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Impact of technical and management adaptations on intermittent piped water systems in Nepal

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Master of Science Thesis
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Abstract

Intermittent piped water systems are common practices and inevitable in many countries. Intermittent piped water system (IPWS) has a serious problem with a risk of contamination, resulted in health threat to communities. In rural Nepal IPWS has been practiced due to low flow of spring discharge it is not able to meet water demands.

The main objective of this research are to identify the potential interventions and management adaptations to reduce level of contamination in IPWS. The study was conducted in Nepa Village Development Committee (VDC), Nepal. Specifically, two systems was evaluated with water sampling point in intake, reservoir and taps with 434 water samples was taken. For microbial water quality analysis, Membrane Filtration (MF) methods was performed.

Based on risk approach, the spring protection was installed. Resulted in >2 log reduction of *E. coli* in the intake and reservoir. Chlorination still the best option since it gives additional protection household storage. Even for a small systems, with 0.5 mg/L of chlorine was sufficient and gives CT value 15.83 minute.mg/L which is enough to inactivate bacteria. Treat water with filtration-UV technology is a solution to overcome problem in contaminated household storage. At least 2.11 log reduction of total coliforms can be achieved. Ceramic candle filters also were tested and the result was not satisfied with only gives less than 0.5 log reduction for total coliforms.

The management practices divided into two categories; first flush test and pressure monitoring. The first flush test shows there is a peak of *E. coli* concentration in the first water sample when the systems was turned on. The pressure at the tap has no correlation with number of *E. coli* ($r_s(32) = 0.118$, $p > 0.05$) or total coliforms ($r_s(32) = 0.335$, $p > 0.05$).

The main conclusions of this study is that applying technical interventions in the system can reduce risk of contamination. The spring protection successfully reduce fecal contamination in spring and reservoir. However, it is still not enough to meet both WHO and Nepal drinking water quality standard. Since the turbidity is low, chlorination still the best option for intervention in IPWS. Promoting filtration-UV treatment in household has advantages in terms of microbial reduction, if the chlorination or spring protection are not possible. In addition, the water quality data also can use as a baseline for further action plan and research study.

Keywords: intermittent piped water systems, water quality, spring protection, chlorination

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Abbreviations

CBS	Central Bureau Statistics
CDP	Compact dry plate
CFU	Colony forming units
DBP	Disinfection by Product
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
ENPHO	Environment and Public Health Organization
FIB	Fecal Indicator Bacteria
FTU	Formazin Turbidity Unit
HPC	Heterotrophic Plate Count
ICSU	International Council for Science
IPWS	Intermittent piped water systems
ISSC	International Social Science Council
JMP	Joint monitoring program
JTU	Jackson Turbidity Unit
MDGs	Millennium Development Goals
MF	Membrane Filtration
MPN	Most Probable Number
NGO	Non-Governmental Organization
NTU	Nephelometric Turbidity Unit
ODF	Open defecation free
POC	Point of collection
POU	Point of use
PWC	Pipe water scheme
SDGs	Sustainable Development Goals
UN	United Nations
UNDP	United Nations Development Programme
VDC	Village Development Committees
VMW	Village Maintenance Worker
WHO	World Health Organization
WSP	Water Safety Plan

CHAPTER 1

Introduction

1.1. Background

Access to safe drinking water is recognised as a human right by the United Nation (UN) General Assembly (GA) (UN, 2010). Just recently, the Sustainable Development Goals (SDGs) were officially adopted by the UNGA and will be the successors to the UN Millennium Development Goals (MDGs). One stand The specific SDG goal 6.1 will focus on equitable and universal safe access of drinking water in 2030 (UN, 2015). It needs serious change of good management and water quality monitoring (ICSU and ISSC, 2015).

Access to improved sources of drinking water, as defined by the Joint Monitoring Programme (JMP) (UNICEF/WHO, 2012), has increased rapidly from serving 76% of the world's population in 1990 to 91% in 2015 (UN, 2015). Even though significant improvements in coverage have been made, drinking water quality for many improved sources globally still remains a major issue. Improved drinking water services include house connections, public taps, water kiosks, boreholes, protected springs or dug wells, and rainwater collection systems. However, these services do not necessarily imply that water of adequate quality is provided and in fact, many countries operators are failing to comply with national drinking water standards and/or World Health Organization (WHO) guidelines (WHO, 2011). Bain, et al. (2014) estimates that 1.8 billion people worldwide use contaminated drinking water sources. Furthermore, in many countries, especially low-income countries water is still delivered through piped-water systems operating with intermittent flow. For systems with an intermittent supply, the risk of cross contamination is higher than for continuous water systems (CWS) (Andey and Kelkar, 2007).

The most significant health risk arising from poor water quality is posed by the presence of pathogens. Waterborne pathogens can cause severe diseases, including diarrhoea, schistosomiasis, cholera, dysentery and hookworm infection (WHO, 2008). Prüss-Ustün, et al. (2014) concluded that 502,000 deaths were caused by diarrhoeal diseases in 2012 as a consequence of contaminated drinking water.

To ensure the safety of drinking water provided by simple piped-water systems, several steps are recommended. Firstly, source protection must be ensured (Ainsworth, 2004). Secondly, preventing microorganisms from entering along the piped distribution system will reduce the risk of contamination during water transport; pathogens can enter the system through pipe breaks. Thirdly, to ensure that drinking water is safe from microbial recontamination during collection and storage, sanitation and hygiene play an important role. Fourthly, several household treatment options (i.e. chlorination, boiling, solar disinfection (SODIS), bio-sand

filtration or ceramic filtration) are available as a final treatment step to handle residual contamination or recontamination during transport (Clasen, 2009). Monitoring programs for examining chemical and microbial contamination in potable water should be developed or improved by governments and service providers; as by knowing the type and levels of contamination, further actions can be planned more effectively.

1.2. Problem statement

Nepal is a developing countries located in South Asia with over 26 million inhabitants in 2011 and a population density of 180 per square meter (CBS, 2014). Nepal is categorized as a low-income country with an estimated gross domestic product (GDP) per capita of 967 US dollar in 2014 (Worldbank, 2015).

In 2015, 92% of Nepal's population already have access to an improved water source (WHO/UNICEF, 2015). Nevertheless, only 24% of the population relies on water piped onto premises in urban areas and only 18 % in rural areas. Furthermore, water quality is inadequate and this affects negatively public health. Based on a survey on diarrhoea in Nepal (UNICEF/WHO, 2009), children under five are the most affected by poor water quality with 37.000 estimated deaths caused by diarrhoea. High percentage of improved water source access is not guarantee that deliver good water quality.

In the study area in Mid-Western Nepal, most of the piped drinking water systems are designed to be intermittent to allow sufficient pressure despite low water discharge volumes at spring level, especially in the dry season. Generally, intermittent supply has higher risk due to contamination compared to continuous supply. Surveillance and maintenance of intermittent supplies are also more difficult and usually manually and need adjustment more frequent, thus it needs additional cost. Loss of pressure generally high because high water flow in a short period (Vairavamoorthy and Elango, 2002). In rural Nepal itself, the piped water systems unavoidable to operate intermittent due to insufficient of intake capacity.

A recent study conducted in five village development committees (VDC) in Mid-Western Nepal, investigated the microbial quality of the water provided by the intermittent piped-water systems and found detectable *E. coli* at 64% of the taps (Daniel, 2015). The gravity-driven systems typically operate 2-6 hour per day, 1-3 hours in the morning and 1-3 hour in the afternoon. Additionally, based on the Department of Water Supply and Sewerage surveillance in 2011, 82.1% of water supply schemes throughout Nepal did not function perfectly (Pant, 2013).

These results suggest that, on one hand, proper monitoring of microbial water quality is essential for consumer's protection; and on the other hand, treatment technologies and other technical and operational adaptations that could be implemented by rural communities should be evaluated. For example, at the point of consumption (POC), the level of contamination could be reduced by applying chlorination. It is cost-effective, easy to operate and widely used in many countries worldwide.

For intermittent water supply schemes, a better understanding of system characteristics are needed to develop an optimal strategy to ensure safe water quality. The proposed research aims at evaluating the extent of faecal contamination in selected piped water systems of rural Nepal and assessing the impact of technological adaptation and operational strategies for reducing microbial contamination.

1.3. Goal and objectives

This master thesis is part of an interdisciplinary research project on intermittent piped water systems carried out in collaboration by EAWAG, HELVETAS and UNESCO-IHE.

The goal of this research to investigate the potentials of technological and management adaptations reducing microbial contamination and to understand characteristics of intermittent piped water systems.

The specific objectives are:

1) To investigate how technical interventions can impact water quality.
2) To investigate how management practices can impact water quality.
3) To compare water quality on adapted intermittent piped water systems to unmodified intermittent piped water systems.
4) To understand the feasibility of technical interventions among local community.

1.4. Research questions

This research study aims to answer following questions:

Specific objective 1

a) Can spring protection improve water quality in intermittent piped water systems?
b) Can chlorination improve water quality in intermittent piped water systems?
c) Can filtration followed by UV irradiation improve water quality consumed at household level?
d) Can ceramic candle filter improve water quality for household usage?
e) How does chlorination practiced in the reservoir affect the microbial water quality of water stored at household level?

Specific objective 2

a) Can first flush practice improve water quality parameters?
b) Does the pressure at the tap have an influence of microbial contamination?

Specific objective 3

a) How does the overall water quality improvement of technical interventions compare to the water quality in unmodified intermittent piped water systems?

Specific objective 4

a) How feasibility of the technical interventions in terms of value and social acceptance?

CHAPTER 2

Literature review

2.1. Intermittent supply

2.1.1. Description of intermittent piped water system

Intermittent piped water system (IPWS) is providing water through a pipe distribution network at a rate less than the maximum hydraulic capacity of the system. On the one hand, for example, in the case of low available water volumes at source, systems may intentionally be designed with limited daily operational hours, as is the case in the study area. On the other hand, systems originally designed as continuous supply may become intermittent due to different factors like limited hydraulic capacity of the systems due to an extension of consumer coverage, depleting water sources or economic and operational limitations (e.g. insufficient water tariff and high leakage) (Klingel, 2012). Mclntosh (2014) reports that even in metropolitan cities in Southeast Asian, intermittent service is still common; it affects more than 30% of consumers in the cities of Jakarta and Medan, Indonesia.

2.1.2. Common problems in intermittent piped water system

Water quality can change during distribution in a piped network system. IPWS in particular bear the risk of water quality deterioration. In IPWS, for instance, pressure, pipe breaks, infiltration, water stagnation, chlorine residual, and household storage are several important factor that related to water quality (Tokajian and Hashwa, 2003). (Vairavamoorthy, et al., 2001) identifies four problems in IWS based on their study in India; shortage of water, the unequal pressure in the system, unequal water distribution and short duration.

When water supply systems are not operated, the probability of contamination occurrence will be higher due to zero pressures in the distribution system. Compare to continuous supply, higher *E. coli* was detected in IWS up to 31.7% compare to a continuous system which was only 0.7% indicate positive in public tap water Hubli-Dharwad, India (Kumpel and Nelson, 2013). Another field study conducted in 4 cities in India, Andey and Kelkar (2007) found that during IWS, negative sample of faecal coliform was detected between 24%-73% while in CWS more than 90%.

Studies have shown that intermittency of piped supplies is linked to higher operational costs. For example, Christodoulou and Agathokleous (2012) found that during IWS operations risk of pipe breaks and pipe failure increase up to 30-70% per year during a four-year study phase. This pipe failure increases maintenance cost and capital investment.

Due to aforementioned contamination risks of IPWS, consumers are faced with the burden investing in household water storage facilities and point-of-use treatment technologies. Water that is stored for extended period is vulnerable to recontamination through contact with hands and extraction devices. In a study of Evison and Sunna (2001) conducted in Amman, the average heterotrophic plate counts (HPC) level increased from log 1.7 to log 5.2, 5.7 CFU/ml after being stored for four to seven days.

2.1.3. Adaptations in intermittent piped water system

Water quality in IPWS can be managed by long-term and short-term. For long-term change IPWS to continuous supply is preferable. Manage water quality in intermittent supply can with various techniques and adaptations. In many countries, a disinfectant residual maintains in the distribution system to prevent regrowth of bacteria. Applying chlorination into distribution system is a way to prevent contamination during intermittent supply.

Chlorination has shown to be effective for killing bacteria and viruses. Furthermore, adding chlorine can also; oxidize inorganic compound, remove colour and odour in the water and aid water treatment processes, such as filtration. In the case of developing countries which have poor sanitary condition and high level of contamination in drinking water distribution, presence of disinfectant residual is become important. Chlorination is the cheapest way to ensure microbial safety in the distribution network. Point of use chlorination also considers as an economical solution while quality in tap water not meet the standard. (Crump, et al., 2004) observed that sodium hypochlorite effective for inactivating *E. coli* in low turbid water, while combined alum with sodium hypochlorite in high turbid water at POU level.

Sediment and particles can be removed by water flush with sufficient velocity. Flushing after system turned-on can improve water quality because accumulated sediment in pipe will be thrown away. A study conducted in Hubli-Dharwad, India, Kumpel and Nelson (2014) observe that during first flushing average total coliform was 341 MPN/100 ml and *E. coli* was 17 MPN/ 100 ml, after flush was finished bacteria concentration decrease to 17 MPN/ 100 ml for total coliform and 1 MPN/ 100 ml. First flow also has risk of water quality degradation, Coelho, et al. (2003) found that HPC reach more than 1500 CFU/ml after restart of supply and after 5 minute HPC decrease below 250 CFU/ml. It might because by infiltration during zero pressure, release of biofilm and regrowth of bacteria during stagnation period.

Elala, et al. (2011) suggest to promote water safety plans (WSP), safe storage and raise public awareness to improve water quality at POU level in IWS scheme. Demand management action allow water consumer to control their usage by installation of low usage water device at household level (Rosenberg, et al., 2008). However, it very dependant with financial capabilities and local circumstances. This adaptations more relevant to developed area which has intermittent supply due to scarcity of water.

To provide equity and minimize risk from IWS, a new design guideline for IWS was established. For a new plan of IWS scheme, design approach is different from continuous supply. Key parameter in new guidelines design are equity in supply, duration of the supply; timing of the supply, pressure and connection type (Totsuka, et al., 2004). Convert IWS to

continuous supply also possible if water scarcity is not an issue. However, it needs more detail study, which involve engineers, policy makers and stakeholders.

Household water treatment and storage (HWTS) grow rapidly in recent years. HWTS is a promising solution to undertake unsafe pipe water system, especially in developing regions (Ojomo, et al., 2015).

Table 2.1 Sample research about intermittent supply

Year	Author	Title	Location	Experiment/analysis	Result
2013	Kumpel E, Nelson KL	Comparing microbial water quality in an intermittent and continuous piped water supply	India	TC and *E. coli* with MPN method from 624 samples	A significant number of TC (64.9%) in intermittent supply compare to continuous supply (17.7%). Only 68.3% sample meet *E. coli* standard in IWS compare to 99.3% in continuous supply.
2012	Christodoulou S, Agathokleous A	A study on the effects of intermittent water supply on the vulnerability of urban water distribution networks	Cyprus	Analyze with available data set associated with pipe break incidents	Breakage incident more likely occurs in intermittent supply
2012	Klingel P	Technical causes and impacts of intermittent water distribution	-	Literature study	Cause and effect analysis in intermittent supply.
2011	Elala D, Labhasetwar P, Tyrrel SF	Deterioration in water quality from supply chain to household and appropriate storage in the context of intermittent water supplies	India	MF test for 188 samples in various point	Difference of microbial quality from tap to POU reach 90%. TTC found at household tap (20%-25%)
2008	Rosenberg DE, Talozi S, Lund JR	Intermittent water supplies: challenges and opportunities for residential water users in Jordan	Jordan	Analyze from water infrastructure and water usage data	Short-term and long-term demand management action to adapt intermittent supply scheme

Year	Author	Title	Location	Experiment/analysis	Result
2003	Tokajian S, Hashwa F	Water quality problems associated with intermittent water supply	Lebanon	*E. coli*, TC, and HPC	An increase in HPC associated with turbidity. Leakage event increase HPC, TC and *E. coli*

2.2. Microbial water quality

2.2.1. Microbial indicator organism

The microbial parameter is one of the important parameters for drinking water quality. Microorganism directly affects human health and are with the cause of multiple waterborne diseases. To assess faecal contamination in drinking water, faecal indicator bacteria (FIB) have been used as a tool. Indicator bacteria are surrogates used to quantify the potential of faecal materials. While FIB do not directly specify type of pathogens, it can give information about the presence of faecal contamination and probably the presence of harmful pathogens.

