Master Thesis Report

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Evaluation of hazard classification systems of water source, sanitation facility and hygiene behaviour in determining drinking water safety

Systematic classification of hazard components coupled with microbial water quality analysis at sources and points of consumption in two rural sites in Thailand and Laos

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Challenge the future

Evaluation of hazard classification systems of water source, sanitation facility and hygiene behaviour in determining drinking water safety

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Abstract

The goal to provide safe drinking water for halve of the world population, formally assessed by the JMP of WHO and UNICEF, was the first MDG to be met. At face value, this is a cause for celebration particularly concerning health benefits. Worldwide, diarrhoea, the most serious disease burden attributable to unsafe water, is responsible for the death of about 3000 children per day. Yet it may be premature to celebrate if a more critical light is cast on the indicator system that is used in the JMP assessment. Essentially the JMP indicator approximates safe drinking water by categorising water supply system into improved or unimproved. The primary assumption is that the use of improved technologies equates access to safe drinking water. This assumption however has been challenged as an oversimplification of the complex realities surrounding the provision of safe drinking water. One of the main aspects that can be directly linked with health is the water quality. Does the improved technology consistently provide safe water? As it turns out, the JMP itself has found that on average 15-35% of the improved technology failed to deliver safe water at sources. In an environment where resources are limited, regular water quality assessment may not also be a feasible option. Furthermore, an entirely different indicator is also undesirable as it would not be compatible with the existing system. Thus, the question rises as to whether or not the current indicator system may be refined by including a more thorough inspection of the hazards that may be present at the water sources? Additionally, it was observed in the study population that manual handling of drinking water that involved collection, transport and storage at households was prominent. Depending on the sanitation and hygiene status of the users, manual handling may elevate the recontamination risk of drinking water at point of use (POU).

The study took place in two rural sites in Laos and Thailand. The preliminary visit in February 2012 served to gather primary information related to water, sanitation and hygiene practices. The main methods used were household questionnaires, sanitary inspection and spot observations. This initial hazard assessment involved 121 and 119 households in Laos and Thailand, respectively. A semi-quantitative hazard assessment method is then formulated to systematically evaluate hazards found at water sources and hazards attributable to sanitation facilities and hygiene behaviours. The water source evaluation is based on the sanitary inspection method recommended by the WHO that assesses the physical structure, operational parameters and external factors that may affect the quality of the water sources. Evaluation of sanitation facilities is based on availability of toilet and the sanitary conditions of the facilities. Hygiene is assessed through hand washing practices. Five hazard classes (very good, good, fair, poor, very poor) based on the semi-quantitative scoring system were then established for the study population. It was found that during the dry season, 80% of the Lao population was dependent of very poor water sources exhibiting high hazard levels. In Thailand, well above half of the water sources were categorised as of fair quality. Sanitation in Laos was also very poor with about 70% practicing open defecation. The hygiene behaviour was also relatively poor with the majority classified as fair or poor. These results are in contrast with the Thai population where large portion of the households owned toilet facilities in relatively good conditions and was also reportedly practicing better hand washing (about 75% scored very good).

The hazard scoring was subsequently compared to actual microbial quality analysis, performed using the standard Colisure/Quanti-tray 2000 method from IDEXX. In addition, paired samples were also tested using a recently developed *E. coli* enumeration method, the CBT by UNC, with the aim to compare the new method to the standard method. The microbial water quality testing was performed three months later in June, 2012 where roughly 30% of the initial households were selected according to the results of the hazard assessment. Water was sampled at both sources and points of consumption. Water quality data were statistically tested for correlations with the hazard classes. Water quality data at

sources were correlated with hazard classes of inspected water sources. Meanwhile, water quality data at points of consumption were correlated with sanitation and hygiene related hazards. The correlations found for the first analysis were only moderately strong (r_s:0.5; $p<0.01$) for Laos and not significant for Thailand. The sanitation and hygiene related hazards were found to have no significant correlation with water quality at points of consumption in both study sites. The results suggest that the hazard classification framework needs further improvement to reflect water quality data more accurately and consistently. Currently the method employs a uniform weighting system for all hazard components. However, a prioritisation of hazards may be beneficial in further refining the method. At the same time, the water quality data used were also relatively limited, spanning over only two periods of sampling. The variations in the water quality datasets may be a confounding factor in affirming the correlations.

In comparing the water quality data at sources and points of consumption, it was revealed that overall there was significant deterioration of water quality that may be attributed to handling practices. In Laos where sanitation and hygiene were considerably worse than Thailand, deterioration was markedly more prevalent. Comparisons of water quality based on various categories of handling practices, namely types of containers, container cover, modes of extraction, types of transfer devices, cleanliness and treatment, were also performed. It suggests that some of the handling practices lead to increased contamination. For instance, there is a trend that the mode of extraction that involved least hand-water contact, pouring or tap, was associated with less contamination than scooping. In Laos, cleanliness of containers was notably associated with lower contamination. This finding however does not hold in Thailand. Treatment, by boiling, was found to be effective in Thailand where no subsequent hand-water contact took place. In contrast, subsequent handling of boiled water was common in Laos and as a consequence the majority of the boiled water samples was found to be microbially contaminated.

With respect to the comparison between the CBT and the Colisure/Quanti-tray 2000 method, it was found that there is significant difference in the paired datasets. A major issue is that the sensitivities of the two tests were of different magnitude and this was not accounted for in this study. Thus it is likely that the power of the statistical test was undermined.

The main conclusions of this study is that the proposed method aimed to refine the indicator system gives minor indication that it may serve to reflect water quality more consistently, in particular with respect to the quality at water sources. As for the water quality at POU, the use of sanitation and hygiene status as indicator is far from consistent. Water quality issue at POU is mainly affected by the quality of the sources as well as various handling practices that may introduce recontamination. For future research, it is recommended that the assessment framework be refined by systematically prioritising the hazard. Whereas to better reflect quality at POU a more direct indicator such as the hazard related with handling practices has to be investigated. In addition, the approach needs to also be validated with the health impacts, which may be provided in collaboration with the DIADEN group. Finally, improving source water quality by opting for more protected sources followed by reducing hand-water contact can help to ensure water quality at POU.

Preface

This MSc report documents the results of my final graduation project in the Sanitary Engineering Section, focusing on the refinement of the indicator system in better reflecting drinking water quality at both source and point of use. This graduation project was enabled through the academic and financial supports from the Sanitary Engineering Section as well as the facilitation provided by the DIADEN research group from the Norwegian University of Life Sciences.

To start with, I would like to convey my gratitude to Prof. Gertjan Medema who had opened up the opportunity for me to work on this project when I approached him with the idea of setting up a study about developing countries. He was also an excellent mentor whose constant guidance I truly appreciate. Many thanks is also directed to the DIADEN research group, Prof. Thor-Axel Stenström, Dr. Hans Overgaard, Nsa Dada, Nanthasane Vannavong, and Razak Seidu, who had kindly accepted and assisted me throughout the research. Without their time and efforts, the project would not have been possible.

On the sites in Laos and Thailand, many individuals had been an important part of the project, directly or indirectly, to whom my gratitude goes to. The villagers who had been cooperative throughout the study periods and the fieldworkers whose assistances were crucial in enabling the data collection. The family of the village head in Laos whose hospitality had made my stay memorable. Mr. Bounsoung from the Manchakiri Health District who had generously provided an accommodation in the Thai site. The colleagues and friends from the Office of Disease Prevention and Control in Khon Kaen, Thailand, Dr. Kesorn Thaewnongiew, Jiralux Roberts, Khaew Rattana, Khun Kittiphit, who had helped tremendously in the practical arrangements of my research materials as well as welcoming me warmly to their city. The process of shipping the research materials to Thailand was also assisted by Prof. Theeraphap Chareonviriyaphap and Naritsara Malaithong. In Laos, the assistance of Thippakone Onesengphet in settling the border crossing procedure was greatly appreciated. My special thanks also go to Nsa and Anan who had in the beginning introduced me to the sites and the people, the latter lent his time in translating my questionnaires and the former was always patiently answering my urgent questions from the fields.

With respect to the research materials and equipment, I would like to thank the IDEXX representative in Amsterdam who had been responsive in providing the Quanti-tray Sealer, Colisure and the Quanti-tray 2000. Similarly, I would also like to thank the UNC group, Dr. Mark Sobsey and Douglas Wait who had provided the CBT.

In Delft where most of the reporting and formal arrangement of the project was carried out, I would like to thank Prof. Jules van Lier and Dr. Mark Bakker for their valuable inputs the report. At the same time, I would also like to thank Mieke Hubert and Jennifer Duiverman for their assistance in settling the financial and practical arrangements of the research. My thanks also go to the Lamminga Fonds that had allowed me to travel from Jakarta-Bangkok-Amsterdam.

Before concluding, I would like to sincerely appreciate the friendships of Shirin Malek Pour and Ravina R Binol. My stay in Delft would not have been so wonderful without them. My greatest appreciation finally goes to my parents and sisters whose love constantly strengthens me through thick and thin.

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List of abbreviations

CBT – Compartmentalized Bag Test

CFU – Colony Forming Units

CI – Confidence Intervals

DALY – Disability-Adjusted Life Years

DIADEN – Diarrhea an Dengue, a project led by the Norwegian University of Life Sciences

GLAAS – Global Analysis and Assessment of Sanitation and Drinking-Water

JMP – Joint Monitoring Project WHO/UNICEF

MDG – Millennium Development Goals

MPN – Most Probable Number

POU – Point of Use

RADWQ – Rapid Assessment of Drinking Water Quality

UNC – University of North Carolina

WSP – Water Safety Plans

1 Introduction

The Millennium Development Goal (MDG) 7 target number 10, “halving by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation”, is chiefly grounded on the notion of health improvement. For long, safe drinking water and basic sanitation have also been acknowledged as vital to human values and were justly formalised by United Nations in 2010 as basic human rights, legally binding upon States. Given its implications, the importance of the target cannot be understated. It is simultaneously recognized as a precondition for fruitful efforts in achieving overall MDG targets (WHO, 2012a).

As of March 2012, well ahead of the deadline, the World Health Organization (WHO) announced that the world has met its first MDG target in halving the proportion of the people without sustainable access to safe drinking water. This certainly is good news. For one, it stands to show that MDG targets are indeed achievable “with the will, the effort and the funds” as summarised by United Nations Children’s Fund (UNICEF) Executive Director. More importantly, the United Nations Secretary General pointed out that the role of MDG as a tool in improving the lives of the poorest is affirmed. Health gain is also claimed, particularly for children, in association with diarrhoeal diseases which are responsible for the death of about 3000 kids per day (WHO/UNICEF, 2012a).

At the same time, words of caution were also expressed, especially with respect to the remaining half which accounts for at least 11% of the world population or around 800 million people still without access to safe drinking water, of which the majority is presumably the poorest. UNICEF and WHO also recognised a major drawback of the current best-practice-monitoring by the Joint Monitoring Programme (JMP) which relies on technology types as proxy indicators. The technology type does not provide adequate pictures of the reality of drinking water access from source up to point of consumption (Payen, 2008). It does not account for the siting of water sources, the impact of groundwater pollution, pollution from wastewater or industry, the delivery of water in pipes, interrupted services, and the need for collection, transportation, and storage in the households (Pers. comm.,Stenström, 2012, WHO/UNICEF, 2011, WHO, 2011c). Those aforementioned factors affect an important aspect that is not directly measured by the current indicators, that is water quality both at source and in households (WHO/UNICEF, 2004).

Hence, the conclusion was that despite the good news, it is unwise to claim victory as greater challenges lie ahead. The effort has yet reached the most disadvantaged. It is also sensible to reiterate the lagged attempts in achieving the sanitation target. One of the most important underpinning notions in pairing the water and sanitation target is that inadequacy of one aspect might reasonably defeat the success of the other.

Finally, a shift of focus may be required while reflecting on the inherent value of the drinking water target, which is its health benefit. How could the available proxy indicators move toward more appropriate evaluation of health benefit? How could the global monitoring system provide a tangible contribution in ensuring drinking water safety at the point of consumption? In the 2011 thematic report on drinking water, the JMP Task Force has recognised the need to incorporate water quality into their monitoring system (WHO/UNICEF, 2011). The measurement of water quality at household level under normal usage conditions is valued as a critical entry point in emphasizing the link between drinking water quality and disease burden. The WHO has published series of guidelines on drinking water quality that aim at the protection of public health since 1983 with the current edition published last year (WHO, 2011b). In support of the WHO drinking water guidelines, an integrated approach for the management of the risks of water supply to public health has been proposed by Davison et al. (2005) widely known as the Water Safety Plans (WSP). It has been suggested by Davison et al. (2005) that adoption of WSP would also be vital in enhancing the confidence of policy makers and sector stakeholders that the MDG drinking water has been truly achieved.

This Master’s thesis research project was designed to address a key challenge posed by the current monitoring system of safe water that is on the water quality aspect and its health risk. The study was executed in two countries in Southeast Asia, Laos and Thailand. It is carried out as a separate project under the project "Link between Diarrhea and Dengue: Fecal contamination and dengue mosquito production in household water containers in Southeast Asia" (DIADEN) of the Norwegian University of Life Sciences. The research activities were funded by the Sanitary Engineering section of Delft University of Technology whereas the DIADEN project is financed by the Research Council of Norway. The latter began in 2010 with the general objective to understand the relationship between causes of diarrheal disease and dengue fever for the potential development of integrated disease control strategies. The project aims to assess health risks associated with household water storage management, contaminated drinking water, and Aedes aegypti production in household water storage containers (Overgaard, 2008) in rural and periurban settings in Thailand and Laos.

In the coming sections, background information, study objectives and a brief overview of the methodologies used in the Master's thesis research project are presented.

1.1 The challenges in the current MDG monitoring approach

At the moment, the WHO/UNICEF JMP is the only global task force issuing regular reports on worldwide coverage of safe drinking water and basic sanitation, thus effectively also in monitoring of the MDG progress. As pointed out earlier, the monitoring proxy used by the JMP is limited in its inference to water quality and even more problematic when health outcome is in question. In this section, the underlying assumptions shall be examined in order to clarify what the monitoring proxy actually represents.

The core assumption used is the water service level as the monitoring proxy for safe drinking water. In its earliest report, a binary classification of the water service level into improved and unimproved technologies was used (WHO/UNICEF, 2000). Essentially, the JMP water service level classification was drawn from experiences in the public health sector that suggest that the unimproved technologies are typically inferior to their counterparts (WHO/UNICEF, 2000). In the following table, the list of the technologies is presented.

Table 1.1 – The JMP monitoring proxy of improved and unimproved drinking water technologies (WHO/UNICEF, 2000)

Improved technologies	**Unimproved technologies**
Household connection	Unprotected well
Public standpipe	Unprotected spring
Borehole	Vendor-provided water
Protected dug well	Bottled water*
Protected spring	Tanker truck provision of water
Rainwater collection	

**) not considered improved concerning the limitations of quantity*

The water service level has undergone some revisions ever since. The first revision was made in the 2008 JMP report in the form of the "drinking water ladder" that classified the water service level into three: piped water on premises, other improved, and unimproved (WHO/UNICEF, 2008). This approach was reapplied in the 2010 report (WHO/UNICEF, 2010). The latest update of the drinking water ladder can be found in the 2012 report which further disaggregated the unimproved category into surface water and unimproved. For the first time, surface water is considered separately, accounting for water obtained directly from rivers, lakes, ponds, irrigation channels and other surface sources (WHO/UNICEF, 2012b). In this report, the unimproved technologies include unprotected dug wells, unprotected springs and water delivered by cart or tanker. The revisions were made in order to unmask relevant information that was disguised under the aggregated categories, enabling a more in depth interpretation of the data. In the figure below the evolution of the JMP data disaggregation can be seen.

