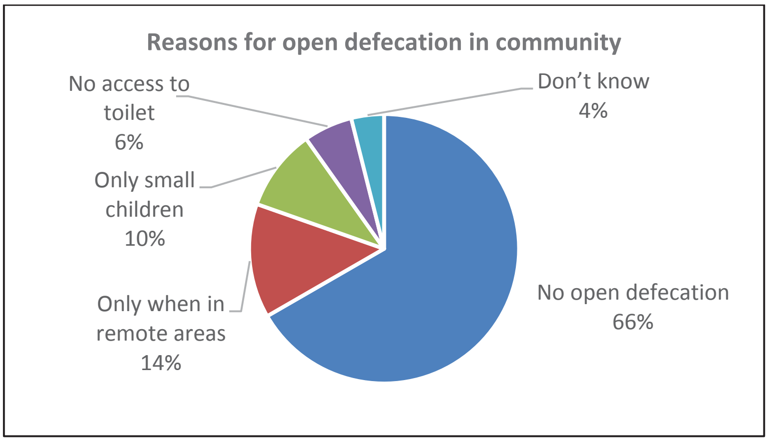


Figure 36 - Reasons for open defecation in the community

Note 1: Pie chart shows number of times an answer was selected, i.e. participants who gave multiple answers counted twice.
Note 2: "No access to toilet" could be interpreted both as having no toilet in the house and as being in a remote area far from a toilet.

Even if the majority of households surveyed reported to have a toilet, "hygiene behaviour in [relation to water and sanitation hardware] often remains a substantial risk to health" (LSHTM/WEDC 1998). A study that investigated the drinking water quality in rural Kathmandu Valley found that contamination at the point of consumption was due to "lack of proper cleaning of water containers, poor personal habits and a lack of awareness of cleanliness" (Pradhan et al. 2005). This same study found that cleaning of local water sources, such as spring boxes or collection tanks, only took place once a year. In half of the VDCs in our study, when it came to handwashing, 95% and 90% of the households owned handwashing stations and owned soap respectively, indicating a fairly high level of knowledge about personal hygiene.

6.3.1. Issues

As Lamjung District has been declared Open-Defecation-Free, the majority of households in our study (98%) owned a toilet with a good level of hygiene observed, but there are still issues regarding sanitation to be addressed which will be discussed further in this section.

Insufficient amount of water for flushing

One sanitation issue found in this study was a lack of water for flushing the pour-flush toilets, especially in the dry season, causing blocked pipes and foul odours. If a toilet is not working correctly it will not be able to safely dispose of the sewage (Griffiths et al. 1997), which will increase the risk of disease transmission.

To properly flush a pour-flush toilet, 2-3 litres of water are required (Tilley et al. 2014), plus another 1-2 litres for anal cleansing (Mara 1985), resulting in between 3-5 litres being required for each use. Considering that 86% of the households surveyed have a daily per capita water consumption of less than 25 litres, it is not surprising that some households raised lack of water for flushing as an issue. Only 16% of houses reported that a lack of water was causing their toilets to malfunction but, as mentioned before, it is suspected that a fear of fines due to the district's Open-Defecation-Free status may have biased participants' answers about problems with their toilets, as many households face water scarcity and using water for flushing is unlikely to be a priority.

Concerns with biogas production

Biogas is a well-developed technology in Nepal, with over 200,000 reactors having been installed across Nepal, and a total of 8,691 reactors in Lamjung District (BSP 2012). In our study area, 34% of households owned a biogas system, which is higher than the overall Lamjung District figure of 21% of households (calculated based on the number of households in Lamjung District as per the 2011 National Census).

Traditionally, many people in rural Nepal cook with wood, which is problematic as it can cause respiratory illnesses and eye ailments, costs time and/or money for wood collection, and contributes to deforestation (SNV 2009). Cooking with biogas provides a solution to these issues (SNV 2009) while also transforming the toilet waste into a valuable fertilizer product (Mendis and Nes 1999). However, reactors require careful design, construction, operation and maintenance to continue working optimally, and have high initial investment costs (Forte 2011).

For many households, issues around high investment costs have been solved by the government's subsidy and loan system (refer Section 6.5.2), however these systems often do not function at their full capacity. According to the *User Survey 2009/10* created by the Nepal Biogas Support Program (BSP), the "majority of sample households were also using other sources of biomass and fossil fuels for cooking purposes" (MoEnv 2010). A seemingly contradicting statistic in the same BSP survey was that 100% of users in the hill areas (n=36) reported the biogas supply was 'very adequate' or 'adequate'. In our study it was found that many of the households with biogas systems reported that they produced insufficient gas, and that as a result they still use wood fires for the majority of their cooking needs. There are a variety of factors that could be causing the sub-optimal performance of the biogas system. These include problems with low temperature, the amount and composition of materials such as manure and organic waste that are fed into the reaction, retention time and maintenance, as well as more technical factors such as alkalinity and pH, the carbon/nitrogen ratio and the presence of chemical inhibitors (UMN 2013).

The BSP survey states that the biogas companies who installed the systems are meant to visit these household systems when problems arise during a guarantee period of three years (MoEnv 2010). Unfortunately, 61% of households in the hill areas reported that they were not receiving this service (MoEnv 2010). The remote location of the houses in Lamjung means that it is difficult for them to receive appropriate technical support (Gautam et al. 2009).

Temperate also effects biogas systems, with outside temperatures of over 10 ºC required for efficient biogas production. The average yearly temperature, which was 20.5 ºC (refer to Table 6), can be used as an estimate of the below-ground temperature if the biogas reactor is located two metres underground. However, as it is unlikely that these systems were buried this deep, the overnight temperature should also be considered, and it consistently drops below 10 ºC in Lamjung during the winter (Poudel and Shaw 2016). As a result, optimal production of biogas is not always feasible in this area (Gautam et al. 2009).

The loading rate of manure and organic waste to the reactor could also be contributing to the lack of gas production. In our study it was found that 23% of households owning a biogas system only had one large animal, and 6% had no large animals. A minimum of two cows or buffalo, or six pigs is required to feed a household reactor, simply connecting the household toilet to the reactor will not produce enough gas to be sustainable (SNV 2009), so these households will not have a fully functioning system until they input more manure.

6.3.2. Solutions

Some of these issues cannot be resolved without an investment of capital that the participants are not able to make themselves. However, some simple improvements can be made to the systems to improve their operation.

One solution for not having enough water for flushing is to augment the water supply through measures such as rainwater harvesting, as discussed in Section 6.1.2.

Another solution to reduce blockages of toilets is to increase the pipe diameter and slope, while ensuring that the diameter is not be too large for self-cleansing to occur during flushing. However, all households reporting problems with flushing said they were able to fix them themselves using a stick to unblock the pipe, so it is not a serious issue. Furthermore, the water used for flushing does not have to be clean, so greywater from the kitchen, bathroom or laundry could be used for this purpose (Franceys et al. 1992). Another potential solution would be to use dry toilets, such as the double-vault composting toilets discussed in section 6.4.2.

Some households reported that less gas was produced in the dry season (winter) due to a lack of water for flushing and hence for the biogas reactor, but in fact, studies show that in Nepal it is common that too much rather than too little water is added to reactors (UMN 2013). It is more likely that the reduced gas production was due to lower temperatures, as the overnight temperature in Lamjung consistently drops below the 10 ºC required for efficient biogas production during the winter and it was likely that the reactors were not buried deep enough to insulate them against the cold (Poudel and Shaw 2016). As such, a potential solution is to bury the reactors deeper into the ground to improve insulation. Furthermore, the standard brick-dome design of the reactor is more prone to gas-leakage than other types of reactors such as fixed-dome plants, and they need to be sized carefully to ensure appropriate retention time in the digester is achieved (ISAT and GTZ 1999). These design issues highlight the need for better education of the contractors installing the systems on how biogas systems function, as well as the need for new and innovative designs of reactors to be made available by BSP. One such potential system is in development, where solar energy is used to raise the temperature in the reactor, increasing the efficiency of the digestion process (Weatherford and Zhai 2015).

Although it may be too costly for households with an insufficient amount of large animals to feed a biogas reactor to purchase more animals, better management of how the livestock's manure is collected could increase the supply of material fed into the reactor. For example, if the animals are kept in a stable with a concrete or even mud floor, a channel can be dug which can facilitate animal manure collection.

Lastly, there needs to be a means to increase the accountability of biogas installation companies who are not providing the required operation and maintenance services. If this is not feasible, then perhaps a local technician should be trained and employed in each VDC where biogas systems are installed, which has the added benefit of creating employment opportunities for these technicians. Increased optimization and use of biogas reactors in Nepal yields benefits in human health, improved hygiene, provides lighting for children to complete their schoolwork after sunset, employment, gender benefits (as woman are mainly responsible for collection of firewood), reduced firewood consumption and deforestation, as well as production of organic fertilizer (Gautam et al. 2009).

6.4. Agriculture

A thorough investigation of water and sanitation would not be complete without considering agriculture, as the topics are closely linked. Agriculture is the world's largest consumer of water (FAO 1993), while ecological sanitation provides the means to 'close the loop' and return nutrients from consumed food back to the soil (Kropac and Conradin 2015).

Over two-thirds of the population in Lamjung District depend on subsistence agriculture, but farming in the rural mid-hills region of Nepal will become more challenging with the impacts of climate change including "erratic rainfall, increasing trend of drying water sources, prevalence of invasive weeds, increasing trend of pest, diseases and frost" (Gentle et al. 2014). In addition to issues caused by climate change, the lack of water for irrigation, over-reliance on chemical fertilizers and poor soil fertility are other issues that are apparent and will be discussed further in this section.

The survey included questions regarding participants' irrigation methods, fertilizer usage and livestock ownership. In addition, participants were asked how much land they own for cultivation. Answers to these questions differed, as it was common for land to be rented to labourers for cultivation and also because it was common for only a part of the land owned to be cultivated in households where the male head of the house was working overseas. Nepalese units of either *ropani* or *hal* (equal to the amount of land two ox can plough in a single day of work) were generally given in the answers. For the purposes of this thesis, it was assumed that one *ropani* is approximately the same as one *hal*, as this is what three of the more educated participants responded when asked about the relationship between the two units. In the hills, one *ropani* is approximately equal to 500 m^2 (IRRI 2002).

In Table 12, the results for the average number of *ropani* owned and cultivated, as well as the average amount of chemical fertilizer used per *ropani* cultivated is shown. The authors attempted to collect data on the composition of the chemical fertiliser, however most participants were unable to estimate how much they used of each type, so only information on the amount of chemical fertiliser as a whole was included in Table 12.

Table 12 - Land ownership and chemical fertilizer usage

VDC	Average *ropani* owned	Average *ropani* cultivated	Average chemical fertilizer use (kg) per *ropani* cultivated
Kunchha	8.5	8.5	1.9
Chandreshwor	5.3	5.3	7.8
Chakratirtha	7.1	6.6	5.0
Simpani	9.5	5.8	2.5
Overall	7.3	6.5	4.7

6.4.1. Issues

Insufficient quantity of water for irrigation

It was discussed earlier that water scarcity for domestic use was an issue in the study area, however, as 88% of the households surveyed depend on agriculture for all or part of their income, water for irrigation was also investigated. For households depending on income from agriculture, water for irrigation is a vital resource (Hussain and Hanjra 2004). In Nepal, the uneven temporal distribution of rainfall results in insufficient water for irrigation of crops in the dry season (Merz et al. 2003). Furthermore, small-scale agriculture water requirements are often neglected in water demand calculations for community water supply projects (Mikhail and Yoder 2008). In Lamjung District, just over 20% of agricultural land is irrigated. Department of Irrigation data indicates that a further 30% has the potential to be irrigated (MOAD 2012).

In our study, participants were asked how they irrigate crops in the dry and rainy seasons. The improved irrigation methods reported were all classified as 'Irrigation method' and included irrigation canals from springs and streams that only run in the rainy season, irrigation canals from rivers that flow all year, and water piped from their community water supplies. Participants who reported no irrigation system or relied solely on rain were categorised as 'None'. A 2015 report by the Nepal Earthquake Assessment Unit reported that 67% of agricultural land in Nepal is rain-fed, that is to say that it is irrigated by rain alone year-round (2015). The situation in our study area was better, as only 30% reported that they relied on rain year-round for irrigation.

However, 52% of the participants reported that they only have improved irrigation systems in the rainy season, and that in the dry season their land is only rain-fed. Considering that less than 100 mm of rain falls in Kunchha and Simpani for approximately six months of the year, as is shown in Table 5, households could substantially increase their crop production if they were able to irrigate their land in the dry season as well as the wet season.

For the 21% of households with no irrigation year around, water scarcity is an even more important issue. According to Mikhail and Yoder (2008), farm households in Nepal that do not have access to irrigation are at greater risk of poverty. In a study of the link between poverty and irrigation in multiple Asian countries, Hussain and Hanjra (2004) found that “poverty incidence is 20–30% lower in most irrigated settings compared to that in rain fed settings”. Results from our study support this trend and are presented in Figure 37, which shows the irrigation method in the dry season followed by the irrigation method in the rainy season.

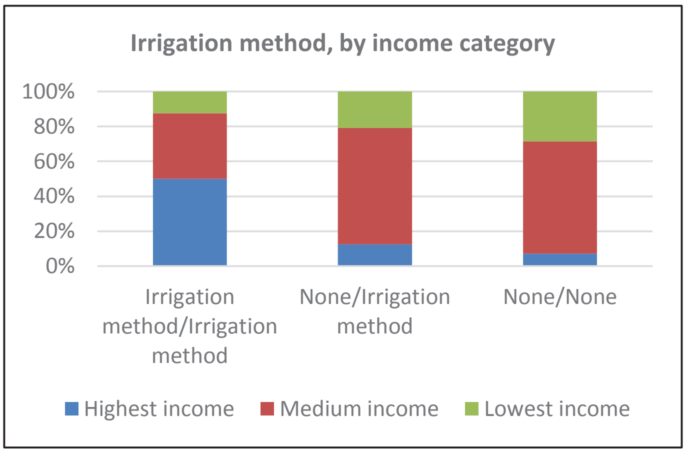


Figure 37 - Income category of houses, compared to whether or not they have improved irrigation systems in the dry/rainy seasons

Only 13% of the houses with improved irrigation all year are in the lowest income category. However, no significant correlation was found between household income and irrigation methods, and participants from all income categories reported having no irrigation in either the dry or rainy seasons.

Various other correlations were investigated to determine the main factors that influenced whether or not households had an improved crop irrigation method, in order to determine how best to address the issue. The only statistically significant correlation found was with a household’s location, based on VDC (p-value 0.007). This was not surprising due to the differences in geography and elevation. Chakratirtha has the lowest elevation, is near a river and had the highest proportion of households to report improved irrigation year-round. Simpani, which has the highest elevation, reported no households with improved irrigation year-round. It can therefore be concluded that lack of water for irrigation is a problem that is dependent on location rather than socio-economic status, as such needs to be addressed for all groups rather than just the relatively disadvantaged groups.

Over-reliance on chemical fertilizer

In Nepal, approximately 21% (32,000 km^2) of the total land area is used to cultivate rice, maize, wheat, millet and potatoes (Gautam 2008). A study by the Nepalese government in 2003 found that 81% of farmers apply both organic and chemical fertilizer to their crops, 10% use just organic fertilizer, and 8% only use chemical fertilizer (Manandhar and Khanal 2004). Our study had similar findings: 79% of households who cultivate land used both organic and chemical fertilizer, while the other 21% only used organic fertilizer.

Unfortunately, all of the chemical fertilizer in Nepal is imported from India and other countries, which leaves a large percentage of farmers vulnerable to price increases and disruptions in supply (MOAC 2010). It is not feasible for Nepal to manufacture its own chemical fertilizer, due to a lack of raw feed stocks and the relatively high cost of electricity compared to neighbouring countries (Thapa 2006). As a result, the production of organic fertilizers and soil conditioning agents through ecological sanitation technology is a suitable option for Nepal from a technical point of view.

Based on 2004/05 data, Nepalese farmers used 0.0125 kg of chemical fertilizer per m^2 (Thapa 2006). This is made up of roughly 67.5% Urea, 30% Diammonium Phosphate (DAP) and 2.5% Murate of Potash (MOP) (Diwakar et al. 2008; MOAD 2012). In our study, the average fertilizer usage per cultivated square metre was 0.014 kg, however the data on breakdown of fertilizer by type was too difficult to collect accurate data on. Using this fertilizer application rate of 0.014 kg/m^2 and the percentage breakdown of fertilizer type mentioned above, in combination with data on the average prices for each of these types from the Nepalese Ministry of Finance (Thapa 2006), it would have cost approximately 0.31 Nepalese Rupees (NPR) to fertilise each m^2 of land, at 2004/05 prices. In our study, the amount of land cultivated ranged from 500 to 12,500 m^2, resulting in a cost of 155 to 3,875 NPR per year (see Appendix E for calculation). As many rural families have little disposable income and mainly live off their land, this money could be better spent elsewhere if much of the chemical fertilizer was replaced with organic sources.

Poor soil fertility

Soil fertility is the ability of a soil to support plant growth by providing adequate amounts and proportions of minerals, organic materials, water, air and living microorganisms (Pariyar 2008). In Nepal, "topsoil colour, texture and terrace type are the most dominant criteria for local land classification and soil fertility management" (Pariyar 2008). One study that looked into soil fertility management in the mid-hills of Nepal found that "continued use of chemical fertilizers apparently increased the hardness of the soil, making it more difficult to cultivate, reduced soil fertility, and caused a decline in crop productivity…[and] no or limited use of chemical fertilizers was associated with an increase in soil fertility" (Pilbeam et al. 2005). Another study that researched fertilizer management in Lamjung District found that, "most of the farmers denied knowing the recommended fertilizer rate, and said that they used fertilizers according to their experience" (Haefele et al. 2014). If farmers are using chemical fertilizers without knowing the appropriate dosage to apply per land area, then this can have a devastating impact on soil fertility (Haefele et al. 2014).

6.4.2. Solutions

In this section, solutions to issues involving the lack of water for irrigation, over-reliance on chemical fertilizers and poor soil fertility will be discussed.

Improving irrigation

There was a lack of water for irrigation identified across all socio-economic groups, and whether or not households had access to improved irrigation methods seemed to be more strongly linked to where the houses are located than to their income or caste. The solutions suggested in section 6.1.2 for augmenting domestic water supply are also relevant for this section.

One of these solutions is rainwater harvesting, which can also be used for small-scale agricultural irrigation – with regard to their domestic household rainwater harvesting systems, 75% of households surveyed by Domènech et al. reported that these systems improved production of their kitchen garden (2012). In our study, a significant correlation was found between opinion of rainwater harvesting and irrigation methods (p-value 0.052), showing that the households without improved irrigation systems were the most likely to be positive to using rainwater harvesting. Conventional rainwater harvesting technology is too expensive to be used on a larger scale irrigation of fields, however, organisations such as IDE are developing low cost water storage bags that could be used for this purpose (IDE 2016), so this could become feasible in the future.

However, rainwater harvesting can only provide, at best, enough water for a large kitchen garden, and not enough to irrigate fields. An alternative solution for larger scale irrigation is to improve the quantity of water available on a communal scale through pumping of water. In Lamjung, less than 4% of households use wells for water collection, so this section focuses on pumping from river sources at lower elevations rather than pumping from groundwater wells (NPHC 2011). Using solar power to pump water is a more attractive option than diesel or the electricity supplied by the grid, as these sources are more expensive and experience frequent supply disruptions, while solar power has low operation costs once the system is built (ICIMOD). Although the operation costs are much lower, according to Belbase (2015) the installation cost of a solar system is at least 5 times higher than a diesel or electricity powered system, resulting in a pay-back period of 25 years compared to a diesel system (Kulkarni 2015). ICIMOD, in partnership with the Consortium of International Agricultural Research Centers (CGIAR) on Water Land and Ecosystems (WLE), is currently piloting such a plant in the Saptari District, which is in the Terai region (ICIMOD 2015a).