There are several indicator organism for the detection of faecal contamination. The most common used FIB are *E. coli*, total coliforms, thermotolerant coliforms, and heterotrophic bacteria. *E. coli* is widely used as an indicator of faecal contamination and is more reliable for this purpose than the broader class of total coliforms. *E. coli* is non-spore forming bacteria gram-negative bacteria with various shape both spherical and filamentous rods. Most strains of *E. coli* are non-pathogenic, although some species, for instance, *E. coli* O157: H7 can cause bloody diarrhoea when it infects the in human intestine (Tortora, et al., 2013).

E. coli is the preferred FIB because it has similar behavior with common waterborne bacteria pathogen. *E. coli* exhibit the following characteristics:

- Easy detected,
- Generally from human and animal excreta,
- The number correlated closely with faecal contamination,
- Applicable both for fresh and saline water (Donna N. Myers, et al., 2014).

WHO (1997) recommended risk classification based on the presence of *E. coli* or fecal coliforms in the 100 ml of water samples. Classification scheme is presented in Table 2.2.

Table 2.2 Risk classification for E. coli or faecal coliforms in water supplies.

Count per 100 ml	Category and colour code	Remarks
0	A (blue)	In conformity with WHO guidelines
1-10	B (green)	Low risk
10-100	C (yellow)	Intermediate risk
100-1000	D (orange)	High risk
>1000	E (red)	Very high risk

Thermotolerant coliforms, also known as fecal coliforms, have been used for many monitoring programs as a surrogate for *E. coli*. *E. coli* are a subspecies of thermotolerant coliforms. Total coliforms group contains *E. coli* and thermotolerant coliform, but also coliforms of clearly non-fecal origin, e.g. originating from soil or vegetation. Figure 2.1 shows a Venn diagram of coliform bacteria.

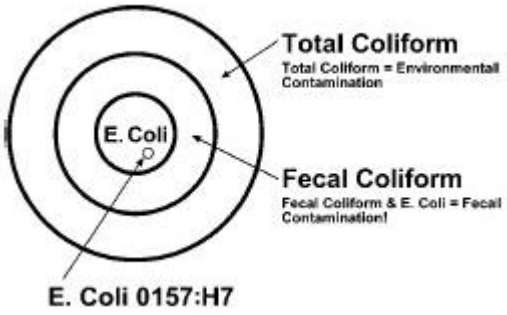


Figure 2.1 Venn diagram of E. coli, fecal coliform and total coliform (Source:http://www.doh.wa.gov/CommunityandEnvironment/DrinkingWater/Contaminants/Coliform)

The HPC presence more abundance than total coliform. HPC suitable for general water quality assessment and lack of evidence that number of HPC directly affect human health (WHO, 2003).

Enterococci are also commonly used as an indicator bacteria, especially for examination of microbial quality in surface water. In many countries Enterococci used as an indicator of facal contamination beside *E. coli*.

2.2.2. Microbial detection methods

Several methods are available for determining the level of contamination in a water sample. Generally, measurement of microbial growth divided into two categories, direct measurement and indirect measurement. Direct measurement is based on visibility of bacteria that grow in

culture media. Plate count is the most frequent method for estimating the level of contamination. For calculating plate counts, it is usually preferable for 20-200 bacteria colonies (Hach, 2012). Colony Forming Units (CFU) is a common unit related to plate count measurement.

Membrane filter (MF) technique is one of a method to achieve viable colonies on a growth media. Generally, the MF method uses a 100 mL sample and, if necessary, diluted sample performed when samples have high turbidity or always too numerous to count. With the narrow pore size of filter, bacteria will be trapped into that filter. Colonies will be growth in the filter with adequate nutrients and environment if bacteria present in water sample. Coliform colonies will have a distinctive colour when growth in filter media. Usually, 100 mL litre sample is enough for low contamination water and 1 mL for high contamination.

Lastly, the Most Probable Number (MPN) method is used for enumerating the number of bacteria based on culture replication in a water sample (Chandrapati and Williams, 2014). Normally the MPN standard procedure is 3, 5 and 10 replications for dilute samples and uses 3 as a number of minimum dilution. Commonly, the MPN suitable for examining low microorganism population ($<100\ g^{-1}$).

The MPN test consists of the presumptive, confirmed and completed test. The presumptive test gives positive and negative results regarding the presence of bacteria. If the result is positive, a confirmed test should follow to make sure that the presence of bacteria is from the coliform group. Lastly, for quality control purpose, the completed test is used to establish the presence of coliform bacteria.

Indirect method does not allow the further examination of specific colonies. However, indirect methods more time consuming, need experienced labour and less cost effective compared to direct method. Additionally, these methods were not popular as a direct measurement for rapid assessment of microbial water quality. Some examples for indirect methods for bacteria examination are relation with turbidity, enzymatic test, nitrate reduction test, Kovacs method, indole test, rapid urease test, IMViC test (Csuros and Csuros, 1999).

2.2.3. Parameter related to microbial quality

Environment factors play an important role of microbial growth performance. Bacteria have a specific condition and favourable condition to growth fast in water media. Physical and chemical parameters that affect the growth of bacteria directly described in the paragraph below.

Temperature

Temperature is the main parameter that can be related to microbial growth. Bacteria grow very dependent with temperature. Every bacteria species has its own optimum temperature to grow. Most common type of microbes grows in temperature between 25°C – 40°C (mesophiles). Although some type of bacteria can grow in extreme temperature condition, both low temperature (psychrophiles) and high temperature (thermophiles) (Tortora, Funke and Case, 2013). Some of *E. coli* strains, such as enterohaemorrhagic *E. coli* (EHEC) grows optimum in 37°C (WHO, 2011).

Turbidity

Turbidity is the presence of suspended and dissolved compound in water. Turbidity is one of the indicator parameters that directly indicate the environmental health of the water. In addition, harmful micro-organism and pollutant metal can stick to suspended particle in water. Common unit for turbidity measurement are Nephelometric Turbidity Unit (NTU), Formazin Turbidity Unit (FTU) and Jackson Turbidity Unit (JTU). However, JTU is less accurate and outdated technology (Anderson, 2005).

Turbidity interferes disinfection efficiency due to a close relationship with an excess of Total Organic Carbon (TOC). The value less than 5 NTU must be achieved to maintain an adequate quality of drinking water (Le Chevallier, et al., 1981). In the case of turbidity of source greater than 5 NTU, requisite treatment such as filtration is applied. For chlorinated water, turbidity less than 1 NTU is preferable.

pH

The level of acidity can be determined quantitatively by pH scale. pH has the direct effect of microbial kinetic rate. Even though mostly of bacteria grow in neutral pH, there are a few varieties that can be found in very acid or very alkaline water. Additionally, pH also determines fraction of hypochlorite acid and hypochlorite ion formation in chlorine disinfection as shown in Figure 2.2 Effect of pH on relative amount of hypochlorous acid and hypochlorite ion at 20°C . Chlorine disinfection works better in lower pH, preferably less than 8.

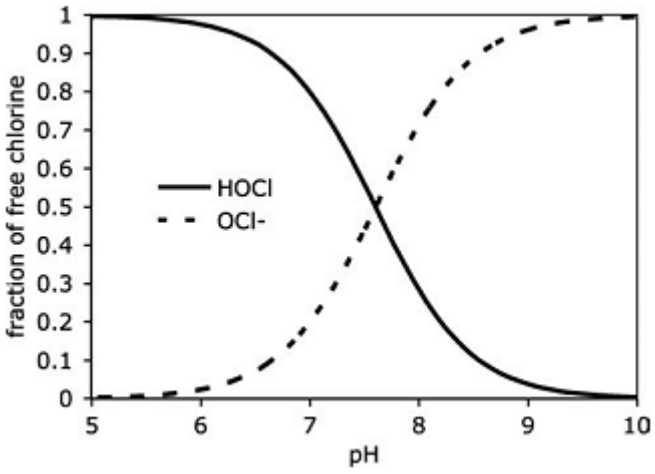


Figure 2.2 Effect of pH on relative amount of hypochlorous acid and hypochlorite ion at 20°C (Haas, 2011)

Chlorine Residual

Residual chlorine is a final barrier in water supply system. There are two types of chlorine residual: combined chlorine and free chlorine. The process by which these are formed is illustrated in Figure 2.3.

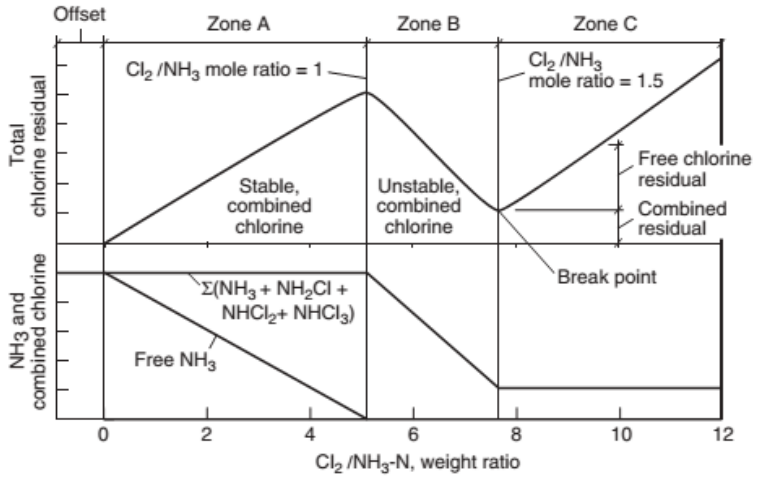


Figure 2.3 Overview of breakpoint chlorination (Grittenden, et al., 2012)

At the breakpoint, chlorine residual will become change free residual. The presence of organic matter, organic nitrogen and reducing compounds (e.g., iron and manganese) will determine the location of breakpoint chlorination. Free chlorine more powerful than combined residual. Thus, in the distribution system, free chlorine is preferable.

CHAPTER 3

Description of study area

Nepal has an area of approximately 147,181 km^2. It divided into 5 development regions and 75 districts. Typically, based on the topography, areas of Nepal divided into three categories: terai (flat area), hilly and mountain. These affect the climate in Nepal, tropic climate can be found in terai area, while the hilly part is cool climate and in mountain area has a cold climate.

Nepa VDC was selected as a research site. Nepa VDC located in the hilly area of Dailekh district. According to Census data in 2011, Nepa VDC has a population over 5000 with around 1000 households. As a larger part, Dailekh district has the lowest coverage of improved sources of drinking water with only 54.2% (CBS, 2014). At the time of fieldwork, this village is not supplied by electricity. Figure 3.1 shows the location of study area.

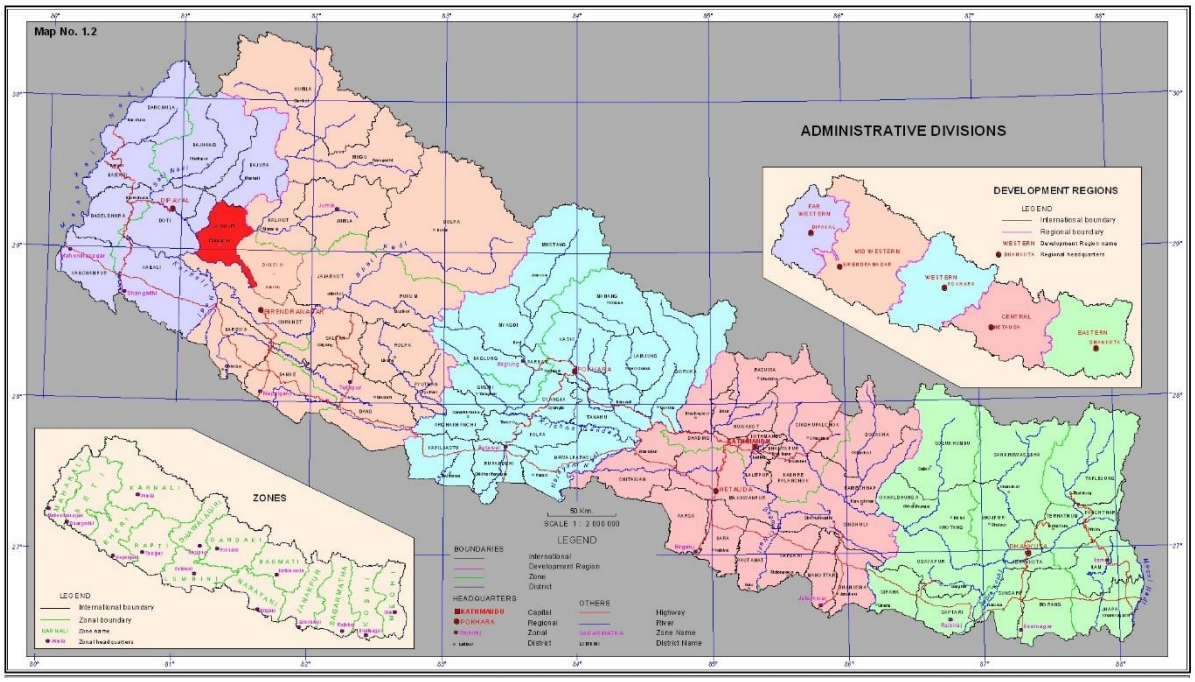


Figure 3.1 Location of study area (red highlight area, Dialekh District) (source:Central Bureau of Statistics (2012))

Furthermore, in Nepa VDC, waterborne disease occur every month. Diarrhoea, typhoid fever and dysentery are common disease in Nepa VDC. Most of the people in Nepa VDC did not treat their water before consumption. In some cases, they only have one container or storage

both for drinking, cooking and feeding animal. Table 3.1 shows the data from health post in Nepa VDC.

Table 3.1 Water-related disease in Nepa VDC (source: Nepa VDC Health Post)

No	Month (Solar calendar)	Number of person get affected		
		Typhoid fever	Dysentery	Diarrhoea
1	Apr/May 2014	7	10	24
2	May/Jun 2014	16	5	14
3	Jun/Jul 2014	24	11	10
4	Jul/Aug 2014	6	4	20
5	Aug/Sep 2014	19	3	15
6	Sep/Oct 2014	13	2	9
7	Oct/Nov 2014	1	1	2
8	Nov/Dec 2014	0	4	8
9	Dec/Jan 2015	4	0	7
10	Jan/Feb 2015	0	2	7
11	Feb/Mar 2015	4	8	11
12	Mar/Apr 2015	2	10	24

Typically, natural springs are used as a water source for daily use; the advantages include constant temperature, better quality and no need for electricity for extracting water compare to surface water and groundwater (Zweig, et al., 1999). After leaving the spring, no proper treatment was applied and water was directly collected and distributed to consumers through pipelines. There are also traditional system in this research area such as direct pipe collection from spring and rainwater tank. Figure 3.2 shows typical of public water supply systems in rural Nepal.

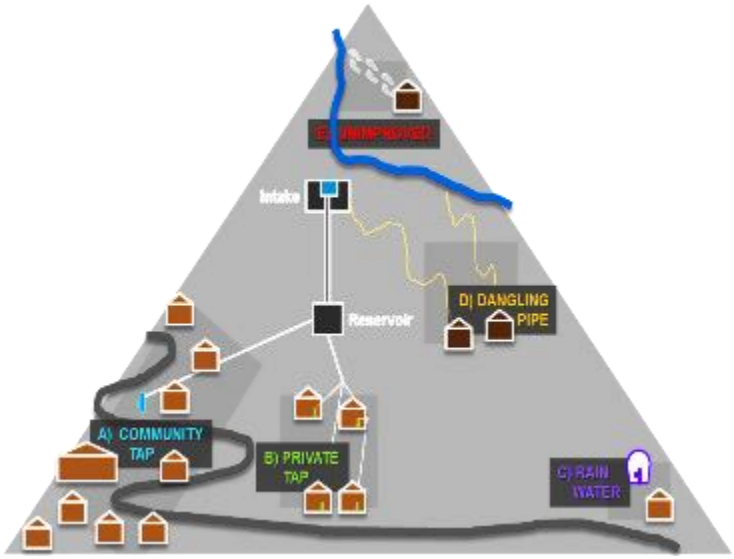


Figure 3.2 Typical public water system in rural Nepal (source: Arnt Diener)

The system was operated by Village Maintenance Worker (VMW). For system 1, 2 and 3 Nauladhara operated by one VMW. VMW responsible for maintenance and operation of the system. Table 3.2 shows the information about systems that will be selected as a research area.

