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Assessing drinking water quality from point of collection to point of use in rural Nepal

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MSc Thesis **ES 15.13**

April 2015

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Master of Science Thesis
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This research is done for the partial fulfilment of requirements for the Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, the Netherlands

Delft
April 2015

Abstract

Despite concerted efforts, Nepal continues to suffer from an underdeveloped water supply infrastructure. Low piped-water supply coverage especially in rural areas have been motivating an increasing number of water provision projects. However, the concern about water quality is very low, especially concerning the microbial water quality, that is related to waterborne disease like diarrhea. A few studies on microbial water quality were performed in Nepal, however, most of them are limited to urban areas.

The main objective of the joint research project of the Swiss Federal Institute of Aquatic Science and Technology (EAWAG) and HELVETAS Swiss Intercooperation (HELVETAS) was to assess the microbial water quality, household water management practices, and opportunities for market-based interventions in remote rural areas in Western Nepal. This shall provide the systematic microbiological data, behavioral, and economic understanding required to design an action plan that can improve the drinking water quality at the household level.

This research was conducted by combining microbial water quality analysis, market analysis, survey-based behavior study complemented by observations and expert interviews. Those methods were used to help draw a big picture of what influences microbial water quality and derive solid recommendations for improving the water quality in the study area. In total, 512 households from five districts in the Mid-Western region of Nepal, mostly in remote rural villages, were interviewed and their drinking water samples collected and analyzed.

Regarding the methodology, the procedure used for microbial analysis showed a good performance and could be copied to another field study all over the world. The water quality analysis showed that the number of *E. coli* bacteria between point of collection (POC) and household storage increases. 91% of households had *E. coli* present in their stored drinking water. At the same time, better water quality at the point of collection was associated with better quality in storage containers. Furthermore, a variation in water quality was observed between different piped water schemes in the same village that were built by the same water supplier. Field observation showed that there was a varying condition of water intake which can lead to varying microbial water quality even among schemes of the same implementing agency. The market analysis showed that water treatment products are not within the top three of main investment priorities for people in rural area. Behavior study showed that most people believe that their water quality is good so they do have no intention to treat their water and only 19% of all interviewees treat their water at the household level. Overall, the study results for Kailali district (flat area) differed from the results for the hilly districts, in terms of point of collection water quality, people's perception about water, and the main water source.

The results suggest two main recommendations to improve drinking water quality in rural Nepal. First, to ensure and improve the water quality at source and improve the pipe water scheme, e.g., standardization of water sources or intake specification for a piped water project, in terms of protection, site selection, and water quality; at the same time, the water quality indicators at source or intake and tap shall be included in a monthly monitoring program. Second, doing presence/absence test in the village to create demand for household water treatment, create awareness about safe water handling, and change people bad habit of getting water from unsafe sources.

Keywords: microbial drinking water quality, remote rural Nepal, market analysis, behavior study, *E. coli*, piped water systems, household-water treatment and storage, water handling

Acknowledgements

First of all, I want to give a big thanks and all glory to Jesus Christ for all things that he has done in my life. Your grace and love is sufficient for me to do all great things in my life.

I express my deepest thanks to Arnt Diener, who not only be my mentor but also my close friend during the project in Nepal and Zurich. I am fortunate to learn many things from you in these 6 months. I would like to thank Dr. Sara Marks for all input and help. Now I realized that statistic is very nice thing to learn in the future. Many thanks also to all Sandec family members, especially for Caterina Dalla Torre, who arranged everything for me. I also appreciate the Swiss Federal Aquatic research Institute (EAWAG), Switzerland, for the opportunity to carry out my research. It was very nice experience for me.

I am grateful to thank Dr. Jack van de Vossenberg who supports me for this thesis. I am motivated to improve my English after seeing all your comments. I do agree with all my friends that you are a nice person. My appreciation also goes to Prof. Ken Irvine for overseeing this research work.

Big appreciation goes to UNESCO-IHE for all the knowledge and learning. You successfully open my eyes to make better water and environment in the future. I am feeling lucky to learn here and met many inspirational lecturers from many places in the world.

Thanks to all friends in IHE who come from different countries, cultures and backgrounds. I will remember all good and fun experiences for these 1.5 years. Hope can visit you in your home country.

I am extremely thankful to my parents for all pray, support, love, and encourage throughout my study in Netherlands. I am really lucky to have parents like both of you.

I have no valuable words to express my great thanks and love to Patricia Amanda Tjandrasa, my life partner, energy, "vitamin", and everything in my life. I am really excited to see God's plan for our future life after this. I really want to say "will you marry me?" soon.

Lastly, thanks to all people who help me through my study in Netherlands. I do believe that God will reward you bigger blessing than what you did in my life.

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Abbreviations

CDP	Compact dry plate
CFU	Colony forming units
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
GEMS	Global Environment Monitoring System
HELVETAS	HELVETAS Swiss Intercooperation
HWTS	Household water treatment and safe storage
JMP	Joint monitoring program
NGO	Non-Governmental Organization
ODF	Open defecation free
POC	Point of collection
POU	Point of use
PWC	Pipe water scheme
SODIS	Solar water disinfection
TNTC	Too numerous to count
UN	United Nations
UNDP	United Nations Development Programme
VDC	Village Development Committees
WASH	Water, sanitation, and hygiene
WHO	World Health Organization
WQ	Water quality

CHAPTER 1

Introduction

1.1. Background

Access to safe drinking water plays an important role in human life related to health. Recently, the United Nations (UN) stated that safe and clean drinking water is a human right. Therefore, the UN declared "Water for life" program in the period from 2005-2015 and made one of the targets of the millennium development goals that shall be achieved by 2015 was halving the number of people without proper access to safe water and basic sanitation (Bloomfield, 2012; WHO, 2011).

Even though this target was already achieved in 2010 (88% of the global population had access to improved drinking water source), still about 748 million people lack access to improved sources of drinking water. Of these people, about 173 million get water from untreated surface water and more than 90% live in rural areas. So one of the big problems now is to overcome the gap of proper drinking water supply between urban and rural area (WHO, 2014).

Although drinking water coverage has increased worldwide,access to reliable water quality is still a challenge. Poor water quality bears the risk to to transport and spread diseases related to water. The problem may not be limited tountreated surface water, but may also arise from improved water sources with poor water quality. WHO (2014) stated that there was no assurance that people who get water from an improved source will get it free of contamination. One of the studies also showed that about 1.8 billion people get water from a source that is already faecally contaminated, which can cause cholera, enteric fever, and many other acute and chronic diseases (Bain, et al., 2014; Jessoe, 2013; Sobsey, et al., 2008; Szabo and Minamyer, 2014)

The most common adverse health impact related to poor water quality is diarrhoea. Diarrhoeal diseases in 2000 contributed 5.7% to the global disease burden and estimated around one and half million children under five years old died because of diarrhoea problem (Prüss-Üstün, et al., 2008; WHO, 2000). A study from Nicaragua also stated that children from homes with low water availability had a 34% higher rate of diarrhoea. Research showed that 75% of children who get diarrhoea in Dhaka, Bangladesh had an enteric pathogen in their faeces which strengthened the hypothesis that water-borne pathogens are a common cause of diarrhoea (Ashbolt, 2004; Gorter, et al., 1998).

A better understanding of the level of microbial water contamination can help us to develop protection program for drinking water systems. Interventions may include measures to improve the water treatment process at household level (St Laurent and Mazumder, 2014). Ideally, the assessment needs to be done not only at the source or piped water system intake, but also at the household level because the result at source may not reflect the water quality that is consumed by people (Wright, et al., 2004).

One of the main issues to understand the global water quality problem and to provide a good solution is the lack of water quality data. Even though the UN tried to collect as much as possible data on water quality from around the world through the Global Environment Monitoring System (GEMS), there still is a big gap of water quality data especially for developing countries. The main reasons for the gap lie in the fact that the number of quality monitoring stations is very low, the access to the data is insufficient or inappropriate method are used during the data collection thus risking inaccurate interpretations (Palaniappan, 2010)

1.2. Problem statement and justification

Nepal is categorized as one of the least developed countries in Asia. According to the latest United Nations Development Programme`s (UNDP) Human Development Index, Nepal ranks 145th among 187 countries in 2013. The gross domestic product per capita in 2013 was $694.1 (UNDP, 2014; World Bank, 2015). 42% of Nepal's inhabitants live below the poverty line, and there is a nationwide literacy rate of 40% and life expectancy is 58.1 years. Nepal had 23 million inhabitants in the 2001 census. 80% of the inhabitants live in rural areas (Annamraju, et al., 2001; Shrestha, et al., 2003). As one of the results of the poor economic situation in Nepal, people face many sanitation and drinking water problems.

A WHO report from 2000 stated that there was a big gap in water supply coverage between urban and rural areas in Nepal. The water supply coverage was about 81%, most of which was in urban areas (WHO, 2000). Due to this condition, many projects were done by Non-Governmental Organizations (NGO's) and the Nepal Government to increase the water supply coverage, especially in rural areas (Bhandari and Grant, 2007).

In general, water supply implementation projects in Nepal consist of three steps: a preparation phase, a construction phase, and a post-construction phase. There are sub-steps that are part of each step. One of the vital parts in the preparation phase is measuring the quality of the water source. Afterwards, the construction phase can be done and water can be distributed. In the third phase, monitoring system and evaluation is done to ensure the project is working well or it needs more improvement. Even though the national coverage has increased significantly, the water quality is still bad due to ineffective drinking water system program and bad economic situation in Nepal (Shrestha, et al., 2003).

The studies about water quality that were done in Nepal can be categorized into two categories with respect to the study area: urban and rural area. For urban areas, the sampling location is commonly around Kathmandu or in the Kathmandu valley. Researchers did studies on drinking water quality (including microbiological water quality and presence of heavy metal), drinking water treatment, social factors for drinking water systems, etc. Few studies have also been performed in rural areas, but far less compared to urban areas (Bhandari and Grant, 2007; Lee, et al., 2013; Shrestha, et al., 2003).

For this study, samples were taken and measured in five districts located in the Mid-Western region of Nepal, mostly in remote rural villages and both in geomorphologally hilly and flat areas. Since this research project will focus on remote areas, the results will fill gaps existing in the scientific microbiological data available on drinking water conditions in remote rural areas of Nepal. It will provide some balance against the large number of research projects in Nepal that focus only on urban areas.

1.3. Research Objective

1.3.1. General objective

The main objective of this research is to assess the microbiological water quality and household water management practices in remote rural areas in Western Nepal. This will provide systematic microbiological data and a better understanding that can serve as a basis for designing an action plan to improve the drinking water quality at household level in the study area.

1.3.2. Specific objectives

The specific objectives are:

1. To analyse the microbiological water quality between the point of collection and the point of use in remote rural areas in Western Nepal.
2. To analyse factors relevant for a possible intervention to reduce microbial water contamination in the study area.

1.4. Research questions

This study aimed to answer the following questions:

1. What is the concentration of *E. coli* bacteria at point of collection as compared to the point of use in remote rural areas in Western Nepal?
2. How is the current condition of the piped water schemes in the study area?
3. What are the key behavioral factors that influence the point of use water quality in the study area?
4. How reliable is the microbial water quality testing methodology applied under field conditions an approach to estimate fecal contamination in remote areas?
5. What intervention can be proposed to improve water quality in the study area by combining the results of the microbial testing with selected analysis of behavior factors?

CHAPTER 2

Literature review

This chapter outlines the scientific background for this research that shall serve as the basis for the methodology and concepts used in this thesis. This information is divided into five parts: Method for microbiological water quality analysis, microbiological water quality indicator, pathogen bacterial contamination in water, method to reduce and remove pathogen bacteria in water, and description of study area.

2.1. Water-borne pathogen

There are four type of water-related disease: water-washed, water based, water-related insect vector, and waterborne. Most of them are the consequences of poor quality of water (Palaniappan, 2010). Drinking water contamination from human and animal excreta is one of the main sources for waterborne disease which water play as a transport medium.

In 1958 Wagner & Lanoix introduced the "F-diagram" which illustrate the possible routes from source (faeces) to new hosts (human body). Faeces can arrive at human body through fluids, food, finger, flies, field (floor). Without knowing anything, people's hand can contain high concentration of pathogen bacteria. From some studies we know also the pathogen bacteria can grow during the food storage (Curtis, et al., 2000; Julian, et al., 2013).

Even though people prevent the source from contamination, the pathogen can be brought through transport and storage (Jessoe, 2013). One research was conducted in Sri lanka and found out that 50% of samples were infected after or during extraction from source (Mertens, et al., 1990). The main factor of water storage that can affect the bacterial growth is storage time and temperature. Other study stated that longer you store the water, the worse the water quality. Other factor is temperature. Bacteria can grow easily between 25-37° C or in common room temperature in tropical country (Nsanze, et al., 1999; Nuria, et al., 2009).

There are some natural factors that can affect the pathogen concentration in water. They are geographical situation, climate, and land use. Elevated temperature and the amount of rainfall have a correlation with the number of Faecal coliform and enterocci. (Staley, et al., 2012). The existence of enteropathogen also is more abundance in summer than other seasons (Pokhrel and Viraraghavan, 2004). Precipitation and snowmelt also can be a facilitator to transfer contaminants (Kistemann et al., 2002; Cha et al., 2010). That is the reason why in rainy season, the number of pathogen bacteria grow rapidly. But in general, land use impact has a greater influence than climate variation (St Laurent and Mazumder, 2014).

2.2. Indicators for microbiological water quality

Drinking water quality can be assessed in terms of the water`s chemical, radiological, microbial and acceptance properties. The main contaminants for drinking water quality from a health perspective are faecal pathogens, arsenic, and fluoride (WHO, 2014).

Since there are a lot of pathogens that can be exist in the water and it is impossible to analyze each of them, indicator bacteria can be used to assess the microbiological water quality. They can be used to assess the level of faecal contamination in water. The three most common indicators are *Escherichia coli*, thermotolerant bacteria, and total coliform bacteria (Field and Samadpour, 2007).

The following characteristics for good faecal indicator bacteria that are stated by WHO (2011) :

1. They are universally present in animals and humans faeces in large numbers
2. They can be detected easily by simple methods
3. They persist in water in the same way as faecal pathogen
4. They can respond to the water treatment process in the same way like faecal pathogens
5. They do not multiply in natural water
6. They must not be pathogen themselves

According to all characteristics, *E. coli* is the best indicator and gives a conclusive evidence of faecal contamination in water. they must not be present in drinking water (WHO, 2006).

Total coliform bacteria are a big group of different type of bacteria. Total coliform can be harmful but most of them are harmless. They can be found in naturally in the environment such as vegetation, soil, and also human and animal faeces (Kanangire, 2013). Since their presence in the environment must not relate to faecal contamination, especially in tropical countries, WHO (2011) have not recommended them as indicator for faecal contamination in water.

Thermotolerant bacteria, also can be called faecal coliform bacteria, are a sub-group of total coliform bacteria coming from intestines and faeces of human or animal. Their presence in water give a strong indication of faecal contamination (Kanangire, 2013). Together with *E. coli*, thermotolerant bacteria are suggested by WHO (2011) as an indicator for faecal contamination.

Escherichia coli (E. coli) is a sub-group of faecal coliform bacteria which usually live in intestines of human and animal. Most of them are harmless, but some types are harmful, like *E. coli* 0157:H7. *E. coli* is stated as the best indicator for faecal contamination. Their detection also are quite simple, cheap, and the bacteria can survive longer than other bacteria in water (Edberg, et al., 2000; Hijnen, et al., 2000; Jessoe, 2013).