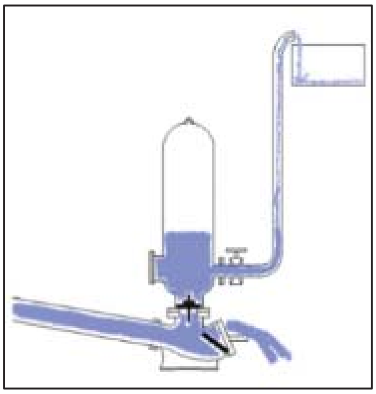


Figure 38 - Hydro-ram design (CRT 2012)

ICIMOD is also researching hydro-ram water pumps, which is a "self-actuating pump operating on the principle of a water hammer that is used to lift water from a position near the water source to a higher location" without any power source except the water itself (ICIMOD 2016), shown in Figure 38. The Centre for Rural Technology Nepal has already built such systems in Nepal, with positive results in female school attendance, improvements in health, reduction of time spent by women collecting water and increased agricultural yields (CRT 2012). If government subsidies are implemented to encourage growth and research in the sector, renewable energy powered water pumps could be a sustainable solution for irrigating farmland in the mid-hills.

A cheaper solution than pumping water is to improve the efficiency of use of existing water sources for irrigation. Traditionally, Nepalese farmers use the furrow method of irrigation, where siphons transfer water from a head ditch to crop furrows (Jha et al. 2016). Drip irrigation, where water drips onto the soil very slowly (2-20 L/hr) using a system of small diameter pipes through outlets called emitters (Brouwer et al. 1990), is substantially more efficient than furrow irrigation (Jha et al. 2016). The main advantage is that water loss through evaporation is reduced, but the disadvantage is the higher cost of installing pipes compared to simply digging furrows (Jha et al. 2016).

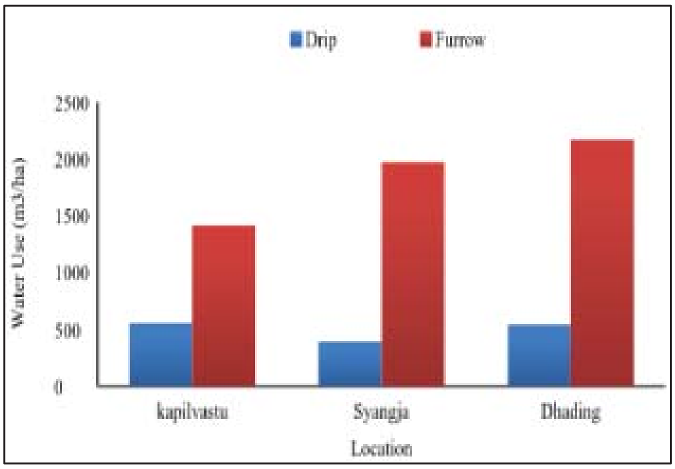


Figure 39 - Volume of water usage per ha for irrigation at three locations in Nepal over the 2013–2014 growing seasons (Jha et al. 2016)

Jha et al. tested the efficiency of drip irrigation compared to furrow irrigation in three locations in Nepal in 2013-14. The results, presented in Figure 39, clearly illustrate that less water is required for the same volume of crop production using drip irrigation. In Lamjung District, this technology has been introduced by some of the PCVs visited during the study, but it is not yet being used on a large scale and the volunteers reported issues with cost and difficulties in sourcing materials locally.

One simple low-cost drip-irrigation system is porous pipes, where small holes are pierced in plastic pipe which is then buried in rows under crops, with one end protruding above the ground. Water is poured into the pipe and slowly percolates into the root zone of the crops, as shown in Figure 40 (FAO 1997).

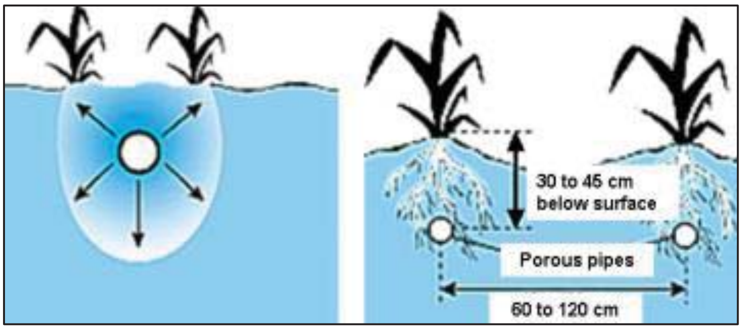


Figure 40- Porous pipe subsurface irrigation (FAO 1997)

The climate in Lamjung District is appropriate for growing fruit trees, so drip irrigation methods for individual plants were also investigated. Two alternative methods are shown in Figure 41, the clay pot method and the bottle method. The clay pot method involves placing a porous clay pot between the roots of two plants, which can be topped up by hand and allows the water to slowly percolate out to the roots. The bottle method works on the same principle, but the bottle must be dug up and refilled each time it is placed next to the roots so the clay pot method is preferable (Stauffer 2012).

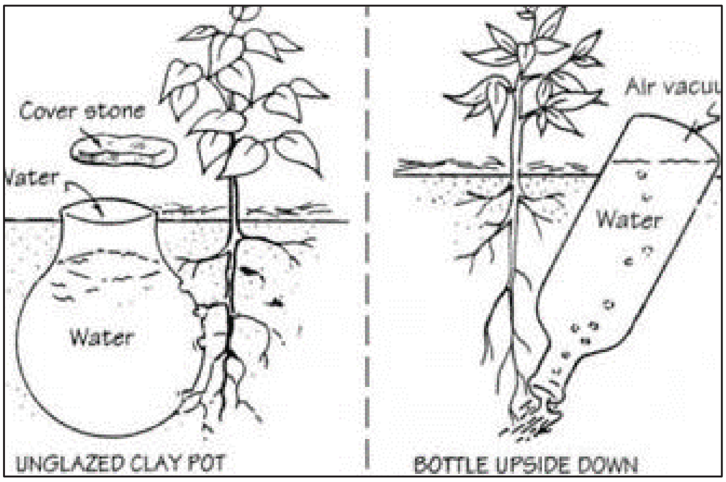


Figure 41 - Clay pot and bottle irrigation methods for small-scale agriculture such as irrigation of household fruit trees (Stauffer 2012)

Other methods can also be used to improve water use efficiency. For example, wastewater such as household greywater and overflow water can be collected in micro-tanks or ponds for use as irrigation water. Nepal Water for Health (NEWAH) are promoting this technology through their *Domestic Plus program*, which is a program aiming to construct technology which augments water supply for both domestic and agricultural needs (2010). Micro-tanks and ponds were installed to collect overflow water from domestic water storage containers and tap stands, and these, in combination with pipes fitted with sprinkler valves, have increased agricultural production in the targeted households (NEWAH 2010). Greywater collection is already done informally in Lamjung District, as during the study it was discovered that participants usually used their greywater to water their kitchen gardens.

Another way of more efficiently making use of the existing water resources is to build recharge ponds above the irrigated land, which would percolate through the soil and increase its water content (NWP 2007).

To summarise, the quantity of water for irrigation can be augmented using the domestic methods outlined in section 6.2.2, or on a larger scale by pumping water from a river at a lower elevation, either with renewable power or conventional power. Other methods that could be used to alleviate the water scarcity issues facing farmers in the Lamjung District are improving irrigation efficiency using drip irrigation, recharge ponds and re-use of wastewater.

Over-reliance on chemical fertilizer and poor soil fertility

It was discussed above that Nepal has poor soil fertility, and that, currently, the most common method of improving this issue is to supplement organic fertilizer from livestock manure with chemical fertilizers. However, chemical fertilizers are costly and are all imported from outside of Nepal, meaning the supply is unreliable. Increasing farmers' access to sources of organic fertilizer through the treatment and re-use of human urine and faeces would work towards solving both of these issues.

According to a study that looked at agriculture in the western region of Nepal, famers in the mid-hills have a well-defined and comprehensive understanding of integrating chemical and physical characteristics, agricultural requirements and factors in the surrounding environment with respect to soil fertility in their fields (Desbiez et al. 2004). In another study that looked into soil fertility management in the mid-hills of Nepal, "households were considered to be the most significant unit for considering the management of soil fertility because they are the focal point for decision-making about resource use" (Pilbeam et al. 2005). Meaning, if households could be persuaded to re-use human urine and faeces as organic fertilizers, then the country's reliance on chemical fertilizer imports as a whole would decrease.

There are various methods to treat and recycle urine and faeces into organic fertilizer, including urine diverting toilets, ecological sanitation toilets and biogas reactors. Biogas has already been discussed extensively so this section will focus on the first two methods.

Using human urine as fertilizer is a simple and cheap technology with the potential to increase productivity and food security for farmers in regions such as Lamjung District. An average person produces around 550 litres of urine per year, which equates to approximately 4 kg of nitrogen, 400 g of phosphorous and one kg of potassium produced per person annually (WaterAid 2008a). As previously mentioned, these are important nutrients for plant growth. According to the *Sustainable Sanitation and Water Management Toolbox*, as a general rule the urine from one person is sufficient to fertilise 300-400 m^2 of land (Gensch 2010). In our study, the average farming household had 3,000 m^2 of land and 4.6 household members, which means that almost half of their fertilizer needs could be met by urine alone. According to calculations in the WaterAid publication *Assessment of Urine Diverting Ecosan Toilets in Nepal*, in monetary terms the value of urine from one standard household is approximately equivalent to 1,200 NPR, based on the market prices of fertilizer in April 2007 (WaterAid 2008a)(refer Appendix E for calculations).

A study by Pradhan et al. (2011) in the Nawalparasi District found that 52% of participants had prior knowledge of urine-fertilizer technology and 100% were positive to the technology. This differs from our study, where the majority of participants had no knowledge of the technology, 71% said they would or might use it, while 22% said they would not use it and 6% were unsure. There are multiple factors that could explain the differences between the studies. Nawalparasi District is located in the Terai region, while Lamjung District is in the mid-hills, and the population surveyed were largely from the Magar ethnic group, of which there were no members of in our study. Furthermore, it is not clear whether Pradhan et al.'s questionnaires were delivered individually or as part of a group discussion. If it was a group discussion it is likely that respondents would be influenced by other people's opinions, which would explain the unanimous positive response to the use of urine as fertilizer (Mosler 2012).

Some examples of participants' opinions on urine application are (paraphrased due to translation and interpretation): *"I have heard of it [urine] being used but that it is only okay on the roots of plants", "I would use urine but only if it was ploughed into the field"* and *"I might use it [urine] but only if I was sure it won't affect my health".* These are valid concerns as, if contaminated with faecal matter during source separation, urine can contain disease causing agents such as viruses, bacteria, protozoa and helminths (Höglund et al. 2002). However, a study by Höglund et al. (2002) found that if urine is stored at 20ºC for at least 6 months it can be considered safe to apply directly onto crops. The average yearly temperature in the study area is 20.5ºC so this is generally feasible. Disease die-off is temperature-dependant, so storage time can be reduced when the temperature is above 20ºC. In addition, applying urine to crops that will not be directly ingested by humans or lightly ploughing after spreading the urine onto the applied area will reduce the risk of transmission of disease. Ploughing has the added benefit of minimising ammonia losses through evaporation (Höglund et al. 2002).

Figure 42 - Urine-diversion pans: the pink pan is for wet toilets and the blue pan is for dry toilets, with a separate hole for anal-cleansing water (Saxena 2009)

The process of collecting urine while keeping it separate from faeces is called source separation and, more specifically, urine-diversion. In Lamjung District, all participants used water for anal-cleansing, so the most appropriate urine-diversion technology is either a wet pour-flush urine-diverting toilet or a dry EcoSan toilet. Both of these toilets use urine-diverting squat pans, shown in Figure 42. A wet pour-flush urine-diverting toilet is similar to the toilets already present in the Lamjung District, however the pan has two holes. The back hole is for faeces and anal-cleansing water, and discharges into the pit as before, but the front hole is connected to a pipe which pipes the urine into a removable container outside of the building where it is collected before application to crops. The dry EcoSan toilets converts faeces into usable fertilizer and soil conditioning products, and has a separate hole for anal-cleansing water in order to keep the collected faeces dry. These toilets will be discussed in more detail below.

For households that do not want to invest in a new toilet, there are simpler urine-collecting technologies that have been used by THE SEWA Nepal, an organisation visited by the authors while conducting our survey in Nepal, which promotes "the Power of Pee". These are shown in Figure 43. For men, a jerry can with a funnel and a ping pong ball, to prevent odours and evaporation, can be placed next to the existing toilet and used directly as a urinal. For women, a small pan can be made from plastic, concrete or even mud (with regular maintenance) that pipes the urine into a jerry placed at a lower level, however, this is too large to simply place inside the existing structure (as could be done with a jerry can) so it would also require the construction of a superstructure for privacy.

Figure 43 – Simple urine diversion technology. Male jerry can urinal (left) and female urine pan (right) to be piped into a jerry can below (Photo taken by authors)

Similarly to human urine, human faeces also contains important nutrients for plant growth, although in lower concentrations. As a result, treated faeces can be used as a low-grade fertilizer or soil conditioner. This has been common practice in Nepal for many years, one report found that traditional inhabitants of Kathmandu Valley sold their excreta to farmers because they recognised that it had inherent value and “had to be recycled for effective management” (WaterAid 2008a). EcoSan toilets are designed to accumulate faeces where “ash, lime or other additives are used to raise the pH of the waste and thereby break down pathogens [and] after about six months of storage without the addition of fresh faeces, the resulting material…may be used as a soil conditioner for agriculture” (WaterAid 2008a). A WaterAid report (2008a), *Assessment of urine-diverting EcoSan toilets in Nepal*, estimated that an EcoSan toilet from an average sized household in Nepal has an annual production of approximately 100 kgs of soil conditioner from human excreta, thus the estimated annual total value of the soil conditioner is 500 NPR, as soil condition is valued at 5 NPR/kg in Kathmandu (WaterAid 2008a). The report found the pay-back period for EcoSan toilets to be about nine years, meaning that a family that invests in an EcoSan toilet will be able to pay back a bank loan if the soil conditioner and urine produced is sold at market value (WaterAid 2008a).

There are a range of these EcoSan toilets available, however two of the more common types will be discussed here. The first EcoSan design is a common double-vault composting latrine (see Figure 44). These are dry toilets, meaning that the urine is diverted and collected separately, and water is not allowed into the main vault. As a result, they are most suitable for toilet-paper users, but they can be adapted for anal-cleansers in Nepal with the addition of a third hole for cleansing water and thorough training on usage, as this behaviour change can be difficult to grasp, especially for children. These toilets have two vaults for collection of dry solids, when one is full users begin using the second one. The advantage over pit latrines is that the contents of the pits can be used as fertilizer faster than two years, however, safe composting requires careful management of water content and temperature so these toilets should only be used after specific training (Barun 2010).

Figure 44 - Double vault composting latrine (Barun 2010)

The second EcoSan option includes twin-pit latrines are simple in design, comprising of a pour-flush toilet that discharges into a pit dug behind the toilet building. However, when the pit is full to within one metre of the top of the cover, it is no longer used and a secondary pit is filled (see Figure 45). Sometimes this pit is built at the time of construction of the toilet, sometimes it is built only when the first pit is almost full. The first pit is filled with soil and left to compost for a minimum of two years, after which time it can be used as fertilizer (Barun 2010). If well designed, constructed and maintained, these types of twin-pit latrines can be as good an option as more sophisticated technology, such as the double vault composting toilet (Barun 2010). In the study area, many households already had pour-flush toilets with offset soak-pits which, with enough land available, could easily be converted into twin-pit latrines.

Figure 45 - Twin pit pour-flush latrine (Barun 2010)

The introduction of the re-use of human waste as fertiliser, as a concept, must be accompanied with sufficient training and education in the construction and use of these toilets to allow farmers to make an informed judgement, and to understand the importance of properly treating the waste. This is imperative, as improper treatment of faeces before application to fields can cause an incomplete die-off of pathogenic bacteria, which greatly increases the risk of transmission of disease (WHO 2006).

In addition, education is required to improve the opinions of the technology. Some people are initially averse to using waste from their toilets to grow crops, which is not an unreasonable concern, given the health risk of using improperly treated waste as fertiliser. However, education with an aspiration to focus on the benefits and proper treatment methods of human waste, should make it possible to persuade many households to use this technology. Our survey found that 69% of participants might be willing to use human urine as fertilizer and 49% of participants might be willing to use soil from human excreta. Figure 46 shows the varying levels of willingness of all participants surveyed in different locations (VDCs). This indicates that some areas, such as Chandreshwor, which had the most participants with negative opinions, would require more intensive education programs than other places.

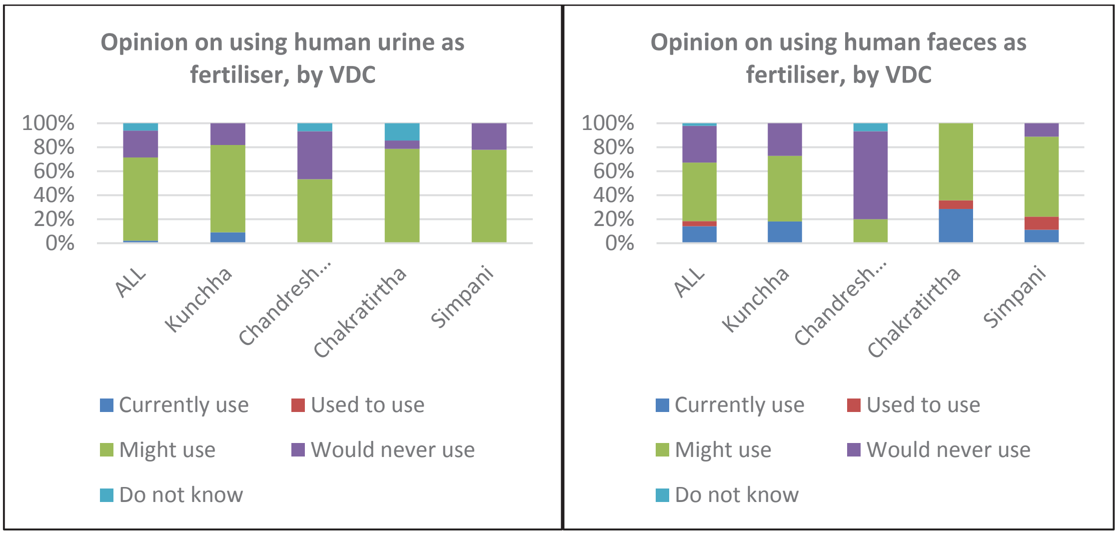


Figure 46 - Percentages of participants' willingness to use human faeces and urine as fertilizer

Our study found that caste correlates with whether participants have a positive opinion of using human excreta or not (p-value 0.068). About 92% of participants that were Brahman, the highest caste, had a positive opinion of using soil made from human excreta, while only 45% of participants that were Dalit, the lowest caste, had a positive opinion. This is possibly due to members of the Dalit caste having a lower level of education and not fully comprehending the benefits of using human excreta as soil conditioner.