Table 3.2 Selected systems for study area (source: Helvetas)

No.	Name	Type	Flow (lps)	Number of taps	Number of household	Description
1	System 1 Nauladhara	Community	0.06	2	14	Not-intermittent
2	System 2 Nauladhara	Community	0.1	7	31	Intermittent
3	System 3 Nauladhara	Community	0.3	14	60	Intermittent
4	System 4 Koyasidhara	Private	0.21	29	29	Intermittent

In rural Nepal, for a pipe water system, it is divided into two categories: private tap and community tap. Usually, community taps serve 4 or 5 households.

CHAPTER 4

Materials and methods

In this section the materials, the analytical and experimental methods that were used during the research, are described.

4.1. Materials

Materials needed for water quality monitoring (microbial and physicochemical parameters) and for experiments are described.

4.1.1. Microbial water quality test

Materials needed for the microbiological analyses are:

a) Whirl-pak®
Two different types of sterile whirl-pak bags was used: the standard Whirl-Pak® and Whirl-Pak® Thio-Bags®. The latter was used for samples containing chlorine, since they contain a small pill of sodium thiosulfate ($Na_2S_2O_3$) for quenching residual chlorine. For samples are not contain residual chlorine, normal Whirl-Pak® bags was used.

b) Membrane filters
Standard membrane filters with 0.45 μm pore size and 47 mm diameter was used to perform membrane filtration (MF) test. These membrane filters were produced by Merck Millipore Corporation. It made from mixed of cellulose acetate and cellulose nitrate (Millipore, 2016).

c) Compact dry plates
Compact dry plates (CDP) EC type by Nissui (Tokyo, Japan) were used as growth media for *E. coli* and other coliforms. These plates contains two chromogenic enzyme substrates: Magenta-Gal and X-Gluc. X-Gluc gives blue appearance for *E. coli*, while Magenta-Gal gives the red/pink appearance to coliform bacteria including *E. coli*. CDP have been incubated for 24 hours at 35 ± 2°C.

For the additional test for *Vibrio* and Enterococci, we used VP plate and ETC plate. Both plates are also made by Nissui. The test condition for VP was slightly different from EC and ETC. Incubation was for 18-20 hours at 35 ± 2°C. Colonies formed in blue or green indicate the presence of *V. parahaemolyticus* while *V. cholera* will develop in pink/magenta colonies. In ETC plate, *Enterococci* will appear in blue or blue-green colonies.

d) Field incubator
A field incubator manufactured by the research partner organization, EAWAG was used. It uses battery and recharged by solar panel. Inside the incubator, a temperature logger was placed to monitor temperature dynamics during incubation period. The field incubator has low energy, require approximately 30 Watt (Diener, 2015). It can contain up to 80 plates for one incubation cycle.

e) DelAgua filtration apparatus
DelAgua filtration apparatus consists of a vacuum cup, vacuum pump, connector, aluminium gasket, funnel and plastic collar. This apparatus is used for performing membrane filtration methods.

Figure 4.1 Laboratory equipment

f) Sample container
This research use a food thermos with insulated stainless steel. It use for transport the sample from point of collection to field laboratory that analysis took place. Since there was impossible to make ice for cooling sample, the container was filled with free contaminant water with temperature around 10°C. Then the sample stored in this thermos containing water. It can carry up to 8 samples per container.

Figure 4.2 Sample containers using food thermos

4.1.2. Physical and chemical water quality test

a.) Portable pH/EC/TDS/°C meter
Two types of meter were used in this research: the Hanna instrument type HI 9813-6 (pH/EC/TDS/°C) and The Lutron type CD-4307SD (EC/TDS/°C).

Figure 4.3 Portable pH/EC/TDS/°C meter

b.) Portable spectrophotometer
For measurement of turbidity and free chlorine, Hanna instrument (HI93414) was used. It consists of portable meter, standard calibration cuvettes, free chlorine reagents, and microfiber cloth for cleaning the cuvettes.

Figure 4.4 Portable spectrophotometer

4.1.3. Experimental test

Spring protection
The spring already protected with surrounding fence. Additional spring protection installation was performed to make spring more protected from fecal contamination or environmental influences. Material for this experiment consist of gravel, fine sand with diameter around 1-2 mm, impermeable plastic, perforated pipe and cotton fabric.

Chlorination
Chlorine material for this experiment uses chlorine solution made by ENPHO. This commercial product contains sodium hypochlorite (NaClO) with 0.5% and 0.7% chlorine concentration. Figure 4.5 shows physical chlorine available in the market. This solution can be found in most of the pharmacies in Nepal.

Figure 4.5 Available chlorine solution in the market

Filtration-UV treatment

This treatment use small UV light as the main part for bacteria inactivation and has 12 Watt power. For turbidity removal prior to UV light, 5 μm of household filter (inside-outside filtration) was installed. The UV lamp was powered with battery that was connected to a solar panel. The DC-AC converter was used to change the current because solar panel gives DC current and the UV lamp requires AC current. All treatment materials were bought in Nepal. The UV lamp used for this experiment shown in Figure 4.6.

Figure 4.6 UV lamp with 12 Watt power

Household ceramic candle filter

Two different brand of candle water filters were tested, which were Apollo and Surya. Both of them equipped with two candles. The candle itself was made from clay material. These filters were locally available in market. The water candle filter has capacity of 10 litre and can treat water with flow of around 0.1 to 1 litre/hour (CAWST, 2011). The device consists of two compartments; the upper compartment is used for untreated water and lower compartment use for storing treated water. Water is poured into the upper compartment and then allowed to filter through the ceramic filter element into the lower compartment. Figure 4.7 shows ceramic candle filters use in this research.

Figure 4.7 Household ceramic candle filters

First flush experiment

This test was conducted to know the water quality of the system when it's started after the systems was off for several hours. First flush experiments use a bucket with volume indicator to indicate the flushing volume.

4.2. Analytical methods

4.2.1. Sample collection and analysis

Water samples were collected in for each water system in the spring, reservoir and taps. Four enumerator went to the location point in the morning around 6.00 – 6.30 AM. After samples were collected, each enumerator bring the water samples to field laboratory. In the laboratory, the sample were analysed by two persons.

For the microbial quality test, the membrane filtration (MF) method was used for the enumeration of *E. coli* and total coliform. In principle, the MF method based on the presence of bacterial colonies in growth media. The procedure for sample collection and MF method shown in Appendix A. This analysis was performed under sterile conditions. Beside analysis of the daily sample and experimental sample, the laboratory control was performed to evaluate the procedure of analysis. In this research, the laboratory control was divided into four categories, which were positive control, negative control, laboratory blank control and field blank control.

Positive controls demonstrate that the Compact Dry Plate (CDP) can support the growth of target microorganisms. For positive controls in this research we used filtered water that contains chicken faeces. Negative controls demonstrate that the CDP do not support the growth or non-target organism and to make sure the disinfection processes in DelAgua filtration apparatus was perfect. The negative control was performed directly after positive control. For negative controls in this research, water was disinfected by SteriPEN® or was boiled for approximately 15 minutes. The 1 log reduction of bacteria by boiling can be achieved with less than 1 minutes at 65°C (WHO, 2015).

The laboratory blank is aimed to check the sterile water that use for moisten CDP. It was demonstrated at the end of sample processes. The aim of this control is to make sure that water used for rehydrating the CDP is still sterile until the end of sample processes.

For each day, two field blank samples have been taken. The goal of this step is to demonstrate that the sample not contaminated during the transport and to ensure the enumerator take the sample hygienically based on procedure. Blank transport sample prepared in the morning before enumerator went to the sample site. Laboratory blank, blank transport control and field blank control were used SteriPEN® treated water or boiled water. Table 4.1 shown summary of laboratory control that was done for this research.

Table 4.1 Laboratory control

No	Type	Source water
1	Positive control	SteriPEN® treated water/boiled water
2	Negative control	Water contain chicken faeces
3	Laboratory blank	SteriPEN® treated water/boiled water
4	Transport blank	SteriPEN® treated water/boiled water
5	Field blank	SteriPEN® treated water/boiled water

4.3. Experimental methods

In order to meet the objectives, this research was structured as follows:

a) Technical interventions at community level (spring protection, chlorination in the reservoir)
b) Technical interventions at household level (filtration/UV treatment, ceramic candle filters)
c) Management intervention at community level (first flush, pressure monitoring)
d) Monitoring of water quality in unmodified piped water schemes
e) Interviews to the local community

4.3.1. Description of the PWS in study area

There are three general parts of this study. Firstly, to apply technical adaptations and see how this interventions affect the water quality. Secondly, to investigate management practices that can be related to level of contamination. Lastly, to study the general water quality overview in intermittent piped water systems. Planned technical experiments can be divided into two categories; interventions for community treatment and interventions at the household. The parameter of water quality will be recorded for each interventions. Comparison analytical for each test basically based on the microbial quality analysis. This research was carried out between November and December 2015. At that time, the weather was cool around 10°C with no precipitation event in a single day. For technical adaptations which are additional spring protection and chlorination, there was carried out in one PWS. Figure 4.8 shows time frame of interventions that took place in system 1 and experiment timeline for first flush test in system 4.

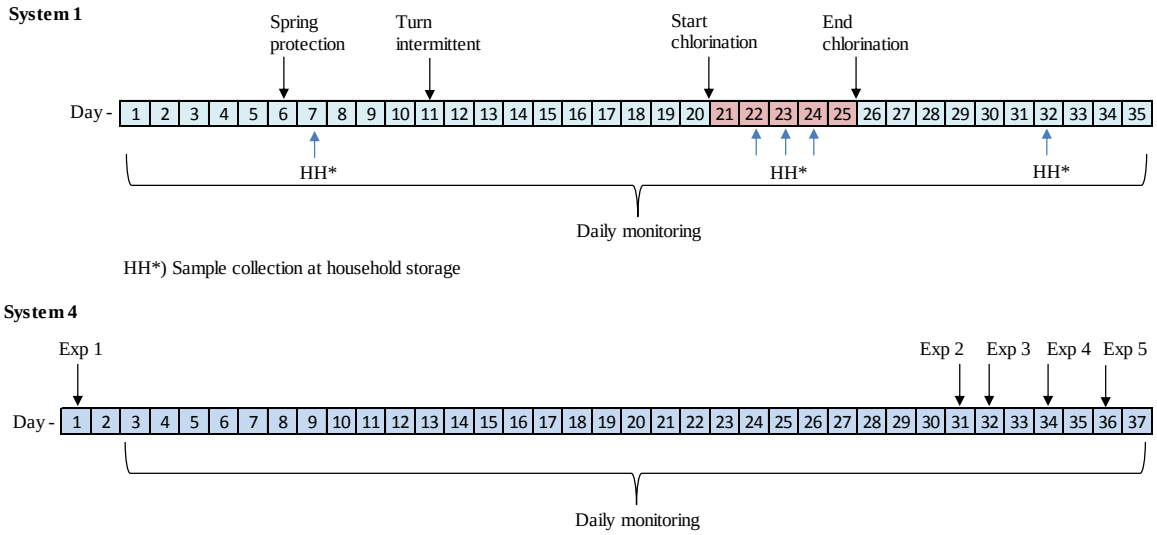


Figure 4.8 Time frame for intervention in system 1, first flush experiment and daily monitoring

4 PWS were used in this overall study of the project. Specifically, only two systems were used for this research, which are system 1 and system 4. All PWS were constructed by HELVETAS Swiss Intercooperation Nepal. These systems was operated by village maintenance workers (VMW). The VMW responsible for operating the system, maintaining the system, collecting the bills from households and coordinating to HELVETAS if there is a major problem. All PWS were gravity feed systems. The system consists of spring intake, reservoir and taps. In some cases, there is also break pressure tank and distribution chamber. Break pressure tank is to reduce high pressure due to high elevation difference. Figure 4.9 shows the schematic system of system 1 and 4.

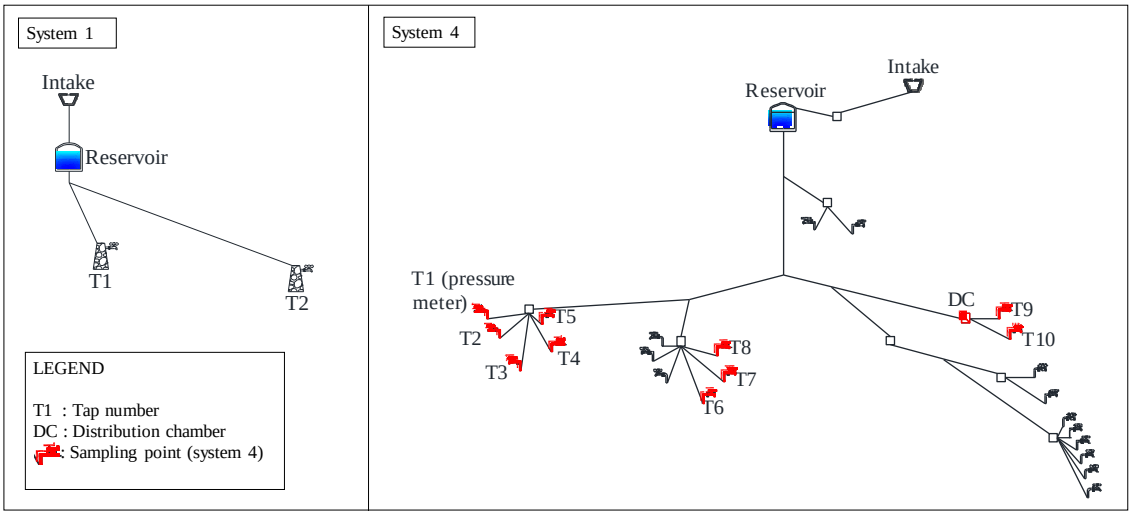


Figure 4.9 Schematic diagram and location of sampling points in system 1 and system 4

For system 1, the daily samples took place in spring, reservoir and two taps. Duplicate sample was taken in one tap. The number of sample per day in system 1 is one sample per point of collection.

Table 4.2 Number of samples in system 1 for daily monitoring

Point	No. of samples	Days	Total
Intake	1	35	35
Reservoir	1	35	35
Tap 1	1	35	35
Tap 2	2	35	59
			164

Remark : only 24 days of the sample in Tap 2 have duplicate

For system 4, the daily samples took place in spring, reservoir, ten taps and distribution chamber. Duplicate sample was taken in tap 1.

Table 4.3 Number of samples in systems 4 for daily monitoring

Point	No. of samples
Intake	33
Reservoir	33
Tap 1	66
Tap 2	3
Tap 3	4
Tap 4	3
Tap 5	10
Tap 6	10
Tap 7	2
Tap 8	10
Tap 9	32
Tap 10	32
Distribution Chamber	32
Total	**270**

4.3.2. Technical interventions

Technical interventions were divided into two categories which are in the system and at at the household. Additional protection in the spring and chlorination were tested for the systems. For household, treatment combination filtration followed by UV irradiation and ceramic candle filter were tested.

The aim of additional protection in the spring is to monitor the microbial quality behaviour of the system by applying some additional protection. The spring was cleaned before the new protection was installed. New collection pipe in the spring was installed 1 meter deeper than the previous intake. The installation of new pipe inlet was supported by disinfected gravel. In the outlet collection pipe itself, it was covered by a sand bag. This sand bag use as a filter step to prevent coarse material or plants enter the reservoir. The sands have diameters range between 1mm and 2 mm. Plastic material was covered around the outlet collection pipe to prevent water get direct contact with intake surface.