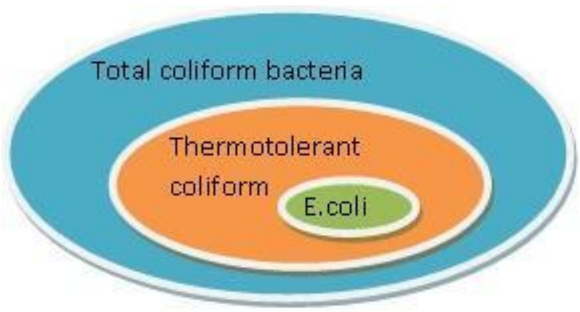


Figure 2.1 The grouping of faecal indicator bacteria (Kanangire, 2013)

WHO (1997) recommended some risk classification based on the number of indicator organism in a 100 ml drinking water sample. This classification can be seen from picture below. This classification is used for this thesis.

Table 2.1 WHO risk classification

CFU *E. coli* / 100 ml	Classification	Colour code
0	WHO guidelines	
1-10	Low risk	
11-100	Intermediate risk	
100-1000	High risk	
>1000	Very high risk	

2.3. Methods for microbiological water quality analysis

Microbiological water quality can be estimated by assessing the presence and concentration of faecal pathogen indicator bacteria, for this study *Escherichia coli* (*E. coli*) and total coliforms. In general, there are two main techniques to analyze the microbiological water quality: a qualitative and a quantitative method.

The qualitative method is trying to know the presence of bacteria in the sample. Common qualitative testsare simple and easy to do. Usually only some ml sample is used and mixed with reagent to show the presence of bacteria in that sample (Rompré, et al., 2002). This method is good to do simple water quality monitoring, but not very good to assess the level of contamination in the water. Qualitative method can be used as the first step to analyze the water quality. But afterward, quantitative method can be done if we want to have deeper analysis.

There are some presence/absence tests (P/A test) that are familiar in the field. For example: colilert, hydrogen sulphide (H_2S) technique, LMX broth, etc. H_2S will give a black colour for positive *E. coli* presence. LMX broth and colilert will give yellow colour for positive *E. coli* presence (Clark and El-Shaarawi, 1993).

A quantitative method is done by counting the number of live bacteria that are developed on the medium. Live bacteria can be seen from the presence of colonies in the medium after incubation. Colony forming units (CFU) is usually used in scientific word as a term to mention the number of live bacteria.

Standard incubation time for *E.coli* and total coliform bacteria is 24 hours. After incubation, direct plate counting is done with naked eye. This is the reason why the counting of colonies is really depending on the people who count it. A report stated that a replicate that give a value within 30% of the average still can be accepted or the relative standard deviation is below 15% (Sutton, 2011; Sutton, 2006). For statistical purpose, triplicate of samples is recommended during analysis.

Since naked eye is used to count the number of bacteria, there is a limitation of bacteria that can be count by naked eye from one plate. Too many bacteria in the plate will make the enumeration of bacteria very difficult. The concentration of the food in the plate will also restrict the bacteria to grow. The bacteria also will compete for space. So nutrient and space can be a limitation for bacteria to grow.

Microbiologist use "too numerous to count" (TNTC) to stated the number of bacteria cannot be counted by naked eye. There are several ways to write TNTC into a number for quantitative and statistical purpose. One of them is use the number of upper limit of the plate. Upper limit can be defined as the highest accepted value of bacteria that can be grown in the plate (Sutton, 2011). But microbiologist also suggested that dilution is a good solution to overcome this problem. So for example, if the 100 ml sample gives TNTC value, we can do 1:10 dilution.

Common method that is used for quantitative method is membrane filtration method. This method has some advantages : short period, can assess large sample, and high accuracy (Cappuccino and Sherman, 2008; Hijnen, et al., 2000). But this method can not be used for turbid sample because it can broke the filter paper and clog the pores.

2.4. Common methods to reduce and remove pathogen bacteria in water

A report stated that more than 50 treatment techniques were introduced around the world, and 8 techniques were seemed to be applicable in rural Nepal. They are iron-oxide coated sand, activated alumina manganese oxide, 2-Kolshi, 3-Kolshi, jerry can, arsenic iron removal plants, activated alumina, and the Kanchan TM Arsenic Filter (KAF) (Ngai, et al., 2007). From evaluation, 2-Kolshi, 3-Kolshi, and KAF were the best one to applied in Nepal (Murcott, 2007). Most of the methods above are related to water filtration.

One pilot project in rural Nepal found out that KAF was the best option for rural Nepal. More than 5000 KAFs are in applied in Nepal in February 2007 for about 35,000 - 50,000 people. An experiment in Nepal showed that KAF can remove 82% bacteria in water. Other advantage from KAF is KAF can remove iron, arsenic, turbidity, bad odour, and humid substances (Ngai, et al., 2006).

Another conventional water treatment is chlorination. A result showed that 1 mg/L chlorine in water has a little effect on bacteria after 1 hour. But 5 and 10 mg/L showed 97% and 99.99% bacteria elimination (Szabo and Minamyer, 2014).

Solar disinfection (SODIS) also showed a good performance. SODIS can reduce more than 90% bacteria in drinking water (Rainey and Harding, 2005). Actually SODIS was accepted in Nepal. but the sustainability in the future is still questionable (Saladin, 2002).

Another simple option to treat water is boiling. Boiling can remove all pathogens in water and already proven for large scale use (Sobsey, et al., 2008). but recontamination can take place due to inappropriate boiling, bad water storage, or recontamination due to contaminated storage (Clasen, et al., 2006).

Another traditional water treatment method is using piece of fabric to filter the solid matter. around 90% pf the people in Siddhipur, Nepal use this method (Rainey and Harding, 2005). In some study areas, we can find cloth installed on the tap. A report from Bangladesh showed that cloth filter is effective to filter 99% bacteria that causes cholera and reduce cholera disease by 48% (Colwell, et al., 2003).

One study was conducted and compared Chlorination with safe storage, combined coagulant - chlorine disinfection systems, solar disinfection (SODIS), Ceramic filter, and Biosand filter according to some criteria. These criteria were ease of operation, cost per liter, water quantity produced, supply chain requirements, time to treat, and ability to treat a different kind of water qualities. From all criterias, they give a conclusion that ceramic and biosand household water filters are the most effective treatment. ceramic and biosand filter technology also can be adopted by large people, as they are used by over 500,000 and 1.5 million people (Sobsey, et al., 2008).

Many reviews stated that improving household drinking water quality at point of use (POU) can reduce diarrhoeal disease by 30-40% and make the treatment easier and effective than improvement at the water source. The main objective of POU household water treatment (HWT) and good water storage technique is to stimulate and support people with no access to safe water to improve water quality in their house. People also have to motivated and commited to do it in their daily live even the program has ended (Sobsey, et al., 2008).

Good water storage at household is important also to prevent from contamination. A study was conducted and showed that cover the water container can reduce pathogen contamination by 50% (Chidavaenzi, et al., 1998). A research in Kenya discovered well source protection increased drinking water quality by 62% and reduce 25% risk of diarrhoea in children (Kremer, et al., 2007).

From F-diagram, experts conclude also that a Hygiene practices is better to be done at first barriers. it means disconnect the route from source (faeces) to environment is more essential than stop the transfer of bacteria from environment to human (Curtis, et al., 2000). Since sanitation closely related with drinking water quality, improved sanitation is a potential way to prevent faecal contamination (Pickering, et al., 2012). According to a study published in the 80s, the combination of hand-washing with soap, safe water, and no presence of faeces in the house yard give reduction of diarrhoea by 40% (Alam, et al., 1989; Han and Hlaing, 1989).

Strategies for implementation of safe water system must take public education into account (Rainey and Harding, 2005). The price of the treatment also must be considered. one study stated that the acceptance of chlorination increase dramatically when people get it for free (Kremer, et al., 2011).

CHAPTER 3

Description of study area

Nepal has three geographical areas due to elevation: mountains, hilly, and flat area (it is called Terai area). There were 5 Village Development Committees (VDCs) in 5 districts in mid and far western Nepal that became study area in this research. They were Jarbuta VDC in Surkhet district, Birpath VDC in Achham district, Nepa VDC in Dailekh district, Pahalmanpur VDC in Kailali district, and Sima VDC in Jajarkot district. A VDC is a smallest administrative unit in Nepal. The mid and far western areas of Nepal is known by inaccessibility, rough terrain, difficult access, food and water shortage and serious poverty (Rautanen and White, 2013).

Birendranagar is a municipality in the mid-western region of Nepal. Birendranagar cover around 3600 hectares. The population in 2001 was around 31,000 inhabitants. The range of temperature is between 10° - 30° C and average rainfall is 1500 mm per year (GENESIS Consultancy, 2010). Birendranagar was the main basecamp during the study and also is the municipal of Surkhet district. This district has different landscape: hilly, valley, and flat area; we went to all the areas. Birendranagar city is located in flat area and quite developed. That was why most of the people get water from piped water system. But in some areas, people get water directly from water source or even river.

Achham, Dailekh, and Jajarkot have similar characteristics. They are located in the hilly area. Most of the people trying to stay in the highest position due to sun light. Lower the position, the more difficult to get the sun light. Not all area can be accessed by car. For instance, Achham and Dailekh can be accessed by car, but not with Jajarkot area. Sima VDC is quite remote and need to walk to reach that place. Some of the location already had the piped water system. But due to geographic condition, not all people can get the water from pipe scheme. Some people get water from water source. In Jajarkot, people can get water from the unclean river. Since the area was not really developed, education and social economic also experiencing the same thing and need to be improved.

Terai area is a flat land south of the Siwalik Hillys and close to the Indian border. Terai area includes 17% of the Nepal total area and contains around 11.2 million inhabitants in 2001 or 48% of the total Nepal population. Kailali is located in Terai area and quite developed because it is located at the main route to India. The majority of the population in Terai area consume groundwater as the source for drinking water. About 90% people in that area get water from tube wells with many kinds of contaminations, especially Arsenic (Lee, et al., 2013; Shrestha, et al., 2003).

Figure 3.1 Nepal map with study area location

From the table below, we can see the main information about water, sanitation, and hygiene (WASH) condition in 5 VDCs.

Table 3.1 WASH information from study area

district	Terrain	Access to sanitation (%)	Access to improved source of drinking water (%)	Total population	% diarrhoea as of total population
acham	Hilly	48	60	257,477	16.9
dailekh	Hilly	49	54	261,770	13.2
jajarkot	Hilly	44	56	171,304	8.9
sukhet	Hilly	71	66	350,804	7.4
kailalli	Flat (terai)	49	94	775,709	4

Source : (Ministry of health and population (MOHP), 2012)

Nowadays, the Nepal government is promoting the Open Defecation Free (ODF) program. This campaign is done to increase the number of toilet throughout Nepal to 100% by 2017 (Adhikari and Shrestha, 2008). The program runs successfully and many districts in Nepal now already declared themselves free from open defecation. Nepal government is also promoting “total sanitation” after the ODF campaign. Total sanitation consists of safe water, better sanitation, personal hygiene, kitchen management, and solid waste management. So if one district already declared their ODF status, they are encouraged to apply total sanitation programme.

A drinking water project in Nepal is usually done at VDC level. Each VDC need to propose their water use plan to the project owner or government before the project is conducted. It means that they need pro-active action from each VDC (Pant, 2013). There was fast increase of water supply coverage in Nepal since 1990 to 2012. In 2012, more than 88% of total population in Nepal has access to improved drinking water source. But there is still a gap between rural and urban water system facilities. 49% of total population in urban area have access tap piped in premises, compared to only 16% in rural area (WHO, 2014).

According to Nepal demographic and health survey 2011, still about 11% of total households rely on non-improved sources of drinking water. Most of the household (82%) do not treat their drinking water. Only 46% of households in urban areas treat their drinking water compared to 13% in rural area. This condition becomes a big challenge for good implementation of Household water treatment and safe storage (HWTS) especially in rural area.

Even though the water coverage in Nepal has increased significantly, but not with the water quality (Shrestha, et al., 2003). One of the indicators for the water quality is the rate of diarrhoea disease. Although sanitation and hygiene practices play an important role for the spread of diarrhoea disease, poor quality of drinking water is a major source for pathogen contamination that can lead to diarrhoea disease (Ashbolt, 2004). Data showed that diarrhoea incidence rate among children less than 5 years in 2013 increased about 52% compared to 2007. This number strengthens the statement of the local doctor in Kathmandu that the mortality rate due to diarrhoea in Nepal is decreasing but the morbidity is increasing.

CHAPTER 4

Methodology

This chapter outlines the combination of methods applied to answer the set research questions. The first research question on *E. coli* concentrations was approached by on-site microbial water quality testing of various water sources and household storage containers. The piped water systems were the dominant water source tested including their intake, community and private taps (both POC). The microbial analysis was complemented by a visual analysis of selected piped water schemes to contribute to the second research question on the current PWS condition. The third research question on factors influencing the water quality at household level was addressed by primary analysis of the survey data. Continuous monitoring of the microbial field test kit allowed to address the fourth research question on the testing methodology. The final research question was tackled by an interdisciplinary reflection on all findings.

My main responsibility within the research project was to coordinate and conduct the microbial water quality analyses. Besides, I observed the visible condition of selected piped water systems, took part in several expert interviews as well as discussions on questionnaire adaptations. The market analysis, expert interviews, and the behavior study were mainly coordinated by an Eawag officer. An interdisciplinary combination of separate primary analyses or quoting of findings from the behavior study, the market analysis, and the expert interviews were included in this thesis. Understanding all factors that influence water quality in the study area, not only microbial water quality, is necessary to give a general picture about the water handling and go deeper to find a possible reason behind the microbial value.

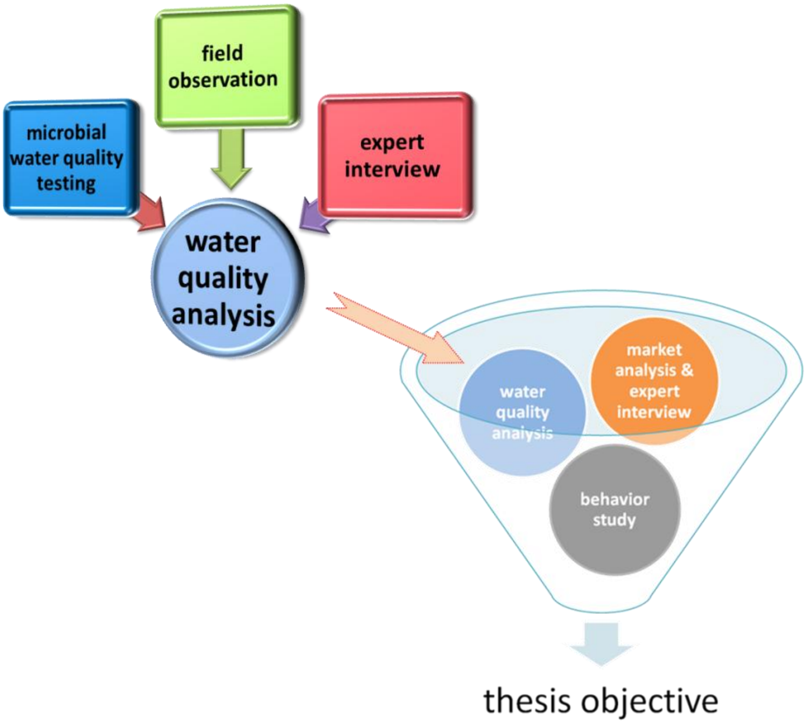


Figure 4.1 scheme of all methodologies

4.1. Microbial water quality testing

4.1.1. Water sampling with THIO-bags

Water sampling was done by six local people who I trained on how to take water samples. They did both the interview and collection of the household and most tap water samples. The samples were carried by the interviewers or support staff from the household to the field lab which was established at a central point in the respective village. The geographical situation, which is dominated by mountainous area, made it necessary to establish the lab in the field because the area cannot be accessed by car and it would require need a lot of time to bring the sample to commercial lab. The 100 ml sample from the house was transferred into a whirl-pak bag, which contains sodium thiosulfate that can neutralize potentially present chlorine in the water. The microbial water testing procedure stated that the maximum time difference between sampling and processing is 6 hours (Mallin, et al., 2000). The sample also should ideally be put on ice or be stored at temperatures below 10° C to reduce or stop bacteria growth. In this study, thermos bottles were used to transport and store the sample. They were were filled with water from the sampled container or point of collection ensuring similar temperature conditions as before sampling. The other purpose was to protect sample from UV solar that can kill the bacteria in the sample (Sichel, et al., 2007).