The results also showed a correlation (p-value 0.014) between whether participants have a positive opinion of using human excreta or not and gender. The males surveyed were found to have a more positive opinion of using human excreta than the females and females were found to be more divided in their opinion of the matter. Men may generally have a more positive opinion because they purchase chemical fertilizer and recognise the potential savings with the use of organic fertilizer, whereas women may need education to understand the financial benefits.

There were no significant correlations found with respect to participants having opinions of using human urine as fertilizer. The correlations made between different demographics and socio-economic factors should be used to help decide how best to change negative attitudes towards using treated urine and faeces as fertiliser.

It is interesting to note that compared to the 49% who were willing to use human excreta as fertilizer, 84% of participants said that they were willing to use the sludge from biogas (containing human faeces). It is possible that mixing the excreta with animal manure and digesting it improved its appeal as a fertilizer, but also that it is easier to handle from the outlet of a biogas plant than having to manually empty a toilet. With this in mind, even if it is not possible to introduce wide-spread use of human urine and excreta due to negative attitudes towards the technology, continuing to develop and improve the biogas industry in Nepal will provide more farmers with an effluent that is "high in nitrogen, potassium and phosphorus contents," and can be used on cultivated land as an alternative to chemical fertilizers (Gautam et al. 2009).

Our survey showed that more than 50% of all participants across all VDCs might be willing to or currently use human urine as fertilizer and treated human excreta as soil conditioner. Faeces has "similar nutrients and effects in soil as that of compost" (WaterAid 2008a), while human urine contains nitrogen, phosphorous and potassium, which are the three most important nutrients for plant growth. In order to utilise these valuable resources, a variety of common EcoSan toilets designed to contain, sanitize and re-use waste as plant nutrients and soil stabilizers will be presented and further discussed (WaterAid 2008a).

6.5. Access to water and sanitation

Disparities in access to improved water and sanitation based on "economic status, gender, caste, ethnicity and location" still exist in Nepal, despite overall improvements in the level of access across the country (ADB 2011). In our study, it was investigated whether these factors have a significant effect on access to water and sanitation in the Lamjung District. As no information was collected on whether households in our survey were male or female-headed households, the impacts of gender could not be investigated.

6.5.1. Issues

Inequality of access to water

According to reports from WaterAid (2008b) and DFID (LSHTM/WEDC 1998), provision of adequate water supply is often neglected for poor and disadvantaged groups in Nepal. Results from the report *Caste, Ethnic and Regional Identity in Nepal: Further analysis of 2006 Nepal Demographic and Health Survey*, presented in Figure 47, confirm this statement (Bennett et al. 2008).

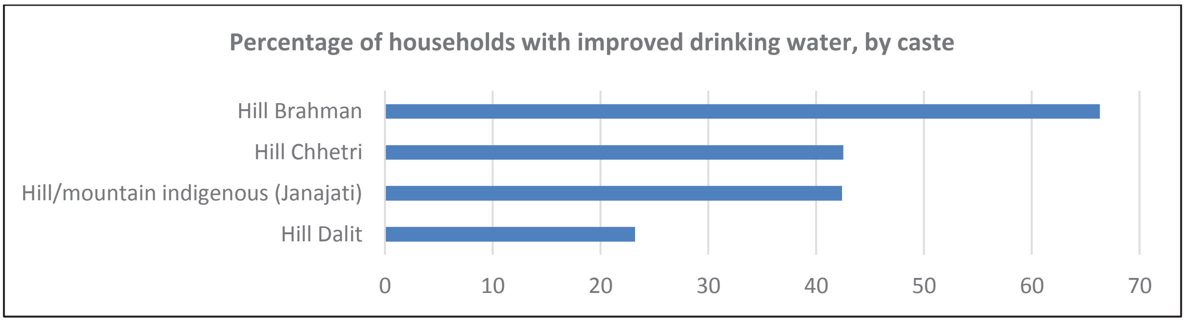


Figure 47 - Percentage of households in each caste with access to improved drinking water (Modified from Bennett et al. 2008).

The findings from our study were in agreement with this trend. Correlations were found between water service level and caste (p-value 0.041) and water service level and income category (p-value 0.033). It was found that households from the lowest caste, Dalits, and households from the lowest income category were more strongly associated with having a 'poor' water service level than the other groups. Similarly, households from the highest caste, Brahman, and the highest income category had a stronger association with a 'good' water service level than the other groups. In general, higher castes generally have higher income (Bennett et al. 2008), so it was logical these correlations would both support the trend.

It should be noted that water service level also correlated with the location of households based on VDC (p-value 0.005), indicating that it is not just socio-economic status that determines service level as each VDC contained a mix of people from all socio-economic groups. The location of the household was a good predictor of their water service level, which is most likely due to whether or not the VDC has a community water system installed, but could also be due to the elevation and hence access to potential water sources.

Inequality of access to sanitation

Differences in access to sanitation between income categories and caste was also considered. Bennett et al. also found that access to sanitation varies between castes in the same way as access to improved drinking water sources (2008). In terms of differences between income categories, the Asian Development Bank (ADB) report *Sectoral Perspectives on Gender and Social Inclusion* found that when analysed by income, the inequality of access to sanitation is even more pronounced than with access to improved drinking water (2011).

In this study, all houses except one had access to a private latrine, so it is difficult to draw conclusions from this data except to say that the study area has a higher level of sanitation coverage than the national average (WHO 2015). At the time of our study (March 2016), the sanitation situation was also better than that reported by the National Census in 2011, when it was determined that in Lamjung 19% of households did not have a toilet, 1% had a flush toilet connected to public sewage, 58% had a toilet with a septic tank and 22% had an 'ordinary toilet' (NPHC 2011). It is likely that 'septic tank' also includes offset soak pits as well as biogas systems, and that 'ordinary toilet' is an unimproved pit latrine. This is compared to our study where 2% did not have a toilet, 34% had a toilet connected to biogas and the remaining 64% had a toilet with a either a septic tank or an offset soak-pit. This could indicate that the four VDCs in our study have a better sanitation situation than the Lamjung average, or it could be an indication of the progress made since 2011 towards installation biogas systems in each house and reaching Open Defecation Free status, which was achieved in 2014 (NWA 2015).

In addition to access to a private latrine, ownership of a biogas system connected to the latrine could be considered as an indicator of level of sanitation service as all of the biogas systems had toilets attached to them, qualifying them as EcoSan technology. Correlations between biogas ownership and indicators such as caste, income category, and land ownership were investigated. A statistically significant relationship found was with land ownership (p-value 0.025), where households with more than 20 *ropani* of land are more likely to own a biogas system than houses with less land. This is an indication that wealthier households are more likely to own a biogas system, but this could also be due to households with more land requiring more fertilizer and hence being prepared to invest the required capital. A significant correlation was also found between biogas ownership and location (p-value 0.061), indicating that biogas installation may depend on whether a biogas company has visited the VDC or not.

Although not statistically significant, the study found that increasing income indicated a higher percentage of households with a biogas system. For example, 50% of households in the highest income category had biogas systems, compared to 38% in the middle income category and 9% in the lowest income category.

The relationship between caste and biogas ownership was more complex. Half of the households in both the highest caste, Brahman, and the indigenous ethnic groups (third highest caste) had a biogas reactor, compared to a third of Chhetri households (second highest caste) and less than 10% of the lowest caste, Dalits. The unexpectedly high uptake of biogas technology amongst indigenous groups could be due to culturally specific attitudes towards using biogas sludge as fertilizer, or it may be due to certain locations where a high proportion of members of these castes live and are being targeted by the government and other organisations for biogas installation.

6.5.2. Solutions

The government has acknowledged that there are inequities in access to water and sanitation, and has begun implementing strategies to improve the situation. An example is presented in the ADB's report, *Gender Equality Results Case study – Nepal* (2015a), where the progress made in the Ministry of Physical Planning and Works' *Community-based water supply and sanitation sector project* is discussed. This project included a focus on disadvantaged groups, by encouraging their participation in the project activities through training and awareness raising. Proportional representation of the poor and caste/ethnic minority groups on the water users' and sanitation committees was a condition for the projects receiving funding (ADB 2015a). The project was successful - in the targeted areas proportional representation of Dalit's and ethnic minorities on water users' and sanitation committees was achieved (ADB 2015a).

Policy changes such as the one described above are effective, however, more needs to be done to tackle financial barriers preventing disadvantaged households from constructing safe and sustainable water and sanitation systems. An example of a successful financial model for encouraging low-income households to install appropriate technology is biogas plant installation in Nepal. BSP subsidises around 30% of the biogas system cost, and coordinates with banks to help farmers loan the rest of the money required (Bajgain and Shakya 2005). Building on lessons learnt by BSP since they began working in 1990, *The Global Partnership on Output-Based Aid (GPOBA) Biogas Support Program* was established in 2006 (GPOBA 2015). This phase of BSP's ongoing project aimed at installing systems in low-income households, by specifically targeting remote households, and subsidising a larger percentage of their total plant costs (GPOBA 2015). BSP's funding scheme could perhaps be used as a model for financing of other water and sanitation technologies.

7. Conclusions

Lamjung District is facing a range of water and sanitation issues, which affect the health and livelihoods of the people living there. However, Lamjung District generally has a better situation, on average, than other rural districts in Nepal. Some of the water and sanitation issues found in this study disproportionately affect marginalised groups such as the poor and members of lower castes, while some are more dependent on location and affect all groups regardless of their socio-economic status. Offering subsidies and micro-finance, alongside programs that target marginalised groups, could improve this inequality.

In terms of water supply, many households in Lamjung have insufficient quantity to satisfactorily meet their domestic water requirements. Some participants have to spend a lot of time fetching water for domestic use, and the unreliability of the sources affected all households. In the dry season, most households have good water quality, but in the rainy season many households have an unacceptable level of water quality and must travel further to a source that they deem acceptable and safe. In general, households do not treat their drinking water, in spite of the presence of waterborne diseases in their communities. Lack of water for irrigation is also a problem, and it was found to be dependent on location rather than socio-economic status, and as such needs to be addressed for all groups rather than just the relatively disadvantages groups.

Better protection and management of the existing water sources to avoid contamination during the rainy season and to improve efficiency of use, as well as investment in new sources such as rainwater or fog harvesting, or irrigation water pumps is needed to improve water security. Water should also be used more efficiently for agriculture through drip irrigation and reuse of runoff water. Furthermore, education on both the importance of treating drinking water and different treatment methods available is necessary to prevent disease and reduce mortality caused by water-related health issues.

The personal hygiene, toilet facilities and environment surrounding households in Lamjung District is a relatively good. In our study 98% of households had a working toilet, 34% owned a biogas reactor and at least 90% were practicing safe handwashing. However, water scarcity causes technical problems with flushing of toilets, and the biogas reactors do not produce enough gas to supply household cooking needs. To address these issues, greywater could be used to flush the toilets and the construction of dry toilets, with amendments for anal-cleansers, could be as considered alternatives. In addition, a range of measures can be used to increase efficiency of biogas production, such as increasing the input of manure and organic waste, better education of owners and those that construct the system, improved access to maintenance staff, and better design and construction of the systems.

Water and sanitation is closely linked to agriculture, and it was found that farmers in Lamjung District are reliant on imported chemical fertilizers such as Urea, Potash and DAP to produce their crops. Implementing ecological sanitation technology such as urine-diversion and EcoSan toilets could increase the availability of organic fertilizer, hence reducing farmers' reliance on imported and expensive chemical fertilizer. Furthermore, re-use of human excreta on the fields could improve the soil fertility, resulting in increased crop productions and better livelihoods. However, introduction of these technologies must be paired with education, so that people know how to safely hygienize the urine and excreta before application to the fields.

In conclusion, although Lamjung District has a reasonably good situation when compared to other areas of rural Nepal, there are many improvements that could be made to the water, sanitation and agricultural situations through implementation of sustainable low-cost technology, and through better education and management practices.

8. References

ADB & ICIMOD. (2006). Environment Assessment of Nepal: Emerging Issues and Challenges. Kathmandu: Asian Development Bank/ICIMOD.

ADB. (2011). Sectoral Series: Monograph 7. Water Supply and Sanitation. *Sectoral Perspectives on Gender and Social Inclusion. Gender and Social Exclusion Assessment 2011*: Asian Development Bank.

ADB. (2015a). Gender Equality Results Case Study: Nepal. *Community-Based Water Supply and Sanitation Sector Project*: Asian Development Bank.

ADB. (2015b). *Poverty in Nepal*. Metro Manila, Philippines: Asian Development Bank. Available at: http://www.adb.org/countries/nepal/poverty (accessed: 27 March).

Bajgain & Shakya. (2005). The Nepal Biogas Support Program: A successful model of public private partnership for rural household energy supply. In Mendis (ed.): Ministry of Foreign Affairs, the Netherlands, SNV - Netherlands Development Organisation, and Biogas Sector Partnership – Nepal.

Barun, J. (2010). Household Latrine Options for Rural Hills of Nepal: SNV Nepal.

Belbase, M. (2015). *Perspectives of Solar Pumping for Irrigation in Nepal*. Launch Workshop for the project 'Reviving springs and providing access to solar powered irrigation pumps (SPIP) through community based water use planning: Multiple approaches to solving agricultural water problems in mid hills and Terai in Nepal and India', Kathmandu: International Centre for Integrated Mountain Development.

Bennett, L., Dahal, D. R. & Govindasamy, P. (2008). Caste, Ethnic and Regional Identity in Nepal: Further Analysis of the 2006 Nepal Demographic and Health Survey. Calverton, Maryland, USA: Macro International Inc. .

Brouwer, C., Prins, K., Kay, M. & Heibloem, M. (1990). Irrigation Water Management: Irrigation Methods. *Training manual no 5*. Wageningen, The Netherlands: Food and Agriculture Organization of the United Nations (FAO).

Bruni, M. A. & Spuhler, D. (2010). *Sustainable Sanitation and Water Management Toolbox*. Slow Sand Filtration. Available at: http://www.sswm.info/category/implementation-tools/water-purification/hardware/semi-centralised-drinking-water-treatmen-2 (accessed: 31 May).

BSP. (2012). BSP 2011/2012 Progress Report. Kathmandu, Nepal.

CAWST. (2009). *Household Water Treatment and Safe Storage Fact Sheet: Ceramic Candle Filter*. Calgary, Alberta, Canada: Cenre for Affordable Water and Sanitation Technology.

CDC & USAID. (2008). *Preventing Diarrheal Disease in Developing Countries: Proven Household Water Treatment Options*.

CIA. (2013). *Nepal*. The World Factbook 2013-14. Washington, DC: Central Intelligence Agency. Available at:

https://www.cia.gov/library/publications/the-world-factbook/geos/np.html (accessed: 27/03/2016).

Conant, J. & Fadem, P. (2008). *A Community Guide to Environmental Health*. Berkeley, California, USA: Hesperian Foundation.

Conradin, K., Kropac, M. & Spuhler, D. (2010). *Sustainable Sanitation and Water Management Toolbox*. Glossary. Available at: http://www.sswm.info/glossary/2/lettera.

CRT. (2012). *Hydraulic Ram Pump*. Nepal: Centre for Rural Technology.

CUHK. (2015). *Sample size for estimation of prevalence in a population*. Stats Tool Box. Hong Kong: Department of Obsterics and Gynaecology - The Chinese University of Hong Kong. Available at: http://department.obg.cuhk.edu.hk/researchsupport/Sample_size_EstPrev.asp (accessed: 20 April).

Dahal, R. K. (2006). *Geology for Technical Students: A Text Book for Bachelor Level Students : Environmental Science, Civil Engineering, Forestry and Earth Hazard*: Bhrikuti Academic Publications.

Dahal, R. K. (2010). *Engineering Geology of Nepal*. Kathmandu: Department of Geology, Tribhuvan University. Available at: http://www.ranjan.net.np/index.php/resources/engineering-geology-of-nepal (accessed: 27/03/2016).

Desbiez et al. (2004). Perceptions and assessment of soil fertility by farmers in the mid-hills of Nepal. *Agriculture, Ecosystems and Environment*, 103: 191-206.

DFID & World Bank. (2006). Unequal Citizens: Gender, Caste and Ethnic Exclusion in Nepal. Kathmandu: DFID and the World Bank (2006).

Diwakar, J., Prasai, T., Pant, S. R. & Jayana, B. L. (2008). STUDY ON MAJOR PESTICIDES AND FERTILIZERS USED IN NEPAL. *Scientific World, Nepal Academy of Science and Technology*, 6 (6).

Domènech, L., Heijnen, H. & Saurí, D. (2009). *Coping with water scarcity in water-rich environments: an integrated assessment of rooftop rainwater harvesting in the hills of Nepal* 14th International Rainwater Catchment Systems Conference, Kuala Lumpur, Malaysia: IRCSA.

Domènech, L., Heijnen, H. & Saurí, D. (2012). Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: benefits and risks. *Water and Environment Journal*, 26 (4): 465-472.

ECONOMICS, T. (2016). *Monitoring Progress Towards The Millenium Development Goals*. Analysis by Country: Nepal: TAC ECONOMICS. Available at: http://www.mdgtrack.org/index.php?tab=c&c=NPL&g=7#goals (accessed: 23 May).

ENPHO. (2014). *About ENPHO*. Nepal: Environment and Public Health Organization. Available at: http://enpho.org/about-enpho/introduction/.

FAO. (1993). The State of Food and Agriculture. *FAO Agriculture Series*. Rome: Food and Agricultural Organization of the United Nations.

FAO. (1997). Small-scale Irrigation for Arid Zones. Principles and Options: Food and Agriculture Organisation of the United Nations

Forte, J. (2011). A glimpse into community and institutional biogas plants in Nepal. Grin, Germany: Integrated Sanitation Solutions for Urban Development

Franceys et al. (1992). *Guide to the development of on-site sanitation*. England: WHO. Available at: www.nienhuys.info/.../HA_TechWorkPaper-13_UDT-UDDT_November_2012_.pdf.

Garmin. (2005). *GARMIN eTrex® series*. Kansas, USA: Garmin Corporation.

Gautam, J. C. (2008). Country Report on The State of the Nepal's Plant Genetic Resources for Food and Agriculture.

Gautam, R., Baral, S. & Herat, S. (2009). Biogas as a suitable energy source in Nepal: Present status and future challenges. *Renewable and Sustainable Energy Reviews*, 13: 248-252.

Gensch, R. (2010). Use of Hygienized Urine in Agriculture. In gmbh, s. i. (ed.). *SSWM*. Cagayan de Oro, Philippines: The Sustainable Sanitation Center (SuSan Center), Xavier University.

Gentle et al. (2014). Differential impacts of climate change on communities in the middle hills region of Nepal. *Natural Hazards*, 74 (2): 815-836.

GPOBA. (2015). Biogas Support Program in Nepal. *OBA Lessons Learned* (8).

Griffiths, O., Henderson, H. & Simpson, M. (1997). *Environmental health practitioner manual: A resource manual for environmental health practitioners working with Aboriginal and Torres Strait Islander communities*. Council, T. A. A. a. t. K. A. M. S. Western Australia: The Office of Aboriginal Health.

Haefele et al. (2014). Spatial variability of fertilizer management and response in rainfed rice of Nepal. *Agriculture, Ecosystems and Environment*, 189: 190-198.

Hardon, A., Hodgkin, C. & Fresle, D. (2004). 5.6 Sample size. *How to Investigate the Use of Medicines by Consumers*. Switzerland: World Health Organization and University of Amsterdam

HELVETAS. (2016). *The Water Resources Management Programme (WARM-P)*. Surkhet: HELVETAS Swiss Intercooperation. Available at: https://nepal.helvetas.org/en/programmes___projects/warm.cfm (accessed: 10 May).