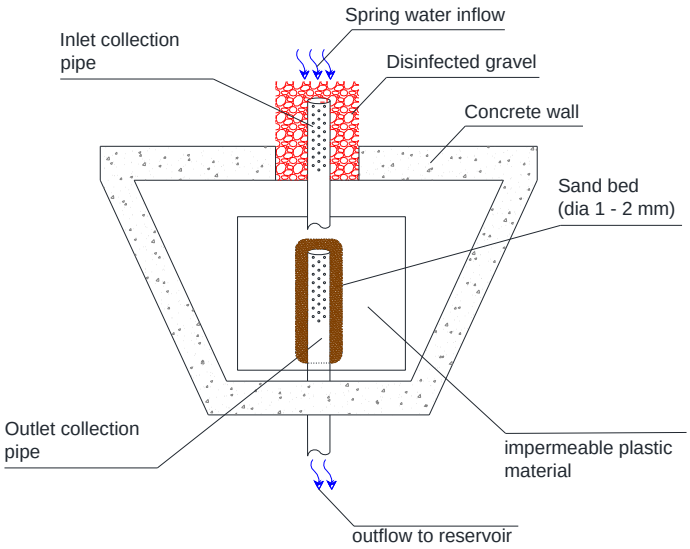


Figure 4.10 Schematic diagram for spring protection installation

For chlorination, a simple chlorination device was installed in reservoir tank: the aim was to achieve free chlorine residual of 0.5 mg/L at the taps. Firstly, the chlorine dose need to be identified on the site via a chlorine demand test. Contact time, temperature and pH plays an important role in chlorine dose and disinfection efficiency. The procedure for determining chlorine demand shown in Appendix C. Schematic diagram for chlorination experiment shows in Figure 4.11.

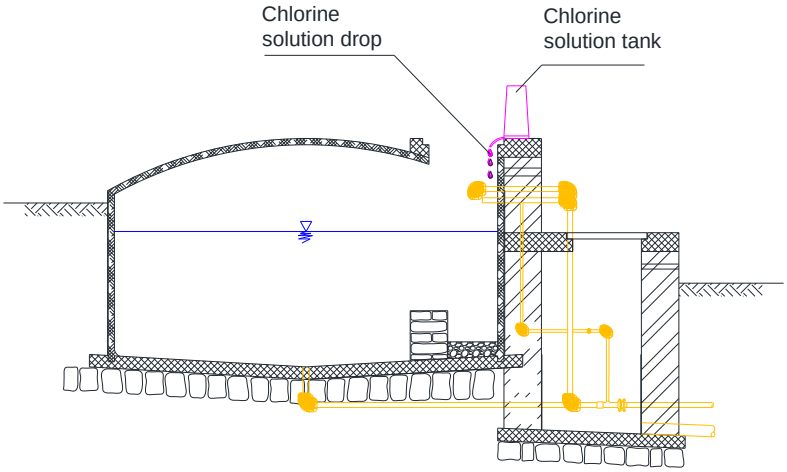


Figure 4.11 Schematic diagram for chlorination experiment

This chlorination experiment ran for 5 days. The residual chlorine was measured directly in the taps with DPD method as described in Appendix B. Furthermore, the water samples of household storage also measured to understand the effect of chlorination. The water quality at the storage measured with approximately 8 hour after water was collected by the local people.

Figure 4.12 Household storage 1 (left) and 2 (right)

The first intervention in household level is UV-filtration treatment. The water sample was taken before and after leave the treatment. Additionally, flow also was recorded by using a glass beaker and a stopwatch. Schematic diagram of UV experiment can be seen in Figure 4.13.

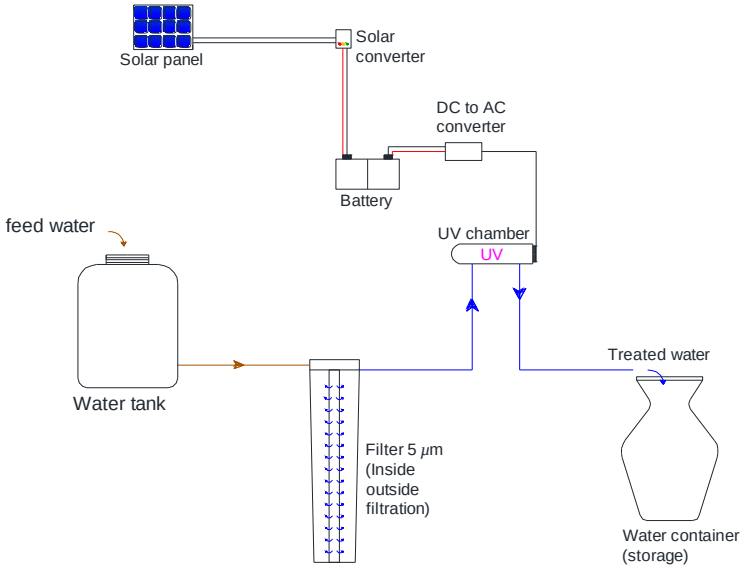


Figure 4.13 Filtration-UV treatment set-up

Another intervention for household was the ceramic candle filter. The experiment conducted two times. The upper compartment filled with raw water, and after 4 hours, the filtered water sample was collected for microbial analysis.

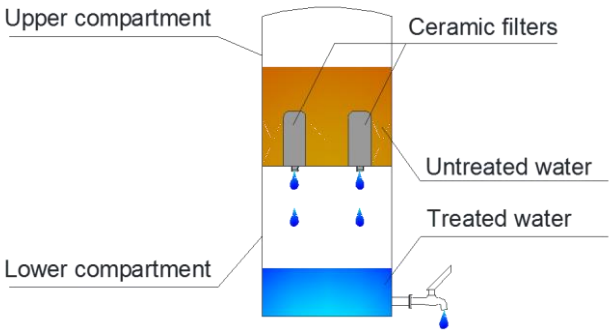


Figure 4.14 Schematic of ceramic candle filters

For analysis of chlorine feasibility, small interview was conducted in the research area. Interview focus on acceptability of chlorine and to understand the basic knowledge of water treatment. Four people was interviewed for chlorination perception. In addition, 16 people was interviewed to know their access to water and how they treat the water. The interview content can be seen in Appendix D.

4.3.3. Management practices

Management practices in this research were divided into two categories, first flush test and pressure monitoring. The first flush test was performed to understand whether discarding a certain volume of water at the beginning of the daily supply cycle can have a positive impact on water quality. This experiment performed in the morning after the system was shut off during the night. The first flush was conducted with the procedure explained below.

1. Open and directly collect the sample with Whirl-Pak bag after opening the tap.
2. Discard the next 10L or 1L of water into the bucket
3. Measure temperature, pH, EC and TDS in the bucket and record in the data log sheet.
4. Collect the next sample after flushing 10L or 1L.
5. Repeat steps number 3 till 5 for ten times.

In addition, the flow meter and pressure gauge installed in the tap 1 of system 4. The enumerator read the pressure gauge while took the water samples in those tap. Figure 4.15 shows pressure gauge that was used in this research.

Figure 4.15 Pressure gauge

CHAPTER 5

Result and discussion

This chapter summarizes and critically reviews the results obtained during the field work.

5.1. Result

5.1.1. Assessment of water quality before the interventions

Prior applying technical interventions, water quality in system 1 was monitored for a period of 5 days to understand level of contamination. The system during that period was operating continuously. Figure 5.1 shows that spring, reservoir and taps were affected by high faecal contamination, with a median concentration of *E. coli* at the spring of 300 CFU/100mL. The reservoir and two taps also has similar risk category with 292 CFU/100 mL for the reservoir and 300 CFU/100 mL for two taps. The system was categorized as an intermediate risk based on WHO guidelines.

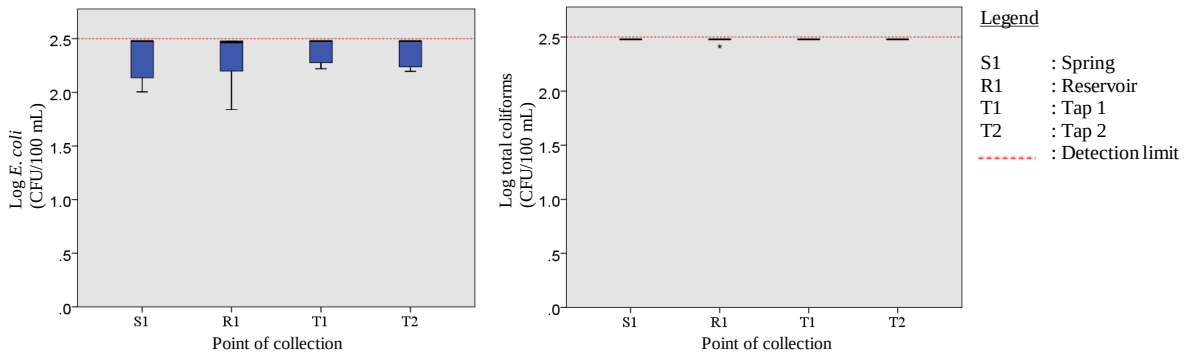


Figure 5.1 Boxplot of E. coli and total coliforms concentration in the system 1 during five days monitoring period

5.1.2. Technical interventions at community level

Spring Protection

The first intervention to be put in place was spring protection. This protection can minimize the risk of faecal contamination in the spring and reservoir. The system was operated in a continuous mode during the assessment of technical intervention, which resulted in a significant decrease of faecal contamination in the spring and reservoir with a reduction more than 2.48

log of median concentration of *E. coli* in the spring and 2.16 log reduction value (LRV) in the reservoir. In the taps only 1 LRV was achieved. Median value of *E. coli* was 0 CFU/100mL in the spring, 2 CFU/100 mL in the reservoir and 30.5 CFU/100 mL in the taps. The risk classification became low risk category. However, the concentration of total coliforms was not affected by this intervention, with the median concentration of faecal coliforms in the spring being 257 CFU/100mL, and so only less than 0.07 LRV was achieved. The open spring contact easily with soil and plants. Bacteria from soil and plants give a high contribution of coliforms bacteria in the spring and reservoir.

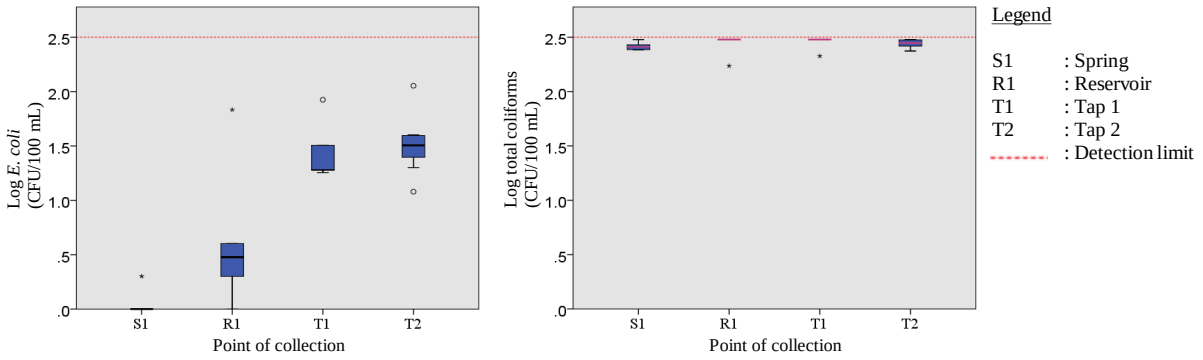


Figure 5.2 Microbial water quality after installation of spring protection (continuous mode)

After 5 days, the operation of the system was changed from continuous mode to intermittent with operational hours from 06.30 AM to 06.30 PM. Water quality was monitored for another 5 days period and the result of microbial contamination were analogous as the ones obtained under continuous operation. Figure 5.3 shows microbial water quality after installation of spring protection.

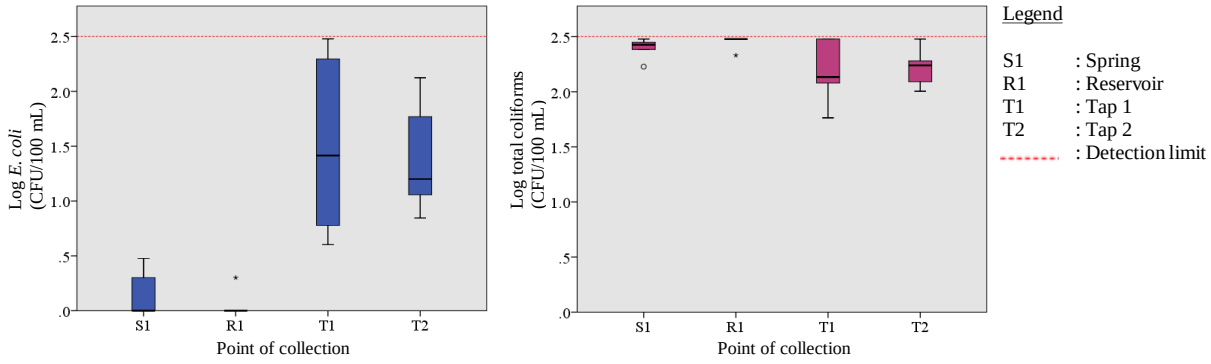


Figure 5.3 Microbial water quality after installation of spring protection (intermittent mode) during five days monitoring period

The concentration of *E. coli* and turbidity dramatically increased in the first day of intermittent supply at the taps. The turbidity raised from 2.0 NTU in the last day of continuous to 26.9 in the first day of intermittent supply in the tap 1. Similarly, a significance increase of turbidity value also was observed in the tap 2. The value rises from 0.96 NTU to 19.4 NTU. In IPWS the water quality in the taps worse than CWS. It indicates with 4 samples has more than 100

CFU/100 mL while in CWS only has 1 sample during 5 days monitoring period. Table 5.1 Comparison of turbidity at the taps between continuous supply and intermittent supply after spring protection.

Table 5.1 Comparison of turbidity at the taps between continuous supply and intermittent supply after spring protection

POC	Turbidity (NTU) under continuous supply					Turbidity (NTU) under intermittent supply				
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 1	Day 2	Day 3	Day 4	Day 5
Tap 1	2.99	1.81	1.27	0.97	2	26.9	19.6	1.68	1.23	0.83
Tap 2	2.16	1.39	1.1	0.89	0.96	19.4	1.75	5.26	3.05	1.42
Tap 2 (duplicate)	-	-	0.82	-	0.83	-	1.75	1.64	1.1	-

Chlorination

The second technical intervention to be put in place was chlorination in the reservoir. The chlorine was dose in the reservoir with flow based on chlorine demand experiment. The chlorine residual was measured in the two taps. The value of chlorine residual in tap 1 was higher than in tap 2 because the distance was shorter. The distance from reservoir to tap 1 is 119 m and to tap is 110 m. The levels of free chlorine at both taps in system 1 were monitored for period of 5 days; the concentration ranged from 0.06 mg/L to 1.32 mg/L. This variation was caused by an inaccurate of dosage. Detail calculation of chlorine demand and dose are presented in Appendix D. Despite this no faecal contamination was detected after chlorination. However, in day 4, coliforms was detected in the tap with 1 CFU/100mL in tap 1 and 2 CFU/100mL in tap 2. The occurrence of coliforms due to elevated turbidity with 16.6 NTU in tap 2 and 23.6 NTU in tap 1. Table 5.2 present water quality result during chlorination.

Table 5.2 Water quality result during chlorination in system 1

Day / Parameter	Day 1		Day 2		Day 3		Day 4		Day 5	
	Tap 1	Tap 2	Tap 1	Tap 2	Tap 1	Tap 2	Tap 1	Tap 2	Tap 1	Tap 2
E. coli (CFU/100mL)	0	0	0	0	0	0	0	0	0	0
Total coliforms (CFU/100mL)	0	0	0	0	0	0	1	2	0	0
Turbidity (NTU)	0.92	0.8	1.08	1.11	1.8	1.17	23.6	16.6	1.38	2.7

Based on estimation, the CT value of 15.83 minutes-mg/L (Appendix E) can be achieved with 0.5 mg/L of residual chlorine. This value was enough for *E. coli* inactivation. Past study found that 99% inactivation can be achieved in less than 1 min with 0.25-1 mg/L of chlorine residual (King, et al., 1988). Figure 5.4 shows chlorine residual and turbidity in the systems.