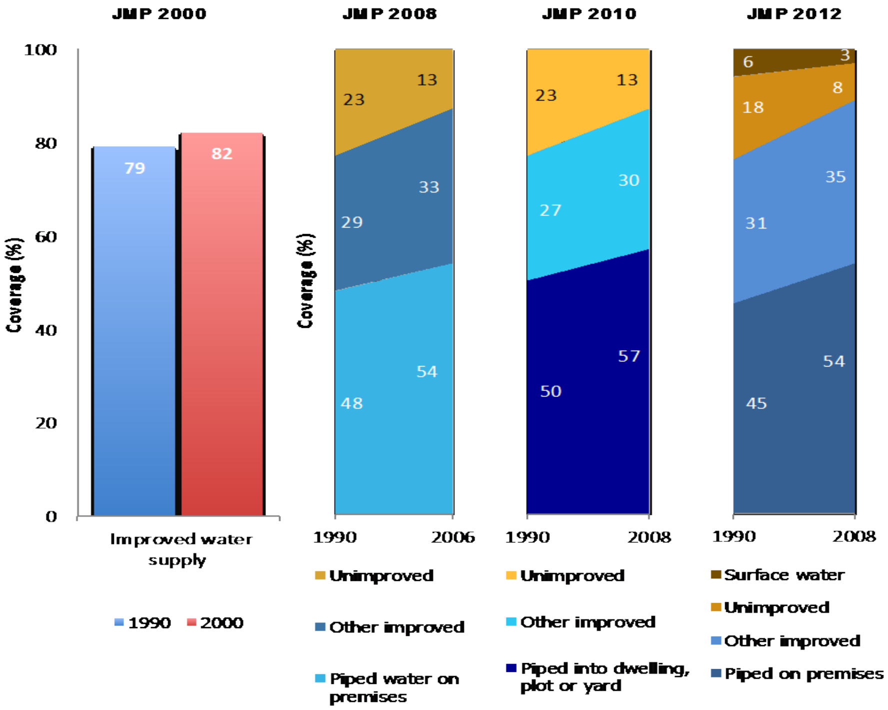


Figure 1-1 – The evolution of JMP data representations throughout the last decade (adapted from corresponding JMP reports)

As was discussed in detail in the thematic report issued by JMP in 2011 on drinking water (WHO/UNICEF, 2011), the concept of the water service level is extremely practical, however it does come with its own limitations. Here, the JMP addresses one of the main challenges that is the water quality by presenting the outputs of the pilot Rapid Assessment for Drinking Water Quality (RADWQ) approach conducted from 2006 to 2010. Measurements of various basic water quality parameters were completed in five countries: Ethiopia, Jordan, Nicaragua, Nigeria, and Tajikistan. Using microbial monitoring, compliances to the WHO guidelines were found to be variable for different types of technologies. For piped supplies, 89% of the samples were compliant; protected dug wells were only 43% compliant, the least of all. Protected springs and boreholes/tubewells were respectively 63% and 69% compliant. This implies that the reported improved access coverage has to be corrected. For the five countries where the RADWQ surveys were conducted, the corrections range from 7-16% reduction in coverage levels. If applied globally, this would mean the current JMP figure is significantly overestimated (WHO/UNICEF, 2011).

Despite general acknowledgement among experts and the scientific community on the limitations of the methods (Payen, 2008, Schäfer et al., 2007, Sutton, 2008), the JMP reported coverage remains useful in measuring progress. However, excessive emphasis on the achievement of the MDG target based on this limited monitoring proxy has to be discouraged. In reality, greater extent of improvement is still needed. Much will be at stake especially if critical efforts in future implementation, monitoring and investments are diverted from involved stakeholders as the illusory target may overrule actual achievement i.e. “the real danger of slippage against the MDG target” as pointed by UN-Water in the latest Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) report (2012b). Although global political and financial commitment have been made since 2010, “in many cases, political will has not yet catalysed the enabling environment required to spur progress and planning is not supported by adequate information and data.” (UN-Water, 2012a).

At this stage, it is clear that the monitoring proxy needs to be refined. It has to be taken care that such working definitions do not fall short as being too general - thus reducing the implications - as well as being too specific which may render them impractical. The limitations of current JMP indicators were reported in the 2006 Human Development Report (Payen, 2008) as:

> "What emerges from research across a large group of countries is that patterns of water use are far more complex and dynamic than the static picture presented in global reporting systems. Real-life patterns constantly adjust to take into account concerns of water quality, proximity, price and reliability."

Similar views were also voiced during the First Consultation on Post-2015 Monitoring of Drinking-Water and Sanitation that was held in Berlin in May 2011 (WHO, 2011c). There, Payen (2012) also suggested that taking all criteria into account, the lack of access to safe water is likely to be closer to 3 billion than the estimated 800 million. Without improvement, he argued that the indicators would remain obsolete for field practitioners.

The key challenge in addressing water quality with respect to the monitoring of safe water access is the main interest of this study. In the field of policy-making, it has been suggested that adopting a preventive risk management approach will contribute in safeguarding water quality and its health impact (UN-Water, 2012b). This approach is what is essentially recommended in the WHO *Guidelines for Drinking-Water Quality* (WHO, 2011b) where there are three main components to safeguarding drinking water as can be seen in the first-tier of the framework in Figure 1-2.

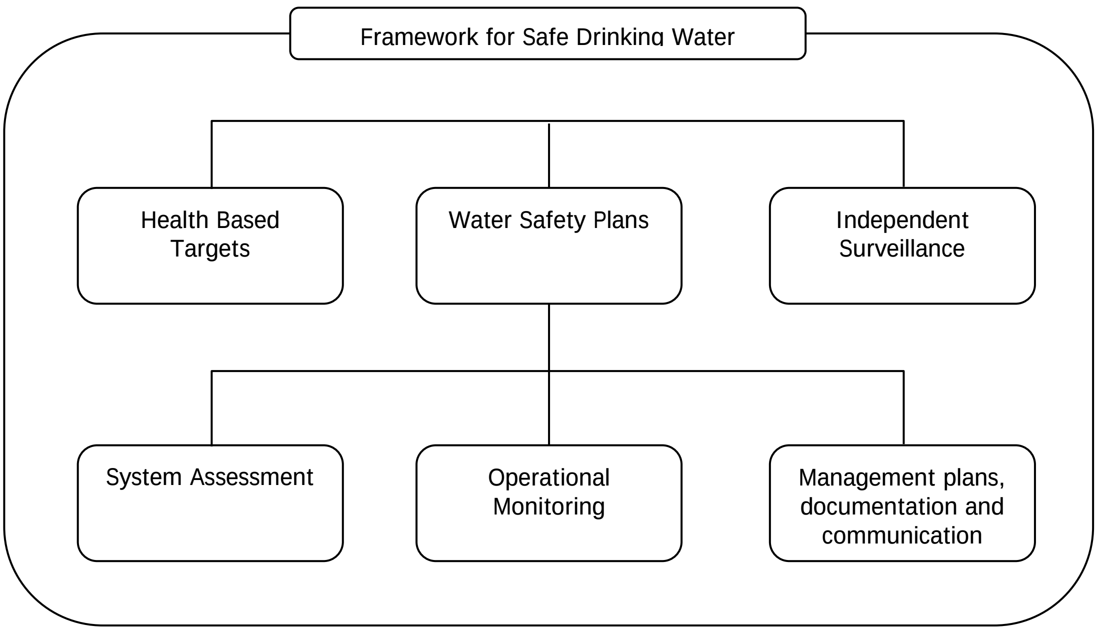


Figure 1-2 – Framework for safe drinking water (Davison et al., 2005)

The second-tier in the framework is an expansion of what consists of Water Safety Plans. Fundamentally a system assessment and management approach, the WSP is a practical tool for practitioners (e.g. policy-makers, water suppliers) to describe a water supply system, identify and assess hazard and risks analytically in order to come up with concrete measures to prevent source contamination, remove contamination with additional treatment if necessary and subsequently prevent recontamination during storage, distribution and handling of drinking water (Davison et al., 2005). Globally, there has been increasing efforts in water safety planning as reported in the GLAAS 2012 report. The survey results (Figure 1-3) show that particularly in the Southeast Asia region and the Western Pacific, a number of countries have made notable progress (UN-Water, 2012b).

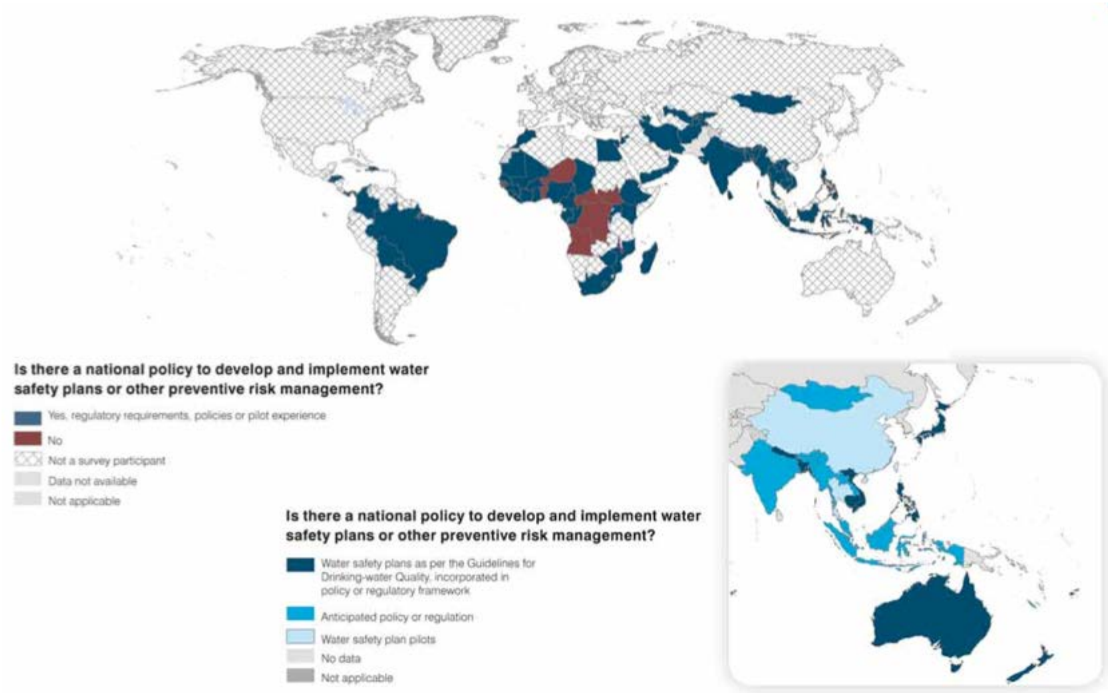


Figure 1-3 – The presence of a national policy to develop or implement water safety plans (UN-Water, 2012b)

Given the evidence of the global momentum in WSP adoption, it is not too far-fetched to investigate if the output of the WSP could be used conjointly as valuable inputs to the monitoring system of the MDG target. One of the main outputs of WSP that has the potential in serving this purpose is the basic risk assessment framework that sought to identify potential hazards in the water supply system and rank the health risks accordingly.

1.2 Health impact of unsafe drinking water

The principal health risks associated with consumption of unsafe drinking water is microbiological by nature (WHO, 1997). Generally speaking, pathogens of human faecal origin are the main concern. Enteric infections such as infectious diarrhoea are the disease types that are most frequently associated with water (Medema et al., 2003). Globally, it is also the most serious burden of disease associated with unsafe water, sanitation and hygiene. Annually 1.6 million deaths due to diarrhoea is attributable to this risk factor, which is comparable to 4.1% of worldwide disease burden (WHO, 2004a). Approximately 90% who suffer are children under 5, mostly in developing countries. It is the fourth leading risk factor that causes death in low-income countries (WHO, 2009). An illustration of global child mortality due to the aforementioned cause is presented in Figure 1-4.

Disease burden attributable to water, sanitation and hygiene is most severe in regions where there are high mortality patterns such as in African and parts of South East Asia (WHO, 2009). In the South East Asia region where this study was conducted, WHO reported that about as much as 8.5% of deaths is due to diarrhoea (WHO, 2000). The recorded Disability-Adjusted Life Years (DALYs) and mortality attributable to water, sanitation and hygiene in Lao PDR per 100,000 inhabitants are 1240 and 40 respectively. In Thailand, DALYs of 264 and mortality of 12 per 100,000 inhabitants were documented (WHO, 2004b).

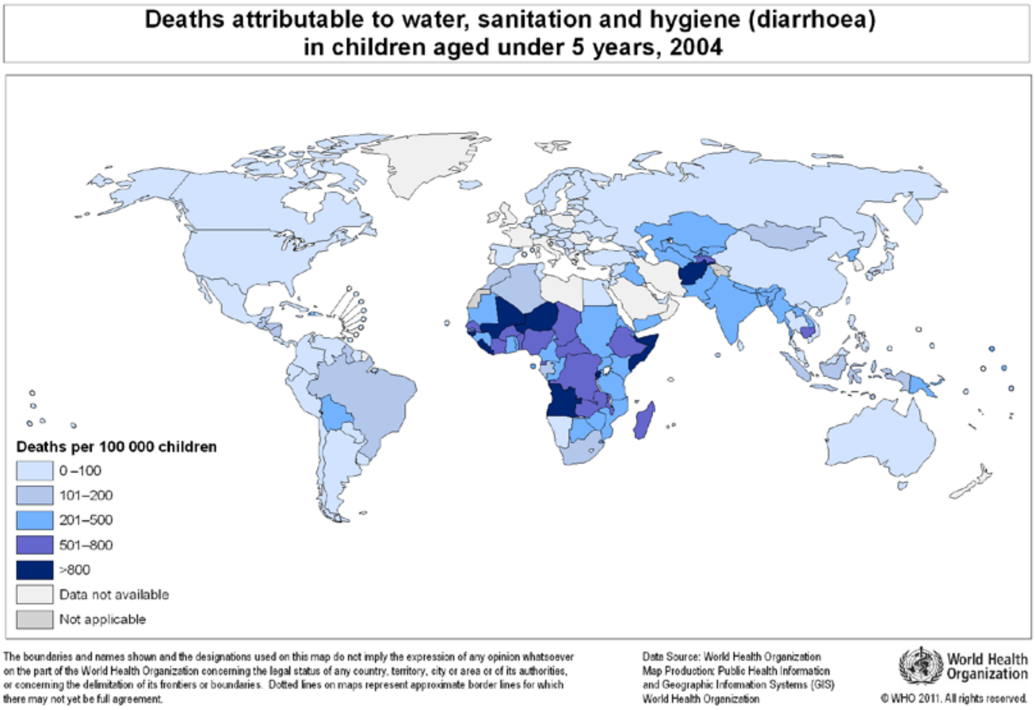


Figure 1-4 – Child mortality attributable to unsafe water, sanitation and hygiene (WHO, 2011a)

Besides diarrhoea, Fewtrell *et al.* (2007) summarised a number of other diseases related to water supply, sanitation and hygiene, namely malnutrition & consequences of malnutrition on most infectious diseases, intestinal nematode infections, schistosomiasis, trachoma, and lymphatic filariasis. A separate group of diseases that is related to water resources management includes malaria, onchocerciasis, dengue, and Japanese encephalitis.

The transmission pathways of pathogens through the faecal-oral routes and their relationships with water, sanitation and hygiene can be illustrated by the F-diagram (Figure 1-5). As shown, water, sanitation and hygiene serve as barriers against the complex transmission pathways. In this scheme, drinking water mainly plays the role of one of the mediums, in which waterborne pathogens of faecal origins can be transmitted from external sources to human hosts, which may then potentially manifest as illnesses (Fewtrell et al., 2007). Removal of faeces from environment is firstly affected by the provision of sanitation facilities such as toilets. Secondly, hygiene behaviour plays the role of ensuring safe handling of food and water. Lastly, treatment of drinking water also acts as a barrier in removing the pathogens from drinking water prior to consumption.