Höglund, C., Ashbolt, N., Stenström, T. A. & Svensson, L. (2002). Viral persistence in source-separated human urine. *Advances in Environmental Research*, 6 (3): 265-275.

Howard, G. & Bartram, J. (2003). Domestic water quantity, service level and health: World Health Organization.

Hussain, I. & Hanjra, M. A. (2004). Irrigation and poverty alleviation: review of the empirical evidence. *Irrigation and Drainage*, 53 (1): 1-15.

ICIMOD. (1996). Lamjung District Information System for Local Planning and Assessment of Natural Resources Using GIS and RS Technology : MENRIS Case Study No. 4. *MENRIS*. Kathmandu, Nepal: The International Centre for Integrated Mountain Development.

ICIMOD. (2003). Mapping Nepal Census Indicators 2001 and Trends. Kathmandu: The International Centre for Integrated Mountain Development.

ICIMOD. (2015a). *Reviving springs and providing access to solar powered irrigation pumps (SPIP)*. Kathmandu: International Centre for Integrated Mountain Development. Available at: http://www.icimod.org/?q=21125 (accessed: 7 May).

ICIMOD. (2015b). Reviving the Drying Springs - Reinforcing Social Development and Economic Growth in the Midhills of Nepal. In ICIMOD (ed.). *Issues Brief*. Kathmandu: ICIMOD.

ICIMOD. (2016). *Hydropower and Water Pumps*. Kathmandu: International Centre for Integrated Mountain Development. Available at: http://www.icimod.org/?q=1707 (accessed: 7 May).

IDE. (2016). *Our Technologies > Water Storage Systems*. Available at: http://www.ideorg.org/OurTechnologies/WaterStorageSystems.aspx (accessed: 23 May).

IRRI. (2002). Rice Almanac: Source Book for the Most Important Economic Activity on Earth. In J.L. Maclean, D. C. D., B. Hardy, and G.P. Hettel (ed.). Wallingford, UK: International Rice Research Institute.

ISAT & GTZ. (1999). Biogas - Application and Product Development. *Biogas Digest*: Information and Advisory Services on Appropriate Technology (ISAT) and German Technical Cooperation (GTZ)

Jha, A., Malla, R., Sharma, M., Panthi, J., Lakhankar, T., Krakauer, N., Pradhanang, S., Dahal, P. & Shrestha, M. (2016). Impact of Irrigation Method on Water Use Efficiency and Productivity of Fodder Crops in Nepal. *Climate*, 4 (1): 4.

Jha, H. B. (2004). Janajatis in Nepal. Lalitpur: International Labour Office.

JMP. (2016). *Improved and unimproved water sources and sanitation facilities*: WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation. Available at: http://www.wssinfo.org/definitions-methods/watsan-categories/.

Jordan, T. D. (1984). *A Handbook of gravity-flow water systems for small communities*. Kathmandu, Nepal: UNICEF.

Karan, P. (2016). *Nepal*. Encyclopædia Britannica Online: Encyclopædia Britannica Inc.

Kawata, K. (1978). Water and other environmental interventions - the minimum investment concent. *The American Journal of Clinical Nutrition* 2114-2123.

Kropac, M. & Conradin, K. (2015). *Linking up Sustainable Sanitation, Water Management and Agriculture*: seecon international gmbh. Available at: http://www.sswm.info/category/concept/linking-sustainable-sanitation-water-management-and-agriculture.

Kulkarni, D. (2015). *Jain Solar Pump – Technology and Challenges*. Launch Workshop for the project 'Reviving springs and providing access to solar powered irrigation pumps (SPIP) through community based water use planning: Multiple approaches to solving agricultural water problems in mid hills and Terai in Nepal and India', Kathmandu: International Centre for Integrated Mountain Development.

LSHTM/WEDC. (1998). Guidance Manual on Water Supply and Sanitation Programmes. In Development, D. f. I. (ed.). London, UK: WEDC.

Luong, N. D. (2002). Harvesting the Rain: A Construction Manual for Cement Rainwater Jars and Tanks: UNICEF.

Luzi et al. (2016). SODIS manual: Guidance on solar water disinfection. Switzerland: Eawag.

Manandhar, R. & Khanal, M. P. (2004). *Commercial fertilisers and their quality control in Nepal*. Micronutrients in South and South East Asia, Kathmandu, Nepal.

Mara. (1985). The Design of Pour-Flush Latrines. *TAG Technical Note No. 15*: United Nations Development Programme (UNDP) and World Bank.

Mendis, M. S. & Nes, W. J. v. (1999). *The Nepal biogas support program: elements for success in rural household energy supply*. Affair, M. o. F. The Hague, the Netherlands.

Merz, J., Nakarmi, G., Shrestha, S. K., Dahal, B. M., Dangol, P. M., Dhakal, M. P., Dongol, B. S., Sharma, S., Shah, P. B. & Weingartner. (2003). Water : A Scarce Resource in Rural Watersheds of Nepal's Middle Mountains. *Mountain Research and Development*, 23 (1).

Mikhail, M. & Yoder, R. (2008). Multiple use water service implementation Nepal and India. Experience and Lessons for Scale-up. Lakewood, USA: International Development Enterprises (IDE).

MOAC. (2010). *Nepal Agriculture and Food Security Country Investment Plan. Attachment 2*. Cooperatives, M. o. A. a. Kathmandu.

MOAD. (2012). *STATISTICAL INFORMATION ON NEPALESE AGRICULTURE 2011/2012 (2068/069)* Development, M. o. A. Kathmandu: Agri-Business Promotion and Statistics Division Statistics Section.

MoEnv. (2010). *FINAL REPORT ON ANNUAL BIOGAS USERS' SURVEY 2009/2010 for Biogas Support Program – Nepal (BSP - Nepal) Activity – I*. (AEPC), A. E. P. C. Kathmandu: GOVERNMENT OF NEPAL MINISTRY OF ENVIRONMENT (MoEnv).

Mosler, H. J. (2012). A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. *Int J Environ Health Res*, 22 (5): 431-49.

Mosley, L. M. & Sharp, D. S. (2005). The Hydrogen Sulphide (H2S) Paper-Strip Test. Suva, Fiji Islands.

MoSTE. (2014). Agro-climatic Atlas of Nepal. Kathmandu: Department of Hydrology and Meteorology, Ministry of Science, Technology and Environment (MoSTE).

Murcott, S. (2006). *Implementation, Critical Factors and Challenges to Scale-Up of Household Drinking Water Treatment and Safe Storage Systems*. Electronic Conference Hosted by USAID, Web.

Nelson, S. A. (2015). *EENS 1110 Physical Geology*. New Orleans, Louisiana: Tulane University. Available at: http://www.tulane.edu/~sanelson/eens1110/groundwater.htm (accessed: 19 May).

Nepal, G. o. *Department of Hydrology and Meteorology*. Nepal. Available at: http://www.dhm.gov.np/.

Nepal, G. o. (2014). *Population Atlas of Nepal*. Statistics, C. B. o. Ramshah Path, Kathmandu: Government of Nepal.

Neset, T. & Cordell, D. (2012). Global phosphorus scarcity: identifying synergies for a sustainable future. *Journal of science of food and agriculture*, 92 (1): 2-6.

NEWAH & WaterAid. (2002). *SUPPLEMENTARY NOTES TO SUPPORT THE DWSS MEETING ON JUNE 7, 2002*. Rural Water Supply and Sanitation Policy Debate.

NEWAH. (2004). Water Consumption Study 2004: NEWAH.

NEWAH. (2005). *Fog Water Collection in Nepal - An Innovative New Approach to Rural Water Supply*: Nepal Water for Health (NEWAH).

NEWAH. (2010). Promoting Domestic Plus in NEWAH WASH Projects. Kathmandu: Nepal Water for Health.

Nichols, J. (2015). Rainwater harvesting systems for a high quality, supplementary water supply in Nepal. *Journal of Humanitarian Engineering*, 3 (1).

Nienhuys, S. (2012). Urine Diversion Toilet (UDT) Urine Diversion Dry (Dehydration) Toilet (UDDT): Ecological Sustainable Sanitation in Himalayan Conditions. *Technical Working Paper: Number 13*: HUYS ADVIES.

NPHC. (2011). *National Population and Housing Census 2011*. Statistics, C. B. o. Kathmandu: National Planning Commission Secretariat.

NWA. (2015). *Nepal WASH Alliance - ODF Status Updates*. Available at: http://www.wash-rcnn.net.np/nwa/odf-updates.html (accessed: 18/01/2015).

NWP. (2007). *Smart Water Harvesting Solutions - Examples of innovative low-cost technologies for rain, fog, runoff water and groundwater*. World Water Week 2007, Stockholm, Sweden: Netherlands Water Partnership, Aqua for All, Agromisa.

OCHA & ACAPS. (2015). Pre-Monsoon Overview Nepal Earthquake: Nepal Earthquake Assessment Unit.

OSOCC. (2015). *Situation Analysis Nepal Earthquake 05.05.2015* Kathmandu.

Pariyar, D. (2008). Country Pasture/Forage Resource Profiles: Nepal.

Pilbeam et al. (2005). Soil fertility management in the mid-hills of Nepal: Practices and perceptions. *Agriculture and Human Values*, 22 (2): 243-258.

Poudel, S. & Shaw, R. (2016). The Relationships between Climate Variability and Crop Yield in a Mountainous Environment: A Case Study in Lamjung District, Nepal. *Climate*, 4 (1): 13.

Pradhan et al. (2005). Knowledge of water quality and water borne disease in rural Kathmandy Valley, Nepal. *Aquatic Ecosystem Health & Management*, 8 (3): 277-284.

Pradhan, S. K., Piya, R. C. & Heinonen-Tanski, H. (2011). Eco-sanitation and its benefits: an experimental demonstration program to raise awareness in central Nepal.(Report). *Environment, Development and Sustainability*, 13 (3): 507.

Rainey, R. C. & Harding, A. K. (2005). Acceptability of solar disinfection of drinking water treatment in Kathmandu Valley, Nepal. *International Journal of Environmental Health Research*, 15 (5): 361-372.

Red Cross. (2013). Community Eye Care and Health Promotion Program (CEHP): Annual Progress Report 2013. Nepalgunj, Nepal: Nepal Red Cross and Swiss Red Cross.

Rosenberg, D. M., McCully, P. & Pringle, C. M. (2000). Global-scale environmental effects of hydrological alterations: Introduction. *BIOSCIENCE*, 50 (9): 746-751.

RVWRMP. (2011). *WUMP review and Baseline - GUIDELINES* (II), R. V. W. R. M. P. Kathmandu: Government of Nepal and Government of Finland.

Saxena. (2009). *2-hole and 3-hole squatting pan from EEDS, India*: NGO Energy, Environment and Development Society (EEDS). Unpublished manuscript.

Scholz et al. (2013). Sustainable use of phosphorus: A finite resource. *Science of The Total Environment*, 461-462: 799-803.

Shah, B. (2008). Report on WASH Cluster Capacity Mapping in Nepal. Kathmandu, Nepal: UNICEF and WASH Cluster Agencies.

Singh, D. (2014). Nepal Country Environment Note. Philippines: Asian Development Bank.

SNV. (2009). Building viable domestic biogas programs: Success factors in sector development. In Wim van Nes, J. L., Felix ter Heegde & Fred Marree (ed.): SNV Netherlands Development Organisation.

Sobsey, M. D. & Pfaender, F. K. (2002). Evaluation of the H2S Method for Detection of Fecal Contamination of Drinking Water. Geneva, Switzerland.

Spångberg et al. (2014). Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment. *Science of The Total Environment*, 493: 209-219.

Stauffer, B. (2012). *Irrigation*: SSWM.

Thapa. (2006). *CONSTRAINTS AND APPROACH FOR IMPROVING FERTILIZER SUPPLY FOR MEETING DOMESTIC DEMAND* Ministry of Finance, G. o. N. Kathmandu: Asian Development Bank

Tilley, E., Ulrich, L., Luethi, C., Reymond, P. & Zurbruegg, C. (2014). Compendium of Sanitation Systems and Technologies 2nd Edition: EAWAG.

Tuinhof, A., Dumars, C., Foster, S., Kemper, K., Garduño, H. & Nanni, M. (2003). Sustainable Groundwater Management Concepts & Tools. *Briefing Note Series: Note 2: Characterization of Groundwater Systems* The World Bank.

UMN. (2013). Biogas - Challenges and Experience from Nepal Vol.1: United mission to Nepal (UMN).

UN. (2015). *Goal 7: Ensure Environmental Sustainability*. Millenium Development Goals: United Nations. Available at: http://www.un.org/millenniumgoals/environ.shtml.

UN. (2016a). *GOAL 6 Ensure availability and sustainable management of water and sanitation for all*. Sustainable Development Knowledge Platform: United Nations - Sustainable Development Knowledge Platform. Available at: https://sustainabledevelopment.un.org/sdg6.

UN. (2016b). *Goal 6: Ensure access to water and sanitation for all*. Sustainable Development Goals: United Nations. Available at: http://www.un.org/sustainabledevelopment/water-and-sanitation/.

Upadhyaya, B. (2011). *Challenges of water for present and future generations of Kathmandu Valley Nepal*. World Water Day, Bagmati, Nepal.

WaterAid. (2008a). Assessment of Urine Diverting Ecosan Toilets in Nepal. Kathmandu: WaterAid Nepal.

WaterAid. (2008b). WaterAid Nepal's experiences in community-based water resource management. Kathmandu: WaterAid.

WaterAid. (2011). People's perception on sanitation: Findings from Nepal. Nepal.

WaterLex. (2014). *Helvetas – Nepal*. Unpublished manuscript.

Weatherford, V. C. & Zhai, Z. (2015). Affordable solar-assisted biogas digesters for cold climates: Experiment, model, verification and analysis. *Applied Energy*, 146: 209-216.

WEDC. *The three-pot water treatment system*: Loughborough University.

WHO. (2006). Guidelines for the safe use of wastewater, excreta and greywater: World Health Organisation.

WHO & UNICEF. (2006). Core questions on drinking-water and sanitation for household surveys. Switzerland. 24 pp.

WHO. (2011). Guidelines for Drinking-water Quality. Geneva, Switzerland.

WHO & UNICEF. (2012). A toolkit for monitoring and evaluating household water treatment and safe storage programmes.

WHO. (2015). World Health Statistics 2015: Part II Global health indicators. Geneva, Switzerland.

WIN. (2012). Assessment of Nepal Water Supply Corportation - Biratnagar Branch: Functionality of water supply services. Final Report. Berlin: Water Integrity Network.

Worldmark. (2007). *Nepal*. Worldmark Encyclopedia of Nations: Thomson Gale.

Worm, J. & Hattum, T. v. (2006). Rainwater Harvesting for Domestic Use. Wageningen: Agromisa Foundation and CTA.

WWF. (2006). *Nepal ecological division*. Online.

Appendices

Appendix A – Coding of Answers to the Survey

Our survey included questions resulting in numeric, categorical and ordinal data. An '*' was used to signify information that was missing or counted as missing (usually when an answer was unknown to participants).

Numeric data

Questions with purely numeric answers

Q1. How many people currently live in your household?

Q2. How old are you?

Questions with numeric answers that were coded into categories as ranges

Answers to some questions were given as numbers, but these were coded into ranges so that they could be used for the statistics.

An example of this is Q24, '*How many cows, buffalo and/or donkeys does your household own?*' because it was important to determine if a household had enough animals for biogas production (a minimum of 2). Q24 was coded as follows:

No. of large animals	Code (numeric)
None owned	0
1	1
≥ 2	2

Other numeric questions that were simplified into ranges and coded are:

Q6. How many gagri/jerry cans/baltin* do you use daily for drinking? Cooking? Bathing? Dishes? Clothes? Livestock? Garden? Other?

Q10. How much time does it take to walk one-way to your water collection point?

Q11. How much time do you spend queuing at your water collection point?

It should be noted that Q10 and Q11 were combined into 'total water collection time' and equal to two times the amount of time to walk one-way for a participant to walk to the collection point, plus the maximum time to queue.

Q22. How many *ropani* do you own for cultivation?

In the field, this was divided into (1) how much land a participant owned, and (2) how much of this land a participant cultivated, thus two variables were created.

Q26. How many bags of fertilizer do you buy per year?

Categorical data

Questions with categorical answers that were coded with numbers

Some of the initial questions asked (name of VDC, ward number, caste, gender) were assigned numerical answers, as shown in the example below:

VDC	Code (numeric)
Kunchha	1
Chandreshwor	2
Chakratirtha	3
Simpani	4

Questions with categorical answers that were simplified and then coded

Some questions had categorical answers that required simplification. These were coded as follows:

Question	Possible answers	Simplified categories	Codes
Q3. What is your occupation?	▪ Farmer ▪ Homemaker ▪ Carpenter ▪ Student ▪ Technician ▪ Teacher ▪ Unemployed ▪ Other*	Agriculture Agriculture and other Other	1 2 3
Q5. Which of the following activities do you use this water source for?	▪ Drinking ▪ Cooking ▪ Bathing ▪ Dishes ▪ Clothes ▪ Livestock ▪ Garden ▪ Other*	Used for drinking Not used for drinking	1 0
Q7. How do you treat/purify your drinking water?	▪ Boil ▪ Add bleach/chlorine ▪ Strain through a cloth ▪ Water filter ▪ Solar disinfection ▪ Let stand and settle ▪ Use water purification tablets ▪ Other* ▪ Don't treat/purify my drinking water	Always treat Sometimes treat Never treat	1 2 3
Q8. Which of the following water borne diseases are common in your community?	▪ Amebiasis ▪ Giardiasis ▪ Cholera ▪ Shigellosis ▪ Dysentery ▪ Typhoid	No diseases 1 disease 2 diseases 3 diseases	0 1 2 3

	▪ Ascariasis ▪ Other* ▪ Don't know		
Q9. In the dry season, how would you judge your water source? In the rainy season?	▪ Colourless and clear ▪ Some suspended particles ▪ Green ▪ Reddish-brown ▪ Brownish-black ▪ Dark and unclear ▪ Other*	Good, no possibility of contamination Moderate, likely to be contaminated Poor, high chances of contamination Very poor, contaminated and intolerable	1 2 3 4
Q12. How often does your water source go dry?	▪ Daily ▪ Weekly ▪ Monthly ▪ Every three months ▪ Yearly ▪ Never ▪ Other* ▪ Don't know	Daily Daily in dry season Yearly Never Don't know	1 2 3 4 *
Q13. Who is responsible for the operation and maintenance of your water source?	▪ Appointed person in community ▪ Shared by whole community ▪ VDC representative ▪ Government ▪ NGO ▪ Nobody responsible ▪ Other* ▪ Don't know	Appointed person in community Shared by whole community Nobody responsible Self-maintained	1 2 3 4
Q17. Where does the sewage from these toilets go?	▪ Community wastewater treatment plant ▪ Pit ▪ Septic tank ▪ Biogas reactor ▪ River ▪ Left out in the open ▪ Other* ▪ Don't know	Biogas reactor Septic tank/Other*(unlined pit) Other* (no toilet) Don't know	1 2 3 *
Q18. What happens when the septic tanks or pits are full?	▪ Dug out and sludge put on farmland ▪ Dug out and sludge buried ▪ Sludge pumped out and taken away ▪ Pit covered and new pit dug ▪ Toilet is no longer in use ▪ Other* ▪ Don't know	Sludge used Sludge not used Other*(biogas reactor) Don't know	1 0 * *
Q23. Which of these water sources do you use for irrigation of your cultivated land?	▪ Rain ▪ River/stream/lake ▪ Spring ▪ Well ▪ Other* (irrigation canals, none)	None/none Irrigation method/none Irrigation method/Irrigation method	1 2 3

Q25. Which of these fertilizers do you use on your farmland?	▪ Animal manure ▪ Crop waste ▪ Urea ▪ DAP ▪ Potash ▪ Other* (biogas effluent) ▪ None	Chemical fertiliser used Chemical fertiliser not used	1 0

Note 1: '*' indicates a missing value, meaning that a simplified category with this label was excluded in correlations (due to correlations not functioning with missing values)
Note 2: For Q9, only answers from the rainy season were used as water was mostly clear in dry season
Note 3: For Q23, answers were collected separately for dry and rainy seasons

Multiple variables created from one question

Q4 '*What is your water source* in the dry season? In the rainy season?*' was a semi-structured question where we tried to collect as much information as possible from the participants regarding their water source. As a result, multiple variables were created from the reported answers to this question.