4.1.2. Microbial water quality analysis

The WHO procedure for microbial water testing was used in this research. This procedure is applied globally to measure faecal contamination in water and allows the results to be internationally comparable. Following the WHO standard, the sample was filtered through a membrane filter with 0.45 µm pore size. The water sample volume filtered was 100 ml (WHO, 2006). Afterwards, the filter was transferred to a compact dry plate (CDP) and incubated for 24 hours at 35±2 °C (Hyserve, 2010). After 24 hours, the petri dish was taken from the incubator and the number of *E. coli* and Total coliform were counted (See appendix A).

All the processing was done with a sterile procedure to prevent contamination from outside. Measures taken were the use of disposable lab gloves, a regularly sterilized metal plate as a base, and a sterilization of funnel and tweezers for each filtration (see appendix A). Positive and negative controls were run every day to make sure the method and equipment were working properly. For the negative control, sterilized water was used. It was obtained by disinfecting tap water using UV light (Steripen®) with proven efficacy for bacteria (Hanson, 2005). For the positive control, a small amount of faecal matter (e.g. animal faeces) was added to 100 ml water. A negative control showing bacteria colonies after incubation, would indicate a poor sterilization process . A positive control without visible bacteria colonies would indicated a problem with the incubation process or the CDP medium. Triplication was done every 20 samples. Triplication was done for one randomly chosen house to ensure the accuracy and estimate the precision of the result.

The decontamination of used CDP's is very important to ensure safe disposal in the field. The bacteria colonies grown on the medium pose a potential health risk to garbage handlers or children playing with garbage in the case of unsafe solid waste management in rural areas. For this research, all the used CDPs were boiled for a minimum of 5 minutes. The effectiveness of this method had been tested by researchers and gave a good decontamination result. Kanangire (2013) found no remaining bacteria colonies on the tested CDPs .

4.1.3. Compact dry plate

The CDP is produced by HyServe and already tested and give a good result for microbiology water quality test. The medium inside the CDP contains colour indicators for different types of bacteria. For this experiment, CDP for coliform and *E. coli* give a blue colour for *E. coli* and red colour for coliform. The colour difference is due to chromogenic substrate in the medium, X-Gluc for *E.coli* and Magenta-Gal for coliform. CDP was approved and validated by AOAC as an analysis tool for microbial testing of food as well as microbial water testing. CDP is good for field microbial water quality testing because it is easy to use, the price is relatively low, easy to carry, and gives a good, reliable, and stable result (Hyserve, 2010).

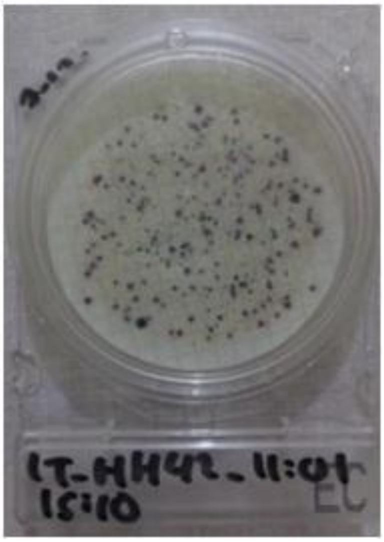


Figure 4.2 CDP with *E. coli* and coliform

4.1.4. Field incubator

The incubator was made in EAWAG to make it fit with the field experiment (See on Appendix D-2). A normal incubator in laboratory needs a lot of electricity and is quite big which cannot be used in the remote area. In case of rural Nepal, there is no sufficient electricity. The field incubator that was made in Eawag was supplied with solar cells for energy source. A temperature logger was put inside incubator to know the temperature variation in the field during incubation time. The field incubator could fit for about 70 CDPs.

4.1.5. Data recording

All the data in the field were recorded and written on paper with some information. The information included type of sample (e.g., source, house, taps, etc.), sampling time, time from sampling time to entering the incubator, incubation time, number of total coliform, and the number of *E. coli*. Afterwards, all the data were typed into an Excel file.

4.2. Behavior study

The purpose of this questionnaire was to understand the people's habit and other social aspects in the field. The questionnaire was developed by EAWAG and used on mobile phones in the field by six Nepalese people (see appendix B). Questionnaires were also used to discover local perception about diarrhoea and drinking water systems in the study area. All questions correspond and relate to the purpose of this thesis. The questionnaire result was linked to the microbial result to help us to interpret the reason behind the microbial value. At the end, behavior study is important to formulate a good recommendation for improvement of drinking water quality in the study area.

There were nine parts of the questionnaire:
1. Household information
2. Access to water
3. WASH know-how, practice, attitude, self-efficacy, planning, behaviour
4. Health status and risk awareness
5. Social norms
6. Information on WASH promotion
7. Market information
8. Wealth index
9. Observation through the interviewer

For this thesis, some behavior study results were used and analyzed to support the interpretation of microbial result.

4.3. Market analysis and expert interviews

Market analysis was done to understand the market situation in the study area and to understand people. Market analysis was conducted by EAWAG officer and from the result we may know people's priorities in their daily life. Market perspective is important also when giving a good recommendation for improvement.

Expert interview was done in a study area (western Nepal) and also in Kathmandu. Expert interview is needed to clarify some issue in the society, to know the real situation in the study area, and to get more input from experts. Interview in Kathmandu was done especially to local doctors, university professors and teachers, or others who are working in water sector.

4.4. Field observations

Field observation was done to find out the field condition and to clarify some unsure results. The objects were water sources, pipe schemes, local houses, local market, local pharmacies, hospital, and other places.

An interview with local people during observation can help to understand the case. Water source or intake observation form can be seen from appendix E.

Another important observation also was to observe how the interviewer worked. This was important to ensure that they worked properly and reproducibly, especially to do an interview, took water sample, drawing a map, chose house, etc. Going together with interviewer to some area or joining them during interview was done sometimes during the research. Some of the people were new to such kind of job. Evaluating was done after observed how they did their job.

CHAPTER 5

Research results

This chapter contains the results of microbial water quality tests, behavior study, market study, expert interviews, and field observation. The main focus of the result is about microbial water quality. Some results and analysis from behavior study, expert interview, and observation were selected to support the microbial result.

5.1. General overview of the research

In this research, 512 questionnaires from 5 villages (VDC) in 5 districts were conducted (table 5.1). Total 505 water samples were collected from the house and also 166 point of collection (POC) samples. From all the samples, 284 household samples can be related with POC sample or about 55.4% from total household.

Table 5.1 overview of the study area

district	Total questionnaires	Total House samples	Total POC samples
Surkhet	93	90	8
Achham	103	101	27
Dailekh	113	111	22
Kailali	129	129	65
jajarkot	74	74	44

Information about water source and pipe scheme in Nepal can be summarized by figure 5.1. The piped schemes are constructed both by non-government organizations (NGO) or government contractors. The water is piped from the intake, mostly spring sources, to the tap(s) usually via reservoir tanks. Most NGO-designed systems in rural areas focus “public” or “community taps” that are shared by several households. However, in some areas, e.g. of Surkhet district, private connections were installed by the government. Helvetas successfully piloted private connections, e.g. in Dailekh district.

In collaboration with the European Union and UNDP, Helvetas installed rain water harvesting systems in some areas, e.g. in Dailekh district. Usually rain water harvesting systems are used only for one house and requires comparably high installation costs. Tubewells, also called “handpump”, were only found Kailali district in the Terai region (see appendix F). They are based on groundwater pumping and are most commonly used by one household each. Due to its geology, many regions in the Terai have problems with arsenic and iron. In Kailali district, The government tried to build a piped scheme based on groundwater from great depth than common pumps to overcome this problem, but the project is no longer in operation due to political issues (see Appendix H).

Even though most of the people get water from an improved water source, there were few people still using unimproved source as their main drinking water source. For example, people in some areas of Surkhet collected their drinking water directly from the river. Dangling pipes are common in some area, especially for people who live near and downhill to open water sources (see Appendix H). Dangling pipe is a pipe that connect directly to the source or intake. This pipe is not a concrete pipe and can be connect-disconnect manually by people who need water.

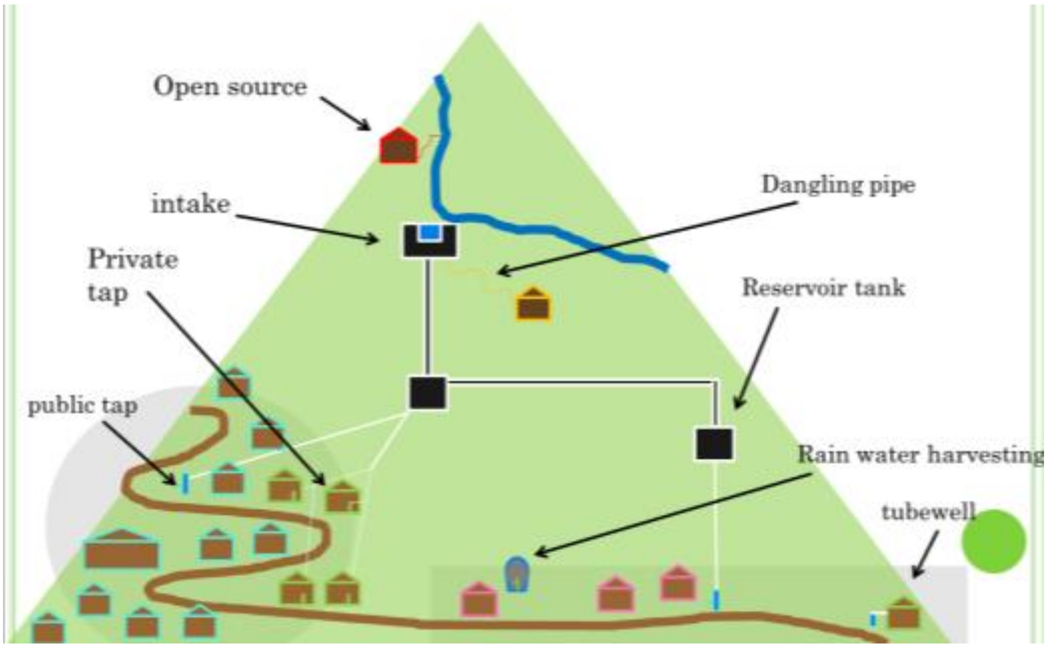


Figure 5.1 water scheme in the study area (adapted from Arnt Diener)

5.2. Evaluation of the procedure and equipment

A field incubator designed by Eawag was used for this research. Even though the performance of the incubator was analyzed before the departure to Nepal, performance in the field still needed to be analyzed especially for low outside temperatures. The temperature inside incubator was monitored with temperature loggers during the research. An example result from the particularly cold Acham district, about 4-12° C in October (World Weather Online, 2012), is depicted in figure 5.2. The temperature was measured every 10 minutes from November 13rd at 09:04 to 09:14 on the next day. In general, the temperature inside the incubator was in the range of 33-36° C. The temperature dropped shortly to 33℃ around midday but rose up again and was quite stable until the next day. The reason for that was because at that moment the incubator was opened for a while to put sample.

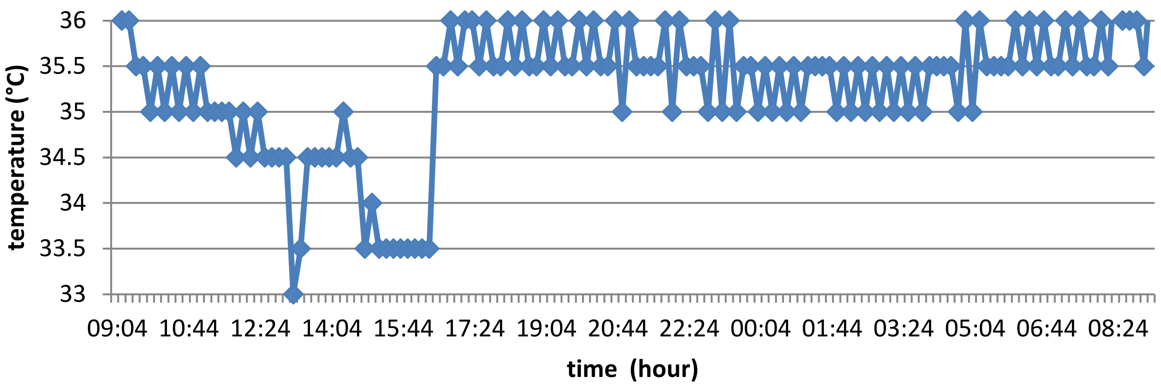


Figure 5.2 temperature log of field incubator

The result of triplication every 20 houses can be seen from figure 5.3. From 505 house samples, 26 triplications were done (5.16% of the total sample). The result showed that most of the samples had a standard deviation below three which means that the triplication showed a high precision. 4 samples had a standard deviation of zero or all triplication showed the same number of *E. coli*.

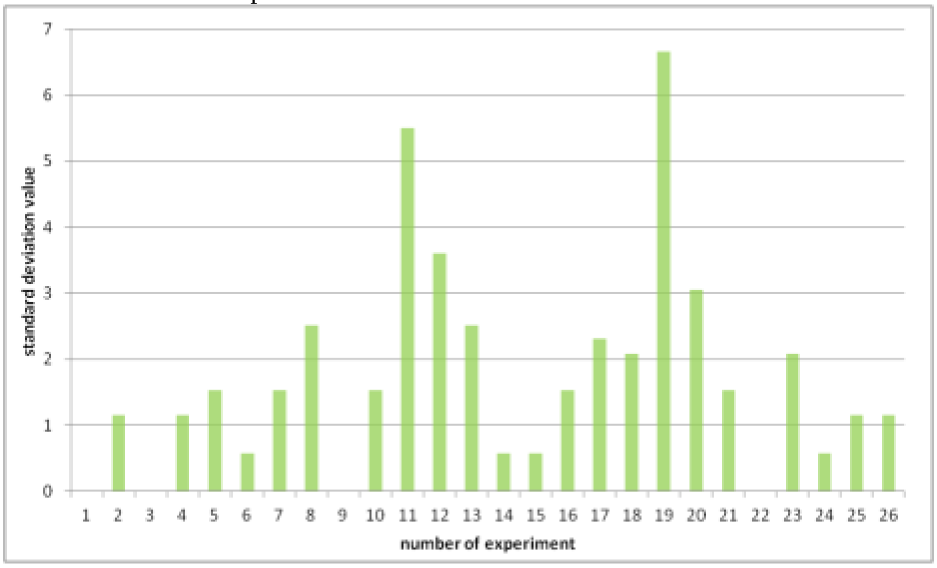


Figure 5.3 Standard deviation of triplication result

5.3. Microbial water quality result

One of the objectives in this research was to understand water quality at point of collection (POC) and household stored water quality. Result of microbial water quality at POC and household can be seen on figure 5.4. WHO colour codes were used for the classification of microbial water quality.