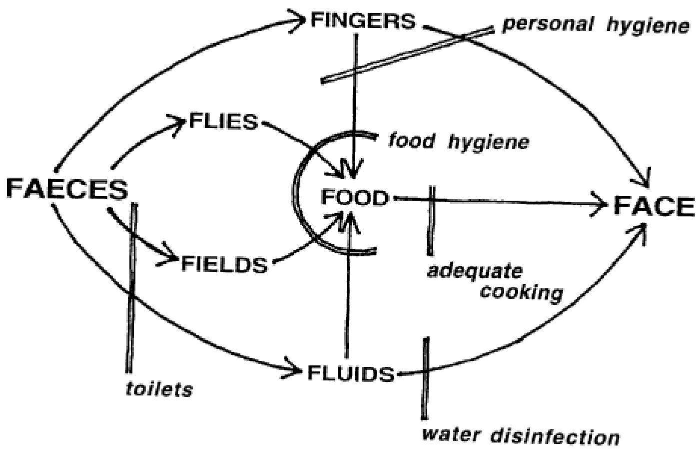


Figure 1-5 – F-diagram: Barriers on faecal-oral transmission pathways (Esrey et al., 1998)

With respect to the relative risk of unsafe drinking water in comparison with the other exposure pathways, the WHO has suggested that "where waterborne disease contributes to a measureable burden, reducing exposure through drinking-water has the potential to appreciably reduce overall risks of disease" (WHO, 2011b). As indicated previously, this is particularly applicable in less developed countries, where Hunter in Medema et al. (2003) estimated that a significant portion (about 33%) of intestinal infections is waterborne.

Health improvement achieved through the reduction of diarrhoea incidence has also been shown in numerous studies. With respect to safe drinking water at points of consumption, a comprehensive review was published in 2005 from 15 selected studies, estimating that the overall relative risk is 0.61 (CI 0.46-0.81) when comparing population with higher water quality to the controls (Fewtrell et al., 2005). The reduction in diarrhoea frequency is estimated at about 31% (reduction from other intervention methods: hygiene 37%, sanitation 32%, water supply 25%, multiple interventions 33%), which is greater than had been reported in earlier reviews. The improvement may be attributed to recent studies that measure the actual water quality at the point of consumption as opposed to quality at sources (Pruss-Ustun et al., 2008).

At last it is still relevant to reiterate the importance of accounting water, sanitation and hygiene as an integral measure in combatting diseases. More so, in underdeveloped regions where variable services and behaviours are frequently present, improvement of drinking water quality, for instances, can be readily undermined by poor sanitary conditions (VanDerslice and Briscoe, 1995).

1.3 Water quality: Source vs. Point of consumption

In a concluding remark of the previous section, it has been suggested that drinking water quality is influenced by various factors. From source up to the point of use (POU), drinking water may be contaminated in several ways. First of all, depending on the source types, a water body may be polluted by sewage discharge, agricultural runoffs, animal faeces, direct human waste, industrial discharge, seepage from onsite latrines, seawater intrusions, household wastes or other sources of contamination having access to the water body. Next, the control measures available in the water supply system (e.g. protection of source, treatment steps, prevention of recontamination during storage, distribution and handling) determine the final quality supplied to / consumed by users. The steps in safeguarding water quality from catchment to consumer are summarised in Figure 1-6.

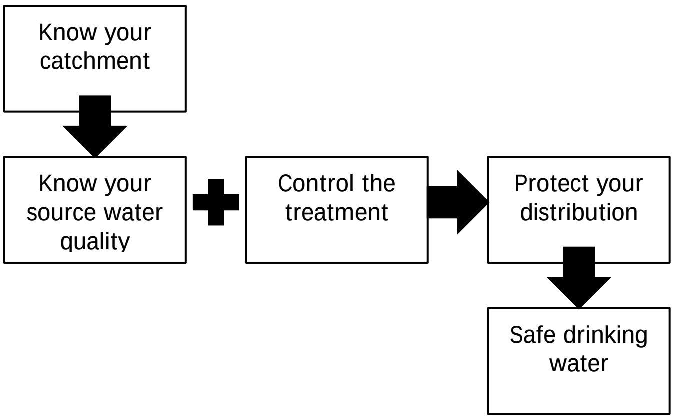


Figure 1-6 – "Catchment to consumer" approach to risk management of the safety of drinking water (Medema et al., 2003)

For conventional water supply system (i.e. piped system), the supplier typically concerns itself with the water quality that leaves the treatment units and occasionally the quality that leaves the networks. Depending on how reliable the entire chain of the water supply system is, the quality that is consumed by users may vary. However, when reviewing the water quality as a proxy to health impact, arguably the quality at point of use is the main concern. Water supplied to the users may be recontaminated depending on the handling practices involved in obtaining the water for drinking. With respect to this, household water management, sanitation and hygiene status of the users are critical in ensuring drinking water quality at point of consumption. For small community water supplies, such as those predominantly found in the study areas, experience has shown that the risks of contamination is even more elevated (WHO, 2012c). This is because small community water supplies are generally more irregular in nature and relatively limited in resources for appropriate management efforts. Furthermore, specifically in the less developed regions where small community water supplies are more applicable, the relation between drinking water quality and lagging sanitation provision and poor hygiene may be ever more relevant.

In the study areas, the main water supply system is point sources such as dug wells, rainwater harvesting systems, boreholes and surface water, where users are required to collect water at the source, transport and store it in their houses. During the dry season, the majority of the population in Laos mainly depend on a few unprotected dug wells situated at some distances away from the dwellings. Transport time varies between 10 to 50 minutes. Alternatively, in the rainy season, the Lao study population shifted to using rainwater. In the Thai study site, most houses depend on a private rainwater collection system, which consists of one or more large rain-jars (about 2000 litres in volume each). This source is utilised throughout the year in Thailand.

When relying on point sources, manual collection, transportation and household storage of drinking water are inevitable. This means that at household and personal levels, particularly where sanitation facility and hygiene behaviours are poor, there is an increased likelihood that user handling practices may contribute to recontamination (Robertson et al., 2003). Accordingly, it has been shown in various instances that water quality significantly decreases from source to household (Pinfold et al., 1993, Genthe et al., 1997, Roberts et al., 2001, Clasen and Bastable, 2003, Robertson et al., 2003, Trevett et al., 2004, Wright et al., 2004, Trevett et al., 2005, Gundry et al., 2006, Hoque et al., 2006, Oswald et al., 2007, Eshcol et al., 2009, Elala et al., 2011).

Mixed results, however, have been found on which risk factors may be associated with the increased recontamination. A number of studies have shown that storage types, which limit hand contacts, were definitely associated with better water quality (Hammad and Dirar, 1982, Pinfold et al., 1993, Roberts et al., 2001, Hoque et al., 2006). The study by Pinfold et al. is particularly interesting within this context, as it was performed in rural Northeast Thailand where rain-jars were popular. It was found that physical height of the jars, availability of working taps and mosquito net coverings were significantly associated with better water quality. Similar suggestions are given by the WHO in promoting safe household storage by using containers with narrow openings and dispensing devices such as spouts or taps/spigots in order to protect drinking water from direct contact with hands, dippers, or other faecally contaminated mediums (WHO, 2012b).

Especially with regards to hand-water contact, it has been suggested by Trevett et al. (2005) that there is strong evidence indicating that hand-water contact is a key contributor in drinking water recontamination. There are other similar findings reported on the link between hand contact and reduction of water quality (Feachem, 1978, Blum et al., 1990, Pinfold, 1990, Hoque et al., 1995, Roberts et al., 2001, Trevett et al., 2005, Pickering et al., 2010).

Some works (Young and Briscoe, 1987, Genthe et al., 1997, Trevett et al., 2004) show that source water quality was the primary determinant of the final water quality at household levels. They found that even after recontamination, water originating from a source with superior quality still ended up having a better quality compare to water that originated from low-quality source. However, these sources with initial low bacterial counts were also experiencing greater decline in quality when recontamination occurred (Wright et al., 2004).

There were also others (VandDerslice & Briscoe, 1993 in Trevett et al. (2004)) who have instead found improvement in water quality. This was plausible as bacterial die-off might have occurred or knowledge gap in the actual water management practice might have confounded the findings (Trevett et al., 2004).

In response to the need to address the various risk factors responsible for recontamination of drinking water between collection and consumption, Trevett et al. (2005) has developed a conceptual framework. They have classified the risks into primary and secondary factors. The primary factors consist of handling practices, hygiene behaviours (exclusively referring to hand washing) and sanitary environment, whereas secondary factors refer to socio-economic characteristics and anthropological values. The primary factors are in line with other findings suggested in aforementioned works.

In view of the WSP approach, a water supply hazard assessment framework that is based on sanitary surveys approach, handling practices, hygiene behaviours and sanitation facilities shall be employed as the starting points in characterising the study population in this research.

To conclude with, it has to be acknowledged that the paradigm in drinking water provision has to expand, not to neglect the actual water quality that is being consumed by users. Too often, the efforts stop at countable numbers and types of water supplies, especially when such target as the MDG is concerned. It is premature, to say the least, to be contented at this point by the MDG achievement. In contrast, it is timely to strive for a better approach in safeguarding drinking water quality and its associated health benefits.

1.4 Research objectives and framework

The main objective of the study can be summarised in the following question:

> "How can the key safe water monitoring challenge be addressed to reflect more closely drinking water quality at point of consumption and its associated health impact?"

It is hypothesised that a refined classification system for water sources, sanitation facilities and hygiene behaviours representing potential hazards of faecal contamination of drinking water can be utilised to address this research objective.

A working framework of the research can be seen in Figure 1-7. The boxed items are the main topics studied in this research. It is important to note that the "Health impacts" is not directly addressed in this study because the disease data input was externally collected by the DIADEN project and further collaborations is still needed to consolidate the results. Therefore, the microbial water quality is used as an intermediate proxy in establishing the correlations among the research topics. The items connected with dotted lines are the methods used in data collection.

In parallel with the framework, the following research questions are formulated:

1. What are the characteristics of the study population based on their water supply system, sanitation facilities and hygiene behaviour?
2. What are the classifications of the study population based on the potential hazards of the water sources, the sanitation facilities and the hygiene behaviour?
3. How well do the water source, sanitation facilities and hygiene behaviour classes correlate with each other?
4. How well do the water source classes correlate with microbial water quality at water source?
5. How well do the sanitation facilities and hygiene behaviour classes correlate with microbial water quality at POU?
6. Does the water quality significantly change between source and POU?
7. How do the changes relate to various household drinking water management practices?
8. How do the water source hazard classes relate to the current JMP water service level?
9. Overall, how well does the proposed approach manage to indicate water quality at point of consumption as a proxy for health impact?

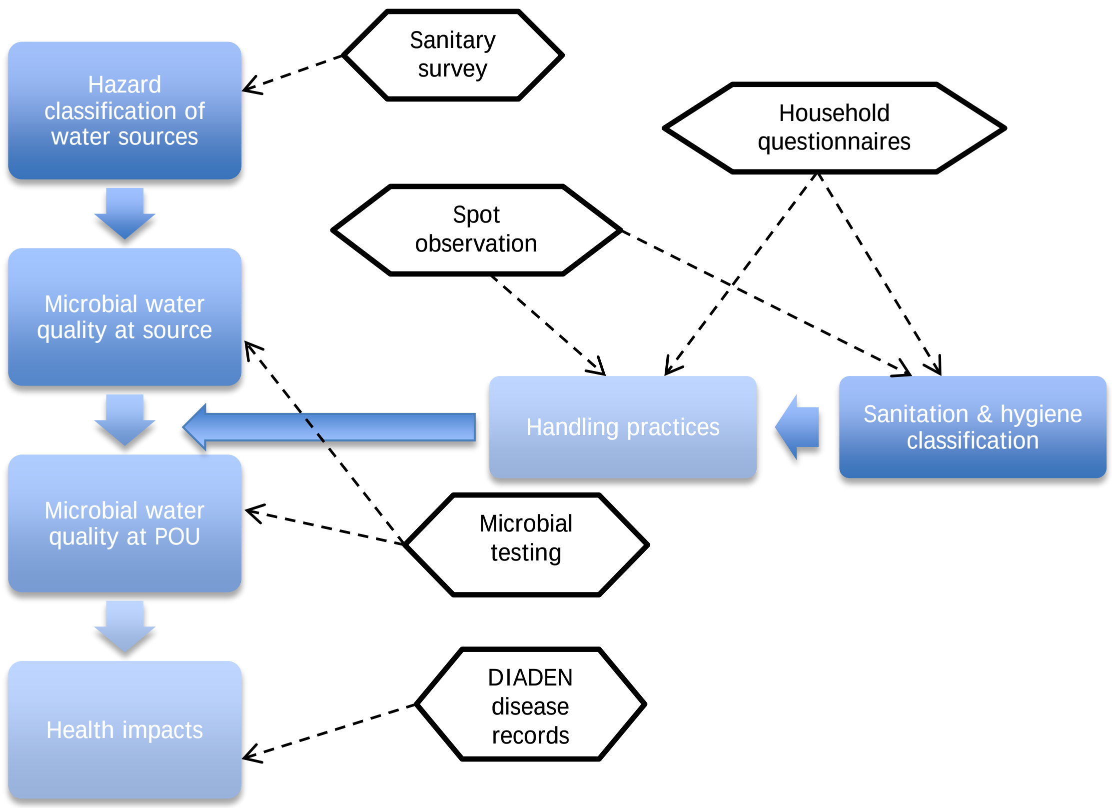


Figure 1-7 – A diagram of the research framework

In addition, the study also has a secondary objective that is to compare a newly developed *Escherichia coli* quantification method, the Compartment Bag Test (CBT), with a standard method from IDEXX, the Quanti-tray 2000.

As a whole, the research is envisioned to contribute to the existing knowledge on drinking water quality at point of consumption as well as to facilitate a better approximation of the water service level indicator used in the current monitoring system of the MDG target on safe water. Ultimately, the main issues raised in this study are expected to favourably direct future efforts on more crucial and rigorous research on the elucidations of the key mechanisms that influence drinking water safety at user's point and the ultimate health impact.

1.5 Overview of research methodologies

The research methodologies shall be explained in more detail in the corresponding chapters. This overview is presented to recap the complete methodologies that were employed to collect necessary information used in the data analysis.

The research officially commenced at the end of January 2012 during the DIADEN Midterm Workshop in Khon Kaen, Thailand. Simultaneously, a preliminary research proposal was discussed and updated under supervision of the DIADEN research group and Prof. Gertjan Medema. It was decided to divide the research into two phases. The first phase was aimed at collection of primary information about the water supply, sanitation and hygiene characteristics of the selected study areas. Following this, data analysis was performed in order to determine a focal issue to be investigated further. The first phase was conducted from January until April 2012. In the second and final phase, a follow-up fieldwork session (June 2012) was carried out to gather data on microbial water quality on selected households. In May 2012, a preparatory session for the fieldwork took place. After the final data collection, new analysis was carried out in July up to mid August 2012.

During the first preparatory phase, it was decided to narrow down the study areas to two sites, from the four study sites that were part of the DIADEN research focus. In the DIADEN project, the sites were classified into two peri-urban and two rural sites. Based on elementary knowledge of the study sites, initial study objectives and general recommendations from the DIADEN project, the rural sites were selected. In Laos particularly, it represents a largely under-serviced areas, where water sources are predominantly unimproved and sanitation facilities were largely lacking. The Thai site has more improved services both in terms of water supply and sanitation facilities.