Variable name	Answers	Categories	Numerical codes
Original water source	• Private connection to pipeline • Private/household well • Public tap stand • Public well • Padhero (spring) • Stone spouts • Kuwa (spring) • River/stream/lake • Rainwater • Bottled water • Other*(mul – usually coded as unknown as it just means source)	Spring River Stream Don't know	1 2 2 *
Water distribution system	• Private connection to pipeline • Private/household well • Public tap stand • Public well • Padhero • Stone spouts • Kuwa • River/stream/lake • Rainwater • Bottled water • Other* (request from neighbours, connect pipe to tapstand, connect pipe to tank)	Private pipeline Pipe from public source Public source/Other	1 2 3
Water collection point	• Private connection to pipeline • Private/household well • Public tap stand • Public well	Shared source Individual connection	1 2

	• Padhero • Stone spouts • Kuwa • River/stream/lake • Rainwater • Bottled water • Other* (request from neighbours, connect pipe to tapstand, connect pipe to tank)		

Note: '*' indicates a missing value, meaning that a simplified category with this label was excluded in correlations (due to correlations not functioning with missing values)

Category created for statistical analysis combining multiple questions

A new variable called 'water service level' was created using answers to Q6, Q9, Q10, Q11 and Q12, and the criteria table from the Rural Village Water Resources Management Project (RVWRMP 2011). Criteria defining water service level include the quality, quantity, reliability, continuity and location of a household's primary water source. The water supply of the households in our survey were categorized as having 'good', 'moderate', 'poor' or 'very poor' service level based on the table, and these were assigned the numeric codes 1, 2, 3 and 4 respectively.

Service Level	Average Fetching Time (minutes)*	Quantity (LPCD)	Quality of Water	Reliability (month/year)	Continuity (hr/day)
Good (Level-1)	≤ 15	≥ 45	Good, no possibility of contamination	12	≥ 6
Acceptable or Moderate (Level-2)	$>15 \leq 30$	$\geq 25 < 45$	Moderate likely to be contaminated	$\geq 11 <12$	$\geq 5 <6$
Poor (Level-3)	$> 30 \leq 45$	$\geq 15 <25$	Poor, high chances of contamination	$\geq 10 <11$	$\geq 4 <5$
Very Poor (Level-4)	> 45	< 15	Very poor, contaminated and intolerable	< 10	< 4

** Fetching time means total time incurred to go to water collection point, wait, collect water and return back to home.*

Ordinal data

Questions with ordinal answers

The opinionated questions had ordinal answers which were categorised as follows:

Variable name	Answers	Categories	Numerical codes
Q27. Willingness to use fertile soil created from human excreta:	• Currently use • Might use • Would never use • Don't know	Currently use Used to use Might use Would never use Do not know	1 1 1 2 *
Q28. Willingness to use human urine as fertilizer:	• Currently use • Might use • Would never use • Don't know	Currently use Used to use Might use Would never use Do not know	1 1 1 2 *
Q29. Willingness to use rainwater harvesting:	• Currently use • Might use • Would never use • Don't know	Currently use Used to use Might use Would never use Do not know Might use/ Sufficient water	1 1 1 2 * 2
Q30. Willingness to use gas for cooking and sludge produced in biogas production as fertilizer:	• Currently use • Might use • Would never use • Don't know	Currently use Used to use Might use Would never use Do not know	1 1 1 2 *

Note: '*' indicates a missing value, meaning that a simplified category with this label was excluded in correlations (due to correlations not functioning with missing values)

Observation of household materials

A system was developed to rank houses in terms of income based on the characteristics of their house. Each variable was ranked in terms of cost, and the sum of the assigned numbers gave the total score. The lowest score was the wealthiest household. These scores were then used to divide the houses into three categories of income. The roof material was excluded, as it was not a good indicator of wealth when compared to the other indicators.

Main material	No. assigned	No. of storeys	No.	Foundation material	No.	Window material	No.	Balcony material	No.	Painted (Y/N)	No.
Brick and concrete	1	3	0	Concrete	1	Glass	1	Metal	0	Yes	1
Concrete	1	2	1	Stone and mud	2	Decorative metal	2	Wood	0	No	2
Brick and mud	2	1	2	None	3	Metal rods	3	Wood/ GI sheet	0		
Stone and concrete	2					Wood/ metal	3	Carved wood	0		
Stone and mud	3					Wood	4	GI sheet	1		
Stone and mud/ Bamboo/ Metal sheets	4					Wood/ fly wire	4	No railing	1		
Metal sheets and wood	5					None	5	No balcony	2		
Metal sheets and mud	5										
Metal sheets, bamboo and mud	5										
Bamboo and wood	6										

Toilet Super-structure	No. assigned
Inside house	0
Concrete	1
Stone and concrete	2
Stone	3
Stone and mud	4
Stone and fabric	4
Bamboo and fabric	5
Metal sheet	5
Bamboo	5
No toilet	6

Total income score range	Code (text)	Code (numeric)
0-9	Highest income category	1
10-18	Middle income category	2
19-27	Lowest income category	3

No coding

Some questions were only used for descriptive purposes (not statistics), often because the majority of participants gave the same answers. These included:

Q14. Which of the following toilets do you have access to in your household?

Q15. How do these toilets flush?

Q16. What other features do these toilets have?

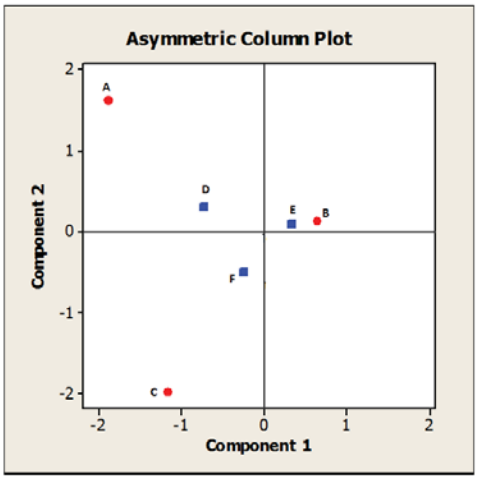
Q19. How often are these toilets not functioning?

Q20. Why do you think these toilets break?

Q21. If any members of your community defecate in the open, why do you think they do this?

Appendix B – Detailed Correlation Analysis

In Simple Correspondence Analysis, frequency tables are constructed with one variable (i.e. water service levels) as the row values, and the other (i.e. income categories) as the column values. The actual count in each cell is compared with the expected count, and higher relative differences between these values result in a higher contribution to the total Chi-Square value (PennState 2016). These results are then plotted on asymmetric row or column plots, or symmetrical plots. In this study asymmetrical plots were chosen as “there can be an intuitive interpretation of the distances between row points and column points” (Minitab 2003).



Asymmetrical column plot of Water service level, by income categories

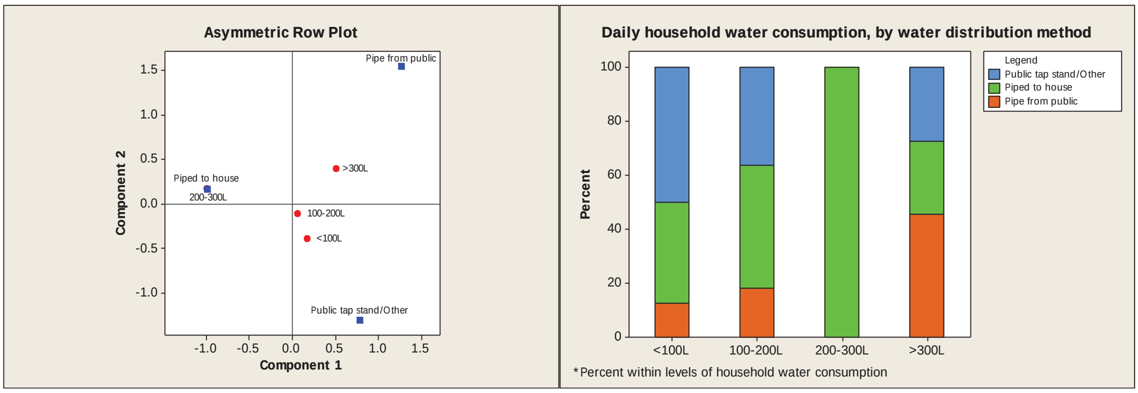
For example, the figure to the left shows the row variables (i.e. A, B and C) will be plotted as vertices distributed around the edge of the graph, with the column variables (i.e. D, E and F) plotted as ‘profiles’, points within the bounds of the row vertices. Associations between row and column categories can be ascertained from the graph as the “closer a row profile is to a column vertex, the higher the row profile is with respect to the column category” (Minitab 2003), i.e. the closer the association is between the two points. So from looking at the figure, it can be deduced that category ‘D’ is most closely associated with category ‘A’, although it is close to the centre of the vertexes so this is not a strong correlation. The ‘E’ is close to and, hence, strongly associated with a ‘B’, while the category ‘F’ is located close to the axis between ‘B’ and ‘C’ categories, indicating that it is not at all associated with category ‘A’.

Using this method, as described above and in Section 4.1.3, the output graphs were analysed to better understand the correlations. These graphs are grouped here under the section headings and titles in the order they appear in the main text.

Domestic water supply

Daily household water consumption, by primary water source distribution method

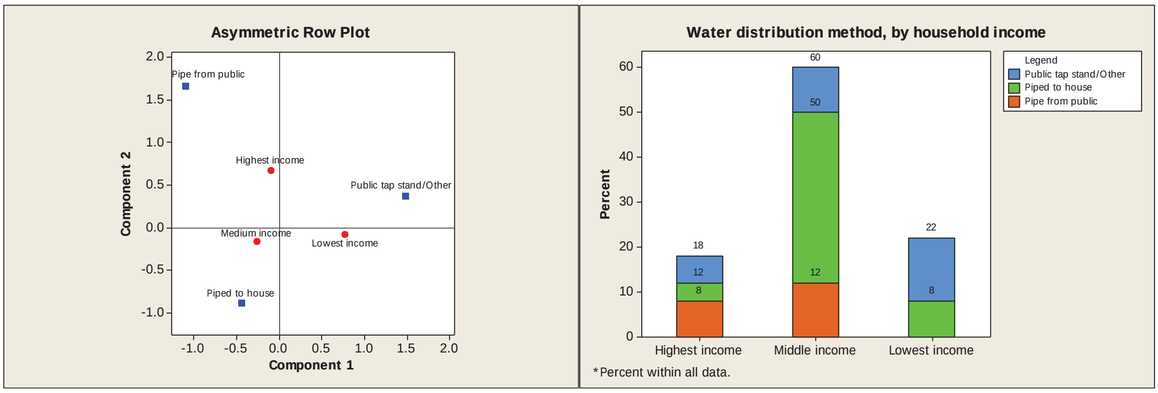
The households’ daily water consumption showed a significant correlation with the distribution method for the household’s primary water source (P-Value = 0.006, n = 50). The correlation results are presented in the figures below. In the asymmetric plot, households in the lowest water consumption category (less than 100L/day) were the most strongly associated with using a public tap stand or asking neighbours for water, although 37.5% had a private connection. Households with over 100L/day were more likely to use a piped source than a public one, but the bar chart demonstrates that there was no strong relationship between water consumption and whether this was a private pipe or a pipe from a shared connection.



Daily household water consumption, by primary water source distribution method (a) Asymmetrical plot (b) Bar Graph

Primary water source distribution method, by household income

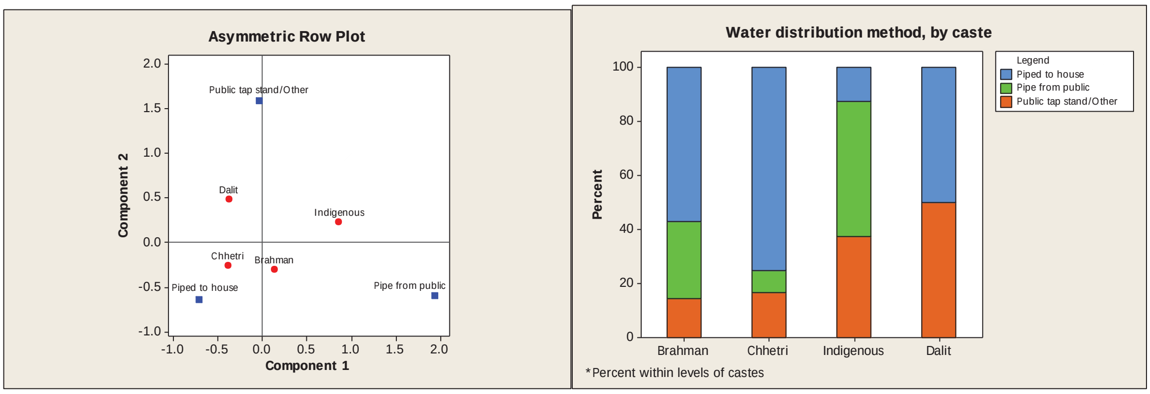
A statistically significant correlation was found between household income and their primary water source distribution method (P-Value = 0.005, n = 50). The correlation results are presented in the figures below. In the figures, households in the lowest income category showed a weak association with "Public source/Other", that is, they are most likely to collect water from a public source (64% of houses in this category), but some also have a private water supply piped to their house. There were households in the medium income category in all three of the distribution system categories, but a high proportion of them (63%) have a private water supply piped to their house. Surprisingly, the figures also show that households in the highest income category were distributed across all distribution methods. Hence, this correlation was not a simple positive correlation where the highest income families had private sources, and the poorest carried water from a public source.



Primary water source distribution method, by household income (a) Asymmetrical plot (b) Bar Graph

Primary water source distribution method, by caste

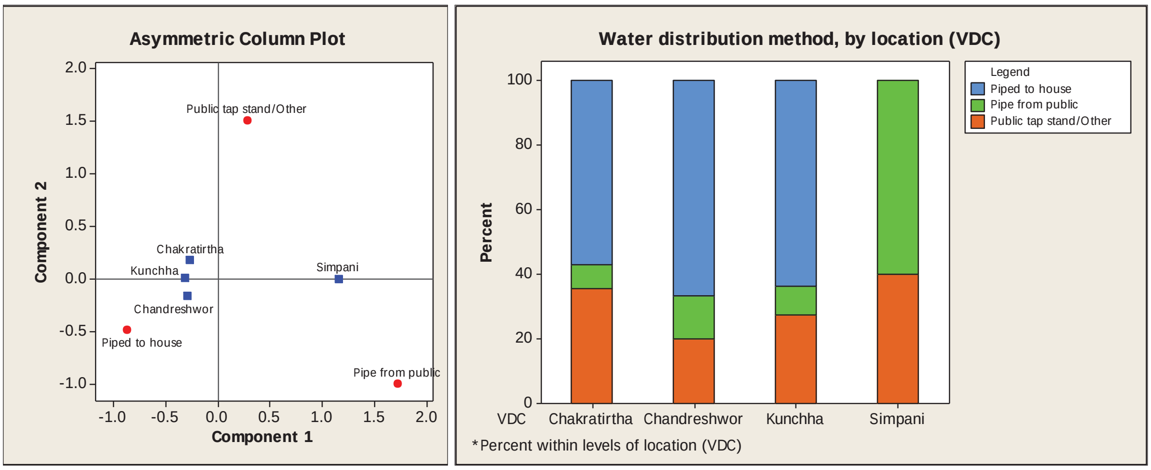
Caste was also shown to have a statistically significant correlation with the primary water source distribution system (P-Value = 0.009, n = 46). The correlation results are presented in the figures below. In general the higher castes are more strongly associated with private pipelines or water being piped from public sources, and lower castes with carrying water. The asymmetrical column plot shows that the two traditionally higher social status castes, Brahman and Chhetri, are associated with having a private pipeline to their house. This is confirmed by the Bar Graph as 57% of Brahman and 75% of Chhetri have a private pipeline to their house. Dalit, the traditionally lowest caste is most strongly associated with carrying water from a public source, which 50% of the Dalit participants do. However, the other 50% of the Dalits have private connections to pipelines, which is much more than the Indigenous caste, where only 12.5% have a private connection.



Primary water source distribution method, by caste (a) Asymmetrical plot (b) Bar Graph

Primary water source distribution method, by location

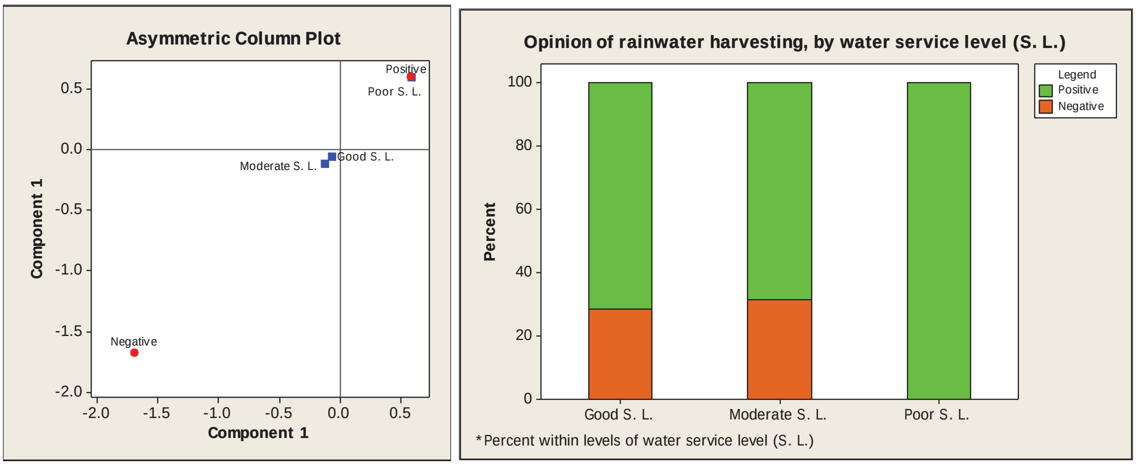
A statistically significant correlation was found between location (based on VDC) and primary water source distribution method (P-Value = 0.003, n = 50). The correlation results are presented in the figures below. The asymmetrical column plot shows that Simpani is almost halfway between "Public tap stand/Other" and "Pipe from public", as 40% of households in Simpani carry their water from a public source, and 60% connect a pipe to a public tap but none have a private pipeline to their house. In contrast, over 50% of households in the other three VDCs had a private pipeline to their house so they are all clustered towards ‘Piped to house’ on the asymmetrical plot.