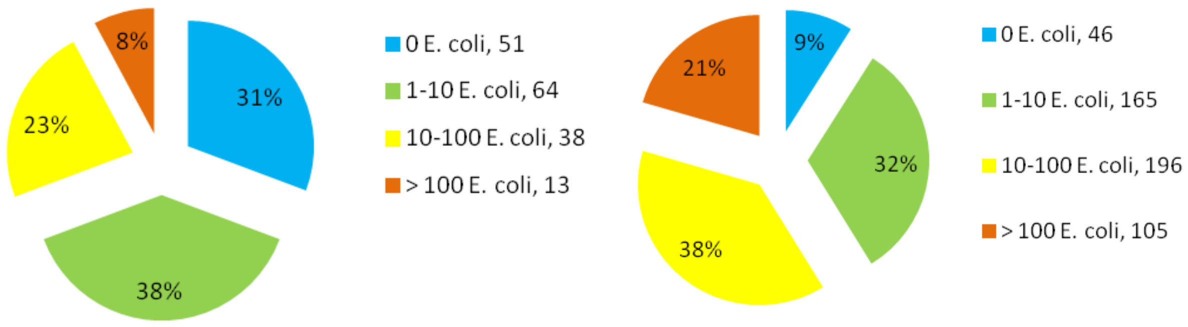


Figure 5.4 microbial water quality (CFU / 100 ml sample) with the number of samples: (left) point of collection (n=166) ; (right) household (n=512)

The pie chart shows that there was a difference between POC and household level. POC microbial water quality was generally better than household stored water quality. 91% from total respondent had *E. coli* in their stored water in house. 21% were at high risk to get sick due to faecal contamination. The result also discovered that more than half people had higher number of *E. coli* in their homes than at the POC (table 5.2).

Table 5.2 Comparison between numbers of *E. coli* in POC and house

	Number of samples	Percetage (%)
Number of *E. coli* at house > POC	203	71.23
Number of *E. coli* at house < POC	82	28.77

From observation, CDP result from Kailali (Terai area) was differerent compared to other hilly areas. The yellow color can be seen on the CDP. The reason for that was because water in Terai contains high arsenic and iron (figure 5.5)

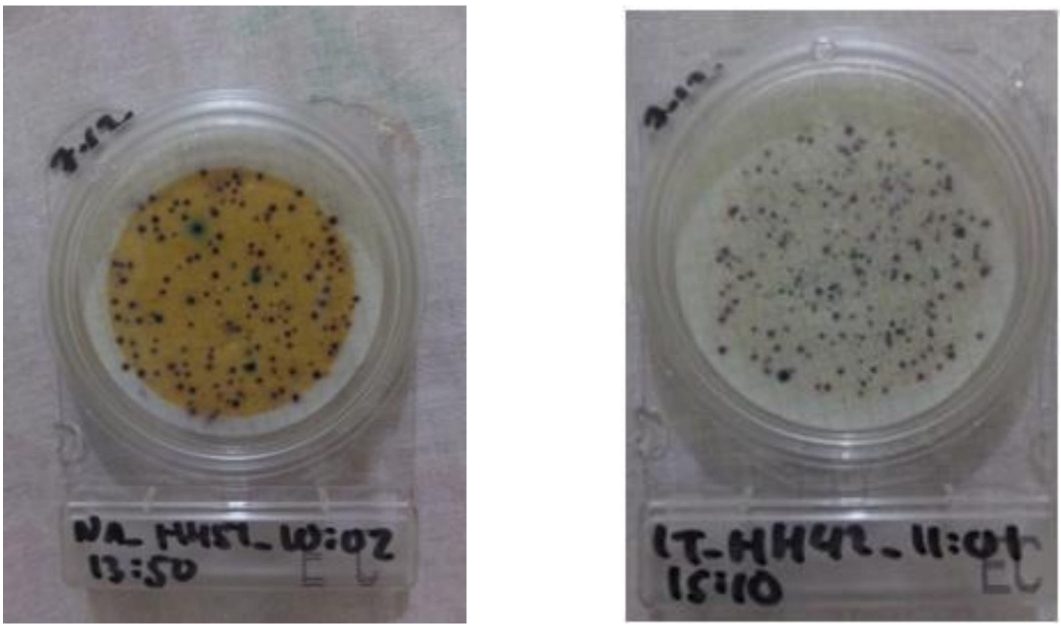


Figure 5.5 CDP result (left) from Kailali; (right) from hilly area

The comparison of the median and average of POC water quality between different VDC revealed that Kailali had better water quality than others (figure 5.6). The average number of *E. coli* in Kailali was 10 CFU/100 ml sample. Jajarkot was the worst POC water quality compare to others with 46 CFU/100 ml sample. But in terms of median value, Jajarkot had the low median value of *E. coli*.

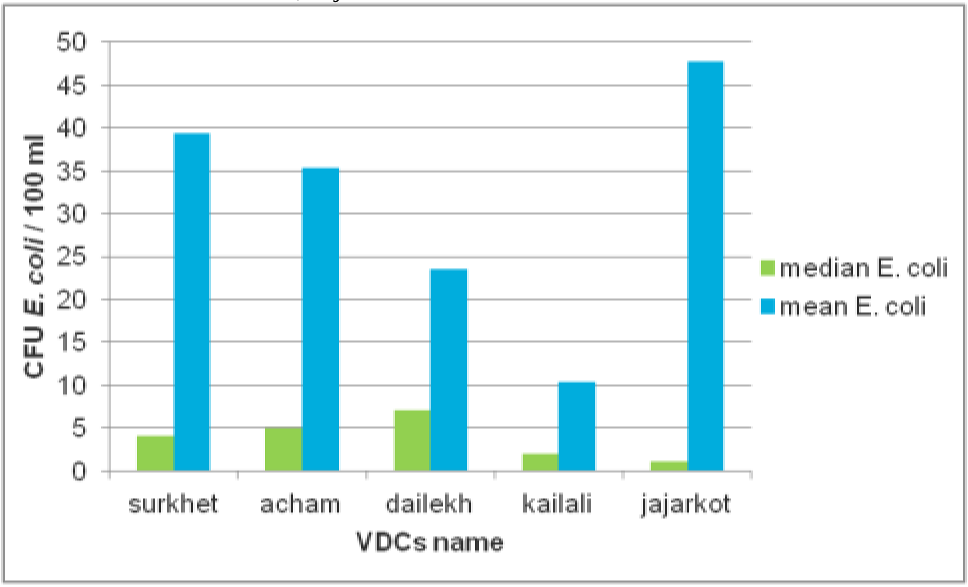


Figure 5.6 median and average number of *E. coli* per 100 ml sample at POC (n=512)

From total 166 POC samples, 100 samples were community tap sample. From 100 community tap samples, 64% samples had *E. coli* below 10 or the quality was generally good. However, about 1 in 10 community tap samples has high number of *E. coli* (figure 5.7).

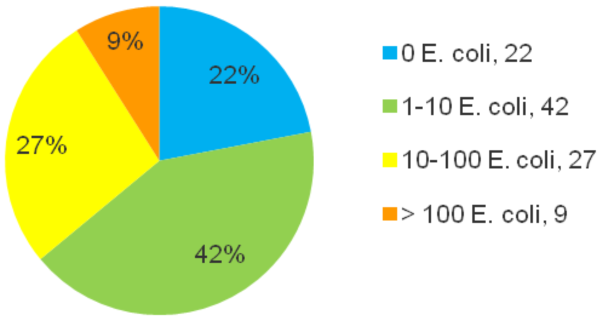


Figure 5.7 community tap microbial water quality ((CFU / 100 ml sample; n=100)

One of the questions in the questionnaire was asking people if they do source conservation or not. The result revealed that source conservation was not common in the study area, only about 9% people did source conservation (table 5.3). Water sample from household who answered "do" source conservation was also analyzed. The result showed that there was no significant difference of household store water quality between people who answered "yes" and people who answered "no".

Table 5.3 practicing of source conservation

Is source conservation practiced? (% households)	Mean (SD) CFU/100 ml	Median CFU/100 ml
Yes (9%)	38 (78)	4
No (33%)	25 (62)	3

One of the problems in the field was some the community taps did not flow every moment. From 100 community taps, only 62 taps always flow every moment (figure 5.8). Statistic result discovered that *E. coli* concentration at the tap was significantly lower if water is always flowing (Mann-Whitney U (196) = 3,380, $p<0.05$, $r = 0.18$).

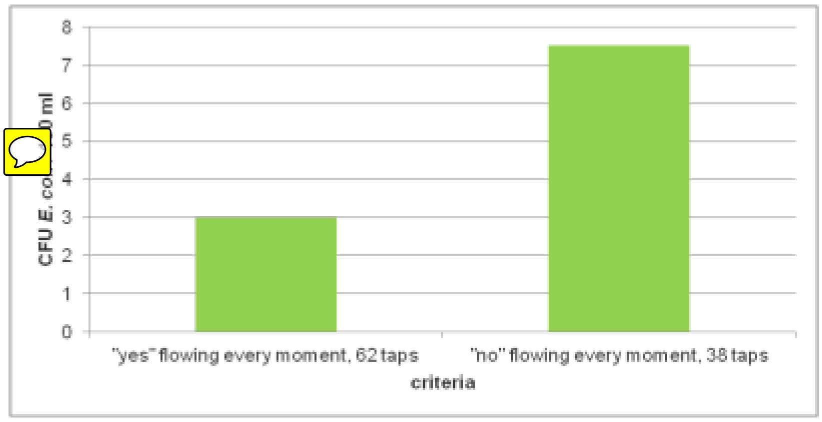


Figure 5.8 median of *E. coli* number for contant flow public tap and intermittent flow public tap (n=100)

Information about how many hours the tap is flowing in a day can be found from questionnaire result. The relationship between hours of time with *E. coli* number can be seen from figure 5.9. The result identified that longer time of tap flowing will lead to low number of *E. coli* in tap.

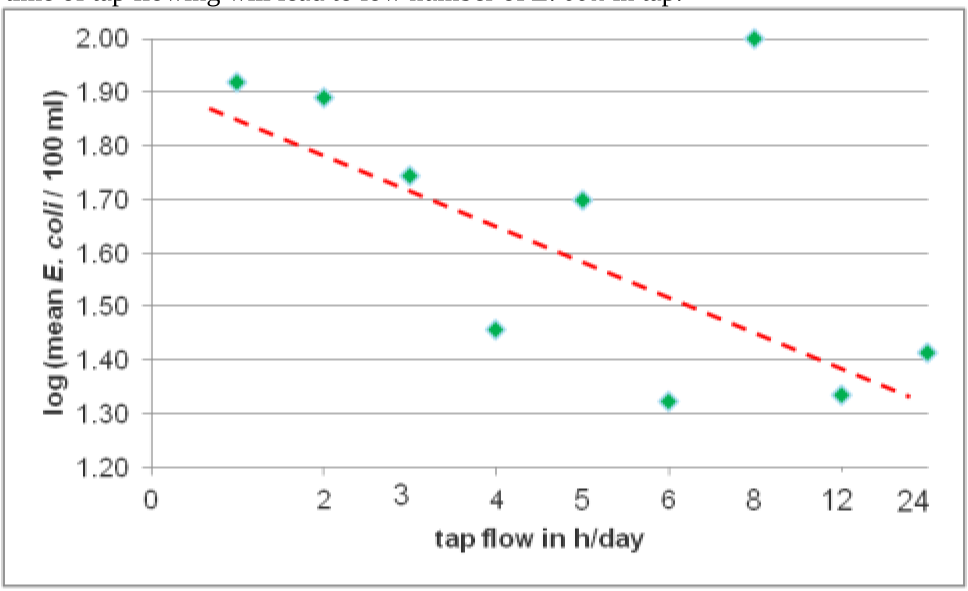


Figure 5.9 Correlation between hours of tap flowing with log mean of *E. coli*

Other important information from the field observation was more than one pipe water scheme system could be found in the village.

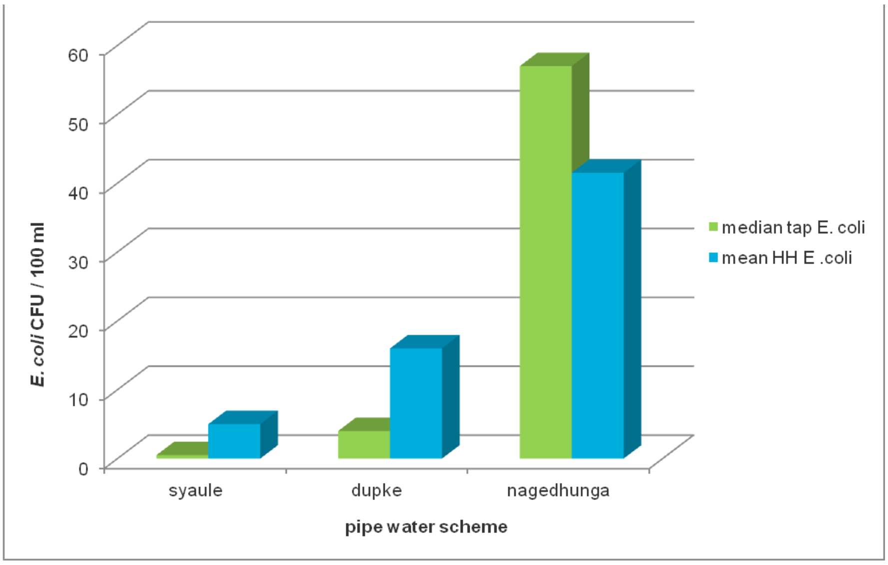


Figure 5.10 comparison between different pipe water scheme from same water supplier in same VDC in Acham

From one case in Acham, three different pipe water schemes from the same water supplier were investigated. The result showed that even the scheme was built by the same water supplier, the quality was different (figure 5.10).

There is one important result from regarding water quality at the point of use. Statistical analysis indicated that better water quality at the point of collection was associated with better quality in storage containers (Spearmans rho (283) = 0.25, $p<0.001$).

5.4. Behavior study result

The first important result from questionnaire was the education level in the study area was low. It can be seen from the questionnaire result about the interviewee education background (figure 5.11).

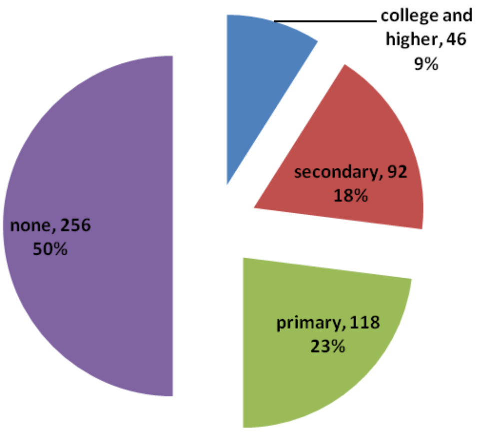


Figure 5.11 education background of the interviewee in the study area (n=512)

The questionnaire result showed that about half of the people get water from piped/community tap. But in Kailali, almost all of interviewee was using private tubewell (figure 5.12). About 9% of total interviewee still using open source and river as a drinking water source which is not safe for drinking purpose. In case of Surkhet, getting water from open source was quite common. It was about 19% of total interviewee in Surkhet draw water from open source.