In order to gather the primary data, household questionnaires, sanitary inspection and spot observations were conducted in the first phase of the study. Sanitary inspection of water sources was principally based on the WHO drinking water quality guideline volume 3 on surveillance of water supply system (WHO, 1997). The sanitary inspection was performed in order to identify potential elements of hazards at and around water source points that may compromise microbiological quality of the water. Household questionnaires were designed according to the WHO/UNICEF recommendations on drinking water and sanitation core questions for household surveys (WHO/UNICEF, 2006) and an existing questionnaire template used in the DIADEN project. With the questionnaires, general household characteristics and practices related to water, sanitation and hygiene were collected. In addition to this, household observations were also conducted aiming to consolidate some of the information gained from questionnaires. Spot observations were particularly aimed on household water management practices and, conditions of private sanitation facilities and key elements that indicate hygiene practices.

The first data collection period lasted for approximately 4 weeks, including provisional activities related to practical arrangement of the fieldwork. In each study site, 130 households were registered as participating in the DIADEN project. It was thus aimed to interview and visit all participating households for the primary database. Similarly, sanitary inspection was also planned for all identified water sources. In practice, there were several households that were excluded because house owners were absent at the time of visit. The results of the preliminary data collection shall be discussed further in the corresponding chapter.

Afterwards, the information gathered was analysed for hazards components on water sources, sanitation facilities and hygiene behaviour. The analysis was aimed to characterise the population into a number of hazard categories, to determine classes representing the health risk associated with water supply, sanitation and hygiene behaviour and see if these are correlated. The classifications were established on a semi-quantitative hazard assessment framework that is explored in details elsewhere in the report.

These hazard classes were utilised for the sample selection strategy in the second research phase, where the microbiological water quality of the sources and household containers was assessed. During the design of the sampling program, a more specific objective was also shaped that was to determine drinking water quality changes between water source and point of consumption. Limited by time and resources, only a portion of the original population could be sampled for water quality verification. Respectively, 31% and 28% of the original population in Laos and Thailand were sampled. A stratified sampling strategy was employed in order to distribute the samples across the pre-determined hazard classes.

The water quality sampling strategy was then designed for the selected household samples and their corresponding water sources. The principal method used was the IDEXX Colisure® Quanti-tray method for *E. coli* quantification. Another recently developed method for *E. coli* quantification from the University of North Carolina, USA, the CBT was also used concurrently. This test is specifically designed for settings similar to this study and as pointed out in the research objective the main aim of the analysis is to compare the CBT method against the IDEXX method.

E. coli was chosen as an indicator organism because it is specifically of faecal origins. This is the recommended standard faecal indicator organism to determine faecal contamination of drinking water. According to the WHO guideline, *E. coli* must not be detectable in any 100-ml sample for all water directly intended for drinking (WHO, 2011b).

Typically, the sampling strategy called for water sample collection from the final household containers (from which water is fetched for drinking) and from all corresponding sources. Duplicate samples were taken at each sampling point. With respect to spatial variation at certain water sources, particularly those with larger water bodies, multiple samples from different locations were collected. Finally, to account for short-term temporal variations, a repeat sampling was performed three days after the initial sampling.

In addition to microbial quality, turbidity measurement was also performed on site with a portable turbidimeter.

The water quality data were then analysed statistically to determine the significance of any changes in *E. coli* counts from water source to point of consumption. Water quality data at points of consumption were also related with the source water classifications. Correlations between the water quality data and the sanitary survey classification were also analysed statistically. All of the analysis mentioned before were strictly performed on the basis of the *E. coli* counts analysed using the standard method, Quanti-tray 2000 IDEXX. Finally, a statistical comparison between the CBT and IDEXX methods was performed using the ISO 17994 method (2004).

1.6 Reading guide

This report consists of eight main chapters. The contents are summarised in the Table 1.2.

Table 1.2 – Reading guide of the report

Chapter	Contents
Chapter 1 Introduction	General overviews of the research background, objectives, study framework and methodologies.

Chapter 2 First-phase research methodolog	Detail on the methodologies used for data collection and data analysis during the first study phase (January-April).
Chapter 3 Primary characteristics of study populations: water supply systems, sanitation facilities and hygiene behaviours	General descriptions of the study population based on their water supply system, sanitation facilities and hygiene behaviours
Chapter 4 Hazard assessment of water sources, sanitation facilities and hygiene behaviours	Application of the semi-quantitative assessment framework to classify the study population based on water source hazard, sanitation facilities and hygiene behaviours.
Chapter 5 Second-phase research methodology	Detail on the methodologies used for data collection and data analysis during the second study phase (May-August).
Chapter 6 Microbial water quality at sources and points of consumption	Data analysis of the microbial water quality at source and point of consumption coupled with the hazard classes
Chapter 7 Discussions	Interpretation of the main findings in light of existing knowledge and methodological limitations.
Chapter 8 Conclusions and recommendations	Conclusions and recommendations based on the main findings.

2 First-phase research methodology

The following methodologies are used to collect primary data concerning the water supply systems, sanitation facilities, hygiene behaviour and other relevant information about the households in the selected study areas. The data collection methods are principally tailored to gather essential information that would be compatible with the hazard assessment framework explained in Section 2.4. Nonetheless, the process was iterative and throughout the data collection period, some circumstantial alterations to the initial framework were also made where appropriate. This was especially true in various cases of sanitary inspections and spot observations where it was found that local conditions were unforeseen. In this report, the modified versions of the data collection forms are presented in the Annexes.

2.1 Household questionnaires

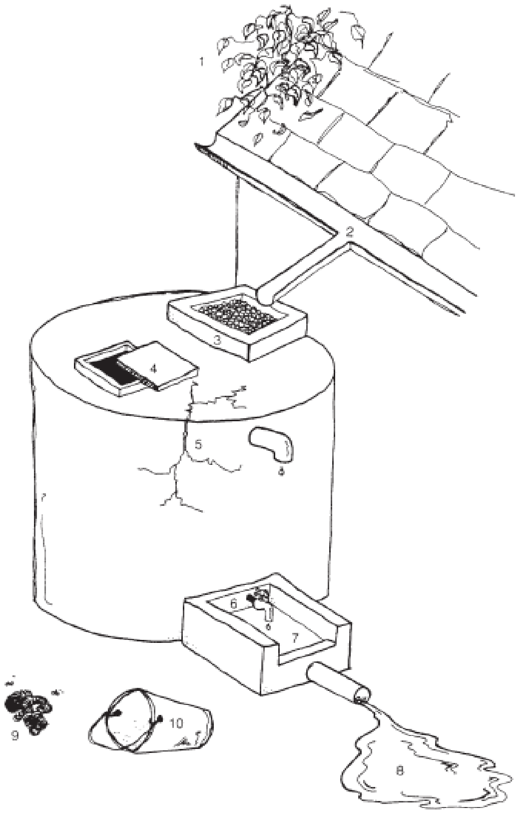
The questions were developed to obtain illustrative information on drinking water practices, sanitation and hygiene behaviours of the study population. The questionnaires used in this study were mainly based on the existing questionnaire template used in the DIADEN project as well as the WHO/UNICEF recommendations on drinking water and sanitation core questions for household surveys. General information about the household such as name, house number, number of family members and number of children under 5 years old were also collected. Questions on household drinking water practices revolve around the types of source, distances when manual collection is performed, times involved, amount of water collected, storage practices (e.g. container types, covers, cleaning of containers), alternative sources, practices in fetching drinking water and treatments. On sanitation and hygiene, twelve questions were composed and asked regarding toilet practices of the household, ownership of toilets, collection of faeces, final removal methods, and hand washing practices.

The questions were firstly drafted in English language and were translated into Thai and Lao languages by Nanthasane Vannavong, a PhD student tin the DIADEN project and a citizen of Laos. Examples of the questionnaire forms can be found in Appendix A. In the translated version of the questionnaire, some of the questions were omitted (can be seen as English texts). The questions were omitted as they are not relevant for the study areas as suggested by Vannavong (Pers. comm., 2012).

In practice, the interviews were conducted by a few local volunteers that were trained previously by the DIADEN group. In Laos, the interviews took place at the house of the village chief where the heads of the households were invited for short interviews during the course of 2 days. In Thailand, houses were visited separately accompanied by two trained volunteers and the interviews were conducted at the houses. The whole process took approximately 3 days to complete.

2.2 Sanitary inspection

Sanitary inspection was carried out to collect information about the water supply and sanitation systems. Sanitary inspection, as defined by WHO, refers to a devised on-site inspection and evaluation of all kind of risk factors that may undermine the service of water supply system, thus posing potential health concerns for the consumers. Inspection serves to identify potential hazards while water quality analysis provides evidence of contamination and its intensity (WHO, 1997). For different types of water sources, examples of survey forms have been compiled by WHO. An example of one such inspection form developed by WHO can be seen in Figure 2-1 below. These forms were refined according to the local situation in the study area. The final forms used here can be seen in Appendix B.



I Type of facility RAINWATER COLLECTION AND STORAGE

1. General information: Health centre ....
   Village ....
2. Code no.—Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken?....... Sample no. .... Thermotolerant coliform grade ....

II Specific diagnostic information for assessment — **Risk**

1. Is there any visible contamination of the roof catchment area (plants, dirt, or excreta)? Y/N
2. Are the guttering channels that collect water dirty? Y/N
3. Is there any deficiency in the filter box at the tank inlet (e.g. lacks fine gravel)? Y/N
4. Is there any other point of entry to the tank that is not properly covered? Y/N
5. Is there any defect in the walls or top of the tank (e.g. cracks) that could let water in? Y/N
6. Is the tap leaking or otherwise defective? Y/N
7. Is the concrete floor under the tap defective or dirty? Y/N
8. Is the water collection area inadequately drained? Y/N
9. Is there any source of pollution around the tank or water collection area (e.g. excreta)? Y/N
10. Is a bucket in use and left in a place where it may become contaminated? Y/N

Total score of risks .... /10

Contamination risk score: 9–10 = very high; 6–8 = high; 3–5 = intermediate; 0–2 = low

III Results and recommendations

The following important points of risk were noted: .... (list nos 1–10) and the authority advised on remedial action.

Signature of sanitarian ....

Figure 2-1 – An example of sanitary inspection form on a rainwater harvesting system developed by WHO (WHO, 1997)

The forms were designed to enable direct quantification of hazards using a semi-quantitative method of assessment. The hazard identification forms were developed for three types of water sources identified in the study areas: rainwater harvesting, unprotected dug wells and boreholes. In additions, other relevant information about the system such as dimensions, materials, and equipment were also noted. Photographs were also taken serving as future references.

In Laos, the households which reported the use of private rainwater harvesting system were visited individually in order to inspect the condition of the sources. This was performed simultaneously with spot observations. Other types of water sources which were not located at residential areas were visited on a number of separate occasions during the course of 1 week of fieldwork. In Thailand where the majority reported the use of rainwater, the source inspections were conducted together with spot observations.

2.3 Spot observations

Spot observations were aimed at consolidating information obtained from the household questionnaires. The lists of things that were checked during the visit are compiled in one form (see Appendix C).

The first part concerns the conditions of the toilet facilities. The observations were performed essentially in the same manner as the sanitary inspection of water sources, where the conditions of the system were judged using a set of common parameters that reflect how well the system is used by people.

To reaffirm the reported hand washing practices, two parameters were checked: the availability of hand washing facilities near the toilet (e.g. wash basins, buckets, or other types of facilities which may supply water) and availability of soap in the toilet.

In addition, drinking water practices were also observed at the houses. For example, types of storage tanks were recorded, as well as types of lids, sufficiency of lids, number of storage tanks, types of POU receptacles, or scooper types. Other relevant information such as cleanliness of the equipment, water turbidity (visibility check) and presence of animals was also noted.

2.4 Semi-quantitative assessment framework

The data collected from the above mentioned methods were primarily used to characterise the study population and as input to a hazard assessment framework. A semi-quantitative framework is used in this study. The method is considered appropriate as the numerical classifications allow for a relatively consistent comparison (FAO/WHO, 2009).

The assessment framework closely follows the simple diagnostic scoring system proposed by WHO in the sanitary inspection method. It has been assumed that the quantified hazards would be proportional to contamination risks. The severity in this case is not defined, as little information can be obtained with respect to relative probabilities on the health outcomes. This method was applied in establishing the assessment frameworks for water source hazards, hazards in sanitation facilities and level of hygiene behaviours.

2.4.1 Framework of assessment for water source hazards

The most important safety aspect in drinking water provision is the microbial safety. Without proper siting, collection method and treatment, ground water, rainwater and surface water may pose increased risks of microbial disease. Except for bottled water, all the water sources used by the households in the study areas were potentially contaminated with pathogens and consumption could be unsafe especially taking into account that the majority of the households did not treat their drinking water prior to consumption.

According to the WHO, a sanitary hazard may be represented by a fault which may reduce water quality and is related to the physical structure, operation and external environmental factors that are affecting a water supply system. There is an increasing likelihood of contamination to occur as more faults are found in a system (WHO, 1997). Based on this concept, the water source hazard components were categorized into four: 1) Physical structures; 2) Operational method of water collection; 3) External environmental factors and 4) Water quality indicator. The latter is a supplementary criterion that is based on visibility check of water turbidity as an indicator for water quality. The detected hazard components were then scored, allowing for objective grouping of the water sources based on the likelihood of contamination. For rainwater harvesting system, as most houses own a private system, the assessment shall be conducted for each discrete system.

In the following sections, the scoring system for the hazard categories and the classifications of the water sources based on the detected hazards are elaborated.

<u>Hazard-scoring system for water sources</u>

Physical structure of a system is judged based on the totality and functionality of the basic components that should constitute an adequately designed infrastructural support at the water source that would minimize the probability of water quality deterioration, in particular with respect to its microbial quality.

To preserve (or improve) the water quality, *proper operational methods in water collection* should also be performed together with adequate maintenance of the physical structures.

The presence of *external environmental factors* that may pose risks of faecal contamination to the system, such as a latrine, animal faeces, rubbish, or stagnant water, shall also be incorporated in the hazard assessment framework.

Although a quantitative analysis of the water quality is not yet available, a rudimentary parameter of *turbidity* based on visibility check is also considered as one of the components in the sanitary survey. This assumes that visibly turbid water would have potentially lower quality than relatively clear water source. The main criteria for turbidity assessment were cloudy appearances and coloured water.

For each specific water source, the hazard components were compiled accordingly. Distinct hazard scales were also assumed for a few hazard components. Assumptions for the modified hazard scales shall be detailed in the respective assessment found in Section 4.1. As a general scoring rule, the minimum score for a recognised hazard is assigned at zero (0). This means that the hazard was not detected during inspection. When the hazard was detected, the hazard score is 1. Overall, the score for each hazard in individual categories (physical, operational, environmental, water quality) is added to produce a hazard score per category.

In the *physical structure* category, the hazard score is assessed for two parameters, the availability of the component and the condition in which the component was found. In the case that the physical structure was present but was found in inadequate conditions (broken or defective) the score shall be added with 1. When the recommended physical structure was unavailable altogether, a score of 2 shall be given.

The *operational category*, as mentioned before, consists of the water extraction method and maintenance of physical structures as the hazard components. The hazard that may be introduced by improper operations is categorised into serious, intermediate, and low with a corresponding score of 2, 1, and 0, respectively. The underlying rationalisations of the hazard scale for the operational category are presented in Table 2.1. Some modifications are due for a few water sources and are explained in Section 4.1 for under the respective assessment.