Primary water source distribution method, by location (a) Asymmetrical plot (b) Bar Graph

Rainwater harvesting opinion, by water service level

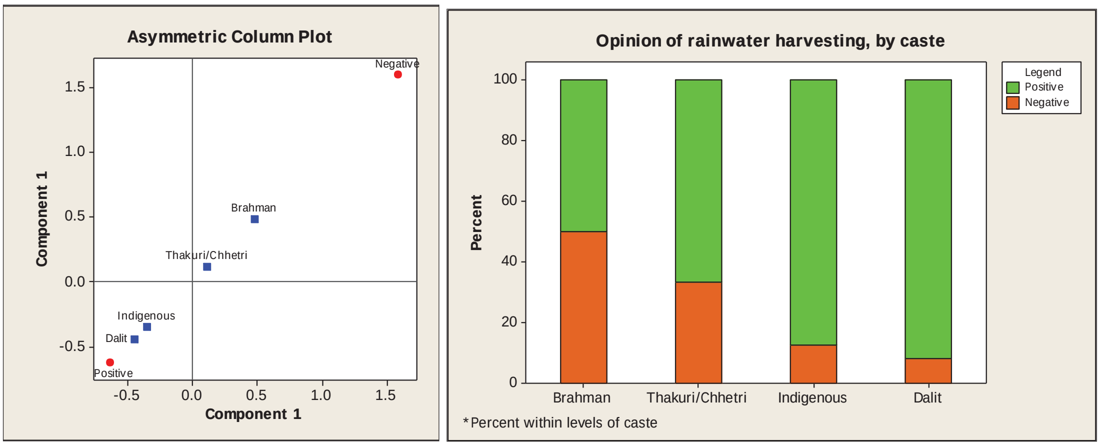
There is a statistically significant correlation between opinion on rainwater harvesting and Water Service Level (P-Value = 0.069, n = 50). The correlation results are presented in the figures below. The asymmetric column plot and Bar Graph show that all households with a ‘poor’ water service level were positive to the idea of rainwater harvesting, while only around 70% of those with good and moderate service levels were not positive to the idea.



Rainwater harvesting opinion, by water service level (a) Asymmetrical plot (b) Bar Graph

Rainwater harvesting opinion, by caste

There is a statistically significant correlation between caste and opinion on rainwater harvesting (P-Value = 0.066, n = 46). The correlation results are presented in the figures below. The figures show that the lower the social standing of the participant's caste in the traditional caste system, the more likely they were to have a positive response to rainwater harvesting.

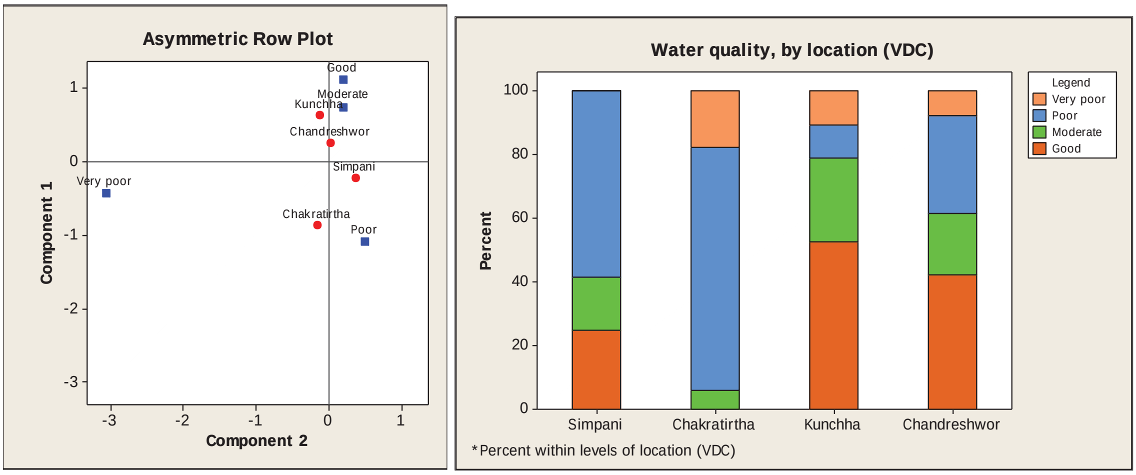


Rainwater harvesting opinion, by caste (a) Asymmetric Plot (b) Bar Graph

Domestic water quality

Water quality, by location (all sources)

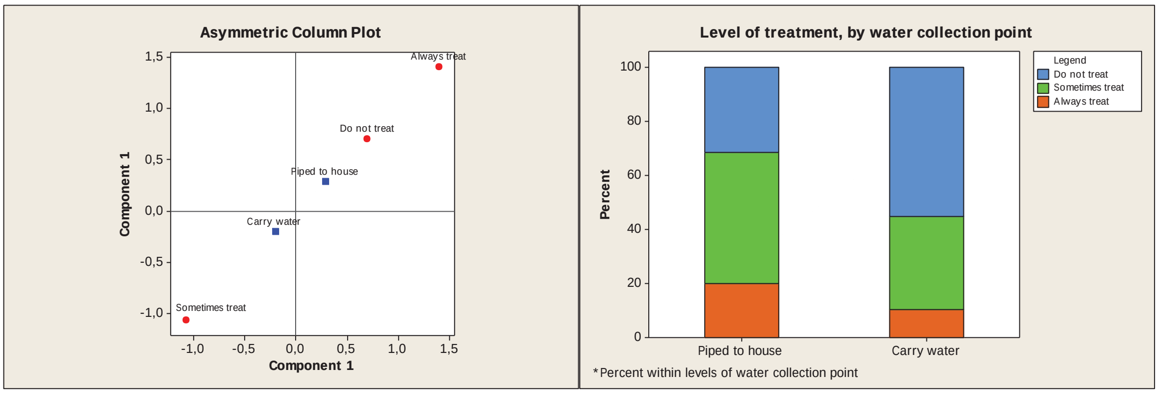
There is a statistically significant correlation (P-Value = 0.000, n = 74) between water quality of all water sources (primary, secondary and tertiary) and their location (based on VDC). The correlation results are presented in the figures below. From the 'Asymmetric Row Plot' the proximity of 'Chakratirtha' to 'Poor' indicates that this VDC has a strong association with poor water quality. According to the Bar Graph, about 76% of the households in Chakratirtha stated that they have poor water quality, higher than any other VDC. None of the VDCs appear to have a strong association with coordinate, 'Very poor', and this is reflected in the 'Asymmetric Row Plot' because of the distance between them. Looking at the Bar Graph, 'Simpani' has no claims to 'Very poor' water quality. From the 'Asymmetric Row Plot' the proximity of 'Kunchha' and 'Chandreshwor' to 'Good' indicates that these VDCs have a stronger association with good water quality than other VDCs. The Bar Graph reflects this, in that VDCs Kunchha has about 53% and Chandreshwor has 42% of households that report 'Good' water quality.



Water quality, by location (all sources) (a) Asymmetrical plot (b) Bar Graph

Level of treatment, by water collection point (all sources)

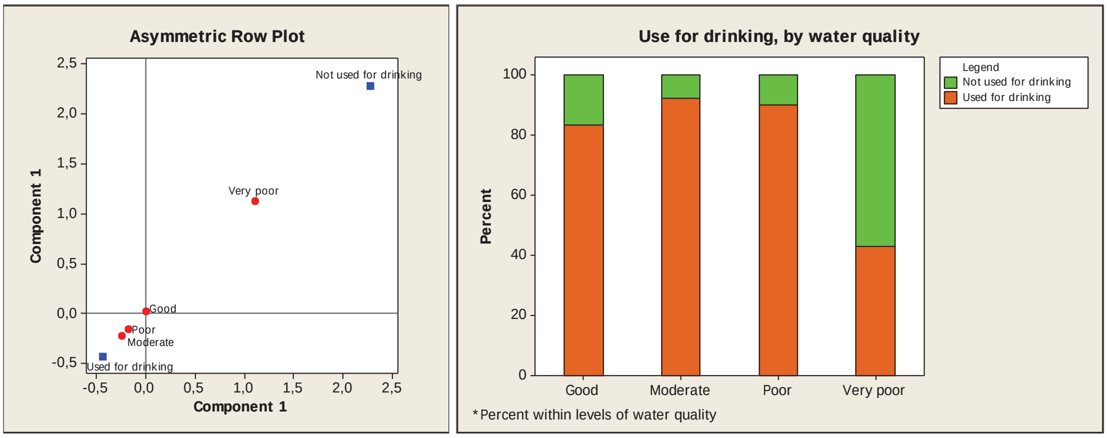
There is a statistically significant correlation (P-Value = 0.084, n = 84) between the level of treatment for drinking water and the water collection of all water sources (primary, secondary and tertiary) in the rainy season. The correlation results are presented in the figures below. According to the ‘Asymmetric Column Plot’ the distance from both sources to ‘Always treat’ indicates a weak association with households always treating their water, regardless of source. This is shown in the Bar Graph because 20% of households that pipe their water supply and about 10% of households that carry their water supply always treat their drinking water. According to the ‘Asymmetric Column Plot’ the proximity of both sources to ‘Do not treat’ indicates an association with households never treating their water. The Bar Graphs shows that 31% of households that pipe water to their home and 55% of the households that carry their water supply do not treat their drinking water.



Level of treatment, by water collection point (all sources) (a) Asymmetrical plot (b) Bar Graph

Used for drinking, by water quality (all sources)

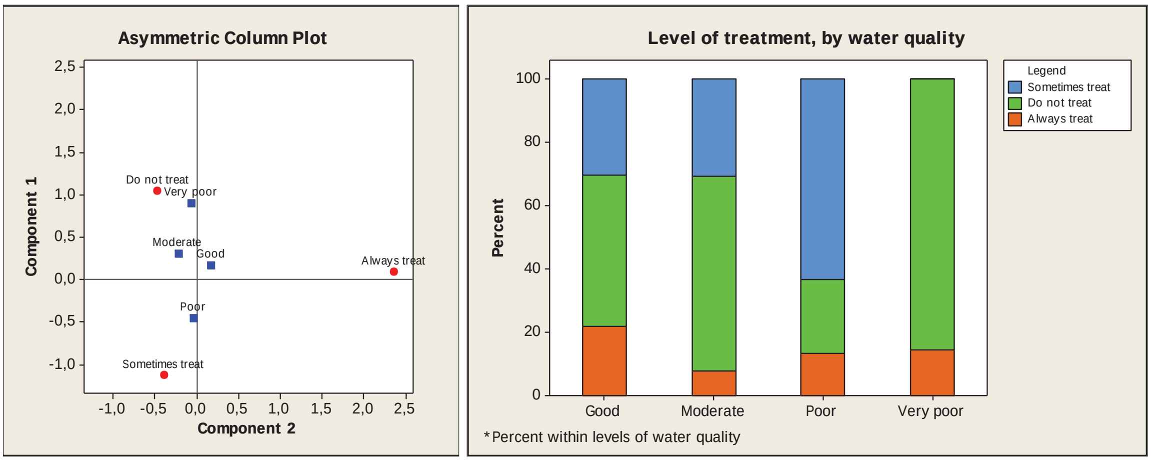
There is a statistically significant correlation (P-Value = 0.049, n = 74) between water quality of all water sources (primary, secondary and tertiary) in the rainy season and whether a household uses water for drinking or not. From the ‘Asymmetric Row Plot’, the proximity of water with ‘Very poor’ quality to the coordinate ‘Not used for drinking’ indicates that water with very poor quality is associated with people not drinking it. The opposite is clearly shown by the proximity of ‘Good’ water quality to the coordinate labelled ‘Used for drinking’ indicating a strong association between people drinking water with good quality. The Bar Graph shows about 57% of the people with ‘Very poor’ water quality are not using that water for drinking. While more than 80% of people with ‘Good’, ‘Moderate’ and ‘Poor’ water quality are using it for drinking.



Used for drinking, by water quality (all sources) (a) Asymmetrical plot (b) Bar Graph

Level of treatment, by water quality (all sources)

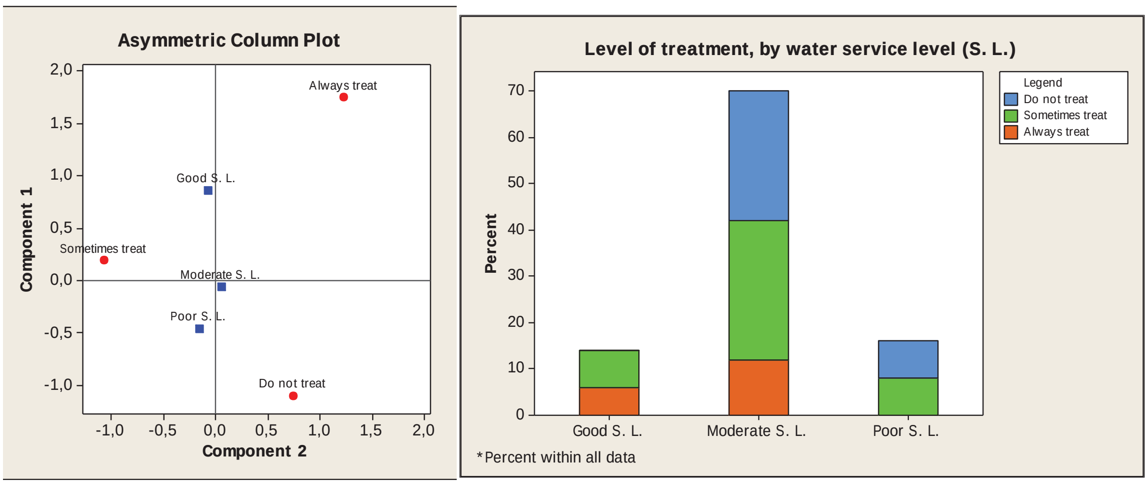
There is a statistically significant correlation (P-Value = 0.007, n = 73) between the level of treatment for drinking water and the water quality of all water sources (primary, secondary and tertiary) in the rainy season. The correlation results are presented in the figures below. From the ‘Asymmetric Column Plot’, the proximity of ‘Very poor’ to ‘Do not treat’ indicates a strong association between households with very poor water quality not treating their drinking water. This is shown in the Bar Graph, with about 86% of the households with very poor water quality never treating their drinking water, the largest percentage of any given water quality level. About 62% of households with moderate water quality, 48% of households with good water quality and 23% of households with poor water quality never treat their drinking water. From the ‘Asymmetric Column Plot’, the proximity of ‘Poor’ to ‘Sometimes treat’ indicates a strong association between households with poor water quality sometimes treating their drinking water. This is shown in the Bar Graph, with about 63% of the households with poor water quality sometimes treating their drinking water, the largest percentage of any given water quality level. In general, the distance of all variables for water quality are quite far from ‘Always treat’, indicating that overall, households are not very likely to treat their drinking water.



Level of treatment, by water quality (all sources) (a) Asymmetrical plot (b) Bar Graph

Level of treatment, by water service level

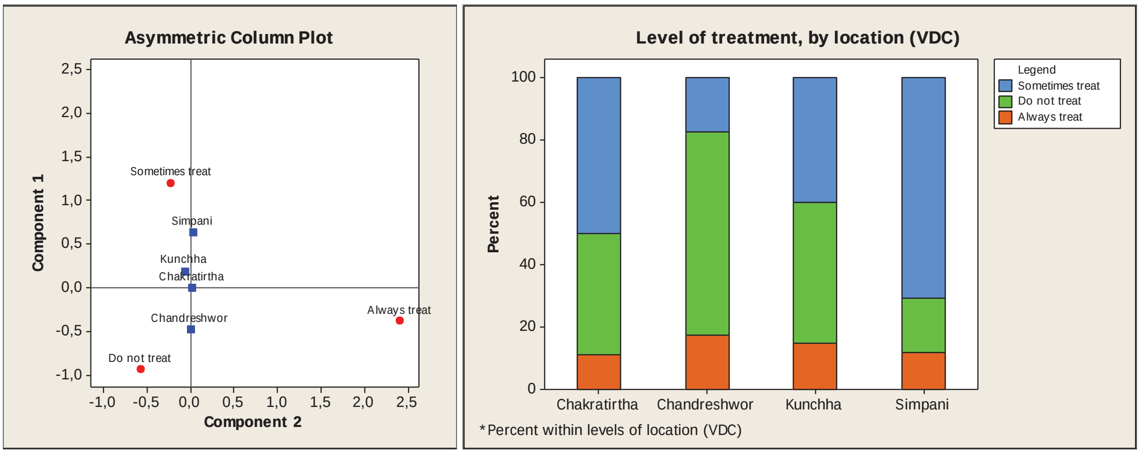
There is a statistically significant correlation (P-Value = 0.033, n = 50) between the level of treatment for drinking water (primary source) and the household’s water service level. The correlation results are presented in the figures below. From the ‘Asymmetric Column Plot’ the distance of ‘Good S. L.’ from ‘Do not treat’ indicates no association between the two coordinates. This is also reflected in the Bar Graph because those with a good service level either ‘Always treat’ or ‘Sometimes treat’ their water. From the ‘Asymmetric Column Plot’ the distance of ‘Poor S. L.’ from ‘Always treat’ indicates no association between the two coordinates. This is reflected in the Bar Graph because those with a poor service level either ‘Sometimes treat’ or ‘Do not treat’ their drinking water.



Level of treatment, by water service level (a) Asymmetrical plot (b) Bar Graph

Level of treatment, by location

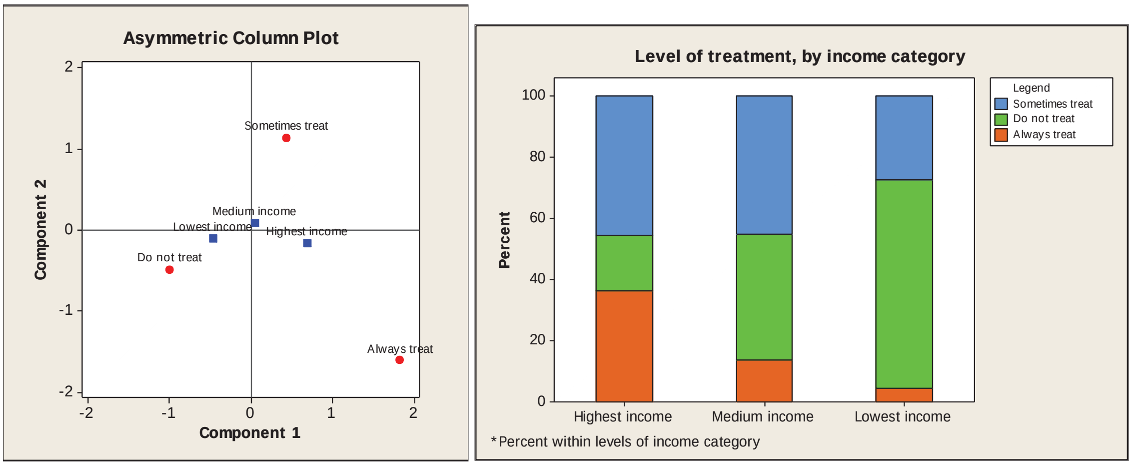
There is a statistically significant correlation (P-Value = 0.020, n = 84) between the level of treatment for drinking water and the household's location (based on VDC). The correlation results are presented in the figures below. According to the 'Asymmetric Column Plot' the proximity of 'Simpani' to 'Sometimes treat' indicates a strong association with households in Simpani sometimes treating their drinking water. This is corroborated by the Bar Graph because about 71% of all households in Simpani sometimes treat their drinking water, the highest percentage for 'Sometimes treat' across all VDCs. According to the 'Asymmetric Column Plot' the proximity of 'Chandreshwor' to 'Do not treat' indicates a strong association with households in Chandreshwor never treating their drinking water. This is corroborated by the Bar Graph because about 66% of all households in Chandreshwor never treat their drinking water, the highest percentage of all VDCs that 'Do not treat' their drinking water supply. In general, the distance of all locations by VDCs are quite far from 'Always treat', indicating that overall, households are not very likely to treat their drinking water.