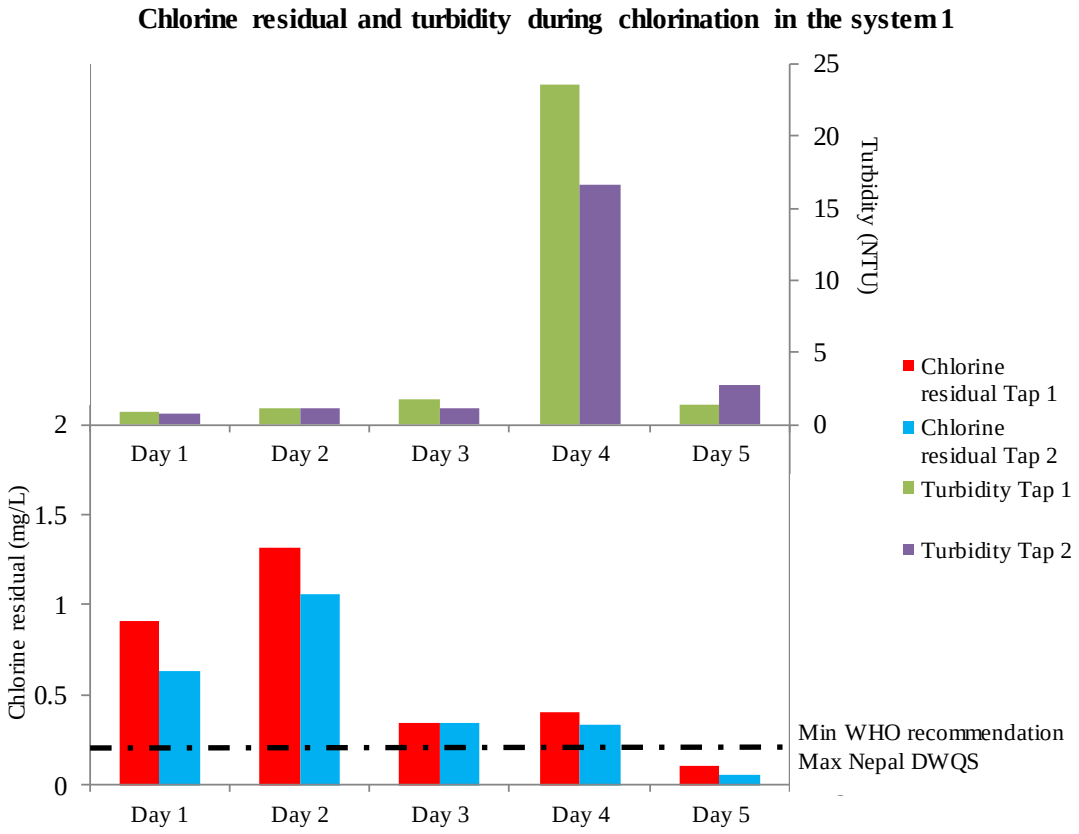


Figure 5.4 Chlorine residual in chlorination interventions

In addition, households sample also were taken to measure chlorine residual and water quality. After stored for around 8 hours in household storage, the chlorine residual was measured. The chlorine residual decreased with average 0.19 mg/L in household storage 1 and 0.38 mg/L in household storage 2 after being stored for 8 hours. There are no lid for both of household storage. Chlorine will decay rapidly due to exposure with air (Sheikhi, et al., 2014). Figure 5.5 shows the chlorine residual in household storage.

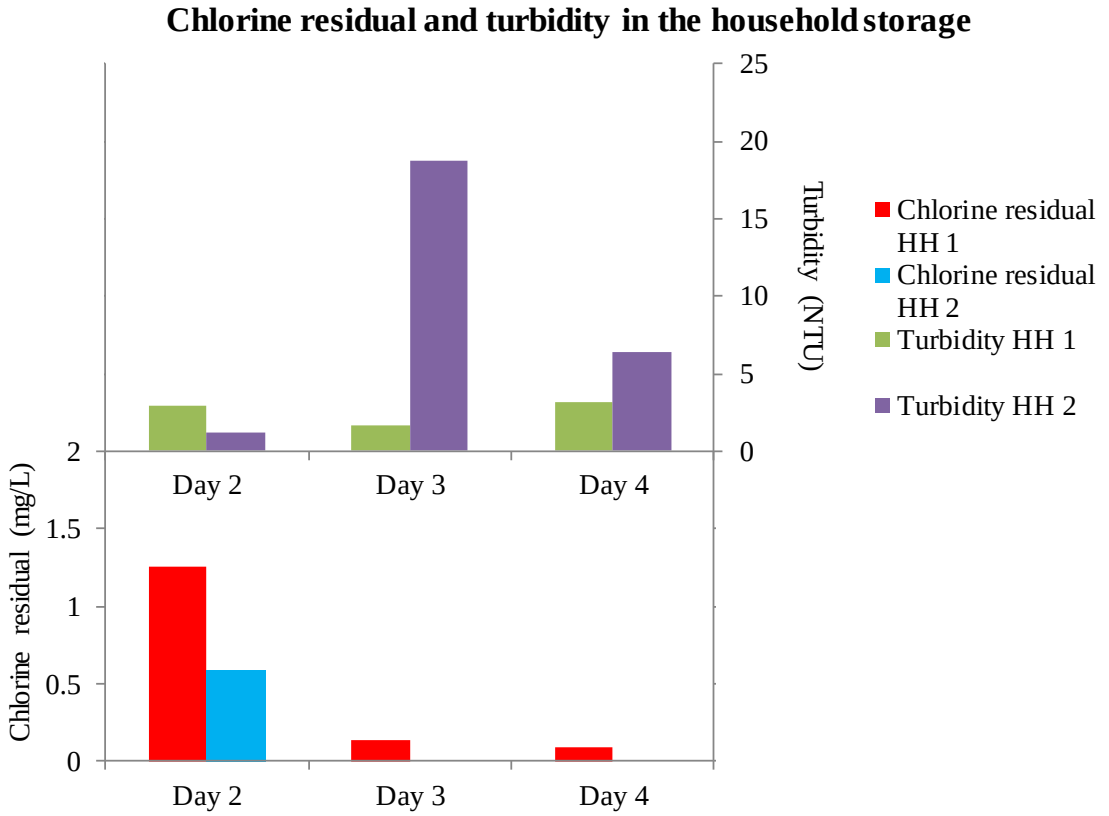


Figure 5.5 Chlorine residual and turbidity in household storage during chlorination in the system

Before chlorination the water sample in household was measured. The water was contaminated with 40 CFU/100 mL of *E. coli* concentration in household storage 1 and 30 CFU/100 mL in household storage 2. Both of storages, total coliforms was in detection limit. Poor water quality in the system gives negative impact to household storage.

During chlorination, the water quality get better with the value below detection limit at day 2 and day 4. However, in day 3, there is 9 CFU/100mL of *E. coli* was detected at household storage 2 due to elevated turbidity and 0 mg/L of chlorine residual. The recontamination seems may occur during storage practice. The people of this village seldom clean the household storage. Table 5.3 explain microbial water quality result in household samples. Even there is no residual chlorine at household storage at the time of collecting sample, there is no *E. coli* present.

Table 5.3 Water quality result in household storage

Parameter \ Day	Before chlorination		Day 2		Day 3		Day 4		One week after stopping chlorination	
	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
E. coli (CFU/100mL)	40	30	0	0	0	0	0	0	9	2
Total coliforms (CFU/100mL)	>300	>300	0	0	1	9	0	0	199	12
Turbidity (NTU)	1.39	2.31	2.99	1.15	1.71	18.8	3.19	6.4	1.31	5.99

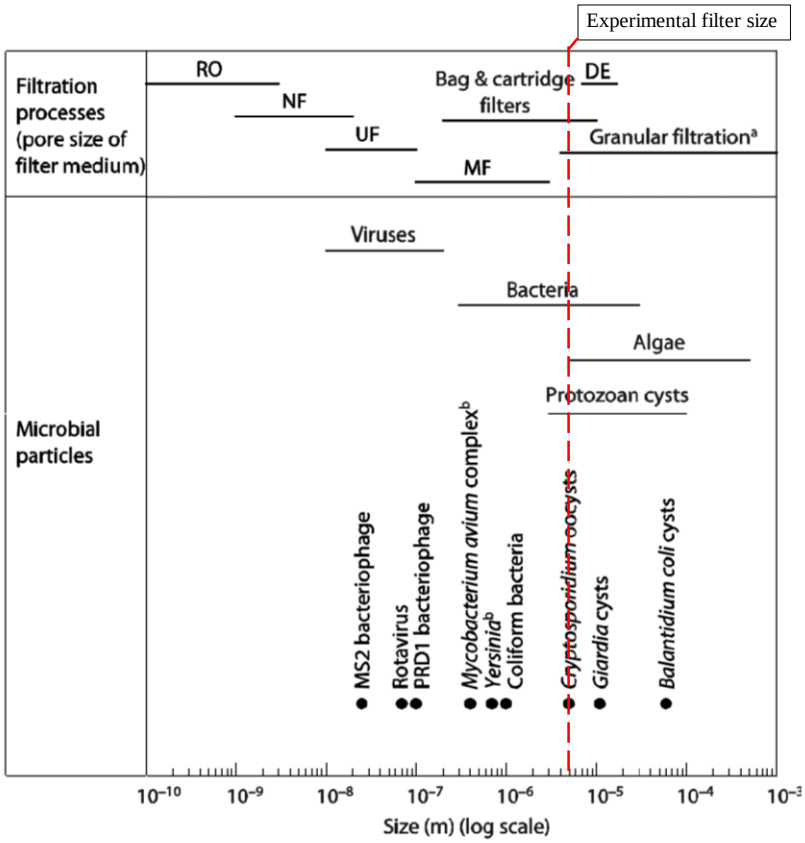
Filtration-UV treatment

Filtration-UV treatment demonstrate very efficient treatment options with less complexity of set-up. No FIB was detected after the treatment. The bacteria removal mechanism caused by filtration and followed by UV irradiation. Prior UV irradiation, filtration step might remove some of bacteria colonies that might attach in particulate matter. Moreover, with low water turbidity after filtration step it might increase the effectiveness of UV light. Low water flow provide a sufficient contact time with UV lamp. Approximate of contact time is UV chamber is around 48 seconds (Appendix G). The low-pressure UV lamps can achieve 50-150 mW.s/cm^2 of UV dose (Laurent, 2005). However, determined the actual UV transmittance and UV absorbance in the laboratory field in rural area was not possible due to limitation of electricity and equipment.

Table 5.4 The water quality result of filtration-UV treatment

No.	Parameters	Filtration + UV		
		Before treatment	After treatment	LRV
1	*E. coli* (CFU/100 mL)	8	0	>0.90
	Total coliforms (CFU/100 mL)	88	0	>1.94
	Turbidity (NTU)	2.5	0.78	-
2	*E. coli* (CFU/100 mL)	4	0	>0.60
	Total coliforms (CFU/100 mL)	128	0	>2.10
	Turbidity (NTU)	11.2	0.8	-
3	*E. coli* (CFU/100 mL)	4	0	>0.60
	Total coliforms (CFU/100 mL)	128	0	>2.11
	Turbidity (NTU)	11.2	0.75	-

Filtration efficiency of microbial reduction depend on filter media size and types. The filter itself has diameter 5 μm and common coliform bacteria has 1 μm in diameter. Thus only bacteria that attached to particulate matter removed by filtration step. Figure 5.6 shows different pore size of filter medium and size of microbe. Smaller pore size means more effective for filtration processes.



DE = diatomaceous earth; MF = microfiltration; NF = nanofiltration; RO = reverse osmosis; UF = ultrafiltration.

Figure 5.6 Different pore size of filter and size of microbes (Source : (LeChevallier and Au, 2004)

The filtration processes use filter cartridge that can be replaced in case of damaged or not functioned. After uses several times, the filter will be clog due to the accumulation of suspended material and decrease in filter permeability (Redner and Datta, 2000). Thus, the filter should change when the flow already decrease significantly. When the filter clog, the flow will decrease overtime.

Ceramic candle filter

Ceramic candle filters can give significant improvement of turbidity value. However, total coliforms still found in the treated water sample. This circumstances occur due to not uniform of pore size and the candle was not function perfectly. The overall performance of candle filter in this research only contribute <0.5 LRV for total coliforms. In Appolo filter, for turbidity value can reach to below 1 NTU, while in Surya filter still above 1 NTU. However, the initial turbidity of water in two filters were different. In the second experiment, the raw water turbidity was high with the value up to 12.2 NTU in Surya filter.

Table 5.5 The water quality result in ceramic candle filter experiment

No	Parameters	Apollo			Surya		
		Before filtration	After filtration	LRV	Before filtration	After filtration	LRV
1	*E. coli* (CFU/100 mL)	13	0	>1.11	10	0	>1.00
	Total coliforms (CFU/100 mL)	189	138	0.14	186	70	0.42
	Turbidity (NTU)	1.09	0.75	-	1.85	1.12	-
2	*E. coli* (CFU/100 mL)	5	1	0.70	9	0	>0.95
	Total coliforms (CFU/100 mL)	185	135	0.14	289	260	0.05
	Turbidity (NTU)	3.71	0.6	-	12.2	1.13	-

5.1.3. Management practices

First flush test

The first flush test was conducted five times for knowing the behaviour and water quality dynamics of the IPWS when it's started to operate. The result shows that more likely get high concentration of *E. coli* in the first 100 mL sample. The next sample indicates the number of *E. coli* get consistent value. Experiment 1, 2, and 3 use interval 10 L. In experiment 1, after 10 L flushing the average *E. coli* concentration was 10.2 CFU/100 mL (n =9, SD = 3.34). In experiment 2, the average of *E. coli* concentration was 7.4 CFU/100 mL (n=5, SD=4.33) and 5.4 CFU/ 100 mL (n=5, SD=1.51) in experiment 3. Experiment 4 and 5 are slightly different from experiment 1, 2, and 3. These experiments use interval of 1 L volume with average 4.2 CFU/ 100 mL (n=5, SD=1.3) in experiment 4 and 2.4 CFU/ 100 mL (n=5, SD= 1.41) in experiment 5 after 1 L flushing. Figure 5.7 shows the result of first flush experiment. The first flush practices is not sufficient to reduce faecal contamination.

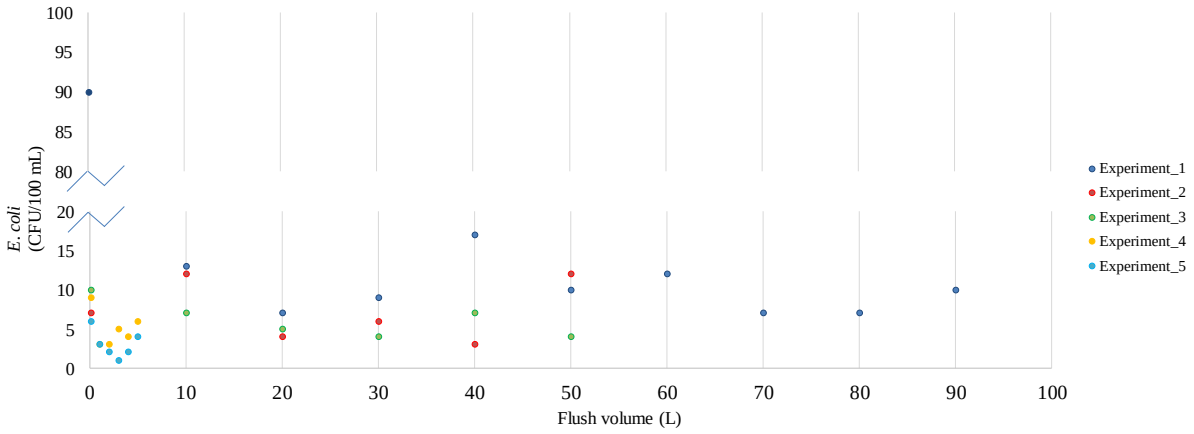


Figure 5.7 Scatter plot of E. coli concentration and flush volume

The variation of *E. coli* concentration in first flush test also influenced by time difference. Experiment 1 was conducted 30 days before experiment 2. Water quality might be change within that time period. Influx from water quality in the spring also has an influence during experiments. The highest *E. coli* concentration in the spring occur in the first experiment. In 4 out of 5 experiments were observed that in the tap *E. coli* concentration was higher in the tap compare to *E. coli* concentration in the spring.

Table 5.6 Comparison of E. coli concentration between spring and tap.