VDC	main water source	percent
surkhet	private tap	33.33
	public tap	27.96
	open source	19.35
acham	public tap	90.29
	private tap	4.85
dailekh	public tap	71.68
	private tap	7.08
	rainwater	8.85
kailali	tubewell	98.45
jajarkot	public tap	63.51
	private tap	17.57
	open source	10.81

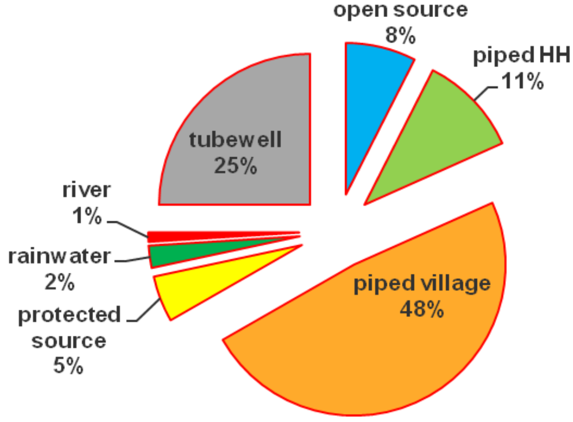
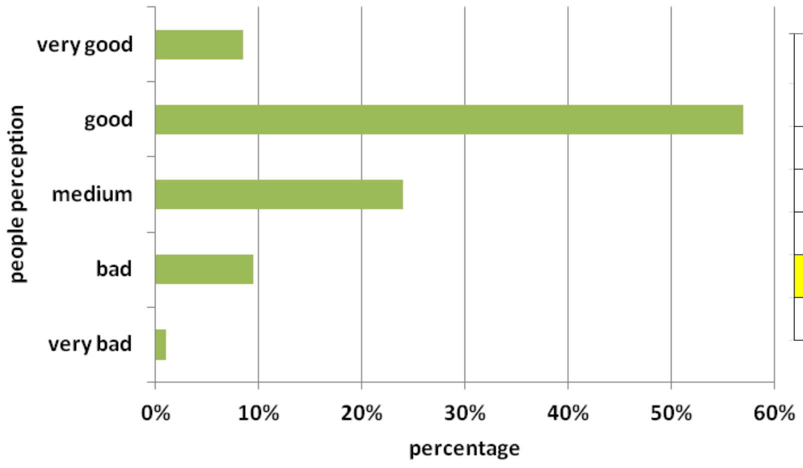


Figure 5.12 (left) main water source per VDC; (right) proportion of people using different sources (n=512)

People's perception about their drinking water quality can be seen from figure 5.13. More than half interviewee perceived their drinking water quality was good, but not in Kailali. If more than 55% interviewee in hilly area said that water quality was good, only 39.5% interviewee in Kailali said the same thing. In Jajarkot, about 7 from 10 interviewee said that their drinking water was good.



VDC	perception		
	bad	medium	good
surkhet	8.6	30.1	55.9
acham	16.5	16.5	64.1
dailekh	24.8	24.8	61.9
kailali	30.2	30.2	39.5
jajarkot	20.3	20.3	68.9

Figure 5.13 (left) people perception of their drinking water quality (n=512); (right) people perception of their drinking water quality per VDC

Almost half of the people also stated that drink directly from source was safe or quite safe. On the other hand, only about 11% people said that it was very risky to drink directly from the source (figure 5.14).

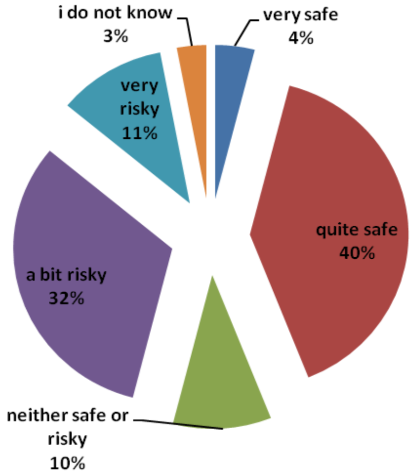


Figure 5.14 people perception about drink water directly from source (n=512)

Another interesting result was more than half of interviewee said that animal waste and toilet waste are the main sources for unsafe drinking water. So people are aware of the source of faecal contamination. But kailali showed the opposite result. From 65 interviewees in Kailali who answered this question, 33 people (or 50%) said that chemical, like arsenic and iron, was the reason for unsafe drinking water (table 5.4).

Table 5.4 people perception about source of unsafe drinking water

source of unsafe drinking water (people perception)	percentage of people (n=219)
animal waste	54.8
toilet waste	40.6
chemicals	30.1
germs	39.3
do not know / others	6.9

One of the solutions to overcome microbial water quality problem in society is to apply household water treatment. But the questionnaire result indicated that household water treatment was not common in the study area (figure 5.15 left). There were some reasons for that. One possible answer was because almost of interviewee said that they do not know about household water treatment (figure 5.15 right).

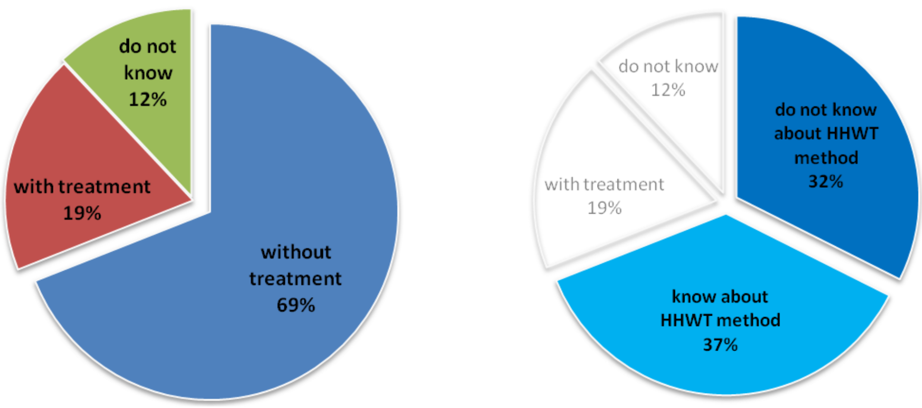


Figure 5.15 pie chart of (left) proportion of people using HHWT; (right) proportion of people without treatment and their knowing about HHWT method

Even though the mean and median of *E. coli* in stored water from people who answered treat their water was not so different with people who answered not treat their water (table 5.5), statistic result showed stored water quality was marginally better if people practiced water treatment at house (p=0.01).

Table 5.5 mean and median of *E. coli* number from people who are treating and not treating their drinking water

Do you treat your water? (% households)	Mean (SD) CFU/100 ml	Median CFU/100 ml
Yes (19%)	42 (67)	10
No (69%)	55 (76)	17

Another observation also showed that knowledge of water treatment method is associated with cleaner water at the point of collection (p<0.01) but not with cleaner stored water.

One of the questions on the questionnaire was about knowing of the people about household water treatment method. Almost half of respondent know how to do boiling. One-fourth people also know how to do a filtration with cloth. We could say that this method was quite popular in some area. Other interesting result was about 13% people know how to do a chlorination and filtration (figure 5.16).

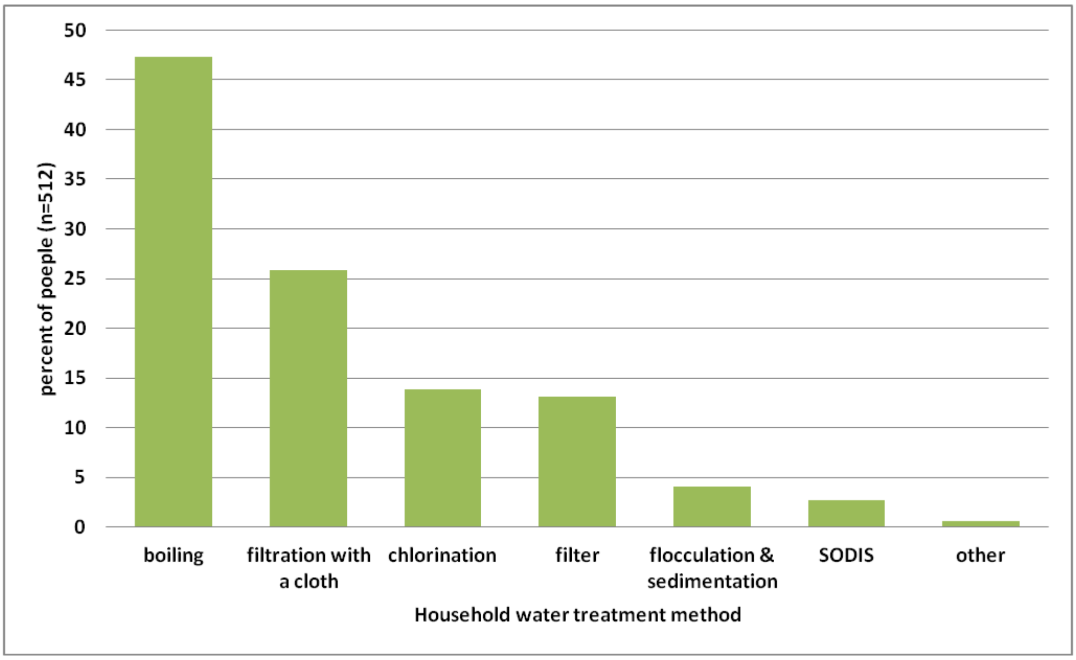


Figure 5.16 percentage of people knowing household water treatment method (n=512)

From the analysis of people perception about water treatment practices from questionnaire result, about 66% of them said that water treatment was quite or very important (figure 5.17 left). Another result also showed that people intention to treat water in the future was quite low (figure 5.17 right). Only 12% from total interviewee had a strong intention to treat their water in the future and 29% do not have an intention at all.

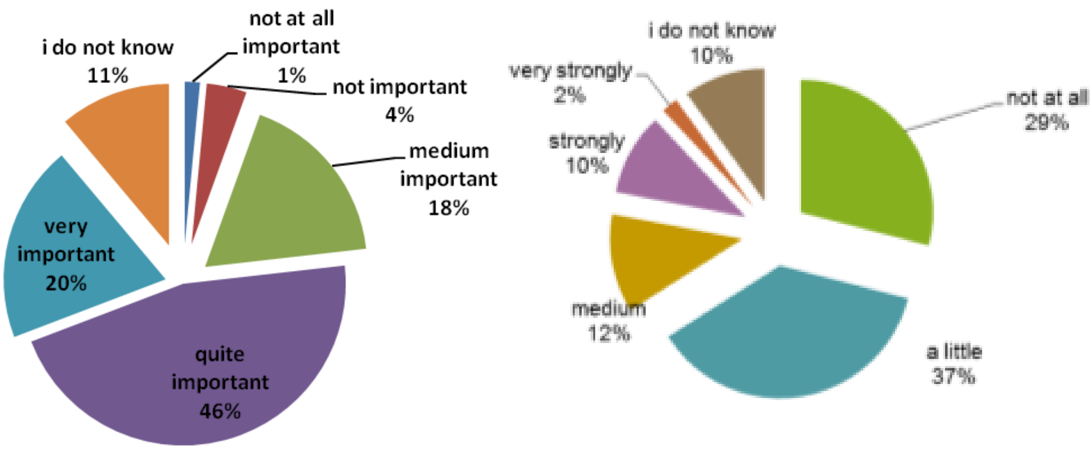


Figure 5.17 pie chart of (left) people perception about importance to treat water (n=512); (right) people opinion about intention to treat water in the future (n=512)

Some of the findings about the relationship between education and water were number of years of education was associated with cleaner water at tap and in the home ($p<0.01$) and likelihood of treating water ($p<0.001$).

Another important result of psychological analysis was an emotional factor (liking to treat water) was a significant factor for people to use household water treatment and safe storage option in house and people habit to do water treatment. Emotional factor has a positive correlation with those two factors. If people love to treat water, then they will do treatment.

5.5. Market analysis and expert interview result

An important finding based on consumer preference questions within the household survey was that water treatment was currently not among the main investment priorities. People prefer to invest in more healthy/nutritious food, improve their housing, and built a toilet (figure 5.18).

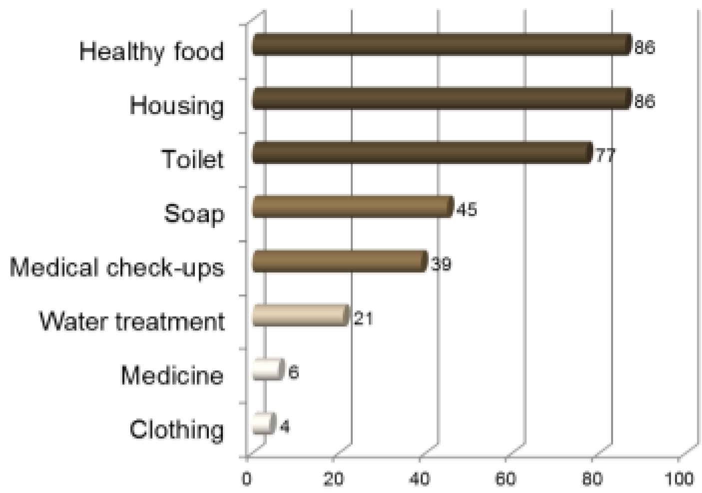


Figure 5.18 Investment priority of the people in the study area (n=164); (source: with permission from Arnt Diener (Diener, 2015))

We also discovered that some of the household water treatment products were available in the market, like chlorine and membrane filtration. Some pharmacies sold chlorine in their shop but only few people buy it. More people will buy chlorine in monsoon season from July to August. Membrane filtration was also available in the study areas, but not in very remote areas. According to shopkeepers, this is due to a lack of interest or felt need for filtration at themoment in remote areas (Diener, 2015).

Another important result was people can get easily medicine to heal diarrhea in the pharmacy. This was what people usually do in the rural area. Government policies which provide many antibiotics and drug for free also become indirect driver for people to buy medicine easily. This problem becomes hot issue in the health sector in Nepal (see appendix H). An expert said in local newspaper that next big problem in the future is a human resistance because of misuse of antibiotic (Dahal, 2014).

From interviews with local doctors and professors of medicine in University, rotavirus was the main cause for diarrhea in Nepal. But normal people in rural Nepal just assessed their water quality from clarity, smell, and color.

5.6. Water Intake and pipe scheme observation

An important aspect of the PWS analysis were field observations of intake, reservoir tanks, taps, and pipes in the study area. The findings are important to strengthen and/or understand the result of the microbial water quality tests, especially for POCs. Some intake pictures can be seen in annex 2.

Structured observations revealed several problems of the piped water systems in the study area:

1. Insufficient intake protection (e.g., only using barbed wire or stone). Current protection made Intake was accessible for animals and/or unauthorized persons ;
2. No protection or cover on top of reservoir tanks;
3. Existence of feces within 5 m;
4. Location of the intake very close to farming area. Some of the sources were located just below the farming area or paddy field;
5. Unorganized information about water pipe scheme in the village. It made some difficulties to to trace scheme from intake to tap;
6. Dangling pipes connected to public taps are common in some areas. In this case, all people can connect-disconnect pipe easily. A leakage occurred due to dangling pipe. Irresponsible people or people with little knowledge, or people with bad intentions can also access this pipe;
7. There is no water quality monitoring or initial testing at intake ;

CHAPTER 6

Analysis and discussion

This chapter contains further analysis and interpretation of the results. The sub-chapter discuss some results related to the research question and objective, particularly about point of collection and point of use which is the main idea of this research. At the end of that part, an advice to improve water quality in the study area is discussed after combination of all the findings. Evaluation of the methodology can be found also in this chapter. Some finding about the government role in water scheme in Nepal will be discussed as an excursus or extra discussion.

6.1. Evaluation of the methodologies

This thesis aims to combine three aspects that were done during the field research in Nepal to give a good recommendation for improvement of drinking water quality in rural Nepal. They are microbial water quality (engineering and science part), market analysis (economic part), and human behavior (psychology) research. The purpose of using and combining those aspects will give a lot of benefit to formulize good recommendation for the implementation project.

In this thesis research, microbial water quality testing was the main part. Other results or methodologies showed more uncertainties than water quality testing. Even though there are some weak points from this methodology, all the strong points give more confidence and trust. Some strength and weakness points from this method can be seen from figure 6.1.

Membrane filtration technique with field equipment that was used for this research was followed WHO guidelines for microbial water testing. Positive and negative controls that were done during the field research to strengthen the reliability of the microbial result. The incubator that was made in Eawag showed good performance during the field research, even though still needs some improvements. The shape is one of the target of improvement. Triplication result also showed a good result. All the triplications had a standard deviation below 7%. From study literature, standard deviation below 15% can be accepted (Sutton, 2011). Daily control to interviewer during sample collection and time management during sample processing were done to ensure the sample can get into the incubator maximum 6 hours after collection from site.