Level of treatment, by location (a) Asymmetrical plot (b) Bar Graph

Level of treatment, by income category (all sources)

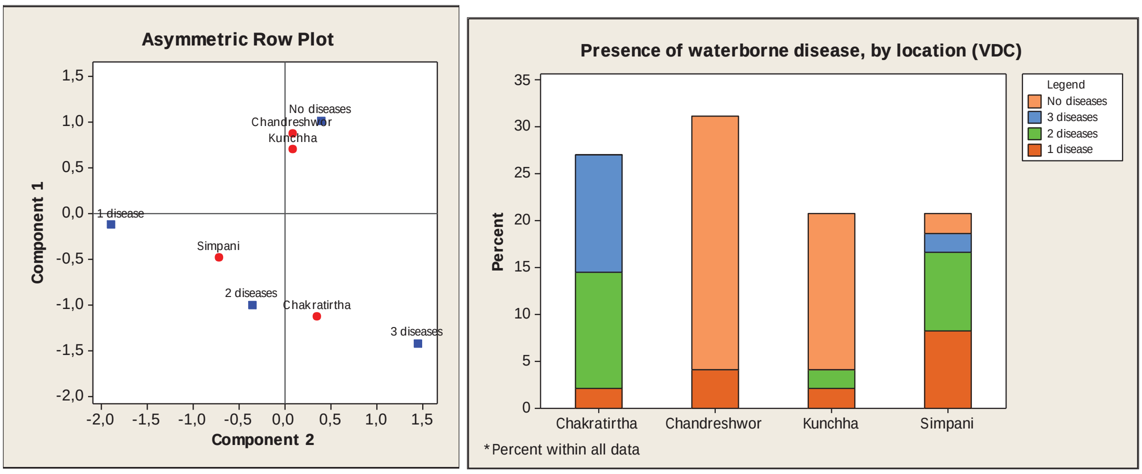
There is a statistically significant correlation (P-Value = 0.030, n = 86) between the level of treatment for drinking water and a households' level of income. The correlation results are presented in the figures below. From the 'Asymmetric Column Plot', the proximity of 'Lowest income' to 'Do not treat' indicates a strong association between households of a lower income category to not treat their drinking water. According to the Bar Graph, 68% of households of the lowest income category do not treat their drinking water. Shown in the 'Asymmetric Column Plot', the distance of 'Lowest income' from 'Always treat' indicates a weak association between the two coordinates. The Bar Graph corroborates this with about 5% of the households in the lowest income category always treating their drinking water.



Level of treatment, by income category (all sources) (a) Asymmetrical plot (b) Bar Graph

Presence of waterborne diseases, by location

There is a statistically significant correlation (P-Value = 0.000, n = 48) between the presence of waterborne diseases and a household's location (based on VDC). The correlation results are presented in the figures below. From the 'Asymmetric Row Plot' the proximity of 'Chakratirtha' to '2 diseases' and '3 diseases' indicates that there is a strong association for two-three different types of diseases to be found in Chakratirtha. This is shown by the Bar Graph because '2 diseases' and '3 diseases' make up about 25% of the diseases found in 'Chakratirtha'. From the 'Asymmetric Row Plot' the proximity of 'Chandreshwor' and 'Kunchha' to 'No diseases' indicates that there is a strong association between these two VDCs not having any waterborne diseases. This is reflected in the Bar Graph because it shows that 'Chandreshwor' is about 27% disease-free and 'Kunchha' is about 17% disease-free.



Presence of waterborne diseases, by location (a) Asymmetrical plot (b) Bar Graph

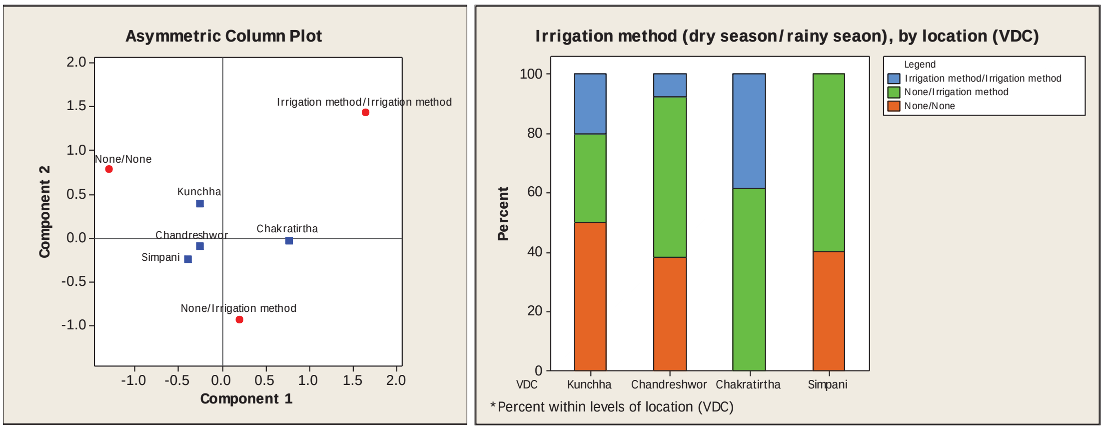
Sanitation and hygiene

No significant correlations were found.

Agriculture

Irrigation method, by location

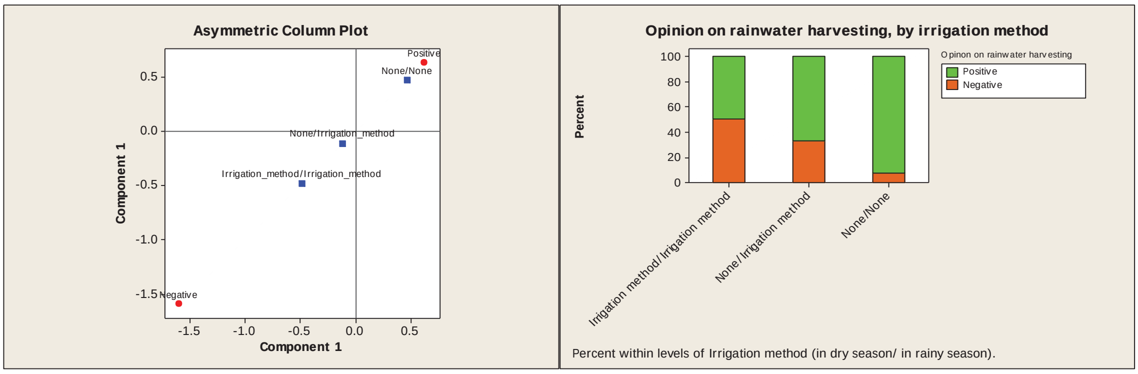
A statistically significant correlation was found between the irrigation method and the household's location (based on VDC) (P-value = 0.007, n = 46). The correlation results are presented in the figures below. Chakratirtha is located on the line between "Irrigation method/Irrigation method" and "None/Irrigation method", indicating that all households in Chakratirtha have improved irrigation methods during the rainy season. Most of wards in Chakratirtha are located at a low elevation and irrigated by a large irrigation canal from a river and the ward at a higher elevation has a spring that runs in the rainy season and can be used for irrigation. Simpani is located on the line between "None/None" and "None/Irrigation method", indicating that no houses in Simpani have improved irrigation methods during the dry season, as it is above the river valley and the springs only run in the rainy season. The other two VDCs showed no significant associations.



Irrigation method, by location (a) Asymmetrical plot (b) Bar Graph

Rainwater harvesting opinion, by irrigation method

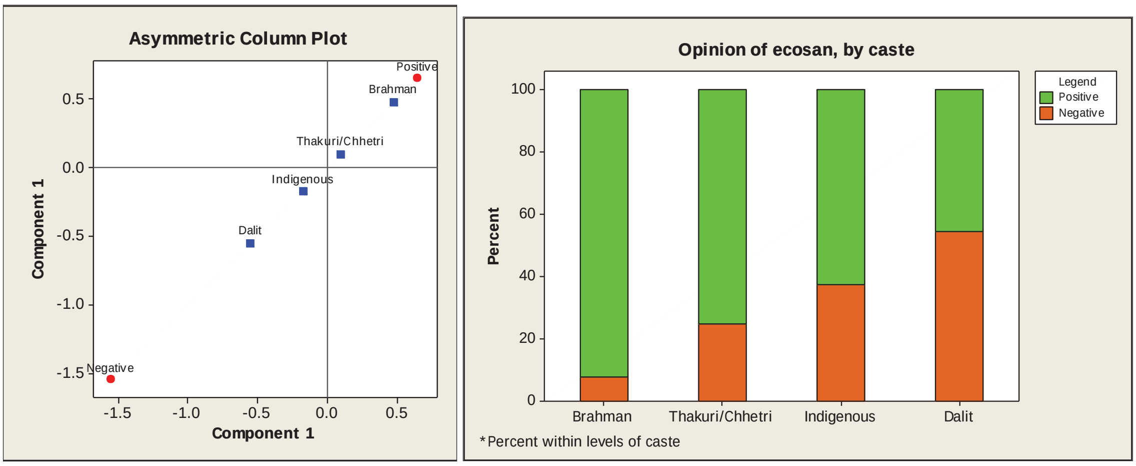
There is a statistically significant correlation between opinion on rainwater harvesting and a household's irrigation method (P-Value = 0.052, n = 46). The results are shown in . The proximity of the "None/None" group to the "Positive" category indicates that households with no improved irrigation methods in both rainy and dry seasons are strongly associated with being positive to the idea of rainwater harvesting. The asymmetric column plot indicates that households in the "None/None" category are most likely to be positive to rainwater harvesting, followed by those in the “None/Irrigation method” category, and finally those in the “Irrigation method/Irrigation method” who have improved irrigation all year around.



Rainwater harvesting opinion, by irrigation method (a) Asymmetrical plot (b) Bar Graph

Opinion of ecological sanitation, by caste

There is a statistically significant correlation between opinion on using human excreta as fertilizer and caste (P-Value = 0.068, n = 44). The results are shown in . From the ‘Asymmetric Column Plot’ the proximity of ‘Brahman’ to ‘Positive’ indicates there is a strong association with households in the Brahman caste having a positive opinion of using human excreta as fertilizer. This is shown in the Bar Graph with 92% of all households within the Brahman caste having a positive opinion. From the ‘Asymmetric Column Plot’ the proximity of ‘Dalit’ to ‘Negative’, in comparison with other castes, indicates there is a strong association with households in the Dalit caste having a negative opinion of using human excreta as fertilizer. This is shown in the Bar Graph with 45% of all households within the Dalit caste having a negative opinion.

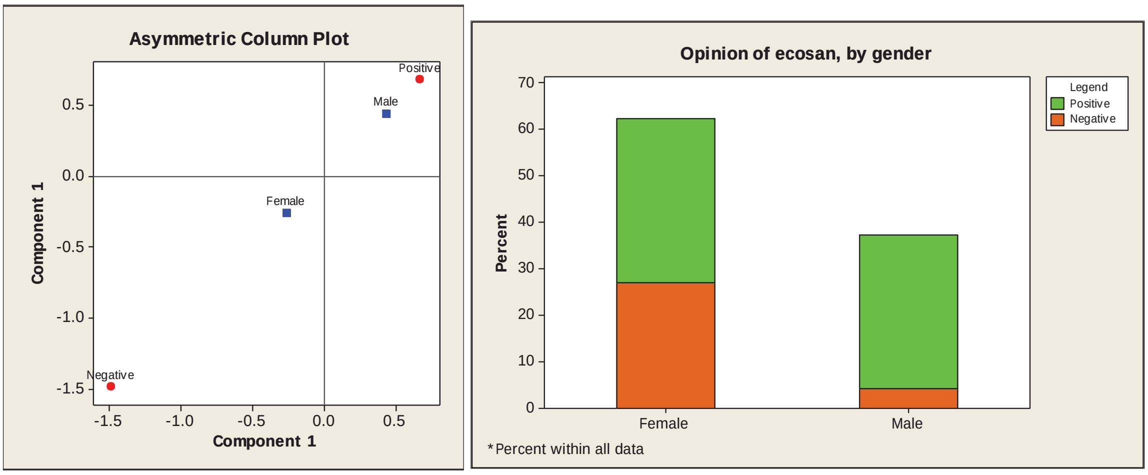


Opinion of ecological sanitation, by caste (a) Asymmetrical plot (b) Bar Graph

Opinion of ecological sanitation, by gender

There is a statistically significant correlation between opinion on using human excreta as fertilizer and gender (P-Value = 0.014, n = 48). The results are shown in . From the

‘Asymmetric Column Plot’ the proximity of ‘Male’ to ‘Positive’ indicates a strong association for men to have a positive opinion of using human excreta as fertilizer. The Bar Graph shows that about 89% of males surveyed have a positive opinion. Women seem to be more divided in their opinion, in that about 57% of females surveyed have a positive opinion and 43% have a negative opinion.

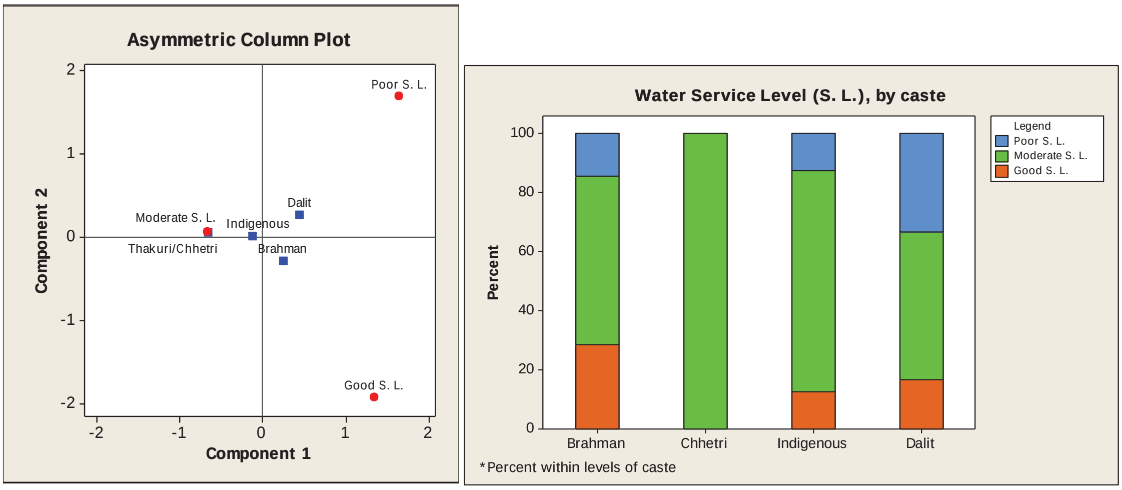


Opinion of ecological sanitation, by gender (a) Asymmetrical plot (b) Bar Graph

Inequality of access

Water service level, by caste

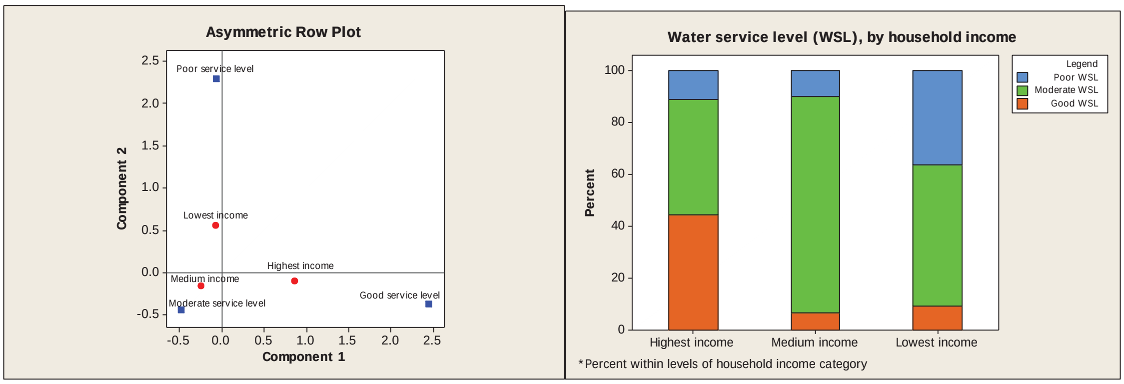
There was a statistically significant positive correlation with the caste of the participant and their water service level (P-value = 0.041, n = 46). The correlation results are presented in the figures below. All castes are clustered nearby the ‘moderate’ water service level category, as this was the most common service level. 100% of the Chhetri participants have ‘moderate’ water service levels, and this is shown by their identical position on the Asymmetric Column Plot. The other castes show weaker secondary correlations: the Brahman caste has a slightly stronger association with ‘good’ water services than the other castes, in the same way that the Dalit caste has a stronger association with ‘poor’ water service levels than the other castes. 12.5% of Indigenous households have a ‘good’ water service level, and 12.5% have a ‘poor’ water service, which can be seen on the plot as it is located evenly between the two apexes. Hence, in this study it can be concluded that higher castes were somewhat associated with a better water service level and vice versa, but that caste is not a strong predictor for water service level.



Water service level, by caste (a) Asymmetrical plot (b) Bar Graph

Water service level, by income level

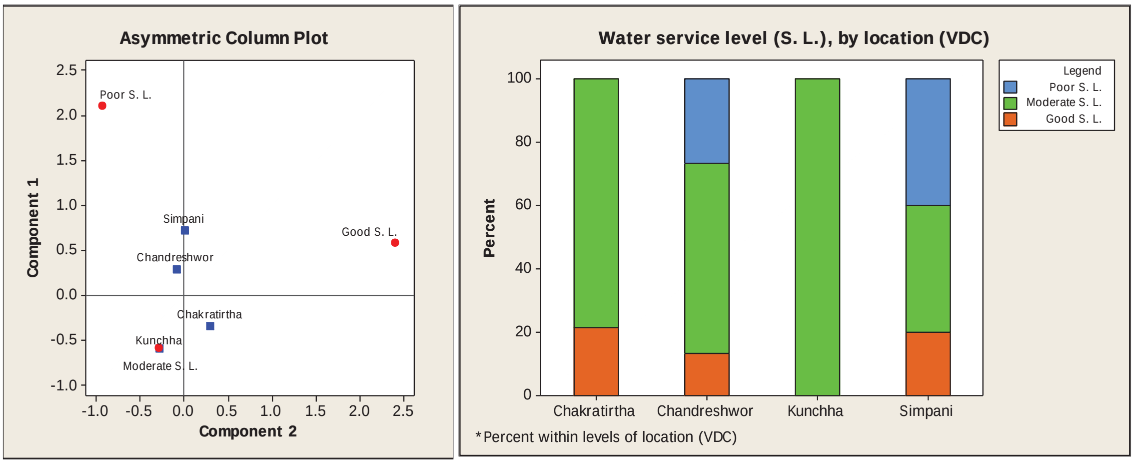
As expected, a statistically significant positive correlation was found between the household income and water service level categories (P-Value 0.033, n = 50). Based on the Asymmetric Column Plot: the proximity of the highest income category (A) to the 'good' water service level indicates that high income is more strongly associated with a 'good' water service level than the other income categories (44% of households with a 'good' water service level were from the highest income category). Similarly, the proximity of the medium income category to the 'moderate' water service level indicates an association (83% of households with a 'moderate' water service level were from the medium income category). The lowest income category is located closest to the 'poor' water service level category indicating that it has a stronger association with a 'poor' water service level than the other income categories.