Experiment	E. coli concentration (CFU/100 mL)	
	Spring	Tap (first flush)
1.	28	90
2.	9	7
3.	1	10
4.	1	9
5.	5	6

The particulate matter in the distribution pipe might be release when the tap was turned on in the very beginning of supply cycle. However, in this system, the low turbidity was observed as shown in Figure 5.8. There is only one experiment has a significant peak value in first water sample. The intrusion of particulate matter in the distribution pipe of the observed taps not occur. Overall, the first flush practice in a small system do not give significant improvement of water quality.

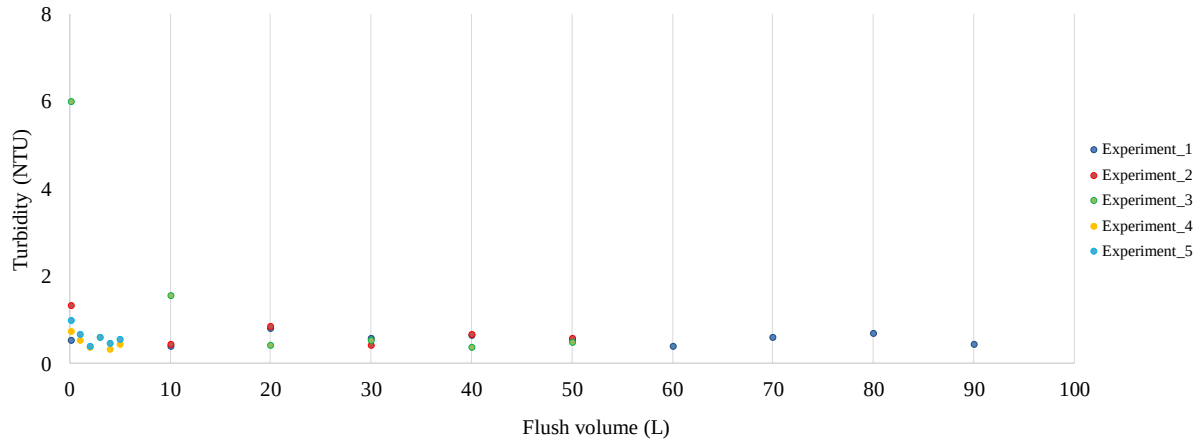


Figure 5.8 Scatter plot of turbidity and flushed volume

Influence of pressure on microbial contamination

Pressure also was recorded in tap 1 in the system 4 to find if there is a possible correlation between pressure and *E. coli* concentration. The type of pressure data is a grab sample, when enumerators collect the water samples, they took the measurement reading of pressure gauge. Based on observation of scatter plot graphs in Figure 5.9. There is no statistically significant correlation between *E. coli* concentration and pressure, $r_s(32) = 0.118$, $p > 0.05$. Similarly, for total coliforms and pressure do not have any significance correlation $r_s(32) = 0.335$, $p > 0.05$. Thus, variation of pressure in the tap actually did not give contribution of contamination level. However, in the past study, Kumpel (2013) observed that high pressure (>1.17 bar) with a free residual chlorine more likely gives low concentration of bacteria. In that findings, the chlorine residual has great influence in bacteria concentration while in this systems there is no chlorine was used.

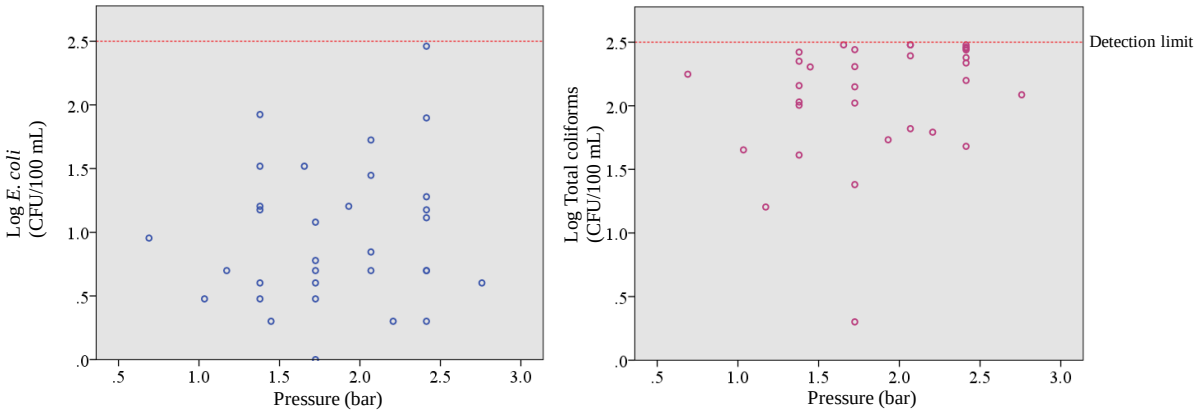


Figure 5.9 Scatter plot of log E. coli vs pressure (left) and log total coliforms (right)

5.1.4. Overview water quality of intermittent piped water systems

In systems 4, all samples were above WHO guidelines and Nepal drinking water guidelines in microbial aspects. The guidelines state that should be no detection of *E. coli* of 100 mL samples. Mostly in intermittent pipe systems in Nepa VDC were not safe because there were indicator bacteria present. The distribution of *E. coli* in every POC varied by sampling day. The *E. coli* concentration rises from the spring to the reservoir. In distribution system, colonies in taps higher than other points.

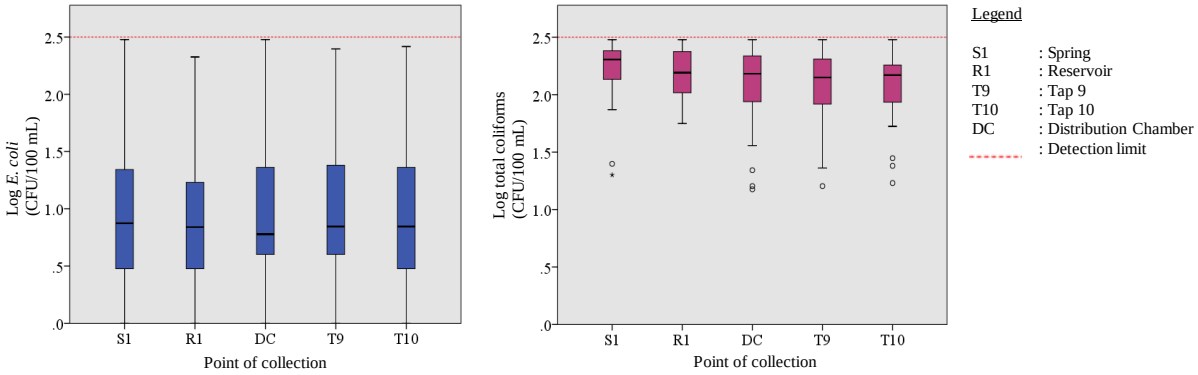


Figure 5.10 Distribution of E. coli at POC in system 4.

Every system has the different characteristic of microbial water quality. *E. coli* concentration was spread equally along the systems. These variation of *E. coli* distribution in the systems due to contamination in spring area and leakage in distribution pipe. The effect of storage in reservoir gives no improvement of water quality. Besides high *E. coli* concentration, high-level total coliforms was observed. The number of total coliforms slightly decreased in the taps. The system was categorized as a low risk with median of *E. coli* concentration 6 CFU/100 mL. Based on this risk classification, the system was not guarantee safe and need a proper treatment.

Naturally, system 4 has a low risk Table 5.7 shown comparison of water quality risk in the system 1 and system 4.

Table 5.7 Risk classification in system 1 and 4

System	Risk classification		
1	Before spring protection	After spring protection	Chlorination
4	No interventions		

Colour code

- In conformity with WHO guidelines
- Low risk
- Intermediate risk
- High risk
- Very high risk

The physicochemical parameters, on the other hand meet WHO and Nepal drinking water standard. For physiochemical parameters, the variability is low. The low variability observed by low value of standard deviation. For pH standard deviation is 0.28 in system 1 and 1.18 in system 4. The EC value not affected by supply mode, whether continuous or intermittent.

Table 5.8 Variability of physicochemical parameters in system 1 and 4

System	pH			EC (mS/cm)			Turbidity (NTU)		
	n	Mean	Std deviation	n	Mean	Std deviation	n	Mean	Std deviation
1	145	7.28	0.28	163	0.06	0.01	162	2.61	3.88
4	207	7.34	1.18	270	0.25	0.02	270	1.34	1.49

In all samples in the taps, pH and EC remain in safe range. Based on Nepal DWQS the range should be between 6.5 up to 8.5 for pH and below 1.5 mS/cm for EC. For turbidity in system 4 11.2 % of samples (n=98) in the taps exceed 5 NTU. Nepal DWQS stated 5 NTU for maximum turbidity value and still accept 10 NTU in case there is no alternative solution. Both in modified system 1 and unmodified system 4, the physicochemical aspects did not have great influence on microbial water quality.

5.1.5. Cost of treatment option

Four technical adaptations were conducted in this research are reliable to be implemented. The availability of local materials can cut the investment cost. Table 5.9 shows matrix about feasibility in terms of capital investment and operational cost.

Table 5.9 Matrix of treatment option feasibility

Treatment	Capital cost	Operational cost
Spring protection	Medium	Low
Chlorination	Low	Low
Filtration-UV	High	Low
Ceramic candle filter	Low	No cost

Preliminary cost estimates indicated that chlorination feasible for small intermittent systems. Based on interview local people detect the smell of chlorine (n=4). However, they interested about the fact that chlorination can achieve high reduction of microbial quantity. Traditionally, the people in this research area only know about boiling the water for treatment options. Only three out of 20 people treat their water with this traditional methods. First implementation of chlorine or chemical product might got little obstacle, i.e. taste and smell. Support from government is very important to promoting the treatment options for IPWS.

High investment cost of filtration-UV treatment may lead the people think twice for use this treatment. The option is to share the capital cost among 2 or 3 households since the volume of treated water is sufficient for drinking purpose.

5.2. Discussion

5.2.1. Overview of technical interventions and management practices

The result of daily monitoring shows that four systems have a risk of contamination. Thus the water must be treated before consumption. At system level, chlorination is easy to be installed in a rural area. However, the dose of chlorine cannot be very accurate if not use a pump dosage, but it is still possible to achieve at least 0.5 mg/L. The Nepal drinking water standard for chlorine residual still very low compare to the other developing country. The WHO guidelines states that chlorine residual should be minimum 0.2 mg/L at the point of delivery. In contrast, Nepal drinking water standard give a range from 0.1-0.2 mg/L for residual chlorine, which was very low compared to the other developing countries.

Applied chlorination may cause disinfection by-products. Dissolved organic carbon is one of persecutors to form disinfection by-products. In this study case, chlorination can be applied in system 1 because DOC is lower than 0.5 mg C/L. Nevertheless, in system 4, the DOC content

up to 21.8 mg C/L. Even there is a risk of cancer by trihalomethanes, infectious disease related to pathogen in water still main priority. Thus, chlorination still an appropriate technology for rural area. It has been tested worldwide that chlorine can kill bacteria effectively.

Additionally, chlorine provide additional protection at household storage. The price of chlorine solution relatively cheap. However, some people can easily detect the smell of the chlorine and usually do not like taste of chlorine, but if they stored for a certain time, the smell might disappear due to chlorine decay.

Filtration-UV treatment also one of the promising solution for household treatment. UV disinfection growth rapidly for disinfection and has been used for replacing chlorine in many countries. UV light attacks cell genetics, thus it unable to replicates. Prior applies UV light, the water should clean from suspended material that can reduce disinfection efficiency. This UV-filtration treatment requires low energy and can be operated easily by household or community. During the day, it will be operated by using solar energy for recharge the battery. Then it will be storage in each house storage. Generally, the water consumption in Nepa VDC categorized as low consumption. Based on observation of flow meter in the tap, 36.55 Lpcd is an estimation for private taps. Similarly the water consumption in public taps are around 35.16 Lpcd. Filtration-UV treatment can treat water for 30 L/h. In the case that this operated within 6 hours, the total volume of treated water equal to 180 L, which is mean can serve 5 up to 6 people. Another advantages of use UV is inactivating chemical resist pathogens, such as *Cryptosporidium parvum* (Craik, et al., 2001) and *Giardia lamblia* (Linden, et al., 2002). These pathogen considered as cause of chronic diarrhoea diseases. Furthermore, the cost of UV treatment decline in a recent year.

In ceramic candle water filter, many research has shown a good performance to remove bacteria .However, this product still depend on how people handling this filter and material itself. In the past study, Lamichhane and Kansakar (2013) discovers that colloidal silver coating can increase performance of ceramic candle filter. However, *E. coli* and total coliforms still detected in this experiment under laboratory condition.

Additionally, the clay material of candle filter cannot give uniformity of filter pore size. The material also fragile. If source water contain too many bacteria concentration, it still insufficient treatment. Moreover, every household filter should be also tested in laboratory scale. So the producers have guaranteed to ensure consumers that their product can treat water with acceptable level and meet drinking water quality standard.

When the system fail to produce water of suitable microbiological quality, HWTS practices are immediately issued to the local communities. There are wide range of HWT technologies and applications. The application of certain technology depend on local conditions and capabilities.

In management point of view, the flushing practices seems ineffective since the systems already deliver water with low turbidity. Modified the pressure in the small systems not feasible. The capital cost such as buy a pressure reducing valve was unrealistic for small systems.

5.2.2. Overview of microbial water quality analysis

MF method that carried out in this research indicate good result and performance. This method can be done relatively quickly and can get an accurate quantitative number. The sensitivity of MF methods was high based on positive and negative control in CDP. In positive control, the result always TNTC, while below detection limit in the negative control. TNTC means the value is above detection limit. In this research, the value of 300 CFU/mL was determined as upper detection limit. CDP only gives accurate number for around 200-300 CFU. More than that value seems to be difficult to count

For transport and collect the sample, enumerators need to clean their hand with hand sanitizer. Since there is no electricity, for keeping the sample cool, it uses thermos that contains clean water with the temperature around 10°C. Average time from collection to sample analysis for water samples approximately 2 hours 14 minutes (n=876).

Equipment performance applicable for a rural area. All equipment work well in 42 consecutive days and there are no major problem. The EAWAG incubator gives a great performance. Not only easy operate to use but also it can carry easily due to lightweight material. Only some minor problem on the sixth week of field work phase, there is a decrease of battery capacity so incubator went off and the temperature went down and to be replaced with another battery. Figure 5.11 Average temperature inside the incubatorshows average temperature in the incubator.

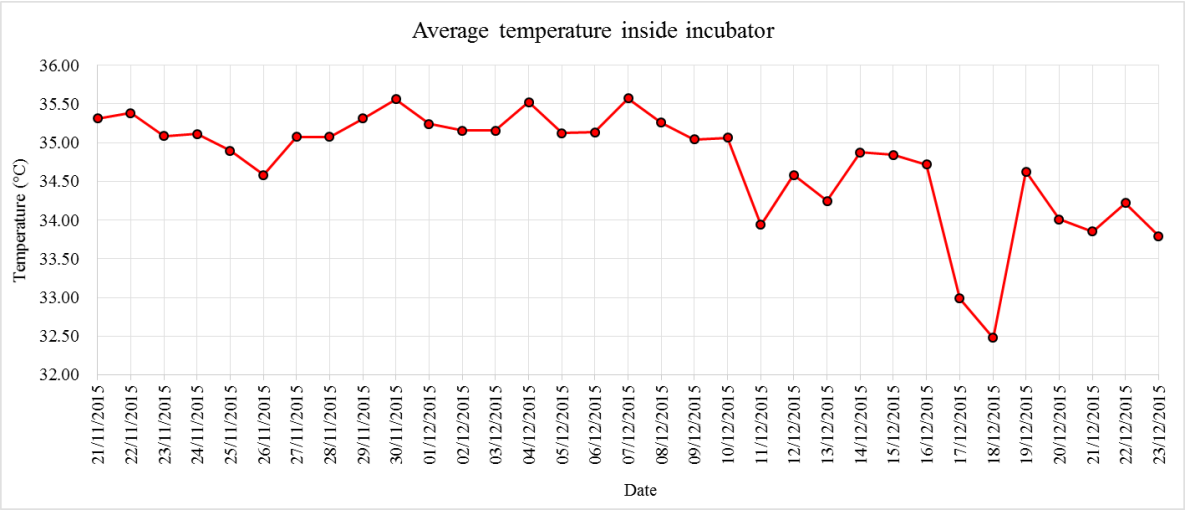


Figure 5.11 Average temperature inside the incubator

The MF method DelAgua test kits also work perfectly. This technique needs clean and hygienic work area. In this research, antibacterial surface wipes was used for clean up the work area. It was handy with simple procedure. This technique can be done relative quickly with approximately 4 samples per hour using one DelAgua test kit. With two or three days of intensive training, the locally trained staff can perform this technique.