Table 2.1 – Underlying rationalisations of hazard scale for operational category

Hazard	Rationales
	Water extraction method
Serious	The use of personal tools or equipment (e.g. buckets, containers, hoses, etc.) by individual users that may introduce external contaminants. Method that requires direct entry of users into the water body is also considered a serious hazard.
Intermediate	The use of onsite tools or equipment (e.g. bucket & rope) that may contaminate the water source indirectly through user handling of the equipment.
Low	The use of mechanised pump that eliminates direct entry into the water source as well as indirect contamination caused by equipment handling.
	Maintenance of physical structures
Serious	There are indications that the physical structures have been completely neglected i.e. dirty super-structures, damages that paralyse the system. Within the local context, a large proportion of non-existent physical structures also fall under this category.
Intermediate	There are indications that the physical structures have been partially neglected i.e. dirty super-structures, sign of damages that may not have major impacts on the functionality.
Low	There are indications that the physical structures have been maintained thoroughly and regularly i.e. clean & functional super-structures (no signs of damages or potential contaminants).

The next hazard category is the *external environmental factors* that are assessed according to detected potential contaminants as well as the proximity of the hazards to the water source. Recommended safe distances of external environmental factors for a specific water source are detailed in the corresponding section. The lowest score, 0, is assigned when no potential hazard was detected during visit. The level of hazard increases by 1 when hazard was detected but it was situated in the safe zone. A score of 2 corresponds with a detection of hazard with close proximity (as defined by the minimum safe distance) to the water source. As for the rainwater system, this was assessed on the basis of proximity to the rainwater storage tanks. In assessing the safe distance, generic guidelines as recommended by the WHO have been consulted. Within the scope of this study, local assessment of the hydrogeological situations was not feasible.

The last category in the water source hazard assessment framework is the *water quality indicator*. The lowest score for this category is set at 1 (relatively clear) and the highest score is 2 (turbid). A zero is not applied because the water quality indicator is not definitive i.e. although the water may appear clear it does not follow that microbial hazard has been eliminated. Water can be categorised as turbid when it has cloudy appearances and discernible colours.

A summary of the basic hazard scale for all water-source-related-categories can be seen in Table 2.2.

Table 2.2 – Summary of basic hazard scales for water source assessment

Hazard category	Score
Physical structure	
Existing physical structure in adequate condition	0
Existing physical structure in inadequate condition	1
Non-existent physical structure	2
Operational	
Low hazard	0
Intermediate hazard	1
Serious hazard	2
External environmental factors	
No detected external environmental factor	0
Detected external environmental factor at safe distance	1
Detected external environmental factor at unsafe distance	2
Water quality indicator	
Relatively clear water	1
Turbid water	2

<u>Classification system for water sources</u>

Once the score for each of the hazard components described earlier has been determined, the water sources are classified according to the detected hazard levels. To enable comparative assessment across the varying frameworks, a normalised score system is applied. This simply means that instead of comparing the absolute values of the accumulated hazard scores, the mean ratio of hazard for all four categories is calculated.

The ratio of hazard in each category can be easily obtained by dividing the total hazard score by the maximum score achievable in that particular category. The final classifying value is then calculated as the average of the ratios obtained in all hazard categories.

In this proposed framework, the water sources shall be classified into five qualitative levels: very poor, poor, fair, good and very good. The maximum hazard level that can be achieved is 100%. Meanwhile, the minimum hazard corresponds with 12.5%. This goes back to the scoring system (Table 1.2) where it can be seen that instead of 0, the water quality indicator has a minimum score of 1 i.e. the minimum ratio of hazard in this category is set at 50%. An average of three 0% hazard and one 50% hazard gives 12.5%. Thus, the range of the hazard ratio will fall between 12.5% to 100%. A system with five classes that have equal distribution results in the following hazard intervals (Table 2.3).

Table 2.3 – Classification system of water sources

Source classification	Interval of mean hazard ratio
Very good	12.5% - <30%
Good	30% - <48%
Fair	48% - <65%
Poor	65% - <83%
Very poor	83% - 100%

2.4.2 Framework of assessment for sanitation facilities

The assessment framework for the sanitation facilities is applicable for individual households that participated in the questionnaire rounds. In Table 2.4, the assessment components are presented. Firstly, the determining questions provide a general status of the toilet facility in the household or lack thereof (open defecation). If open defecation is detected, the highest hazard score of 12 shall be given. Shared toilet comes next with a score of 11. This comes with the assumption that ownership of a toilet facility makes it more likely that faeces are disposed in its place. However, the likelihood of dysfunctional toilet may not be neglected and so a privately owned toilet facility shall further scored by assessing 11 parameters as shown in Table 2.4. Positive answers mean reduction of hazard scores. An initial hazard value of 11 shall also be used which implies that if a private toilet presents all the hazard factors, it shall obtain the same score as a shared toilet. The range of score for private toilets is thus between 0-11. The lower the hazard scores, the better the facilities are. A summary of the score intervals and their corresponding qualitative assessment can be found in Table 2.5.

Table 2.4 – Assessment framework of sanitation facilities

	SANITATION ASSESSMENT	
	Main questions	**Answer**
1.	Is there private toilet facility?	y
2.	Is the toilet shared?	n
3.	Is open defecation practiced?	n
	Assessment of toilet facility	
1.	The toilet appears to be used by the family	y
2.	Any member of HH still do open defecation	n
3.	Toilet door is not broken or missing	y
4.	Toilet door is closed	n
5.	Toilet walls are clean	y
6.	Toilet floor is clean	y
7.	Toilet does not smell badly	y
8.	Toilet seat is clean	y
9.	There is toilet cover	n
10.	There are no flies around toilet	y
11.	The ground around the toilet is not muddy	y
	Scoring of sanitation facility	
	Positive score	8
	Initial hazard score	11
	Total sanitation facility score	**11-8 = 3**
	Class	**Very good**

Table 2.5 – Classification system for sanitation facilities

Sanitation hazard score	Classfication	Types of facility
0 – 2	Very good	Private toilets
3 – 6	Good	Private toilets
7 – 10	Fair	Private toilets
11	Poor	Shared/Private toilets
12	Very poor	Open defecation

2.4.3 Framework of assessment for hygiene levels

The assessment of the hygiene level in the study population is principally based on hand washing practices. The hygiene level is determined based on five basic parameters that were assessed using inspection and responded by individual households in the questionnaire, namely:

1. The availability of a hand washing facility near the toilet
2. Provision of soap for hand washing after toilet use
3. Reported hand washing after toilet use
4. Reported hand washing before eating
5. Reported mode of hand washing (water only or with soap)

For the first two parameters, a score of 0 or 1 was given corresponding to no and yes, respectively. This principle is also applied for hand washing before eating (Table 2.6). Hand washing after using toilet is checked against the availability of a hand washing facility near toilet (Table 2.7). If, for example, the household responded with yes, but no hand washing facility was observed during the visit, a score of 2 was given. The score will increase to 3 if both parameters were answered yes. The lowest score, zero, was given when the respondent did not report hand washing after toilet use, regardless of the availability of a hand washing facility, since it is quite likely that the facility was not used to that effect. In the case where the facility was not observed close to the toilet, there is a possibility that the householders may wash hands elsewhere in the house. The assessment of the reported mode of hand washing is dependent on the provision of soap and the reported hand washing after toilet or before eating. The comprehensive scoring method in assessing the parameter is presented in Table 2.8.

Table 2.6 – Assessment of hygiene parameters: Framework I

Parameter assessment I		
Parameters	**Answer**	
	Yes	**No**
1. Availability of hand washing facility	1	0
2. Provision of soap	1	0
3. Hand washing before eating	1	0

Table 2.7 – Assessment of hygiene parameters: Framework II

Parameter assessment II			
Precondition	**Hand washing after toilet**		
Availability of hand washing facility	**Yes**	**Sometimes**	**No**
Yes	3	2	0
No	2	1	0

Table 2.8 – Assessment of hygiene parameters: Framework III

Parameter assessment III						
Precondition I			**Mode of hand washing: Water**	*Precondition II*		**Mode of hand washing: Water + Soap**
Hand washing after toilet	*Hand washing before eating*	*Initial score*		*Provision of soap*	*Additional score*	
Yes	*Yes*	2	**2**	*Yes*	1	**3**
				No	0	**2**
Yes/Sometimes	*No*	1	**1**	*Yes*	1	**2**
				No	0	**1**
No/Sometimes	*Yes*	1	**1**	*Yes*	1	**2**
				No	1	**1**
No	*No*	0	**-0**	-	0	**0**

According to these frameworks the maximum score that can be obtained is 9. And it shall be used as a starting score in calculating the level of the hand washing practices. An example of such assessment can be seen Table 2.9. The hygiene level shall be classified into five classes: very good, good, fair, poor, and very poor respectively corresponding with score intervals of 0-1, 2-3, 4-5, 6-7, and 8-9.

Table 2.9 – An example of hygiene assessment

	HYGIENE ASSESSMENT	
	Household status	**Answer**
1.	Availability of hand washing facility	No
2.	Provision of soap	No
3.	Hand washing after toilet	Yes
4.	Hand washing before eating	Yes
5.	Mode of hand washing	Water
	Assessment	
1.	Availability of hand washing facility	0
2.	Provision of soap	0
3.	Hand washing after toilet	2
4.	Hand washing before eating	1
	Precondition I – starting score	*2*
	Precondition II – additional score	*0*
5.	Mode of hand washing	2
	Scoring	
	Assessment score	5
	Initial score	9
	Final score	**9-5=4**
	Level	**Fair**

3 Primary characteristics of study populations: water supply systems, sanitation facilities and hygiene behaviours

3.1 Study sites and population

In this section the information obtained from the questionnaires, sanitary inspection and spot observations is summarised to describe the study population. The selected population was located in two rural locations in Laos and Thailand. In Laos, Okad village situated in Salavanh province was selected (A pin drop in Figure 3-1). In Thailand, Ban Waileum village in the Manchakiri district was studied (B pin drop, Figure 3-1).

Figure 3-1 – Geographical locations of the study sites (Google map, 2012)

In Table 3.1 below, the general properties of the study areas can be seen. In both villages, the same numbers of households were included in the study. The population in Okad, Laos is somewhat larger than in Waileum, Thailand. In both places, agriculture is the main occupation. The difference observed during the visit was that the Thai village was a more compact community where houses were clustered in one designated area. The houses in the Lao village were more scattered, especially the farm houses which were located at some distances from the main road.

Table 3.1 – General properties of the study site

Properties	**Okad, Laos**	**Waileum, Thailand**	**Unit**
Number of households	130	130	households
Total population	696	459	capita
Average occupants per household	5.35	3.53	capita/household
Occupancy rate ≤ 2.5 persons/room	80	97	households
In percentage	*61.5*	*74.6*	%
Occupancy rate > 2.5 persons/room	50	33	Households
In percentage	*38.5*	*25.4*	%
Occupation			
• Agriculture	95.4	88.5	%
• Commerce	2.3	1.5	%
• Service	2.3	3.1	%
• Others	-	6.9	%
Education level			
• Primary school	89.2	88.5	%
• Junior secondary school	3.1	2.3	%
• Senior secondary school	2.3	6.9	%
• Tertiary	-	0.8	%
• Others	5.4	1.5	%

Generally the houses in the Thai site were of better constructions than those in Laos. Traditional houses of both places are built from wood structures where the living place is reserved above ground level (Figure 3-2: left) and the ground level mainly serves as kitchen and guest receiving area. The houses in Okad, Laos were of this nature. In Thailand, most of the traditional houses had been refabricated and built on brick and cemented constructions and many of the ground floor areas were also closed with walls or partial walls (Figure 3.2: right).

Figure 3-2 – Left: Traditional Lao and North eastern Thai houses (McMorrow, 2007); Right: Refabricated tradition houses in Thai study site (Overgaard, 2008)

3.2 Water supply, sanitation and hygiene

In the coming section, details on the water supply systems, sanitation facilities and hygiene behaviours of the study population are presented. A general note that should be added is that the numbers of the households visited in the period of the fieldwork were less than those reported initially. In Laos, only 121 households were visited and in Thailand 119 houses. In the Lao village, some of the householders emigrated to Thailand and a few were out on vacations. In the Thai site, there were a few cases where two houses with different house numbers actually belonged to one owner. And in this case they were merged as one in the database. Finally, as the visits were planned on limited period, absence of householders due to work/outings or other activities during the visiting hours exclude them from the study population.

3.1.1. Water supply systems

In this section, the data collected with regard to the water supply systems in both villages are presented. The main focus is given for drinking water supply. However, some basic information on non-drinking water supply is also included.

Water sources

During the first fieldwork in February which coincided with the dry season, the reported drinking water sources in the Lao village consisted of five categories: unprotected dug wells, rainwater collection systems, boreholes, surface water and bottled water. Figure 3-3 depicts the population distributions (in percentages) for each source category. The rundown of the number of users can be seen Table 3.2.

Table 3.2 – Numbers of users for each drinking water source in Okad, Laos

Main DW source	Numbers		
	Households	People	Children <5 years old
Unprotected dug well	94	526	66
Sang Tieng	85	479	64
Nong Ta Kai	1	5	1
Houay Lam Phong	2	8	0
Temple	3	17	1
Other	3	17	0
Rainwater	11	74	8
Borehole	3	15	1
Surface water	2	12	0
Bottled water	11	73	11

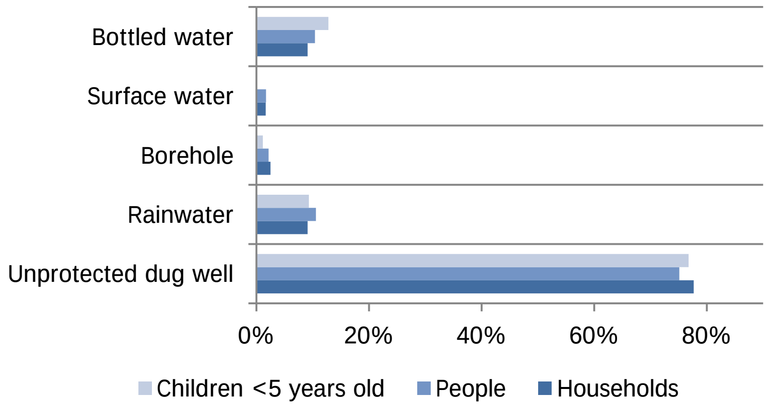


Figure 3-3 – Population distribution in Okad, Laos based on drinking water sources

<u>Unprotected dug wells - Laos</u>

Four of the unprotected dug wells were identified during the fieldwork. The main source was called Sang Tieng (pictured in Figure 3-4). About 90% of the unprotected dug well-users relied on this source. The other three, Nong Ta Kai, Houay Lam Phong and Temple were serving limited numbers of households. These four dug wells were inspected. The other three households reported using 'other' dug wells were not visited due to the relatively far distance and time constraints.

Figure 3-4 – Main unprotected dug well in Okad, Laos – Sang Tieng

Figure 3-5 – Nong Ta Kai: an unprotected dug well in Okad, Laos

The main dug well, Sang Tieng, was a relatively large open dug well with a diameter of about 2.5 m and a depth of about 3 m. The water table fell to about 1-2 m deep? during the dry season although according to the locals, it never fell dry. As can be seen in the picture, this dug well featured almost no protection, except for some fencing with barb wires which were also not sufficiently protective. Water in the well was also noticeably turbid which might be attributed to the ingress of organic matter (leaves, plants, etc.) and soil. The well was located in a farming area and it was adjacent to a fishpond that was filled only in rainy season. During the sanitary inspection, animal faeces, most possibly cows, could be found in close proximity to the water source. The well was privately owned by a farmer and occasionally the owner would also receive water orders from some villagers which would cost about 5000 LAK (50 euro cents) per 200-litre-drum. The access to the well was very poor and took about 40 minutes (return trip) from the main road by motorcycle. The road was made of red soil and sands in some areas hence quite difficult to navigate. Normally villagers would use their tractors to transport the water. The practice of water collection in the well was direct water extraction using the containers.