Even though we tried to do all the procedure correctly, still there were some lacks in the field. A few samples exceed the 6 hours rule (but not more than 6.5 hours) due to long distance walk from the house to the lab location. The samples were processed even exceed that rule. Accidental contamination during sampling cannot be absolutely avoided. Especially from interviewer who took the sample. Since the sample was taken only once, confirmation to strange data cannot be done. Some variations also in the tap cannot be recorded due to this reason.Another limitation is the result only valid for summer season. Number of *E. coli* could vary throughout the year. We expect if the number of *E. coli* will increase dramatically in mansoon season (St Laurent and Mazumder, 2014).

In general, this procedure showed a good result and performance. Membrane filtration technique that was done in the field can be copied to other field studies all over the world. But still need some improvements for current practice and equipments. For exampe, solar panel or electricity source is needed for incubator which is not very expensive, easy to bring to field, and give enought energy for incubator for 24 hours.

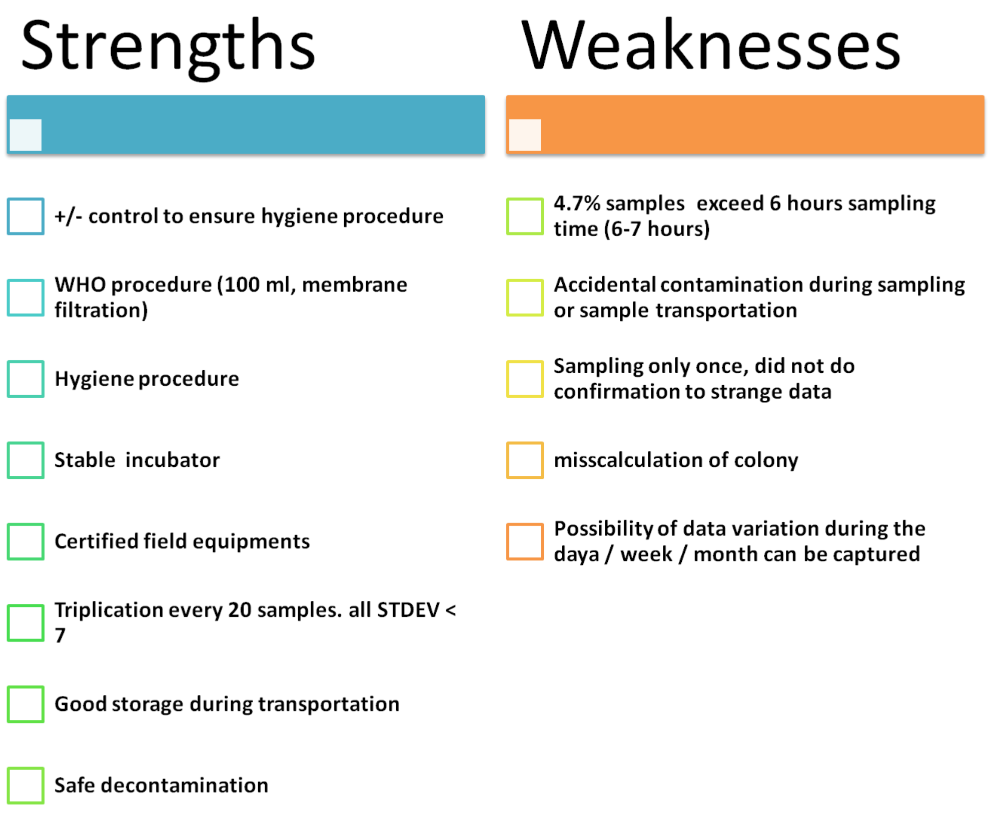


Figure 6.1 Strength - weakness of microbial water quality testing

Market analysis gives better understanding about market situation and people investment priority in the area. Market analysis was done by Arnt Diener, Eawag officer during the field research. Since market analysis was done in all sites in the study area that was visited, the result can give an overview of market situation for the study area. But the market analysis did not distinguish between low-medium-high economic level in the study area or a differentiate based on caste that is common in Nepal. More research on that topic is still needed to give a solid picture about market situation in that area.

Human behaviour research has a bigger uncertainty compared to other results. There are some reasons for that. One of the challenges is the education level of the interviewee is relatively low (figure 5.11). We realized in the field that some of the questions were difficult to understand even for educated people. So the reliability of the answer for some questions is unconvincing.

For example the answers on questions about source conservation and water treatment are not really trustworthy. The questionnaire asked people if they do source conservation or not. From the field observation, the definition and understanding about source conservation among the people themselves in the village are not really clear. The source conservation itself has a varying condition between one place to other places or between one water constructer to other constructors. Water treatment question has a big uncertainty as well. People could answer whether they do water treatment or not but we do not know exactly if they really do a treatment at that moment. So the relation between *E. coli* numbers with practices of water treatment is not convincing.

An observation form was made to help analyzing the condition of water source or intake. The form was useful and easy to understand and can be used not only for an expert but also for new people in this study (see appendix C).

6.2. Result summary of point of collection and point of use

In terms of main stakeholders that have an influence over water quality in Nepal, point of collection is closely related to water supplier and household level is a community. There are some results which related to each of them and some factors which influence them. Figure 6.2 was made to simplify all the findings related to those stakeholders.

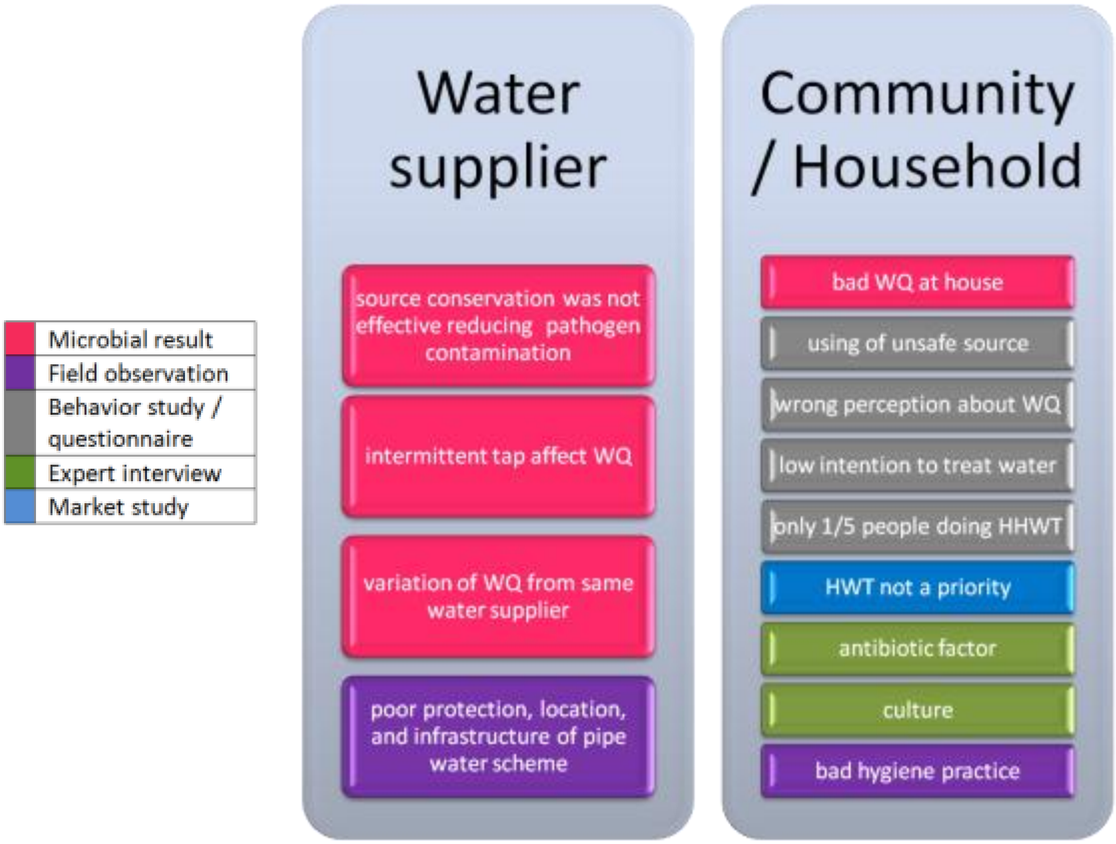


Figure 6.2 Result summary for water supplier and community or household in the study area

For water supplier or NGO, most of the problems come from the infrastructure. This result is in line with what Shrestha, et al., (2003) argued that ineffective drinking water system programme was one of the reasons why water quality in Nepal is bad.

6.2.1. Microbial water quality result on point of collection and point of use

The main idea of this study is to understand water quality at point of collection and point of use or household level. The result showed about 70% of household samples had higher *E. coli* number compare to point of collection. Increasing concentration of *E. coli* bacteria at point of use or house compare to point of collection in this research shows a similar result with another study in Sri Lanka. In that study was found out that about 50% of samples were infected after or during extraction from source (Mertens, et al., 1990).

Even though water quality at point of collection showed better result compared to house, still 9% of community tap samples had more than 100 *E. coli*. WHO (2014) stated the same things that there was no assurance if people get water from improved source will get free contamination. About 69% of the total POC samples had *E. coli* strengthen the previous study by Bhandari & Wickramanayake (2000) that showed that most of pipe scheme intakes in Nepal have faecal contamination.

Microbial result showed that ineffective source conservation to reduce or prevent contamination, intermittent problem at taps which affected the water quality, water quality variation from the same supplier at same village were the main problem at current pipe scheme. Observation also showed that protection, location, and infrastructure (e.g., dangling pipe) of the scheme were not good.

One of important finding from the field was almost all of water suppliers in Nepal never do water testing at source and only focus on infrastructure rather than water quality, even tough Nepal drinking water regulation (2005) mention that water testing at source should be done by water supplier. In some areas, government plays this role also because the water scheme there was built by government.

Microbial result showed that the stored water quality at house was bad. There are some results from behavior study and observation that can be a reason for that. They were using of unsafe water, wrong perception about water that can lead to low intention to treat water, not using household water treatment, culture, and bad hygiene practices.

6.2.2. Economic, cultural, and behavioral factors that affect the microbial water quality

Important result that cannot be ignored was low intention to treat water although people said if water treatment was important (figure 5.18). This situation also occurs in urban slum people in Delhi, India. Although most of mother said that clean drinking water was important to reduce diarrhoea, only 36% mother practiced water treatment in house (Chaudhary, et al., 2015).

Knowledge holds an important role to ensure people doing water treatment correctly in their house (Merga and Alemayehu, 2015). Poor education in the study area becomes big disadvantage to apply household water treatment.

Economic factor is one of the big challenges. People in the study area prefer to invest their money not for water treatment, but for food, housing, and toilet. Many of people in remote rural areas also face an economic problem in their daily life. Since some of water treatment tools are quite expensive, so it is not affordable for some people, especially from low economic status.

The existence of low price antibiotic in the society made bad effect for society. Not only make a human resistance problem but also make people like to cure disease rather than prevent them. Since people get antibiotic and medicine for free or cheap price, future intervention could consider this factor that any intervention that offered should change the place of curing disease using antibiotic and medicine in people habit, in terms of price and easiness to do.

Culture plays an important role in society in Nepal. Nepal is a Hindu country and they apply caste system in their society. For people who have low caste, it is not easy to get better livelihood as people who are high caste. So it is common in village if low caste people face a poverty problem. Another cultural problem is that women who have a menstrual period have to live separately from society. Usually they will stay in jungle or hill. So for them, open source water is the main option for drinking purpose.

6.3. Improving water quality in the study area

After see the result summary for water supplier and community on part 6.2, main problems from my perspective that come from water supplier are current pipe water scheme infrastructure is not enough to prevent contamination and water quality is not a water supplier's priority; and from household are wrong perception about water quality and people's bad habit of getting water from unsafe sources.

To address those problems, there are three options of intervention here: an intervention from water supplier, from community (household side), and from both sides together. In my view, doing intervention from both sides will give a better result to improve water quality. An overview about recommendation can be seen on figure 6.3.

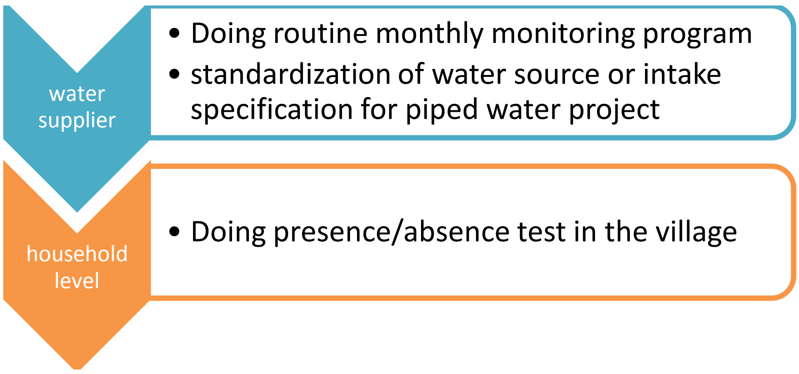


Figure 6.3 Recommendation's overview

6.3.1. Improving water quality at piped scheme

There are some reasons why improving water quality at pipe scheme is necessary in remote rural Nepal:

- Most of people in rural Nepal get water from public tap or private tap
- Responsibility of water supplier regarding water quality in their system
- High trust of society to pipe water scheme
- Maintain good image of the water supplier
- Compliance to water monitoring regulation

According to WHO, drinking water supplier have a responsibility for quality control and quality assurance of water that they distribute (2011). One of the results showed that there was a relation between water quality at house and at POC. Better water quality at POC will make better water quality at household level (figure 4.12). And also because people in rural Nepal still do not care about water quality and they perceived their water is safe, water supplier could take this role to take care about the water quality. Other result also showed that there was variation of water quality between different pipe water scheme in the same village from same water constructor (figure 4.11). All those reasons strengthen the argument that water supplier should take a responsibility to improve the water quality in the study area.

Even though there is no direct evidence, from some of questionnaire results we can assume that people trust the water quality that they get from current pipe water scheme. Questionnaire result showed that people perceived that their water quality was good, although most of them never treat their water at home. Other results showed that people feel safe to drink directly from source. Big trust from society to current pipe scheme should be balance with good water quality from water supplier.

Another good reason for water suppliers to improve the water quality in their scheme is to maintain their good image in front of the international donor, not also from community. Water supplier usually get funding from international donor to do their project. Of course water supplier want to have a good image to earn more funding from donor.

The main recommendation for the water supplier is to ensure and improve the water quality at source and improve the pipe water scheme quality. Doing monthly routine water quality monitoring at source and public tap is needed to ensure the water quality. The variation of water quality can be recorded and if there is a contamination along the pipe scheme, the source can be found. Monthly regular monitoring also can be used to warning local people if the water quality is bad so they can start to treat their water in home. According to Nepal drinking water standard (2005), microbial water quality monitoring should be done every month by water supplier.

If the water source is bad, water supplier can do a treatment at the source, like slow sand filtration or using chlorine (Logsdon, et al., 2002). Source treatment in this case is not trying to reduce the number of pathogen bacteria to zero or it means perfect treatment. At least should be lower than 5 *E. coli* is detected from the public tap. The reason for choosing 5 *E. coli* rather than 0 is because very efficient treatment, like in developed countries, seems difficult to apply in remote rural Nepal. But still need more research to find the best treatment concept for rural Nepal.

Village maintenance worker can be a potential person to do the monitoring procedure in the village. Every village in Nepal has them. This person usually is chosen by the community to take care the water pipe scheme condition in that village (Pant, 2013). Train this person to do a simple microbial water quality testing can be a first nice step to apply regular water quality monitoring in the village. Simple mini laboratory equipment can be established at local health post. From field observation, every village usually has at least one health post. If they do not have it, mini lab can be established at local pharmacy. So water quality monitoring can be a joint project between water supplier and Nepal health ministry.