5.2.3. Development of water quality laboratory in rural area

One of main point to achieve SDG number six is quality control of drinking water. However, in remote rural area, providing high technology of water laboratory is very difficult and need a lot of capital cost. In modern water quality laboratory requires high operational cost, trained staff and complex analysis procedure. Water quality testing usually had constraint in low setting or remote area.

This research use low capital cost which is around 2000 CHF and already can give a glance for water quality overview for the system. Basic water quality laboratory should be built near the systems to reduce transport time and operational cost. However, the sustainability of laboratory still remain an issue, because it should have a regular employee to work in the laboratory. Another challenge for laboratory in rural area is electrical supply since this area did not electrified yet. Basically, large area of solar panel and battery are needed. These equipment mainly to support the incubator. The battery should have enough capacity to incubate for 24 hours in the case no sun during the day. HELVETAS will play an important role for conducting the development of laboratory in this particular area.

The mass production of portable water test kit grow rapidly in the world. Many test kits available for monitoring both chemical and microbiological parameters. . Commonly, portable kits are easy to use. As a reference, local NGO, ENPHO already made the presence-absence test kit for coliforms bacteriaThe accuracy of measurements depend on the people who operate it and capability of the equipment itself.

Prior development of water quality laboratory, list of water quality parameters that should be decided. Nepal DWQS do not mention regulation for water quality that use spring as a source. The regulation only mention water quality parameters for surface and groundwater supply systems. Based of Nepal DWQS the following parameter should be tested for rural surface and ground;

a) Microbial parameter
   E. coli, Total coliforms
b) Physical parameters
   Turbidity, pH, color, taste & odor, Electrical conductivity
c) Chemical parameter
   Iron, Manganese, Chromium (surface water), Arsenic (groundwater), Flouride, Ammonia, Nitrate, Total Hardness, Calcium, Residual chlorine (if system use chlorination)

5.2.4. Development of monitoring program in rural area

Many people in the Nepal rural area are unaware to the hazard that caused by contaminated drinking water. A field test or monitoring program should be developed for the communities. The local community members should see the information about water quality that they consume. The impression about water quality test can change behaviour of the people. People will aware and think to treat their water before consumption. The information about water

quality also can improve local's knowledge. Thus Participation among locals should be considered for treatment that will be applied in the systems.

By looking at chlorination experiment, there are no FIB detected at the POC. Thus, there is no need for test microbial water quality. It implies the cost of monitoring since conducted residual chlorine measurement are easier and cheaper than perform microbial water quality analysis.

For microbial water quality monitoring, the presence of faecal indicator bacteria is sufficient. This methods do not lead to specific pathogens. However, providing the information about the presence of FIB can lead to water safety plan. Additional indicators also were tested which were *Vibrio cholera* and Enterococci. As a result, Enterococci was detected of 100% samples (n=32) with median value 31.5 CFU/100 mL. On the other hand, there are no detection of *Vibrio cholera*.

Based on WHO recommendation. According to WHO and Nepal DWQS suggest that one minimum sample in distribution with a population approximately 5000 inhabitants. Additionally, Nepal DWQS stated that for physical parameters (turbidity, pH, colour, taste and odor) should be tested daily while microbial parameter once per month. Many low-cost monitoring kits available worldwide. In Nepal, the water quality result data of water systems was limited and in some place even did not have.

Even for restricted area in Nepa VDC, this research showed that it is possible to perform both microbial and physicochemical test in comprehensive way. The fluctuations of temperature during incubation compare to standard laboratory test did not affect much of *E. coli* growth.

For sustainability of water quality laboratory in rural area, fund support either from government, loan agreement, or local NGO should be used effectively. However, it is still quite challenge to monitor all chemical and microbial parameter. The local authorities should select carefully for parameter that will be used for daily monitoring due to limited human resources and equipment. The procedure should simple as much as possible.

Additionally, sanitary inspection also should be done to support laboratory water quality. The sanitary inspection can gives comprehensive knowledge about water systems. Additionally, it can identifies all the possible hazard and cause of contamination. Together with water quality data, the sanitary inspection can deliver a risk assessment. Flow chart diagram to determine technical intervention in IPWS shown in Figure 5.12.

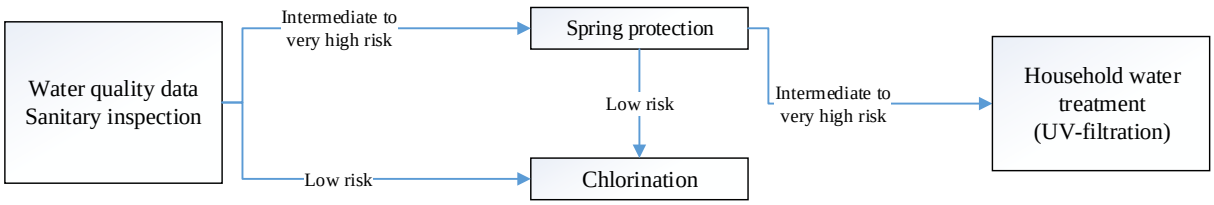


Figure 5.12 Flow chart to determine technical intervention in IPWS

CHAPTER 6

Conclusion and recommendation

This chapter give a general of conclusion in this research. In second part, recommendation will be explained and also give a feedback for possible future research related to this topic.

6.1. Conclusion

Intermittent supply can cause several problem during operation. Each system has different characteristic which was influenced by environmental, water quality in the spring and quality of the infrastructure itself. Based on risk approach, protection in the spring give more than 2 log LRV for *E. coli* concentration both in spring and reservoir. This interventions easy to adapt for a small systems with low flow of intake. For larger systems with high flow capacity, applied slow sand filter prior to reservoir is strongly recommended.

Chlorine treatments still a promising technologies for developing country. Another advantage gained by using chlorination is no need for additional household treatment. Even for small systems with low CT value, free chlorine still effective against bacteria. However, for *Cryptosporidium* and *Giardia* need longer CT thus continuous dose of chlorine still has an advantage if the water systems went off during intermittent period. Event ought *E. coli* not present in the water sample, the quality of water not guarantee safe. Hence for treatment options still need attention for removal other pathogens i.e. *Cryptosporidium, Giardia* and viruses.

The UV-filtration gives best performance for household treatment with minimum 2.11 LRV for total coliforms compare to candle water filter.

The first flush test shows there is a peak of *E. coli* concentration in the first water sample when the systems was turned on. In general, first flush practices for a small systems are not necessary since there is no significant improvement of water quality. The pressure at the tap has no correlation with number of *E. coli* ($r_s(32) = 0.118$, $p > 0.05$) or total coliforms ($r_s(32) = 0.335$, $p > 0.05$). Thus, manage the pressure at the tap do not give an impact to microbial water quality.

6.2. Recommendation

Expand the supply duration to 24 hours is impossible in this typical hilly rural area. Springs has limited flow capacity compare to the water demand. The population in village of this rural area increase significantly. Thus providing interventions at system levels or household levels are necessary.

For daily usage, the first suggestion is not to share water storage for drinking purpose and animal purpose. Some household only has one storage container and both for drinking water purpose and animal. While they use for animal purpose, the storage can easily contaminate. Each family should have minimum two storages, one for drinking purpose and one for another purpose.

In operational point of view, highly recommended for increasing maintenance frequency. Nowadays, VMW cleans intake and reservoir twice per year. Every two months or one month is highly recommended. Additionally, frequent monitoring in vicinity of reservoir and intake should be take into consideration to prevent or reduce potential contamination. Visual observation necessary for detect leakages in the systems.

For further research, the following topic can be done:

1. Multi-criteria analysis for treatment adaptation in IPWS includes cost benefits for each treatment.
2. Development of another treatment option, such as slow sand filter.
3. A risk model for prediction contamination in IPWS.

There are several limitations of this research, it not considered the seasonal effect of the area. Due to information from the local, the water in the spring will become very turbid when the rain came.

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Appendices

Appendix A. Standard procedure for microbial water quality test

Sample collection

1. Disinfect hand with hand sanitizer before taking the water sample.
2. Label Whirl-Pak® bag with the sample ID, sample point and date/time of collection with a permanent marker.
3. For each Whirl-Pak® bag will be filled with 100 mL for microbial analysis and around 20 mL extra for turbidity analysis.
4. Close and seal Whirl-Pak® bag carefully. The upper part of the Whirl-Pak® must not be touched and direct contact with the source of the sample.
5. Put the sample in a sample container.
6. Process the sample within six hours and keep at an original temperature (insulated container), if delayed more than 6 hours, the sample must be stored in low temperature storage with 5°C ± 3 or discarded.

Sample processing

1. Clean up the work area with antibacterial wipes.
2. Label the compact dry plate with sample ID and processing date/time with a permanent marker.
3. Disinfect hand with hand sanitizer and use a pair of medical gloves before analyse the water sample.
4. Sterilize the tweezer with flame using lighter, remove membrane filter from sterile package and put the filter into sterilized funnel.
5. Shake well the water sample and open Whirl-Pak® bag. Transfer a 1 ml of clean/sterile water with a pipette onto the plate to moisten it and pour 100 ml of sample into the funnel and filter through with vacuum hand pump.
6. Transfer filter paper to the compact dry plate using sterilized tweezers. Check that there are should no bubbles trapped under the filter.
7. Replace the lid, invert the plate, and incubate for 24 hours at 35°C in the field incubator.
8. Sterilize Del Agua membrane filtration apparatus and tweezers with methanol for the next water sample.
9. Dispose of Whirl-Pak® bag, a pippete tips and clean-up work area.

Sterilizing Del Agua filtration apparatus

1. Clean all parts of kit with clean dry cotton.
2. Drop approximately 15-20 drops/ 1 mL of alcohol into a sample cup.
3. Burn methanol with a lighter.
4. Wait for a moment until fire almost completely disappear.
5. Put filtration head cover into a sample cup.

6. Wait for approximately 10-15 minutes before it uses for the next sample.
7. The Del Agua membrane filtration apparatus ready to analyse next sample.

Plate counting and data recording

1. Remove plates from the incubator.
2. Using the colony counter, count the number of colonies appearing from the backside of the plate. Colonies will be pigmented in different colours. *E. coli* will produce blue colonies, other coliforms group with red or violet colour while another bacteria or fungi with white and yellow pale colour.
3. Record the total number of *E. coli* and total coliforms per 100 mL of water samples on the plate and in data log sheet. If sample will be taken with 1 ml, calculation of colonies per 100 mL based on equation (A.1 and (A.2).
4. Compact dry plates should be discarded properly.

$$E.coli/100\ mL = \left(\frac{Number\ of\ blue\ colonies}{Volume\ of\ sample\ filtered\ (mL)}\right) x\ 100 \qquad (A.1)$$

$$\text{TC}/100\ mL = \left(\frac{Number\ of\ blue\ +red\ colonies}{Volume\ of\ sample\ filtered\ (mL)}\right) x\ 100 \qquad (A.2)$$

Appendix B. Procedure of physio chemical parameters measurement

Temperature, Electro conductivity, pH and TDS

1. Clean the glass beaker for take water sample.
2. Fill water sample to the glass beaker.
3. Put the probe into glass beaker.
4. Read the measurement until it get constant reading.
5. Record the reading into data log sheet.

Turbidity measurement

1. Clean the cuvette with microfiber cloth before use.
2. Rinse the cuvette with water sample.
3. Fill water sample to the cuvette up to printed mark (approximately 10 mL).
4. Shake the cuvette for proper mixing.
5. Put the cuvette into the instrument.
6. Read the measurement and record into the log sheet.

Residual chlorine measurement (DPD method)

1. Clean the cuvette with microfiber cloth before use.
2. Rinse the cuvette with water sample.
3. Fill water sample to the cuvette up to printed mark (approximately 10 mL).
4. Shake the cuvette for proper mixing.
5. Put the cuvette into the instrument.
6. Press zero button to until the display show 0.
7. Remove the cuvette from the instrument and add one package of free chlorine reagent.
8. Shake smoothly for 20 seconds.
9. Again, put the cuvette into the instrument and wait for 1 minute for read chlorine residual in mg/L.

Appendix C. Procedure for chlorine demand test in field remote setting

Sample collection

1. Collect the water samples in clean plastic bottle.
2. Immediately analyse the samples as soon as possible. If not keep the samples at 6°C or below for maximum 24 hours.

Test procedure

1. Measure and record the temperature and pH of the sample
2. Prepare six chlorine demand-free bottles. Put the label in each bottle
3. Rinse each bottle with sample
4. Fill the bottle with 500 mL sample
5. Use a pipet to add 0.1 mL chlorine solution.
6. Shake the sample bottle gently for proper mixing.
7. Put the sample bottle in a dark location and wrap with foil.
8. Repeat the step 4-7 for remaining bottles. Chlorine solution added with increment of 1 mg/L.
9. After the specified contact time, analyse the residual free chlorine.

Appendix D. Interview content

Chlorination perception

a) Gender of respondent
b) Age of respondent
c) Frequency for treating water
d) Water treatment has been used
e) Knowledge about chlorine product
f) Perception about chlorine for treating water (smell and taste)

Access to water

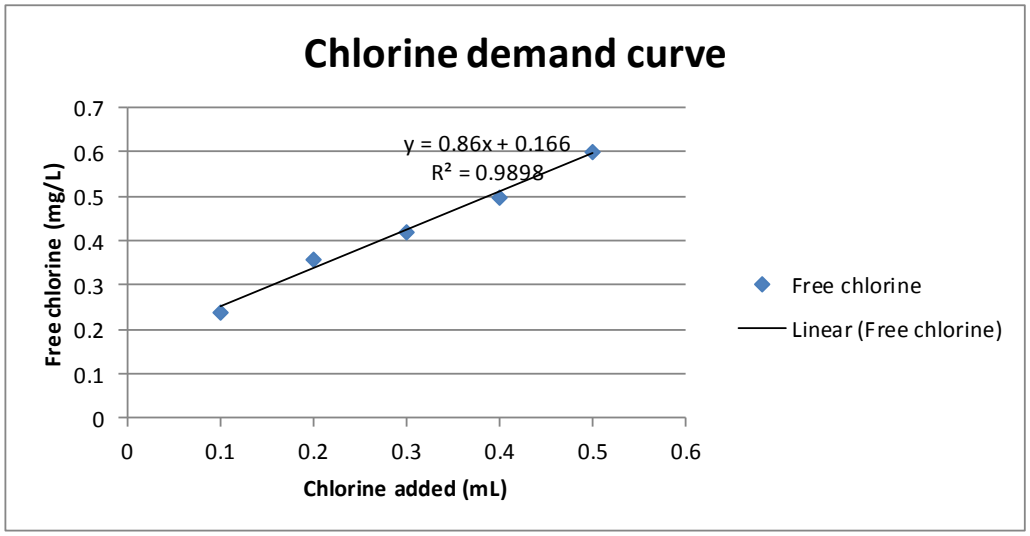
a) Gender of respondent
b) Age of respondent
c) Collection time to current water source and past water source
d) Amount of water collection per trip
e) Distance to current water source and previous water source
f) Water treatment has been used
g) Cost for pay water bills

Appendix E. Chlorine demand test and dosage calculation

Chlorine demand experiment

Source : Nauladhara subsystem 1 intake
Chlorine solution : Piyush 0.5% with 10 times dilution
Residence time : 30 min
Sample volume : 500 mL
Raw water data
pH 7.3
Temperature 14.3

No.	Chlorine added (mL)	Residual chlorine (mg/L)
1	0.1	0.24
2	0.2	0.36
3	0.3	0.42
4	0.4	0.5
5	0.5	0.6



Chlorine dosage

Based on chlorine demand test data to achieve 0.5 mg/L free residual chlorine we added 0.4 mL (10x dillution) to 500 mL water

$$Rate_{Ms} = \left(\frac{Flow_{sup}}{Vol_{test}} \right) \times Ms_{test}$$

Flow	0.06	L/s	(with bucket & stopwatch)
Vol_{test}	0.5	L	
Ms_{test}	0.4	mL	
Dose rate	0.05	mL/sec	
Actual dose rate	0.02-0.20	mL/sec	(with bucket & stopwatch)