In terms of its dimensions the Nong Ta Kai (Figure 3-5) dug well was comparable to Sang Tieng. It was slightly bigger in diameter (3-4 meters). It was however more remote and more difficult to access than the former, which led to low usage. A return trip with motorbike took almost 1 hour on a relatively narrower road than the one going to Sang Tieng. The well was located in a wooded area. Water was also turbid and contaminated by organic materials. During the inspection no faeces was detected close to the well. Similar to Sang Tieng, water collection was also performed by directly entering the well mouth and scooping out water using water containers.

The two other dug wells, Houay Lam Phong (Figure 3-6) and Temple (Figure 3-7), were much smaller hand-dug wells with diameters of around 0.5 and 1 m, respectively. These dug wells were located on the banks of dried rivers and were only functional during the dry season. No physical reinforcement or protection was built to support the wells. The stagnant water on the hole was visibly turbid and very likely to be organically contaminated (floating leaves, branches, etc.). It has been reported that during normal collection procedure, the stagnant water would first be emptied and fresh water flowing out of the well would be collected. The access to Houay Lam Phong took about 30 minutes round trip by foot to the nearest houses. The Temple took about 10 minutes round trip.


Figure 3-6 – Small unprotected dug wells in Okad, Laos: Houay Lam Phong (left); Temple (right)

Rainwater collection systems - Laos

All of the households reporting rainwater as their main drinking water source owned private rainwater collection systems. The most common rainwater collection systems consisted of a roof catchment or corrugated iron (CI) sheets (Figure 3-7), which was followed by several rain-jars. With the roof catchment, rainwater was collected simply by placing the rain-jars directly below the edge of the roof, often without any additional supporting tools (e.g. gutters or pipes). The CI sheets pictured in 3-8 were not in use, however when the rainy season came, they were erected in a downslope on top of the rain-jars supported with some wooden beams. Variations in numbers of rain-jars and types of rain-jars did exist. Of the 11 rainwater collection systems, 6 houses were using medium size earth jars (about 250 litres in volume) to store the rainwater and the remaining was using large concrete jars (about 2000 litres in volume). On average, each household owned about 2 rain-jars. Most of the rain-jars were covered although from time to time it was noted that the covers appeared to be insufficient. Collection of water from rain-jars varied between scooping with household storage containers and filling from tap.

Figure 3-7 – Examples of rainwater collection systems in Okad, Laos: CI & medium earthen jars (left); A large concrete jar fitted with a tap (right)

<u>Boreholes - Laos</u>

For the borehole users, one household was using a private surface-mounted-centrifugal-pump for its borehole (shall be designated as mechanical boreholes for future references) and another household, a communal handpump borehole. A mechanical borehole is pictured in Figure 3-8, a property of the sample household. Originally, it was reported that two mechanical boreholes were used by two different households. However, during the second phase of the fieldwork, it was found that only one of the boreholes was used for drinking by both houses. The mechanical borehole was reported to be 14 m deep. A centrifugal pump was in use and was fitted with a tap. A concrete platform was also available which was rectangular 1.5 x 1.5 m in dimensions. The drainage of the area however was poor, stagnant water may be seen in close proximity. The borehole was also used for other non-drinking purposes such as showering, cooking, washing, etc.

The communal handpump borehole as pictured in Figure 3-9, was located in the centre of a residential area. The borehole was most commonly employed for non-drinking purposes and only one household was using it for drinking water purpose. The borehole was well constructed, possessing all of the essential physical elements that could ensure water quality protection. However, the maintenance was not carried out properly. The well platform was littered with garbage, mostly packaging of soaps, shampoos or detergents. Furthermore, stagnant water resulting from the drainage was found just outside the fenced area. About 10-15 m away from the handpump, there was also a pit latrine.

Figure 3-8 – A mechanical borehole in Okad, Laos

Figure 3-9 – The communal handpump borehole in Okad, Laos

Surface water - Laos

Surface water was reportedly used by two households. There were two ponds identified in the areas. One of them is owned privately and the other was accessible by public. Both were located in farm areas. Figure 3-10 shows the private pond and the farm pond. Both ponds were of about 20 m wide and were quite shallow (about 10-20 cm). Water was brown, obviously of high suspended solids and organic contents. During inspection, in the farm pond, herd of cows were bathing in the water. Collection of water from ponds were performed by simply extracting the water with containers.

Figure 3-10 – Surface waters in Okad, Laos: Private pond (left); Farm pond (right)

Bottled water - Laos

The last type of drinking water source in Okad was bottled water (Figure 3-11) which was used by 11 households. Most of the houses were using plastic gallon-bottles as their containers. Water was supplied by a refill centre. Only 2 households were buying smaller volume bottled water (600 ml or 1.5 litres bottles).

Figure 3-11 – An example of a gallon-bottled water

Water for non-drinking purposes - Laos

In the Okad village, water for non-drinking purposes was mainly drawn from boreholes (97%). The majority of the households owned private boreholes. In houses where toilets were absence, showering and washing generally took place on the well platforms. The fact that ownerships of boreholes were quite high was surprising and counterintuitive. Especially when considering that people did actually prefer to drink water from the unprotected dug wells which was noticeably more turbid in appearances as compared to water from the boreholes. Upon inquiries, it was disclosed that they found the taste of the borehole water to be unpalatable, possibly due to its mineral contents.

Alternative water source in Laos

One final thing to be noted regarding the drinking water sources in the Okad village is the alternative water sources used in the rainy season. The questionnaire form (Appendix A) includes questions which probe on the sufficiency of drinking water sources during dry or rainy season as well as a question on an alternative source when the primary source was unavailable. The reported response on these questions in the preliminary fieldwork suggested that in both seasons only a small number of households change their water sources. Those who changed were particularly houses that reported the use of rainwater as their main source and did not have sufficient quantities in dry season. They would then use unprotected dug wells as an alternative. This information was however inconsistent as discovered in the second fieldwork (rainy season, June) where all users of unprotected dug wells had changed their source to rainwater. The information discrepancy is likely to be attributable to contextual misinterpretation of the questions. The questions were formulated in a way that restrict the answers to the alternative water source only during dry season. This can simply be explained that actually the populations in Laos were reliable on two main sources depending on the season. So, for a respondent in the dry season who was already using the dug well, when he/she is asked “what is your alternative source in dry season?” they would have rightly answered none since the dug well had become a main source. For those who had kept on using rainwater even in the dry season, the question made more sense, as they would need to resort to an alternative source if the rainwater is finished.

Water supply system in Thailand

Drinking water sources in Waileum, Thailand were predominantly private rainwater collection systems (98%) followed by a small number of bottled water users. For other non-drinking purposes, the houses were connected with a central piped water supply. However, the piped water was perceived as of lower quality (associated with high turbidity). The piped water came from a pumping station that pumped water from a large pond located at the fringe of the village. The pumping station took up water from the pond to a water tower where chlorine was dosed. Subsequently water was distributed to houses. The actual capacity and treatment design of the pumping station however were unknown as it was not possible to make contact with the officials. The piped water was only used for showering, washing dishes, rinsing food, washing clothes, toilet flushing, and cleaning. Water for drinking and cooking was taken from collected rainwater.

Figure 3-12 – Rainwater collection systems in Waileum, Thailand: Gutter & piping systems (left); Rough filter made of mosquito net (right)

In general, the rainwater collection systems in Waileum village did have relatively more complete elements compared to those in Okad village. For instance, the roof catchment was commonly equipped with gutter (Figure 3-12). The gutter was then fitted with a funnel which may or may not be connected with an additional pipe or hose to reach the rain-jars. Some houses also had simple filters, normally mosquito nets were used (Figure 3-12), attached on the mouth of the funnel. The quantities of water stored per household in Thailand were also larger than in Laos. The median numbers of rain-jars were 3 large concrete jars (~2000 litres each) per household. The practice of water extraction from the rain-jars varied from scooping, filled from tap and sucking out with a hose.

The users of bottled water were relying on either refilled gallons or bought smaller amount of bottled water (6 litres).

<u>Household drinking water practices in the study sites</u>

It is presumed that the water quality may change from the source to the point of consumption, influenced by transport, distribution, storage, and consumption components. In the study settings where drinking water was collected manually from the source and subsequently stored and consumed, mostly without treatment, a crucial component that may determine the occurrence of recontamination is handling practices by users. The handling practices were defined as the various ways in which drinking water is stored, treated, and fetched for drinking within the households. In principal, it has been assumed that proper handling practices would prevent faecal recontamination originating from human or animals.

Thus, the most relevant information gathered through the household questionnaires and spot observation with respect to household drinking water practices are the types of household storage containers, modes of fetching, household point of use containers, devices used for scooping, and treatment of drinking water prior to consumption. To clarify the distinction between household storage containers and household point of use containers: the latter is exclusively referring to the final containers from which water is fetched for drinking whereas household storage containers acted more as intermediary storage facilities between sources and the final containers. Nevertheless the distinction was not so clear-cut. On many occasions the storage containers were interchangeable with POU containers. Figure 3-13 illustrates typical patterns of household drinking water consumption in the study area. In Figure 3-14 the pictures of various POU containers identified in both study sites can be seen.

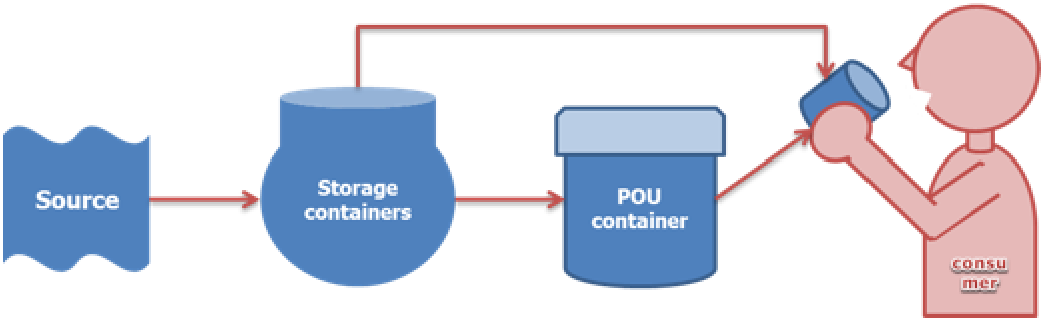
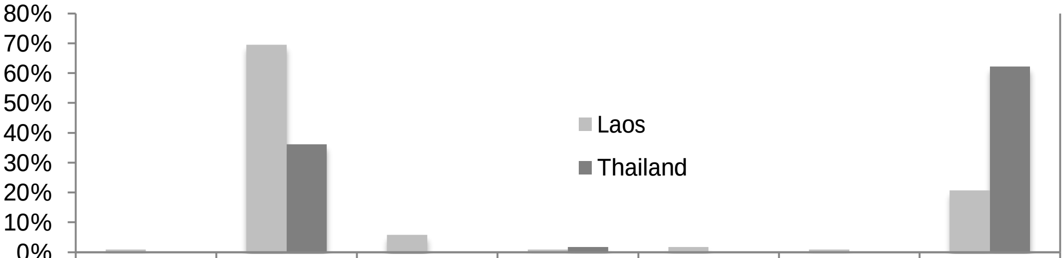


Figure 3-13 – Typical patterns of household drinking water consumption

Figure 3-14 – Household POU containers: thermos canister, plastic gallon, small earthen jar, plastic jug (from left to right)

The different household water handling practices that were documented through household questionnaires and spot observations are presented graphically in Figure 3-15 to 3-18 with respect to the population percentages belonging to the identified variables.

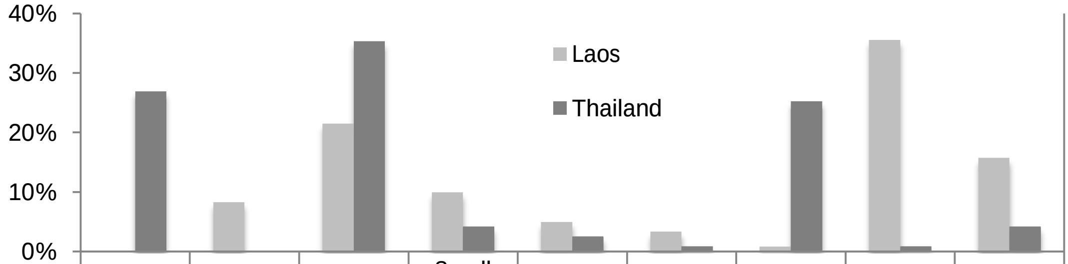
In Figure 3-15, the different types of storage containers are plotted. As can be seen, in both study sites, the majority of the households were using medium earth jars as their storage containers. It should be noted that in the cases of rainwater users, the main rain-jars were not considered as household storage; rather they were assumed as the sources. In most cases the rain-jars were followed by medium earth jars as intermediate storage containers. Only in limited number of cases did the rain-jars serve as both sources and storage.



	Small earthen jar	Medium earthen jar	Large concrete jar	Plastic drum	Metallic drum	Other	NA
Laos	1%	69%	6%	1%	2%	1%	21%
Thailand	0%	36%	0%	2%	0%	0%	62%
Laos (n)	1	84	7	1	2	1	25
Thailand (n)	0	43	0	2	0	0	74

Figure 3-15 - Population percentages using various types of household storage containers

The subsequent figure shows the types of POU containers used by the study population. In Thailand, three dominating types of POU containers were present, namely plastic bottle, thermos canister and more than 1 type of container. In Laos, unfortunately the types of POU were not recorded in more than half of the population. This was mainly due to absence of householders during visiting hours hence it was not possible to get access to the POU containers which were often located inside the houses. Nevertheless it can be seen that from the available data, thermos canisters were also popular followed by small earthen jars and plastic gallons.

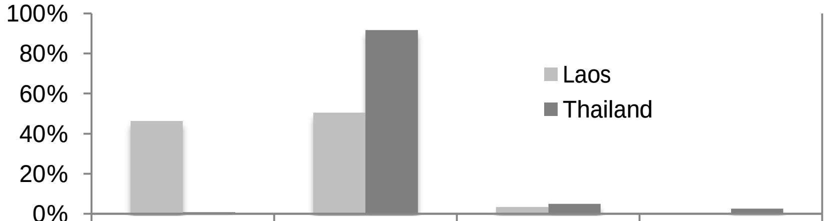


	Plastic bottle	Plastic gallon	Thermos canister	Small earthen jar	Plastic jug	Plastic bucket	more than 1 type	Other	NA
Laos	0%	8%	21%	10%	5%	3%	1%	36%	16%
Thailand	27%	0%	35%	4%	3%	1%	25%	1%	4%
Laos (n)	0	10	26	12	6	4	1	43	19
Thailand (n)	32	0	42	5	3	1	30	1	5

Figure 3-16 - Population percentages using various types of household POU containers

Figure 3-18 refers to the modes of fetching of drinking water from the POU containers. It can be seen that in Laos, pouring and scooping were equally practiced. In Thailand, the majority reported scooping out their drinking water. It has to be noted that the reported results of fetching practices have to be evaluated in relation with the reported types of POU containers. Specifically when more than one type of container is used and if the types of container are not identical, this implies that different modes of fetching are also practiced. Given the relative popularity of plastic bottles in Thailand, it is rather surprising that the reported modes of fetching was predominantly scooping since it practically impossible to scoop water out of the plastic bottles (normally 600 ml to 1200 ml in volumes). It is likely that the answers are reflecting the mode in which people were filling their plastic bottles[1]. This distinction is important since it becomes apparent that there is not a simple way to characterise the population based on their daily drinking water practices. Imagine a contradicting scenario in which the respondents have understood the question as intended, meaning that they would have answered “pouring” (from bottles to cup). In this case, the practice would have been categorised as safe since pouring limits hand contacts with the water. Nonetheless, that is not accurate, simply because an important piece of information has been lost, which is that somewhere along the chain of household water management, scooping was performed (rain-jars to bottles) which may well compromise water quality.