Another recommendation for the water supplier is a standardization of water source or intake specification for piped water project, in terms of protection or conservation, site selection, and water quality. The result of this study also showed that the practice of source conservation is not good enough to prevent from contamination (table 4.4). Water source and intake observation result revealed that there was a variation in specification between one source to other sources (see also appendix E). Other studies showed that improving well protection will increase drinking water quality by 62% and reduce 25% risk of diarrhoea in children (Kremer, et al., 2007).

6.3.2. Improving water quality at household level

The importance of doing point of use water quality improvements

Even though from the water scheme stakeholder there are more obstacles from community side (see figure 6.2), a small step to improve water quality at house can be done. This is because household is the object of all the improvement intervention and improving household drinking water quality at point of use (POU) can reduce diarrhoeal disease by 30-40% (Sobsey, et al., 2008). Bhantari & Wickramanayake (2000) conclude that "preparing the community before planning and construction of water system is a prerequisite for the long-term effectiveness and sustainability of drinking water system".

There are three main purposes of improving water quality at household level:

- Create demand for water treatment
- Change people bad habit of getting water from unsafe source
- Make people aware about safe water handling

One of the challenges from community side is there is no demand for water treatment. One of the reasons is because they perceive that their water is good and safe. This argument is inline with what Bhantari & Grant (2007) showed in their study in rural Nepal that people in rural Nepal perceive that their water is good even though the water quality analysis showed the water is bad. This is one of the reasons why we believe that any intervention will not affect a lot to change people habit. From market perspective, if there is no demand for product in the market, people will not buy the product. For example, people are not interested to buy chlorine because they think their water is good and they do not need to treat their water.

Creating demand from community itself means making people to have a willingness to buy the product. From this perspective, the sustainability of the program will be guaranteed for a long period because they will do the program themselves and there is no need to force people doing the program because they believe that they need it.

There are two other purposes of doing presence/absence test in the village. Changing people habit that gets water from unsafe source is necessary. The result showed that 9% of the total interviewee still gets water from river and open source, which are not safe. P/A test will show them that the water from river or unsafe source is

People may change their habit and start to get water from current pipe scheme. Another purpose is to show people if recontamination from tap to house can take place (Jessoe, 2013). If water suppliers start to improve their water quality, P/A test have to show the water quality from tap is good. And if P/A test show the water quality at house is bad, then there is something wrong between tap and house. So people may aware about their water handling practice. They can do either water treatment or improve their handling practice.

Presence/Absence (P/A) test

Since people perceived their water quality is good, one of the ideas to create demand is to make them know that their water quality is bad. One of the ideas is to do a presence/absence test (P/A test) with their drinking water. There is a common microbial water test in the field like hydrogen sulphide (H_2S) technique which produces black color if there is an *E. coli* in the water. In the practice, 3 glass of water will be used like a picture below.

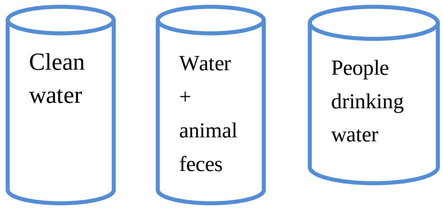


Figure 6.4 Three types of glasses for P/A test

H_2S technique will be done to all glass. Animal feces are chosen here after seeing the questionnaire result. People said if animal and toilet waste were the source for unsafe drinking water. If their drinking water is polluted and turn into black, then people will think if inside their water there is an animal feces. This test can change people mindset and make them to start to do the water treatment. Since this technique is not difficult, this demonstration can be done by village maintenance worker in every village.

P/A test can be done after water supplier already improved the water quality in their system to show the water from improved piped scheme is good. If water suppliers do not improve their system or postpone for a while, P/A concept also can be done in order to create awareness of people to ensure the water quality in their house themselves. Another reason is because all piped scheme improvement will not create 100% free pathogen bacteria in water. So household water treatment is necessary to kill the remaining bacteria.

Pathogen removal at household level after P/A test

Another important point is if the demand for the water treatment starts to grow, the product should ready in the market. The product or option should be affordable and accessible by people in the village. Village maintenance worker not only demonstrate the H_2S technique, but also give and teach people how to treat their water.

According to expert interview and some journals, the main cause of diarrhea case in Nepal is rotavirus (Ansari, et al., 2013). Boiling and chlorination are chosen because these two methods are effective to remove rotavirus (see part 5.5).

There are some reasons why boiling is recommended for household water treatment in Nepal. This is because most of people know how to do it and easy to do (see figure 5.17). Effectiveness of boiling to remove pathogen in water has already proven (Sobsey, et al., 2008).

Chlorination can also be a good solution. But since people do not like it, which will give a strange taste in water, they should be taught how to use it properly. Bad taste can be a result from incorrect using of chlorination.

6.3.3. Difference between hilly and terai (flat) area

One important result is there was the difference characteristic between people in hilly area and people in flat area (Terai area) in terms of point of collection water quality, people perception about water, and main water source (table 6.1). In this study, Surkhet, Acham, Dailekh, and Jajarkot are categorized into hilly area; and Kailali is a terai area.

Table 6.1 Difference between terai and hilly area

Characteristics	Terai area	Hilly area
Water quality at POC	Relatively good	Relatively bad
Main water source	tubewell	Public tap
Perception about water quality	bad	good

Microbial results at POC in hilly area were worse than Terai area. One study stated that number of *E. coli* was decreased with the arsenic content inside the well (Van Geen, et al., 2011). This argument can be the reason why number of *E. coli* in Kailali was lower than in hilly area.

Most of people in the hilly area use public tap as their main source for drinking water. In contrast to hilly area, almost all people in Kailali using private tubewell as their main source for drinking water and other purposes. But people in Kailali have a problem with arsenic. To overcome this problem, a groundwater project by government was conducted. But now the project stopped due to political issue.

Since people in Kailali have a problem with discouloration due to arsenic and iron, they perceived their water quality was bad and about 50% interviewee believed that chemical was the main reason for contamination. In contrast with that, people in hilly area perceived if their drinking water quality was good and safe and said that animal waste was the main source of contamination for drinking water.

Different approach is needed for hilly and Terai area. Since we know that microbial quality of POC (most of them are public tap) in hilly area was worse than Terai, improving public tap system in hilly area is one of the improvements methods that can be done. Applying household water treatment (e.g., KAF) for people in Terai area is relatively easier because most of people there already perceived if their water quality was bad. But now for hilly area because we have to change their perception about their drinking water quality. Household water treatment method for terai area also should consider removing arsenic and other chemicals rather than removing pathogen contamination. But in hilly area, removing pathogen should be prioritized.

6.4. Implications of the study

One of the main challenges of global water quality monitoring is reducing the gap of water quality data between developed and developing country. (WHO-UNICEF, 2011). One of the reasons is number of the stations or appropriate labs are very low, especially in developing countries (Palaniappan, 2010). This thesis can be an overview of water quality data in western area in Nepal. The result can contribute to global water quality data.

This study contributes to make a good balance about water quality study in Nepal. This is because many studies about water quality in Nepal were conducted in urban area in eastern Nepal and Terai area, but not in hilly rural area in western Nepal. From this study, we can have a simple comparison between hilly and terai area in western Nepal.

The result about water quality in this thesis can be used also by water supplier in Nepal for their activity plan, monitoring, and evaluation of their pipe scheme and also for future project or intervention to improve water quality in the study area.

This research tried to overcome all the problems regarding water quality testing in remote area. One of the problems is expensive equipment and complex procedure (Bain, et al., 2012). Even tough the equipments still need some improvements, but the performance showed a good result. The idea of this research can be applied globally, especially for developing countries.

The information about microbial water quality in this research can be shared with government. Since the result discovered water quality in remote rural Nepal, Nepal's government can get a better understanding about it and to formulize a policy regarding water supplier and water quality.

Another important lesson from this study is multidisciplinary knowledge is needed to draw better and clearer picture about the problem. Hmelo-Silver (2004) argued that intervention that is proposed only from one side of knowledge will not really effective to address the problem

6.5. Excursus: Government influence regarding water quality in Nepal

In the previous section, improving water quality in the study area just looks at the water supplier and community or household part. But government has an influence as well as other stakeholders in the water scheme. But like others, government also has obstacles which hamper them to influence a lot to improve water quality.

There are three challenges from government side: different priority, unstable political situation, and low compliance to water regulation.

Nowadays, the Nepal government focus on Open Defecation free (ODF) campaign and put a lot of effort on it. Another priority, like safe water, becomes the second priority of the government. Nepal government aims to reach the national target of 100% sanitation coverage by 2017. But since the program run rapidly, the target can be reached sooner than expected.

As a result of that, toilet becomes one of the social statuses in the society now. People want to invest their money for toilet because of ODF campaign by the government. Government forces every house to have their own toilet. From the information from local people, if people do not want to construct toilet, then government will stop some facilities for that house. This campaign also creates social pressure in the society. If you do not have your own toilet, your neighbor will say something bad about you. Those are the main reasons why Open Defecation Free (ODF) campaign successfully conducted throughout Nepal.

Another obstacle from government side is unstable political situation in Nepal that can affect the ongoing project. For example, a huge groundwater project in Kailali was stopped for about 5 years due to political conflict. The project was built to overcome arsenic problem in Kailali and the water quality also was very good. Just need to finish some infrastructures and people can get clean groundwater, but it seems no plan to continue the project (see appendix H).

Government also played an important role here through regulation and national priority and target. Nepal already had a drinking water regulation National policy on rural drinking water supply and sanitation since 2005. But the implementation still low due to different priority by government because still focussing on increasing number of toilet in Nepal and increasing water coverage rather that water quality. So, low compliance to water regulation in Nepal is still low (Unicef Nepal, 2014).

But of course the role of government is still needed to improve the water quality in Nepal. Even though we cannot really put high hopes to the government now, but we could predict if their influence will really change situation regarding water quality in Nepal in the future.

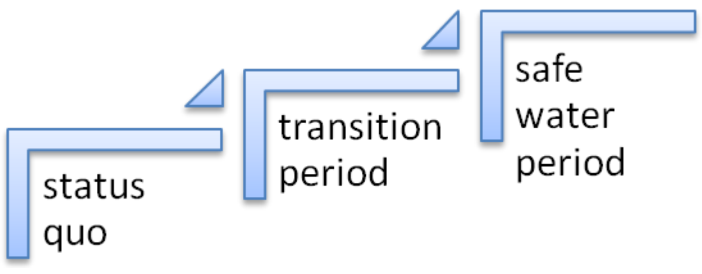


Figure 6.5 Nepal water quality time frame scheme

There are 3 main periods in this case: status quo - transition - safe water. Status quo is the current situation where people still do not care about water quality, poor practice of safe water handling, ODF campaign, wrong perception about water quality, etc. Transition period is a period when all stakeholders start to think about safe water handling or start to do and initiate something to have a safe drinking water. And "safe water period" is a period when people really care about their drinking water. Time from status quo period to "safe water" period is unpredictable.

Government influence can make a safe water at house becomes hot issue and people demand in the future. If we see from market perspective, toilet becomes “people’s demand” after government’s pressure through ODF campaign. Government’s pressure also becomes indirect driver to make toilet as a social status in society. If this concept can be done for safe water, then government can make water treatment method as a people’s demand.

But since the total sanitation campaign, which include safe water, is the next step after ODF campaign, we have an expectation if in the next couple years, safe water will become people priority or it means we reach “safe water period”. Could be the position of toilet in the third position of investment priority will be changed by water treatment. Because if people already have toilet in their house, they will not put toilet as their investment priority and change to other investment priority. But need some time to reach this period or we can say after all houses have their own toilet.

CHAPTER 7

Conclusion and Further research

7.1. Conclusion

This research was conducted in order to know microbial water quality in remote rural area and to give a recommendation to improve the water quality by combining microbial water quality analysis, market analysis, behavior study, and expert interview. Those methods were done to understand the the main factors that influence microbial water quality in order to give a solid recommendation on how to improve the water quality in the study area.

The water quality analysis showed that the number of *E. coli* colonies between point of collection (POC) and household increases. 91% of households had *E. coli* present in their stored drinking water. The current piped water schemes in the study area often showed poor water quality at one or more taps as well as weaknesses in design and maintenance. This study revealed that a wrong perception on water quality was the main behavioral factor that influences household water quality in the study area.Field water quality procedure that was done in field showed a good perfomance and give a strong confidence. We believe, this procedure can be applied all over the world after small improvement to do water quality testing and monitoring.

Two main recommendations for implemenation can be derived to improve drinking water quality in rural Nepal. First, to improve current pipe water scheme in Nepal, e.g., standardization of water source or intake specification for piped water project, in terms of protection, site selection, and water quality; and water quality aspect of source or intake and tap are included in routine monthly monitoring program. Second, doing presence/absence test in the village to create demand for household water treatment, change people bad habit of getting water from unsafe source, and create awareness about safe water handling. On the other hand, intervention for Terai area should differ compare to other hilly area due to different characteristics.

7.2. Further research

Some improvements for the field equipment and procedure are needed so the field microbial water testing that was done in this research can be applied all over the world.

Further research is needed to find out the reason behind some strange or unsure data, like why some houses had number of *E. coli* lower than POC (cleaner water quality). Further analysis of all data is also needed to get a better understanding especially to see the relationship between numbers of *E. coli* with other parameters from questionnaire result.

Some further researches that can be done are:

1. The efficiency of source conservation in order to prevent source contamination.
2. The efficiency of current water treatment in the study area.
3. Further analysis on pipe water scheme in one study area in order to find source of contamination along the pipe scheme.
4. The best source treatment in the study area. If the source is already contaminated, we need suitable water treatment to remove the contamination that happened at the source. That would make the water quality at public tap better than source.
5. Further research to find out the effect of the container for transport and storage. Another thing about container is finding the suitable container for transport and storage that can be used by people in study area.

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Appendices

Appendix A Protocol for Measuring *E. coli* and Total Coliform in Water Using Compact Dry Plates and the Del Agua Testing Kit

Equipment and Materials:

- Compact dry plates for EC/TC enumeration
- Membrane filters, 0.45 µm pore size
- Whirl-pak bag with sodium thiosulfate for field water sampling
- 1 ml and 100 ml pipettes and tips
- Coolers with Ice/Ice Paks
- Sterile Water for dilution and negative control
- Fecal Sample (e.g., chicken feces) for positive control
- Incubator (35-37 ^{o}C) with thermometer
- Metal preparation plate
- Metal tweezers for filter handling
- Disinfectant
- Flame
- Colony counter
- Latex gloves
- Permanent ink marker

Protocol:

Sample collection

1) Label Whirl-pak bag with the sample ID, and date/time of collection
2) Open Whirl-pak bag and fill with at ~200 mL of water in a manner similar to local practices (e.g., ladel, spigot, etc.)
3) Close and seal Whirl-pak bag
4) Store on Ice for 6 hours or less

*Sample processing**

1) Label compact dry plate with sample ID, volume (100 mL), processing date/time, and your initials.
2) Flame sterilizes tweezers and put filter into sterilized funnel.
3) Shake water sample and open Whirl-pak bag. Using pipette transfer exactly 100 ml of water to the funnel and filter through.
4) Carefully transfer filter to compact dry plate using sterilized tweezers. Check to be sure there are no bubbles trapped under thefilter.
5) Replace the lid, invert the plate, and incubate for 24 hours at 35-37 ^{o}C.
6) *If also processing 1 mL (only for very turbid or contaminated samples)*: Label compact dry plate with sample ID, volume (1 mL), processing date/time, and your initials.
7) Using pipette transfer exactly 1 ml of water the center of the compact dry plate.
8) Replace the lid, invert the plate, and incubate for 24 hours at 35-37 ^{o}C.