Appendix F. Calculation of CT in chlorination experiment

CT value in reservoir

Peak Flow = 0.216 m^3/h

Baffling factor (BF) = 0.1 (unbaffled/mixed flow)

Volume of reservoir = 1 m^3 (estimation based on low water level)

Time = (Volume/Flow) x BF = (1/0.216) x 0.1 = 0.46 hour = 27.78 min

CT value at the reservoir = Concentration x Time = 0.5 x 27.78 = 13.89 minute.mg/L

CT value in distribution pipe

Pipe diameter = 0.0127 m

Baffling factor (BF) = 1 (plug flow in pipe)

Area of pipe = $\frac{1}{4}\pi d^2 = \frac{1}{4}\pi\ 0.0127^2$ = 1.267 x 10^{-4} m2

Total volume of pipe = Area x length = 1.267 x 10^{-4} x 110 = 0.0139 m^3

Time = (Volume/Flow) x BF = (0.0139 /0.216) x 1 = 0.06 hour = 3.87 min

CT value at the pipe = Concentration x Time = 0.5 x 3.87 = 1.94 minute.mg/L

Total CT value = 13.89 minute.mg/L + 1.94 minute.mg/L = **15.83 minute.mg/L**

Appendix G. Estimation of contact time in UV-filtration treatment

Characteristic of low-pressure UV lamp (USEPA, 2003)

Germicidial UV light	Monochromatic at 254 nm
Electrical input (W/cm)	0.5
Germicidal UV Output (W/cm)	0.2
Electrical to Germicidal UV coversion efficiency	35-38
Arc length (cm)	10-150
Lifetime (hours)	8000-10000

UV light dosage calculation

Input (Q)	0.0083	lps
Lamp capacity	12	Watt
Lamp diameter	15	mm
Reactor diameter	50	mm
wave lenght	254	nm
Distance (inlet to outlet)	225	mm
Reactor volume	401821.875	mm^3
Discharge	8300	mm^3/s
Contact time	48.4122741	s

Appendix H. Point of collection pictures and coordinates

System 1 Nauladhara	
	
Intake, Elevation 1515 m N 28°51.341, E 81°34.476	Reservoir , Elevation 1511 m N 28°51.344, E 81°34.478
	
Tap 1, Elevation 1481 m N 28°51.403, E 81°34.468	Tap 2, Elevation 1493 m N 28°51.417, E 81°34.433

System 2 Nauladhara

Intake, Elevation 1506 m
N 28°51.352, E 81°34.505

Reservoir , Elevation 1480 m
N 28°51.455, E 81°34.468

Tap 1, Elevation 1475 m
N 28°51.458, E 81°34.474

Tap 2, Elevation 1460 m
N 28°51.463, E 81°34.526

Tap 3, Elevation 1442 m
N 28°51.461, E 81°34.559

Tap 4, Elevation 1421 m
N 28°51.515, E 81°34.493

System 2 Nauladhara

Tap 5, Elevation 1403 m
N 28°51.546, E 81°34.465

Tap 6, Elevation 1396 m
N 28°51.554, E 81°34.501

Tap 7, Elevation 1423 m
N 28°51.593, E 81°34.404

System 3 Nauladhara	
	
Intake, Elevation 1463 m N 28°51.526, E 81°34.331	Reservoir , Elevation 1393 m N 28°51.839, E 81°34.209
	
Tap 1, Elevation 1393 m N 28°51.839, E 81°34.209	Tap 2, Elevation 1325 m N 28°51.955, E 81°34.220
	
Tap 3, Elevation 1348 m N 28°51.920, E 81°34.258	Tap 4, Elevation 1310 m N 28°52.019, E 81°34.307

System 3 Nauladhara

Tap 5, Elevation 1345 m
N 28°51.914, E 81°34.310

Tap 6, Elevation 1342 m
N 28°51.944, E 81°34.326

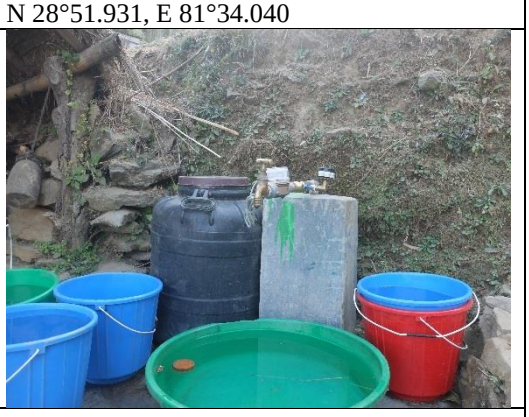
Tap 7, Elevation 1355 m
N 28°51.918, E 81°34.204

System 4 Koyashidara

Intake, Elevation 1397 m
N 28°51.981, E 81°33.784

Reservoir , Elevation 1372 m
N 28°51.931, E 81°34.040

Distribution chamber, Elevation 1347 m
N 28°52.008, E 81°34.025



Tap 1, Elevation 1347 m
N 28°51.964, E 81°34.173

Tap 2, Elevation 1352 m
N 28°51.968, E 81°34.165

Tap 3, Elevation 1351 m
N 28°51.969, E 81°34.163

System 4 Koyashidara

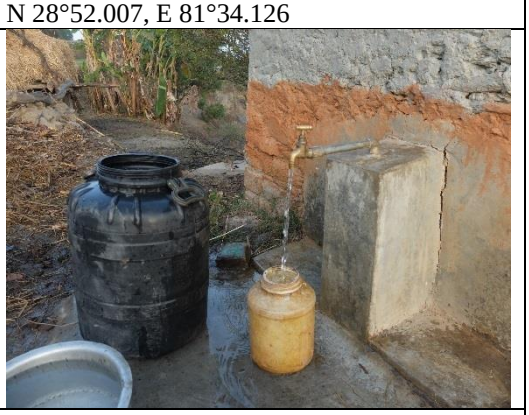
Tap 4, Elevation 1341 m
N 28°51.976, E 81°34.158

Tap 5, Elevation 1345 m
N 28°51.987, E 81°34.153

Tap 6, Elevation 1339 m
N 28°51.995, E 81°34.145

Tap 7, Elevation 1339 m
N 28°52.007, E 81°34.126

Tap 8, Elevation 1348 m
N 28°51.996, E 81°34.118



Tap 9, Elevation 1346 m
N 28°52.011, E 81°34.024

System 4 Koyashidara

Tap 10, Elevation 1336 m N 28°52.018, E 81°34.015

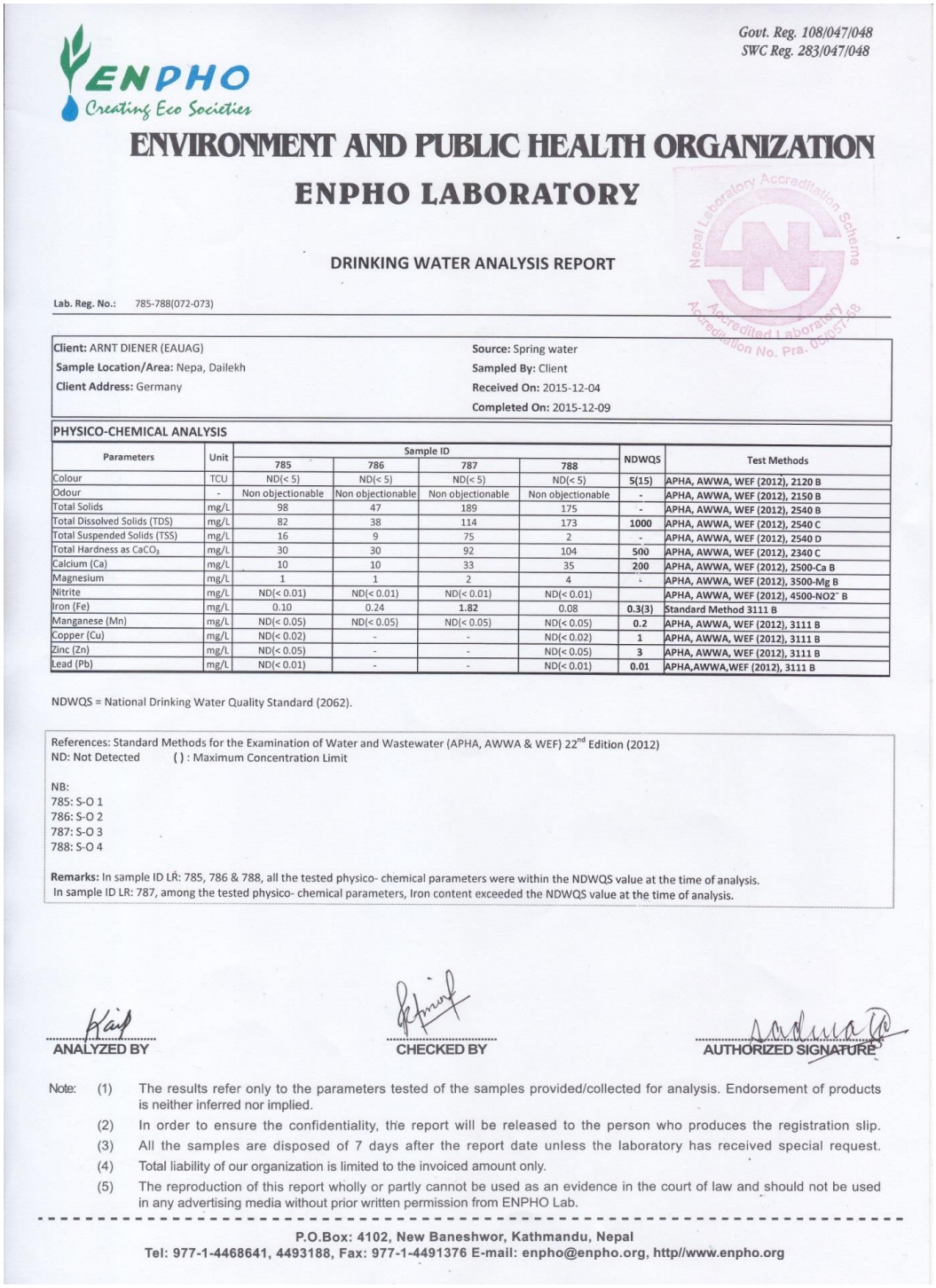
Appendix I. Nepal drinking water quality standards

S.N.	Category	Parameters	Units	Concentration Limits	Remark
1	Physical	Turbidity	NTU	5 (10)	
2		pH		6.5-8.5*	
3		Color	TCU	5 (15)	
4		Taste and Odor		Non-objectionable	
5		TDS	mg/L	1000	
6		Electrical conductivity (EC)	µs/cm	1500	
7	Chemical	Iron	mg/L	0.3 (3)	
8		Manganese	mg/L	0.2	
9		Arsenic	mg/L	0.05	
10		Cadmium	mg/L	0.003	
11		Chromium	mg/L	0.05	
12		Cyanide	mg/L	0.07	
13		Fluoride	mg/L	0.5 -1.5*	
14		Lead	mg/L	0.01	
15		Ammonia	mg/L	1.5	
16		Chloride	mg/L	250	
17		Sulphate	mg/L	250	
18		Nitrate	mg/L	50	
19		Copper	mg/L	1	
20		Total Hardness	mg/L as $CaCo_3$	500	
21		Calcium	mg/l	200	
22		Zinc	mg/L	3	
23		Mercury	mg/L	0.001	
24		Aluminum	mg/L	0.2	
25		Residual Chlorine	mg/L	0.1-0.2*	in systems using chlorination
26	Microbiological	E. Coli	MPN/100 ml	0	
27		Total Coliform	MPN/100 ml	0 in 95% samples	

* These values show lower and upper limits

( ) Values in parenthesis refers the acceptable values only when alternative is not available.

Appendix J. Chemical analysis result



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Accredited Laboratory
Accreditation No. Pra. 053/57

DRINKING WATER ANALYSIS REPORT

Lab. Reg. No.: 785-788(072-073)

Client: ARNT DIENER (EAUAG)
Sample Location/Area: Nepa, Dailekh
Client Address: Germany

Source: Spring water
Sampled By: Client
Received On: 2015-12-04
Completed On: 2015-12-09

PHYSICO-CHEMICAL ANALYSIS

Parameters	Unit	Sample ID				NDWQS	Test Methods
		785	786	787	788		
Colour	TCU	ND(< 5)	ND(< 5)	ND(< 5)	ND(< 5)	5(15)	APHA, AWWA, WEF (2012), 2120 B
Odour	-	Non objectionable	Non objectionable	Non objectionable	Non objectionable	-	APHA, AWWA, WEF (2012), 2150 B
Total Solids	mg/L	98	47	189	175	-	APHA, AWWA, WEF (2012), 2540 B
Total Dissolved Solids (TDS)	mg/L	82	38	114	173	1000	APHA, AWWA, WEF (2012), 2540 C
Total Suspended Solids (TSS)	mg/L	16	9	75	2	-	APHA, AWWA, WEF (2012), 2540 D
Total Hardness as $CaCO_3$	mg/L	30	30	92	104	500	APHA, AWWA, WEF (2012), 2340 C
Calcium (Ca)	mg/L	10	10	33	35	200	APHA, AWWA, WEF (2012), 2500-Ca B
Magnesium	mg/L	1	1	2	4	-	APHA, AWWA, WEF (2012), 3500-Mg B
Nitrite	mg/L	ND(< 0.01)	ND(< 0.01)	ND(< 0.01)	ND(< 0.01)		APHA, AWWA, WEF (2012), 4500-NO_2^- B
Iron (Fe)	mg/L	0.10	0.24	1.82	0.08	0.3(3)	Standard Method 3111 B
Manganese (Mn)	mg/L	ND(< 0.05)	ND(< 0.05)	ND(< 0.05)	ND(< 0.05)	0.2	APHA, AWWA, WEF (2012), 3111 B
Copper (Cu)	mg/L	ND(< 0.02)	-	-	ND(< 0.02)	1	APHA, AWWA, WEF (2012), 3111 B
Zinc (Zn)	mg/L	ND(< 0.05)	-	-	ND(< 0.05)	3	APHA, AWWA, WEF (2012), 3111 B
Lead (Pb)	mg/L	ND(< 0.01)	-	-	ND(< 0.01)	0.01	APHA,AWWA,WEF (2012), 3111 B

NDWQS = National Drinking Water Quality Standard (2062).

References: Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF) 22nd Edition (2012)
ND: Not Detected ( ) : Maximum Concentration Limit

NB:
785: S-O 1
786: S-O 2
787: S-O 3
788: S-O 4

Remarks: In sample ID LR: 785, 786 & 788, all the tested physico- chemical parameters were within the NDWQS value at the time of analysis.
In sample ID LR: 787, among the tested physico- chemical parameters, Iron content exceeded the NDWQS value at the time of analysis.

ANALYZED BY | CHECKED BY | AUTHORIZED SIGNATURE

Note: (1) The results refer only to the parameters tested of the samples provided/collected for analysis. Endorsement of products is neither inferred nor implied.
(2) In order to ensure the confidentiality, the report will be released to the person who produces the registration slip.
(3) All the samples are disposed of 7 days after the report date unless the laboratory has received special request.
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AuA | Springwater Analysis iPWS Nepal | Laboratory Dübendorf

Sample handed in: 07/12/2015

Results: 14/12/2015

AuA-Sample-Nr.	Labelling		DOC mg C/L	Conductivity µS/cm 20°C	pH	Alcalinity mmol/L	Total Hardness mmol/L	Chloride mg / L
1512035	System	1	<0.5	73	7.01	0.91	0.36	<0.5
1512036	System	2	<0.5	72	7.17	0.82	0.31	<0.5
1512037	System	3	<0.5	192	7.11	2.04	0.94	2.0
1512038	System	4	21.8	219	6.96	2.58	1.10	1.0

AuA-Sample-Nr.	Labelling		NO3-N mg N/L	Sulfate mg / L	Na mg/L	Mg mg/L	Ca mg/L	K mg/L
1512035	System	1	<0.25	<5	5.0	<2.5	9.3	<1
1512036	System	2	<0.25	<5	5.2	<2.5	8.9	<1
1512037	System	3	0.4	6	7.8	3.2	32.4	<1
1512038	System	4	<0.25	<5	9.1	5.5	34.0	<1