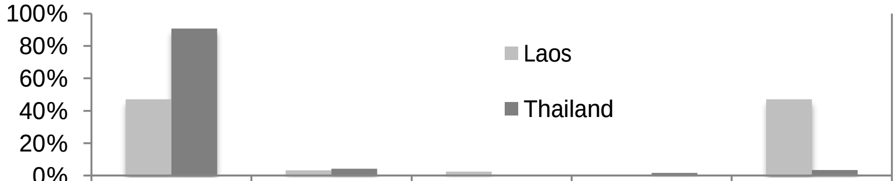
[1] During the second visit in June, it was confirmed that most of the houses using plastic bottles as POU containers were filling the bottles by dipping them into the rain-jars which can be interpreted as scooping.



	Pour	Scoop	Pour&Scoop	NA
Laos	46%	50%	3%	0%
Thailand	1%	92%	5%	3%
Laos (n)	56	61	4	0
Thailand (n)	1	109	6	3

Figure 3-17 – Population percentages employing various fetching modes

For the types of scooping devices, by far, cup with handles were the most popular in both sites. In line with the previous reflection on the scooping mode, it would be logical that plastic bottles were reported in Thailand. However, this option was unfortunately unavailable in the original questionnaire. Hence, the implication of the recorded datasets suggests that the cups were those intended for the final act of drinking.



	Cup with handle	Cup without handle	Cup without handle	Ladle	NA
Laos	47%	3%	2%	0%	47%
Thailand	91%	4%	0%	2%	3%
Laos (n)	57	4	3	0	57
Thailand (n)	108	5	0	2	4

Figure 3-18 – Population percentages using various types of scooping devices

Finally in Figure 3-20, reported treatment performed by the study population can be seen. The treatment performed was strictly boiling. As many as 82% of the population in Laos did not treat their drinking water prior to consumption whereas in Thailand, all of the households did not treat their drinking water.

	Treatment	No treatment
Laos	18%	82%
Thailand	0%	100%
Laos (n)	22	99
Thailand (n)	0	119

Figure 3-19 – Population percentages with different drinking water treatment practices

Aside from household water handling practices, efforts needed to collect drinking water are also illustrated as the amount of time spent to collect water from the source. Frequencies of collection are also presented. This information is available for those sources situated outside housing compounds e.g. unprotected dug wells, boreholes, and surface water. As can be seen in the figure below, the time spent for collection of drinking water in Laos is predominantly more than 30 minutes per trip. This is of course directly related to the types of the sources reported in the dry period which were mainly the unprotected dug well that were situated quite far away from most houses. Figure 3-22 shows the frequencies of water collection in Okad, Laos. During the dry season, mostly water collection was carried out once a week or once a month. Amount collected per visit varied between one to five jars with a volume of about 200 litres each.

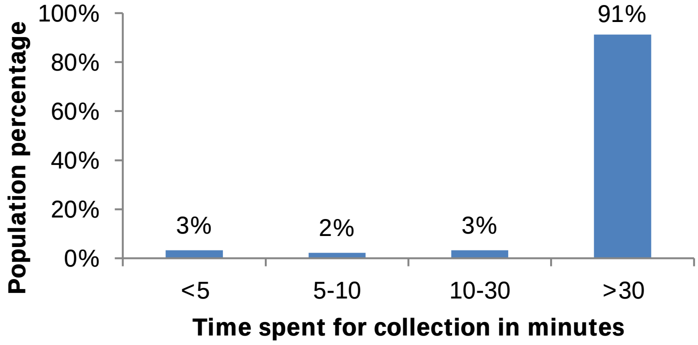


Figure 3-20 – Time spent for water collection each trip in Okad, Laos

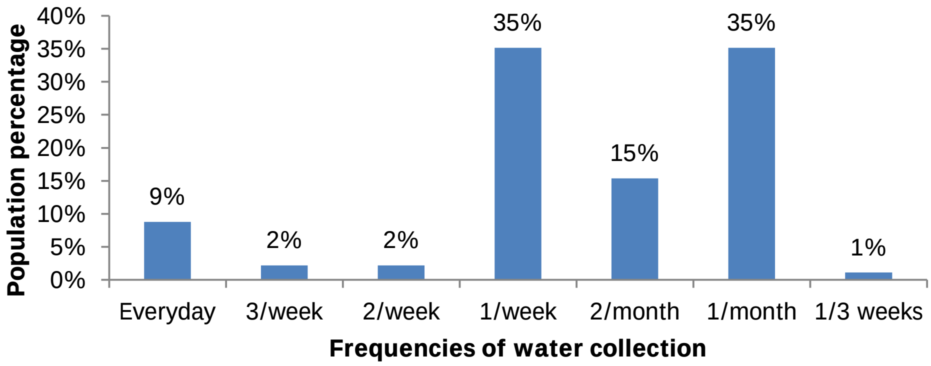


Figure 3-21 – Frequencies of water collection in Okad, Laos

3.1.2. Sanitation facilities

In line with study objective, the availability of sanitation facility is also assumed to be a crucial factor that may indirectly affect the pathways of (re)contamination of drinking water at household level. In Thailand all of the household participants owned private toilet facilities and only 1 household was sharing a toilet with a neighbour. Meanwhile in Laos the population was far more underserviced where about 70% (84 out of 121) of the population did not owned private toilets. Six out of the 84 shared toilet facilities and the remaining practiced open defecation. About 40% defecated in bush and 60% in the farm fields. All of the reported toilet facilities in the two study sites were pour-flushed pit latrine types.

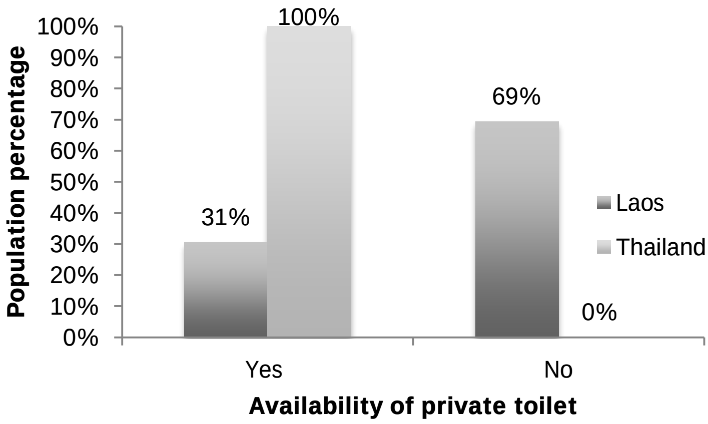


Figure 3-22 – Availability of private toilets in the study sites

3.1.3. Hygiene behaviour

In this study, hygiene behaviour singularly refers to hand washing practices. Hand washing practices may be linked to (re)contamination of drinking water at household level, because of hand-water contact through various water handling practices described earlier. Hand washing variables that were taken into account are mode of hand washing, hand washing after toilet and hand washing before eating.

In both sites, hand washing before eating is reported by 100% of the respondents. In Thailand this is also the case with hand washing after toilet visits. In Laos as can be seen in Figure 3-23, hand washing after toilet corresponded with availability of toilets. Respondents who did not own a toilet facility were less likely to wash their hands after defecation (46 households or <60% of those who did not own a toilet washed their hands) than respondents who owned a toilet (33 households or >90% of those who owned a toilet washed their hands). The majority of the study population washed their hands with water only; 69% in Laos and 85% in Thailand.

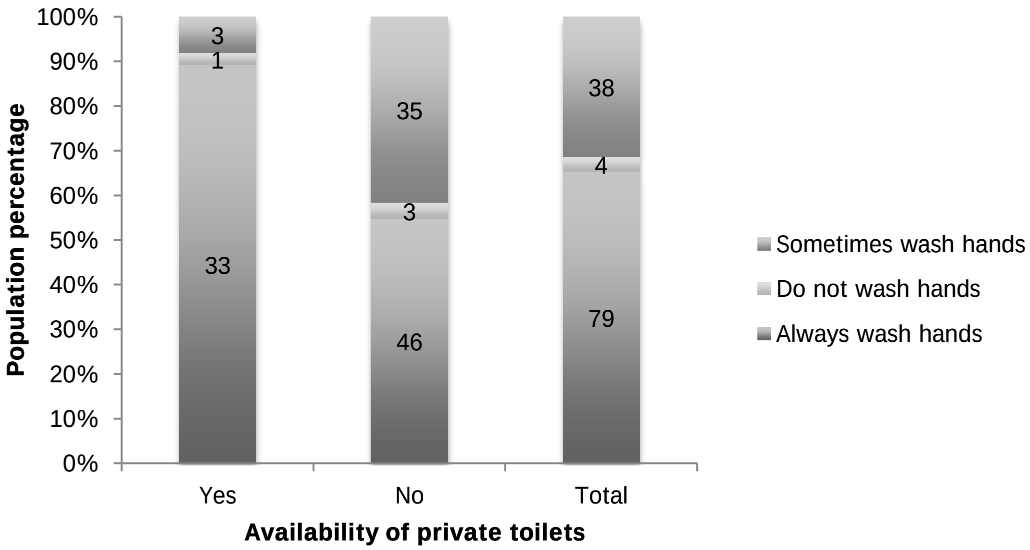


Figure 3-23 – Hand washing after toilet in association with toilet ownerships in Okad, Laos

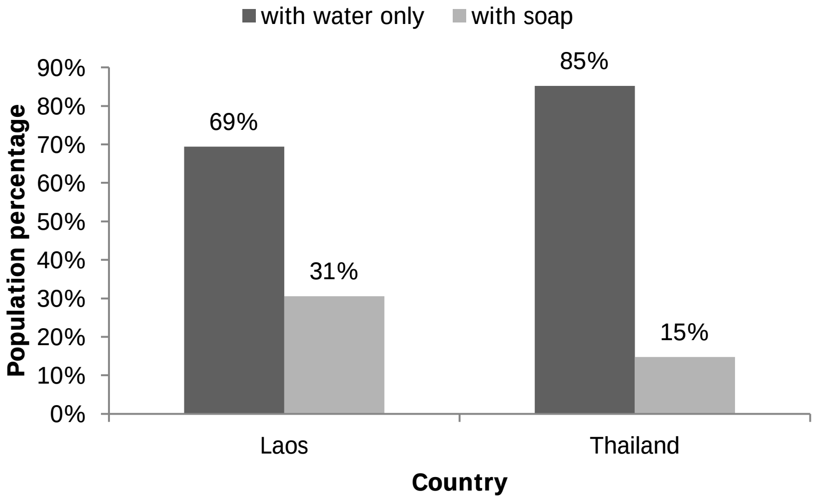


Figure 3-24 – Mode of hand washing in Okad, Laos and Waileum, Thailand

4 Hazard assessment of water sources, sanitation facilities and hygiene behaviours

In the following section, information obtained from the preliminary fieldwork is analysed using the semi-quantitative assessment framework. The main objective of the assessment is to allow for a systematic classification of the study population into certain risk categories. The first classification of the population is based on the water source hazards. Subsequently, the hazards associated with sanitation facilities and hygiene behaviours were also assessed. The aim was to provide a complete picture of the water, sanitation and hygiene status of the individual households in the study site, as well as to evaluate the relationships between water source and the corresponding types of sanitation facilities and hygiene behaviours found in the study population.

4.1 Assessment of water sources

As shown previously in Figure 3-3, by far the unprotected dug well, Sang Tieng, was the favourite source of drinking water in this Laos. This was mainly due to the relatively higher reliability of supply by this particular well, especially in the dry season, as compared to other sources. The well water was available whole year round according to the locals. During the inspection period, some 30% of the rainwater users suffered from water deficits, thus reserving to their preferred alternative sources, mainly from unprotected dug wells. Although boreholes were available widely and were used by the majority of the population for non-drinking purposes, this type of deep groundwater in the study area was largely associated with objectionable taste as a consequence of high mineral contents.

Based on the assessment framework explained previously, the water sources were scored and classified accordingly. In this assessment, bottle water users are excluded. The summary of the hazard scores for each of the source is presented in Table 4.1. A histogram depicting the population frequency distribution based on the semi-quantitative classification can be seen in Figure 4-1.

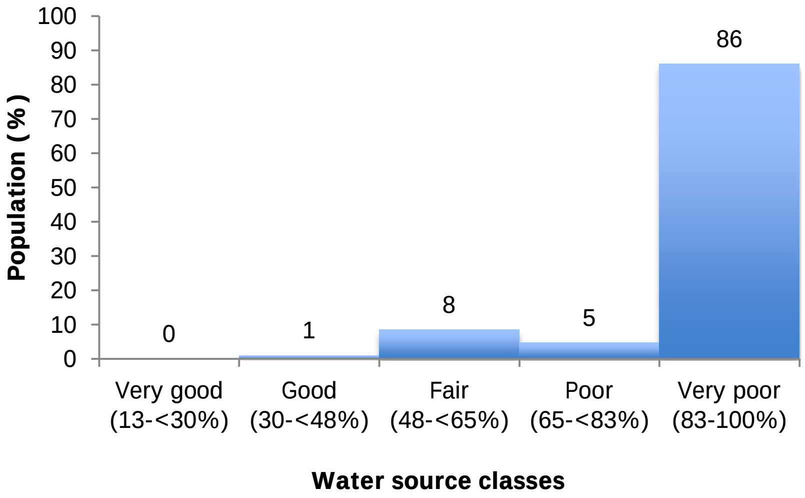


Figure 4-1 – A histogram of water source hazard scores in Laos

From the figure above, it is clear that a large percentage of the population in the Lao site was dependent on very poor water source. The biggest contributor is the users of Sang Tieng which amounted to about 80% of the population. As can be seen in Table 4.1, variations in scores in the unprotected dug well type are fairly small. This also holds for all borehole and surface water type. For the rainwater systems, 6 out of 11 were assessed as fair and one as good. Four rainwater systems showed high hazard levels although there is little variation among the individual scores. The majority of the scores range over 60% which is the grey areas between fair and good. The single house that scored as Good (36%) had a tap connected to the rainwater tanks. This significantly reduced the score across all hazard categories. In addition, the observed operational practices were compliant with nearly all of the requirements (only lacking in cleanliness of floor area).

The assessment shows that, overall, the unimproved sources (unprotected dug wells & surface water) were very likely to offer significantly inferior water quality to consumers compared to improved sources. Nevertheless, it should also be stressed that only one of the improved sources was assessed as good.

Table 4.1 – Summary of water source classification in Okad, Laos

Water sources	Mean hazard ratio	Class
Unprotected dug well		
Sang Tieng	91%	Very poor
Temple	91%	Very poor
Nong Ta Kai	81%	Poor
Houay Lam Phong	93%	Very poor
Mechanical borehole		
House 67 (Form 34)*	60%	Fair
House 68 (Form 47)*	63%	Fair
Handpump borehole		
No house number (Form 72)*	63%	Fair
Surface water		
Farm pond House 19 (Form 93)*	97%	Very poor
Private farm House 66 (Form 33)*	91%	Very poor
Rainwater harvesting		
House number 39 (Form 18)*	36%	Good
House number 2 (Form 19)*	65%	Fair
House number 42 (Form 24)*	63%	Fair
House number 38 (Form 25)*	67%	Poor
House number 52 (Form 37)*	65%	Fair
House number 42 (Form 41)*	67%	Poor
House number 6 (Form 89)*	67%	Poor
House number 26 (Form 90)*	63%	Fair
House number 5 (Form 92)*	61%	Fair
House number 16 (Form 109)*	61%	Fair
House number 10 (Form 112)*	79%	Poor

**) The form numbers are used as a cross-reference for the individual houses because in the Okad village, several houses had identical house numbers.*

In the coming section, an example of hazard scoring for each source type is given (Table 4.2 to Table 4.6). Accompanying explanations on exceptional scoring rationales are also presented.