9) Sterilize funnel and tweezers for next water sample, dispose of Whirl-pak bag, and clean up work area

**Please wear latex gloves for sample process. However, it's not necessary to use a new pair of gloves for every sample; just rinse with disinfectant periodically and replace them if they become excessively dirty.*

Plate counting and data recording

1) Remove plates from incubator.
2) Using the colony counter, count the number of colonies appearing from the underside of the plate. For very high counts, divide the plate into quadrants with the marker and count one quadrant only, and then multiply by 4 for the total count. Some people also find it helpful to use the marker to make dots over each colony that has already been counted.
3) Record the total number of *E.coli* (blue colonies) and Total Coliform (red and blue colonies) per 100 mL of water on the plate AND in the data log sheet.
4) Dispose of compact dry plates using a hygienic method (e.g., seal in polypropylene bag and submerge under boiling water for ~10 minutes). DO NOT dispose of or keep plates around with growing bacteria colonies on them, as this presents a potentially serious health risk.

Quality control

1) Daily control: Each day run a negative and positive control to be sure the method above is sound. Label these plates as "+ control" and "- control" with the date/time and your initials.
    a. Negative control: process 100 mL of sterile water as usual
    b. Positive control: add a small amount of fecal matter (e.g., chicken feces are usually readily available) to 100 mL of water and process as usual
2) Replicates: Collect and process a replicate sample in the field on about 10% of your samples. Label these plates the same way as the original sample but add "REP" to the sample ID.
3) Plate counting: Have another person re-count about 10% of the plates (randomly chosen) to be sure the enumeration and recording is correct

Parameters to record:

Sample ID (please use this format: water sample #-village#-sample type -volume-date-initials, e.g., w051-v23-TAP-100-nov5-sjm)
Collection date and time
Collected by
Processed by
Processing time
Volume processed
Incubation time IN
Incubation time OUT
E. coli colonies counted (blue)
E. coli per 100 mL (if different from above)
Total Coliform colonies counted (red + blue)
Total Coliform per 100 mL (if different from above)
Comments

Appendix B Questionnaire content

A - Household Information
Name of person interviewed
What is the gender of the repondent?
What is the age of the respondent?
What is your mobile phone number?
How many people live in your household?
How many children do you have?
How many children are below the age of 5?
How many children go to school?
Are you able to read or write?
What is the highest education level you have completed?
What is your main employments?
What îs the main employment of your spouse?

B - Access to water
Which water sources do you use to collect drinking water?
Which is your primary drinking water source?
Which water sources do you use for dish washing, washing body and hands?
Which water sources do you use for washing clothes and cleaning the house?
Which water sources do you use for other activities at or near your home such as gardening or watering livestock?
How much time does it take to fetch your water from the **pipe in the house or yard**, wait in the line, fill the container and come back (1 Trip)?
How much time does it take to go to the **piped water source**, wait in the line, fill the container and come back (1 Trip)?
How much time does it take to go to the **handpump**, wait in the line, fill the container and come back (1 Trip)?
How much time does it take to go to the **open water source (well, spring**), wait in the line, fill the container and come back (1 Trip)?
How much time does it take to go to the **protected water source (well, spring)**, wait in the line, fill the container and come back (1 Trip)?

How much time does it take to go to the **river, stream or canal**, wait in the line, fill the container and come back (1 Trip)?
How much time does it take to go to the **lake**, wait in the line, fill the container and come back (1 Trip)?
How difficult is it for you to fetch your water from the **pipe in the house or yard**?
How difficult is it for you to fetch your water from the **piped water source**?
How difficult is it for you to fetch your water from the **tubewell**?
How difficult is it for you to fetch your water from the **open water source (well, spring**)?
How difficult is it for you to fetch your water from the **protected water source (well, spring)**?
How difficult is it for you to fetch your water from the **river, stream or canal**?
How difficult is it for you to fetch your water from the **lake**?
How much water do you collect each day from the **pipe in the house or yard**?
How much water do you collect each day from the **piped water source**?
How much water do you collect each day from the **tubewell**?
How much water do you collect each day from the **open water source (well, spring**)?
How much water do you collect each day from the **protected water source (well, spring)**?
How much water do you collect each day from the **river, stream or canal**?
How much water do you collect each day from the **lake**?
Does your tap provide you water throughout the whole day?
How many hours in a day do you get water from your tap?
Is water available throughout the year from your main drinking water supply?
How many months in a year do you get water from your main drinking water supply?
Do you feel any depletion of the source of your main drinking water supply?
Have you implemented any measures for source conservation for your primary drinking water supply?

Do you have to pay fees for the water from the **pipe in the house or yard**?
Do you have to pay fees for the water from the **piped water source**?
Do you have to pay fees for the water from the **tubewell**?
Do you have to pay fees for the water from the **open water source (well, spring**)?
Do you have to pay fees for the water from the **protected water source (well, spring)**?

How much do you pay per month for the water from the **pipe in the house or yard**?

How much do you pay per month for the water from the **piped water source**?
How much do you pay per month for the water from the **tubewell**?
How much do you pay per month for the water from the **open water source (well, spring**)?
How much do you pay per month for the water from the **protected water source (well, spring)**?
Now I am going to go through a list of CONCERNS that some families in this area have expressed. Suppose that the government could help your village with just ONE of these issue
Please specify other:

C - WASH knowhow, practice, attitude, self-efficacy, planning, behaviour
How is the quality of the water you use for drinking?
What do you think are the major causes for contamination of your drinking water source?
Please specify other:
Do you use any method to treat your drinking water?
How important is it for you to treat the water?
How safe is it to drink the water directly from the source?
What do you think is in the water that makes it risky to drink?
Please specify other:
Which methods for water treatment do you know?
Please specify other:
Which methods for water treatment do you use?
Can you explain to me the procedures of the different methods (the ones the interviewee knows) for water treatment?
How often do you treat your water?
Why do you not or not regulary treat your water?
Please specify other:
Why do you regulary treat your water?
Please specify other:
How strongly do you intend to treat your water in future?
How effortful do you think it is to always treat your water?
How much time consuming do you think it is to always treat your water?
How much do you like to always treat your water?
Imagine that you have much work to do. How confident are you that you can always treat your water?

How much do you pay attention to have the products in the household you need to treat the water?
Do you have a plan how you can assure that you always have the products required to treat your water
Within the last 24 hours: How often did it happen that you intended to treat your water and then forgot to do so?
How much do you feel that you automatically treat all the water before it is consumed? (how much is it a habit)
What kind of containers do you use to collect & transport water from the source
please specify other:
What kind of containers do you use to store the drinking water
please specify other:
Do you use the same container for water transport and water storage?
How do you clean your safe storage container?
YESTERDAY, can you tell me how many times you washed your hands with water AND soap?
When do you wash your hands?
Why do you not or not regularly wash your hands?
Why do you regularly wash your hands?
How often do you use soap to wash your hands?
What kind of soap do you use to wash your hands?
How much do you spend on soap for handwashing each month?
How much do you spend on all soap each month(wash, bath - powder, brick)?
Are you planning any investments to improve your family`s health?
please specify other:
Where do members of your family usually go to the toilet?
If you sometimes use the bushes – why do you not use a toilet?
please specify other:
Do you think it is important to use a toilet instead of going to the bushes?
How satisfied is your family with your current sanitation situation?
Why is your family not satisfied with the sanitation condition?
Where do your family members go to the toilet during the menstruation period?
Which water source do your family members use during their menstruation period for washing and bathing?

D - Health status and risk awareness

What are the causes for diarrheal diseases?
Now, I will present you some measures that may help to prevent diarrhea. Please tell me for each option if you feel it is suitable as a preventive measure.
Drink treated water
Drink oral rehydration solution
Wash hands with soap after eating
Wash hands after toilet
How high do you feel is the risk that you will get diarrhea if you drink untreated water?

Imagine you have diarrhea, how severe would be the impact on your daily life?

Imagine your child below 5 years has diarrhea, how severe would be the impact on his life and development?
How many members in your family above 5 years suffered from diarrhea in the last 3 days?
How many children under 5 years in your family suffered from diarrhea in the last 3 days?
How many members in your family above 5 years suffered from respiratory illness in the last 3 days?
How many children under 5 years in your family suffered from respiratory illness in the last 3 days?
How certain are you that always treating you water will prevent you from getting diarrhea?

E - Social norms
How strongly do you feel an obligation to yourself to always treat your water before consumption?
How many of your neighbours treat their water?
How many of your neighbours wash their hands at critical times?
How many of your neighbours have their own toilet?
People who are important to you, how do they think you should always treat your water before consumption?
People who are important to you, how do they think you should always whash your hands with soap at critical times?

People who are important to you, how do they think you should use a toilet?

F - Information on WASH Promotion
Have you ever received any information on hygiene or sanitation?
Have you ever received any information on water treatment?

From whom have you received the information?
Please specify other:
From whom would you prefer to receive information on water, hygiene and sanitation?
Please specify other:
Was the information on water, hygiene and sanitation useful?
Did the information on water, hygiene and sanitation change your behavior?
Which behaviours were changed? Please specify:

G - Market information
Where **did** you purchase chlorine solution?
Where would you prefer to purchase chlorine solution?
Where **did** you purchase a ceramic water filter?
Where would you purchase a water filter?
Where **do** you purchase soap?
Where **do** you purchase a safe storage container?
Where **did** you purchase materials to construct a toilet?

Would you be interested to purchase 1 bottle of chlorine (Piyush) for the following price if it is available in the market?

Why would you purchase chlorine (Piyush, WaterGuard)?

Why would you not purchase chlorine (Piyush, WaterGuard)?

Would you be interested to purchase a ceramic filter for the following price if it is available in the market?

Why would you purchase ceramic filter?

Why would you not purchase a ceramic filter?

How much would you be willing to pay per month for treated drinking water

H - Wealth index

For how many months do you have sufficient food from your own farm production?

Does anyone from your household own/ have any of these items?

What kind of fuel do you use mainly for cooking?

Are you the owner of your house?

How many rooms does your house have

What type of walls does the main house have?

What type of roof does the main house have?

What type of floor does the main house have?

How much land does your family own?

How much rice does your household consume in one month?

How much lentils does your household consume in one month?

How much cooking oil do you use for your household in one month?

How much flour (total of: maize/wheat/millet) does your household consume in one month?

I - Observation through the interviewer

Can you show me the product you use for water treatment?

Can you show me the containers you use for water transport?

Please specify other:

In which condition is the container used for water transport?

Can you show me the containers you use for water storage?

Please specify other:

In which condition is the water storage container?

Please take picture of container in its original positon

Can I have a "glass/cup = WHIRLPAK of water" from your water storage container. Please pour it into my WhirlPak bag.

How full is the container?

From where did the household fetch the water you just took a sample of?

How long ago did you take this water from the source/tap?

How long did it take to transport this water from source/tap to the home?

Did you transfer the water into a different container after transport?

Is the storage container you took the sample from open or covered?

Could you see flies around or on the water storage container?

Is there lifestock close to the house?

Where does the household dispose its waste water?

What kind of toilet does the HH have on the compound?

In which condition is the toilet?

What kind of handwashing facilities does the HH have?

In which conditions are the hand washing facilities

Thank you for answering these questions!

This is the end of the interview.

Take a picture of the structure where the household lives

Ward #

HH ##

PWS Name

Did you take a sample of the TAP/SOURCE used by THIS household for drinking water?

Enter TAP/SOURCE sample number

Time of HH water sampling HH:MM

Appendix C Water source observation form

1. General information

No	criteria	Answer / description
1	Name of the water source	
2	location	
3	Date of visit	
4	Time	
5	Type of water source	
6	Size of the source	
7	Weather condition	
8	Weather temperature	

2. Observation frame

No	criteria	Answer / description
1	type of source protection	
2	Existence of cover on top	
3	Condition of source protection (hole, crack, deficiency, etc)	
4	Can animal access within 10 m of the source?	
5	Can human access within 5 m of the source?	
6	Can human take the water directly from the source? If yes, how do they take the water?	
7	Can water from outside flow into the source?	
8	is the water source stagnant or flowing?	
9	Existence of feces within 10m of the source	
10	Existence of latrine upstream the source (yes/no; distance)	
11	Existence of septic tanks (yes/no, distance)	
12	Distance to human house	
13	Distance to agriculture activity	
14	Distance to farming	
15	Source smell / odor	
16	turbid	
17	Existence of algae at source	
18	Water color	
19	Cleanliness around the source	
20	Pipe condition (e.g., corrosion, etc.)	
21	Do they treat the source? If yes, what kind of water treatment do they use? The frequency of treatment?	
22	Do we have the water supply map?	
23	Do we have the groundwater map / catchment map?	
24	What is the type of soil around the source?	
25	Is there a possibility of soil erosion near or at source?	

3. Sample collection

No	criteria	Answer / description
1	Is water sample collected	
2	Collected by	
3	Sampling point at source	
4	Sample identity info	
5	Number of *E. coli* colony	
6	Number of total coliform colony	
7	pH	
8	Water temperature	

How often the monitoring procedure be done?

4. General description of the source area
5. comment

Appendix D Microbial water quality field test

Figure D.1 Methodology in pictures

Caption figure D.1:

1. Top left: Enumerator doing interview to local people using smartphone. Each of them brought thermos to maintain the sample temperature.
2. Top right: Enumerator collected water source sample using whirl-pack bag.
3. Middle left: Choosing sample for analysis. "First collected, first analyze", this is to ensure sample was analyzed less than 6 hours after taken from house.
4. Middle right: Sample was processed with sterile procedure.
5. Bottom left: Colony of bacteria was counting at night after 24 hours incubation time. The result was written on the paper before transfered to laptop.
6. Bottom right: Decontamination of all the samples. The sample was boiling with more than 80° C water. Afterwards the sample can be thrown away.

Figure D.2 Field equipments

Caption figure D.2:

1. Top left: Handphones for interview was charged using car battery
2. Top right: Field membrane filtration equipments
3. Bottom left: Field incubator with solar panel and car battery
4. Bottom right: Inside the field incubator. This incubator was fit for about 60-80 samples.

Appendix E Water source (or intake) pictures

Figure E.1 water source in the study area: (top right) Surkhet; (bottom left) Acham; (bottom right) Dailekh

Figure E.2 Source protection: (top right) just cover by stone in Acham; (top left) stone + wire but still accessible by animal and human in Acham; (bottom left) protected by wire in Acham; (bottom right) protected by concrete and wire

Appendix F Point of collection pictures

Figure F.1 public tap: (left) not working, location; (right) working; (bottom) dirty environment around tap; all pictures was taken from Dailekh

Figure F.2 handpump (tubewell) in Kailali (top); rainwater harvesting in Dailekh (bottom)

Appendix G Water container pictures

Figure G.1 water container: aluminium and copper gagri (top left); plastic container with tap (top right); jerry can (bottow left); small water pot for drinking (bottow right)

Appendix H Pictures related to water quality issue in Nepal

Figure H.1 (top left) toilet in the study area; (top right) freshly washed kitchen utensils are place near to toilet and on open space in Dailekh; (bottom left) cattle always be next to the house in Dailekh; (bottom right) dangling pipe in local pipe water scheme in Jajarkot

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Antibiotic abuse

Figure H.2 (left) government groundwater project in Kailali that have stopped due to political issue; (right) antibiotic abuse article in local newspaper from medical student (right)

Figure H.3 (left) ODF sign in Pokhara (source: http://www.ekantipur.com/the-kathmandu-post/2012/03/12/development/not-so-free-after-all/232547.html); (right) Total sanitation poster (source: http://practicalaction.org/blog/news/first-healthy-community-declared-in-nepal/)