Household income compared water service level. (a) Asymmetrical plot (b) Bar Graph

Water service level, by location

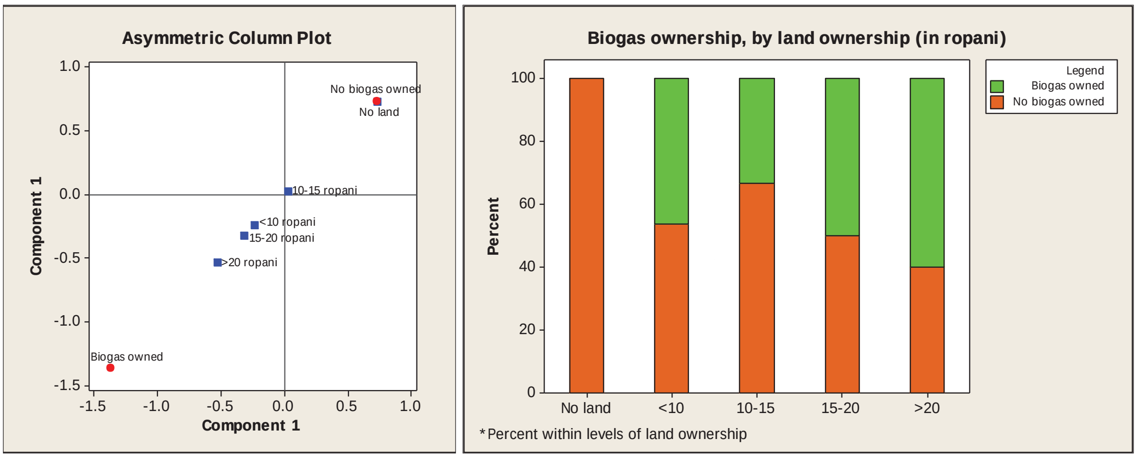
A significant correlation was found between the VDC in which the household is located, and their water service level (P-value = 0.005, n = 50). The correlation results are presented in the figures below. The Asymmetric Column plot shows that all households in Kunchha have a ‘moderate’ water service level. On the Asymmetric Column plot Chakratirtha is located between ‘good’ and ‘moderate’ water service levels (21% and 79% of its water supply respectively) with no households with a ‘poor’ water service level. Chandreshwor and Simpani have no significant associations, and they have households in all three water service level categories.



Water service level, by location (a) Asymmetrical plot (b) Bar Graph

Biogas ownership, by land ownership

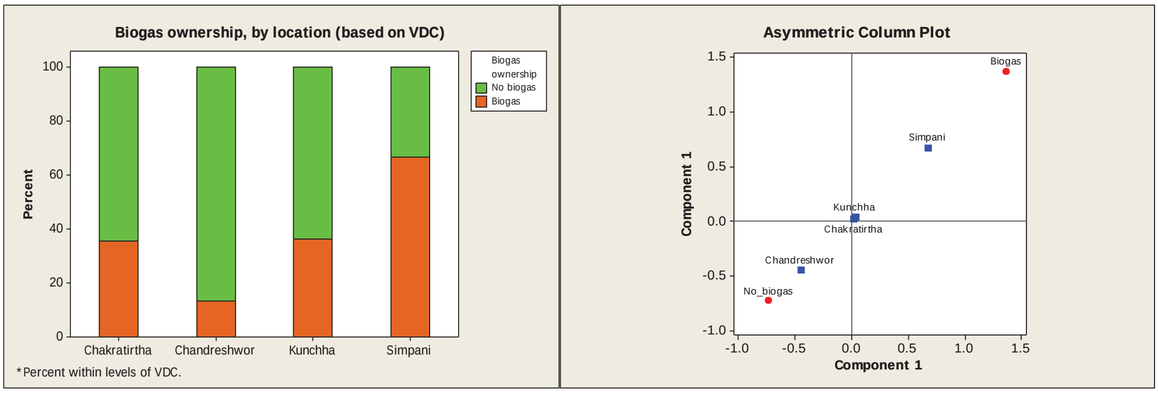
A statistically significant correlation was found between biogas system ownership and land ownership (P-value = 0.025, n = 49). The correlation results are presented in the figures below. On the asymmetric column plot “No biogas” and “no land” are 100% correlated. The proximity of the “>20 ropani” category and “Biogas owned” categories, along with a high Chi-square value for this pairing, indicates that households with more than 20 ropani of land are more strongly associated to ownership of a biogas system than the other categories of land ownership.



Biogas ownership, by land ownership (a) Asymmetrical plot (b) Bar Graph

Biogas ownership, by location

There is a statistically significant correlation between a household's location (based on VDC) and biogas system ownership (P-Value = 0.061, n = 49). The results are presented in the figures below. The asymmetric column plot and high Chi-square value shows that Simpani is more strongly associated with biogas ownership than the other VDCs- Conversely, Chandreshwor has a high negative Chi-square value, which, combined with its position on the plot, indicates that it is has a negative correlation with biogas ownership. The other two VDCs show no significant correlations.



Biogas ownership, by location (a) Bar Graph (b) Asymmetrical plot

Appendix C – Rainwater Harvesting Calculation

The following tables show the calculations done to determine the required tank size for a given daily per capita water consumption.

Kunchha – 15 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)
May	31	276.3	9.4	1.86	7.5	5.0
June	30	499.7	17.0	1.8	15.2	5.0
July	31	655.6	22.3	1.86	20.4	5.0
August	31	555	18.9	1.86	17.0	5.0
September	30	364	12.4	1.8	10.6	5.0
October	31	85.1	2.9	1.86	1.0	5.0
November	30	8.8	0.3	1.8	-1.5	3.5
December	31	5.8	0.2	1.86	-1.7	1.8
January	31	16.6	0.6	1.86	-1.3	0.5
February	28	38.4	1.3	1.68	-0.4	0.2
March	31	53.1	1.8	1.86	-0.1	0.1
April	30	126.5	4.3	1.8	2.5	2.6

Roof area (m^2)	40
C	0.85
People/HH/HH	4
LPCD	15
Tank size	5

Kunchha – 20 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)
May	31	276.3	9.4	2.48	6.9	6.9
June	30	499.7	17.0	2.4	14.6	8.0
July	31	655.6	22.3	2.48	19.8	8.0
August	31	555	18.9	2.48	16.4	8.0
September	30	364	12.4	2.4	10.0	8.0
October	31	85.1	2.9	2.48	0.4	8.0
November	30	8.8	0.3	2.4	-2.1	5.9
December	31	5.8	0.2	2.48	-2.3	3.6
January	31	16.6	0.6	2.48	-1.9	1.7
February	28	38.4	1.3	2.24	-0.9	0.8
March	31	53.1	1.8	2.48	-0.7	0.1
April	30	126.5	4.3	2.4	1.9	2.0

Roof area (m^2)	40
C	0.85
People/HH	4
LPCD	20
Tank size	8

Kunchha – 45 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)
May	31	276.3	9.4	5.58	3.8	3.8
June	30	499.7	17.0	5.4	11.6	15.4
July	31	655.6	22.3	5.58	16.7	27.0
August	31	555	18.9	5.58	13.3	27.0
September	30	364	12.4	5.4	7.0	27.0
October	31	85.1	2.9	5.58	-2.7	24.3
November	30	8.8	0.3	5.4	-5.1	19.2
December	31	5.8	0.2	5.58	-5.4	13.8
January	31	16.6	0.6	5.58	-5.0	8.8
February	28	38.4	1.3	5.04	-3.7	5.1
March	31	53.1	1.8	5.58	-3.8	1.3
April	30	126.5	4.3	5.4	-1.1	0.2

Roof area (m^2)	40
C	0.85
People/HH	4
LPCD	45
Tank size	27

Simpani – 15 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)
May	31	213.3	7.3	1.86	5.4	4.5
June	30	576.4	19.6	1.8	17.8	4.5
July	31	896.3	30.5	1.86	28.6	4.5
August	31	761.2	25.9	1.86	24.0	4.5
September	30	446.2	15.2	1.8	13.4	4.5
October	31	109.2	3.7	1.86	1.9	4.5
November	30	5.1	0.2	1.8	-1.6	2.9
December	31	5.8	0.2	1.86	-1.7	1.2
January	31	28.6	1.0	1.86	-0.9	0.3
February	28	46.2	1.6	1.68	-0.1	0.2
March	31	67.8	2.3	1.86	0.4	0.7
April	30	139.6	4.7	1.8	2.9	3.6

Roof area (m^2)	40
C	0.85
People/HH	4
LPCD	15
Tank size	4.5

Simpani – 20 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)
May	31	213.3	7.3	2.48	4.8	4.8
June	30	576.4	19.6	2.4	17.2	7.0

Roof area (m^2)	40
C	0.85
People/HH	4

July	31	896.3	30.5	2.48	28.0	7.0		**LPCD**	20
August	31	761.2	25.9	2.48	23.4	7.0		**Tank size**	7
September	30	446.2	15.2	2.4	12.8	7.0			
October	31	109.2	3.7	2.48	1.2	7.0			
November	30	5.1	0.2	2.4	-2.2	4.8			
December	31	5.8	0.2	2.48	-2.3	2.5			
January	31	28.6	1.0	2.48	-1.5	1.0			
February	28	46.2	1.6	2.24	-0.7	0.3			
March	31	67.8	2.3	2.48	-0.2	0.1			
April	30	139.6	4.7	2.4	2.3	2.5			

Simpani – 45 LPCD

Month	Days in the month	Rainfall mm	40*C*rainfall (m^3)	Demand (m^3/p/d)	Surplus/ Deficit (m^3)	Cumulative water stored (m3)		Roof area (m^2)	40
May	31	213.3	7.3	5.58	1.7	1.7		**C**	0.85
June	30	576.4	19.6	5.4	14.2	15.9		**People/HH**	4
July	31	896.3	30.5	5.58	24.9	24.5		**LPCD**	45
August	31	761.2	25.9	5.58	20.3	24.5		**Tank size**	24.5
September	30	446.2	15.2	5.4	9.8	24.5			
October	31	109.2	3.7	5.58	-1.9	22.6			
November	30	5.1	0.2	5.4	-5.2	17.4			
December	31	5.8	0.2	5.58	-5.4	12.0			
January	31	28.6	1.0	5.58	-4.6	7.4			
February	28	46.2	1.6	5.04	-3.5	3.9			
March	31	67.8	2.3	5.58	-3.3	0.7			
April	30	139.6	4.7	5.4	-0.7	0.0			

Appendix D – The Survey

Directions: Please, specify the most appropriate answer. Some questions may have more than one answer that applies.

General

1. How many people currently live in your household?
   - o 1
   - o 2
   - o 3
   - o 4
   - o 5
   - o 6
   - o 7
   - o More than 10*
2. How old are you?
   - o 18 and under
   - o 19-25
   - o 26-34
   - o 35-44
   - o 45-54
   - o 55-64
   - o 65 and over
3. What is your occupation?
   - o Homemaker
   - o Farmer
   - o Carpenter
   - o Student
   - o Technician
   - o Teacher
   - o Unemployed
   - o Other*

Water

4. What is your water source* in the dry season? In the rainy season?
   - o Private connection to pipeline
   - o Private/household well
   - o Public tap stand
   - o Public well
   - o *Padhero*
   - o Stone spouts
   - o *Kuwa*
   - o River/stream/lake
   - o Rainwater
   - o Bottled water
   - o Other*
5. Which of the following activities do you use this water source for?
   - o Drinking
   - o Cooking
   - o Bathing
   - o Dishes
   - o Clothes
   - o Livestock
   - o Garden
   - o Other*
6. How many gagri/jerry cans/baltin* do you use daily for drinking? Cooking? Bathing? Dishes? Clothes? Livestock? Garden? Other?
   - o 1
   - o 2
   - o 3
   - o 4
   - o 5
   - o 6
   - o 7
   - o More than 10*
7. How do you treat/purify your drinking water?
   - o Boil
   - o Add bleach/chlorine
   - o Strain through a cloth
   - o Water filter
   - o Solar disinfection
   - o Let stand and settle
   - o Use water purification tablets

- o Other*
- o Don't treat/purify my drinking water

8. Which of the following water borne diseases are common in your community?
    - o Amebiasis
    - o Giardiasis
    - o Cholera
    - o Shigellosis
    - o Dysentery
    - o Typhoid
    - o Ascariasis
    - o Other*
    - o Don't know
9. In the dry season, how would you judge your water source? In the rainy season?
    - o Colorless and clear
    - o Some suspended particles
    - o Green
    - o Reddish-brown
    - o Brownish-black
    - o Dark and unclear
    - o Other*
10. How much time does it take to walk one-way to your water collection point?
    - o 5 minutes or less
    - o 5-15 minutes
    - o 15-30 minutes
    - o 30-60 minutes
    - o 1-1½ hours
    - o 1½ hours or more*
    - o Don't know
11. How much time do you spend queuing at your water collection point?
    - o 5 minutes or less
    - o 10 minutes
    - o 15 minutes
    - o 20 minutes
    - o 25 minutes
    - o 30 minutes or more*
    - o Don't know
12. How often does your water source go dry?
    - o Daily
    - o Weekly
    - o Monthly
    - o Every three months
    - o Yearly
    - o Never
    - o Other*
    - o Don't know
13. Who is responsible for the operation and maintenance of your water source?
    - o Appointed person in community
    - o Shared by whole community
    - o VDC representative
    - o Government
    - o NGO
    - o Nobody responsible
    - o Other*
    - o Don't know

Sanitation

14. Which of the following toilets do you have access to in your household?
    - o Standard squat pan
    - o Urine diverting squat pan
    - o Hole without squat pan
    - o Sitting pan
    - o Bucket
    - o Other*
    - o Community toilet*
    - o No toilet
15. How do these toilets flush?
    - o Bucket-flush
    - o Button-flush
    - o No flush
    - o Other*

- No toilets

16. What other features do these toilets have?
    - Windows
    - Ventilation chimney
    - Bin for disposal of menstrual rags
    - Drain
    - Other*
    - No toilets

17. Where does the sewage from these toilets go?
    - Community wastewater treatment plant
    - Pit
    - Septic tank
    - Biogas reactor
    - River
    - Left out in the open
    - Other*
    - Don’t know
18. What happens when the septic tanks or pits are full?
    - Dug out and sludge put on farmland
    - Dug out and sludge buried
    - Sludge pumped out and taken away
    - Pit covered and new pit dug
    - Toilet is no longer in use
    - Other*
    - Don’t know
19. How often are these toilets not functioning?
    - Daily
    - Weekly
    - Monthly
    - Yearly
    - Never
    - Don’t know
20. Why do you think these toilets break?
    - Too expensive to operate and maintain
    - Lack of water for flushing
    - Smell
    - Dirty
    - Difficult to use
    - Toilets never break
    - Other*
    - Don’t know

21. If any members of your community defecate in the open, why do you think they do this?
    - No access to toilet
    - Toilet expensive to operate and maintain
    - Toilet smells
    - Toilet is dirty
    - Toilet is difficult to use
    - No education on importance of toilets
    - Other*
    - Don’t know

Agriculture*

22. How many *ropani* do you own for cultivation?
    - 5 or less
    - 10-15
    - 16-20
    - 21-25
    - More than 25
    - No *ropani* owned

23. Which of these water sources do you use for irrigation of your cultivated land?

- o Rain
- o River/stream/lake
- o Spring
- o Well
- o Other*

24. How many cows, buffalo and/or donkeys does your household own?
    - o 1
    - o 2
    - o 3
    - o 4
    - o 5 or more
    - o None owned
25. Which of these fertilizers do you use on your farmland?
    - o Animal manure
    - o Crop waste
    - o Urea
    - o DAP
    - o Potass
    - o Other*
    - o No fertilizer use
26. How many bags of fertilizer do you buy per year?
    - o 1
    - o 2
    - o 3
    - o 4
    - o 5
    - o 6
    - o 7
    - o More than 10*

Directions: Please, indicate level of willingness to use the following if they were introduced into your community.

Opinionated Response

27. *Toilets can be designed so that the contents in a storage area under the toilet become a fertile soil after a long time. This soil can be used as a fertilizer on agricultural land.* Willingness to use fertile soil created from human excreta:
    - o Currently use*
    - o Might use
    - o Would never use
    - o Don't know
28. *At the Institute of Engineering at Tribhuvan University in Kathmandu, they have researched using human urine as a fertilizer on vegetables. Their research has shown that the safe use of human urine as fertilizer increases production. Toilets can be easily designed to collect urine in a removable container. Using urine as a free source of fertilizer would mean spending less money purchasing chemical fertilizer.* Willingness to use human urine as fertilizer:
    - o Currently use*
    - o Might use
    - o Would never use
    - o Don't know
29. *Rainwater tanks can be installed to collect water from roofs during the rainy season. This can be used as an additional water source.* Willingness to use rainwater harvesting:

- o Currently use*
- o Might use
- o Would never use
- o Don't know

30. *Biogas means using waste from animal manure, crop waste, garden waste and kitchen waste to produce energy used for cooking. Toilets can be connected to a biogas reactor to increase biogas production to produce energy used for cooking. During biogas production, pathogens are reduced and a sludge is produced that can be used as fertilizer.* Willingness to use gas for cooking and sludge produced in biogas production as fertilizer:
    - o Currently use*
    - o Might use
    - o Would never use
    - o Don’t know

Appendix E – Calculations regarding fertilizer

Calculation of the amount spent by the average household on fertilizer per year

	Total	Urea	D.A.P.	Potash	Reference
Percentage of each type used in Nepal	100 %	67.6 %	29.8 %	2.6 %	(MOAD 2012)
Nepal average use in 2004/05 (kg/ha)	125.2	84.7	37.3	3.2	(Thapa 2006)
Lamjung Price in 2004/05 (100kg)	6800	2 000	2 800	2 000	(Thapa 2006)
Lamjung Price in 2004/05 (1kg)	68	20	28	20	
Cost per house/ha (NRs)	2802	1694	1044	64	
Cost per 500m^2 (NRs)	140	85	52	32	
Cost per 12,500m^2 (NRs)	3503	2117	1306	80	

Calculations of the value of a households' urine if it were used as fertilizer

Excerpt from 2008 WaterAid report *Assessment of Urine Diverting Ecosan Toilets in Nepal*:

> *"An average person produces 550 litres of urine per year. The volume of urine contains, on average, four kgs of nitrogen, 400 grams of phosphorus and one kg of potash. Thus an average family of six members produces 24 kgs of nitrogen, 2.4 kgs of phosphorus and six kgs of potash.*
> *The average prices of nitrogen, phosphorus and potash on the market in April 2007, as calculated based on their contents in urea, DAP and muriel of potash are NRs.47.82/Kg, NRs.60.90/Kg, and NRs.46.75/Kg respectively. Therefore, the total annual value of urine produced by an average family is estimated at NRs.1575.00."*

In our study, the standard household size was 4.6 members rather than 6:

$$1575 \times 4.6/6 = 1207.5$$

Hence the value of urine as fertilizer from one household is approximately 1207.5 NRs, based on 2007 pricing.

References for the Appendices

Minitab. (2003). Minitab User Manual - Multivariate Analysis.

MOAD. (2012). *STATISTICAL INFORMATION ON NEPALESE AGRICULTURE 2011/2012 (2068/069)* Development, M. o. A. Kathmandu: Agri-Business Promotion and Statistics Division Statistics Section.

PennState. (2016). *9.1 - Chi-Square Test of Independence*. USA: The Pennsylvania State University. Available at: https://onlinecourses.science.psu.edu/stat500/node/56.

Thapa. (2006). *CONSTRAINTS AND APPROACH FOR IMPROVING FERTILIZER SUPPLY FOR MEETING DOMESTIC DEMAND* Ministry of Finance, G. o. N. Kathmandu: Asian Development Bank

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