Table 4.2 shows the hazard assessment framework for unprotected dug well. The physical structure criteria were developed based on the requirements for constructing a protected dug well. This standard was chosen because the assessment is aimed at demonstrating the hazards that may be contributed by the lack of appropriate physical supports at the water source.

Regarding the operational criteria, a unique water renewal technique was performed in smaller dug wells, where water was reportedly collected after draining away “old water” that has accumulated in the hole. Although it may be considered beneficial to the quality of collected water, there is doubt whether the quality is substantially improved. It is likely that microbial contamination may still occur due to wash away. Therefore, a score of 2 (high hazard) was given.

In the external environmental factor category, four hazard components were put together, each with its own accessibility. The accessibility is defined as the minimum safe distances suggested in the WHO guideline. These are 10 m for latrines, animal excreta and rubbish and

2 m for stagnant water. For the open defecation component, the assessment was based on prior knowledge that open defecation was widely practiced in the area, hence it was considered as a hazard. However, during the inspection no detectable human faeces were found, therefore a score of 1 (medium hazard) was considered representative.

Table 4.2 – Hazard assessment of unprotected dug wells e.g. Sang Tieng

	Unprotected dug well	**Sang Tieng**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Well head	n	na	2
2	Cover	n	na	2
3	Well floor	n	na	2
4	Drainage	n	na	2
5	Well lining	n	na	2
6	Fence	y	inadequate	1
7	Bucket/rope	n	na	2
	% Hazard for physical structure			93%
	Operation	*Status*		
8	Water extraction method	serious		2
9	Maintenance of physical structures	serious		2
	% Hazard for operation			100%
	External environmental factors	*Status*	*Accessibility*	
10	Latrine	n	n	0
11	Open defecation	y	unknown	1
12	Animal excreta	y	y	2
13	Stagnant water	y	y	2
14	Rubbish	y	y	2
	% Hazard for environmental factors			70%
	Water quality indicator	*Status*		
13	Is water visibly turbid?	y		2
	% Hazard for water quality indicator			100%
	Mean hazard ratio			**91%**
	Class			**Very poor**

Abbreviations used: y (yes); n (no); na (not available)

The assessment for mechanical borehole and handpump borehole are summarized in Table 4.3 and Table 4.4. The systems are assessed according to the basic framework rationales explained in the beginning. The criteria under physical structure are established based on a standard design for such borehole systems. No out of context circumstances were found in these water sources.

Table 4.3 – Hazard assessment of mechanically pumped boreholes

	Mechanically pumped borehole	**House 68 (Form 47)**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Concrete platform	y	inadequate	1
2	Sanitary seal	y	inadequate	1
3	Well casing	y	inadequate	1
4	Drainage	n	na	2
5	Fence	n	na	2
6	Distribution piping	y	insufficient cover	2
	% Hazard for physical structure			75%
	Operation	*Status*		
7	Water extraction method	no hazard		0
8	Maintenance of physical structures	moderate		1
	% Hazard for operation			25%

Table 4.3 – Hazard assessment of mechanically pumped boreholes (cont.)

	Mechanically pumped borehole	**House 68 (Form 47)**		
	Hazard criteria	**Hazards**		**Score**
	External environmental factors	*Status*	*Accessibility*	
9	Latrine	y	unsewered, accessible	3
10	Animal excreta	y	y	2
11	Stagnant water	y	y	2
12	Rubbish	y	y	2
	% Hazard for environmental factors			100%
	Water quality indicator	*Status*		
10	Is water visibly turbid	n		1
	% Hazard for water quality indicator			50%
	Mean hazard ratio			**63%**
	Class			**Fair**

Abbreviations used: y (yes); n (no); na (not available)

Table 4.4 – Hazard assessment of hand pumped boreholes

	Hand pumped borehole	**No house number (Form 72)**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Concrete platform	y	adequate	1
2	Sanitary seal	y	adequate	1
3	Well casing	y	adequate	1
4	Drainage	y	inadequate	2
5	Fence	y	inadequate	2
6	Pump	y	adequate	1
	% Hazard for physical structure			67%
	Operation	*Status*		
7	Water extraction method	No hazard		0
8	Maintenance of physical structures	Moderate		1
	% Hazard for operation			25%
	External environmental factors	*Status*	*Accessibility*	
7	Latrine	n	n	0
8	Animal excreta	y	y	2
9	Stagnant water	y	y	2
10	Rubbish	y	y	2
	% Hazard for environmental factors			75%
	Water quality indicator	*Status*		
10	Is water visibly turbid	n		1
	% Hazard for water quality indicator			50%
	Mean hazard ratio			**63%**
	Class			**Fair**

Abbreviations used: y (yes); n (no); na (not available)

For surface waters (Table 4.5), the physical structure criteria were selected based on the assumptions that those components (platform, intake, pump, and treatment) shall improve the quality of the collected surface water. Surface water is commonly characterised as a relatively large open water body, unlike groundwater that has a more protected natural structure, is subjected to various sources of contamination such as runoff, animals or human activities. The quality of surface water is therefore less stable and generally of worse quality as that of groundwater. For this reason, a treatment step has to be present to improve the quality prior to consumption, at least disinfection has to be performed (Howard, 2002). In the external environmental factor category, the hazard component 'open defecation' replaces latrine because users in this area did not own latrines. Although no observed evidence of open defecation was found during the visit, this does not eliminate the possibility that open defecation on the water body may take place given the common practice or that runoffs or indirect user contacts may carry the human faeces to the water source. Pollution sources of the ponds may also originate from agricultural runoff as livestock farm areas were surrounding the water body.

Table 4.5 – Hazard assessment of surface waters

	Surface water	**Farm pond House 19 (Form 93)**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Platform steps	n	na	2
2	Intake structure	n	na	2
3	Pump	n	na	2
4	Treatment	n	na	2
	% Hazard for physical structure			100%
	Operation	*Status*		
5	Water extraction method	serious		2
6	Maintenance of physical structures	serious		2
	% Hazard for operation			100%
	External environmental factors	*Status*	*Accessibility*	
7	Open defecation	y	unknown	1
8	Animal excreta	y	y	2
9	Rubbish	y	y	2
10	Agriculture or industrial runoff	y	y	2
	% Hazard for environmental factors			88%
	Water quality indicator	*Status*		
11	Is water visibly turbid	y		2
	% Hazard for water quality indicator			100%
	Mean hazard ratio			**97%**
	Class			**Very poor**

Abbreviations used: y (yes); n (no); na (not available)

The assessment of a rainwater collection system can be seen in Table 4.6. For this type of water source, the hazard components under operational category were further expanded based on the inspection checklist provided by WHO. A more comprehensive operational mechanism is expected at this source type, given the fact that rainwater in its purest form is free from harmful microorganisms. Contact with atmospheric contents may deteriorate the physical and chemical quality of rainwater. And subsequent collection system, storage and consumption practices may further deteriorate the quality if proper operational and maintenance efforts are not performed. Due to practical limitations, observation of roof catchment was mostly unfeasible, hence the "unknown" condition. Guttering materials were also not always observable in Okad since the visiting period coincided with the dry season and the rainwater collection system was uninstalled. It was assumed, however, that the hazard should be relatively low when first flush or cleaning mechanisms takes place prior to the first collection of rainwater. In the third hazard category, external factors considered were the presence of animals and the introduction of contaminants through user's behaviours. The two components were scored 0 and 1 for undetected hazard and detected hazard, respectively.

Table 4.6 – Hazard assessment of rainwater harvesting system

	Rainwater harvesting	**House number 39 (Form 18)**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Rain catchment	y	unknown	1
2	Gutter	y	not in use	1
3	Filter	n	na	2
4	Storage tank	y	adequate	0
5	Storage tank cover	y	adequate	0
6	Tap	y	adequate	0
7	Location of rain-jar (above ground)	y	adequate	0
	% Hazard for physical structure			29%

Table 4.6 – Hazard assessment of rainwater harvesting system (cont.)

	Rainwater harvesting	House number 39 (Form 18)	
	Hazard criteria	**Hazards**	**Score**
	Operation	*Status*	
8	Cleaning mechanism of catchment area before first collection	y	0
9	Cleaning of rain tank at least once a year	y	0
10	Drinking water collection using tap	y	0
11	Is water collection tool kept safe from contamination?	y	0
12	Proper drainage of water collection area	y	0
13	Is the tank floor area clean?	n	1
	% Hazard for operation		17%
	External environmental factors	*Status*	
14	Contamination due to collection (scoop/pour/tap)?	n	0
15	Presence of animals	y	1
	% Hazard for environmental factors		50%
	Water quality indicator	*Status*	
16	Is water visibly turbid	n	1
	% Hazard for water quality indicator		50%
	Mean hazard ratio		**36%**
	Class		**Good**

Abbreviations used: y (yes); n (no); na (not available)

In Waileum, Thailand only rainwater collection system was assessed since this was the predominant source of drinking water for the population. Because almost every household in Waileum had its own rainwater collection system, an individual assessment was conducted. The complete scores of the water source assessment for each household can be seen in Appendix D. A summary of the population percentage based on the source classification can be found in Figure 4-2.

The score distribution for the rainwater collection systems in Thailand appears to be fairly similar to Laos. Majority of the systems fell under Fair category. Some 30% of the systems were of higher hazard levels whereas only about 10% were of low hazard. This again shows that even though the rainwater harvesting systems can be categorised as improved technology, the identified hazard levels were not necessarily low, even at the water source domain.

Figure 4-2 – A histogram of water source hazard scores in Thailand

The assessment framework for the rainwater collection system is the same as the one used previously in Laos. An example of for a system in Thailand can be seen in Table 4.7.

Table 4.7 – Hazard assessment of rainwater harvesting system in Waileum, Thailand

	Rainwater harvesting	**House 203**		
	Hazard criteria	**Hazards**		**Score**
	Physical structure	*Status*	*Condition*	
1	Rain catchment	y	not in use	1
2	Gutter	y	inadequate	1
3	Filter	n	na	2
4	Storage tank	y	adequate	0
5	Storage tank cover	y	adequate	0
6	Tap	n	na	2
7	Location of rain-jar (above ground)	y	adequate	0
	% Hazard for physical structure			43%
	Operation	Status		
8	Cleaning mechanism of catchment area before first collection	y		0
9	Cleaning of rain tank at least once a year	y		0
10	Drinking water collection using tap	n		1
11	Is water collection tool kept safe from contamination?	n		1
12	Proper drainage of water collection area	n		1
13	Is the tank floor area clean?	n		1
	% Hazard for operation			67%
	External environmental factors	Status		
14	Contamination due to collection (scoop/pour/tap)?	y		1
15	Presence of animals	n		0
	% Hazard for environmental factors			50%
	Water quality indicator	Status		
16	Is water visibly turbid	n		1
	% Hazard for water quality indicator			50%
	Mean hazard ratio			**52%**
	Class			**Fair**

Abbreviations used: y (yes); n (no); na (not available)

4.2 Assessment of sanitation facilities

In the figures below the classification of the sanitation facilities in both study sites can be seen. The summary of the individual scores can be found in Appendix D. The population in Laos largely practiced open defecation whereas in Thailand the minimum facility available was shared toilets. Most of the private toilets inspected in Thailand were also of relatively better conditions.

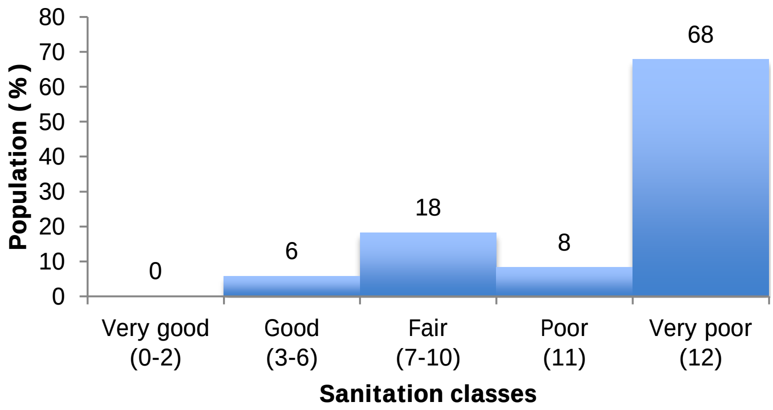


Figure 4-3 – A histogram for sanitation scores in Laos

Figure 4-4 – A histogram for sanitation scores in Thailand

4.3 Assessment of hand washing practices

The frequency distribution of the hand washing practices behaviour scores in both study sites can be found in Figure 4-5 and 4-6. The complete summary of individual hygiene scores can be found in Appendix D.

There is a contrast between the two populations in terms of hand washing behaviours. In Laos most of the households scored 4 or more (75%), as compared to Thailand where the majority scored less than 2. This means that hand washing practice is significantly better in Thailand than in Laos. Referring back to Section 3.1.3, it has been reported that in Laos, hand washing after food was always performed. Nevertheless, the total hygiene score is a subset of a number of parameters. And in the case of the Lao population, it is likely that the lack of hand washing after toilet and lack of hand washing facilities contribute to the overall low scores.

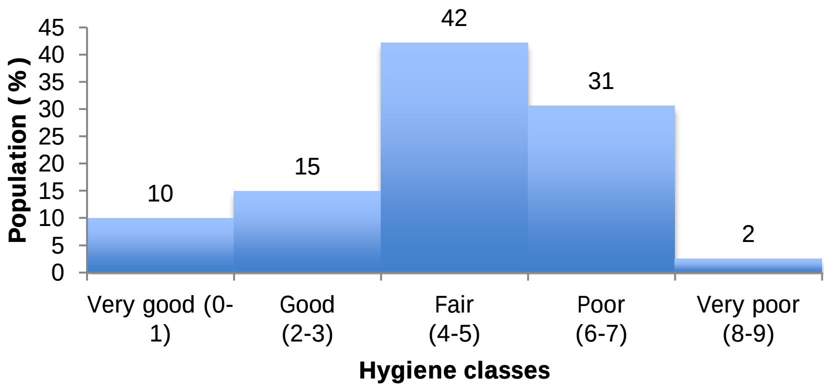


Figure 4-5 – A histogram for hygiene behaviour scores in Laos

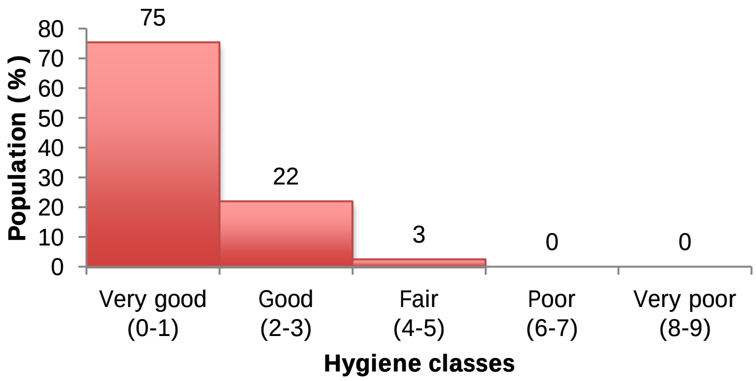


Figure 4-6 – A histogram for hygiene behaviour scores in Thailand

4.4 Correlating the hazard assessment scores

In this section a non-parametric statistical test was carried out on the hazard assessment scores. The main objective of the test is to clarify the assumed correlations between water source service levels and determinants at household levels such as sanitation facilities and hygiene behaviours. Given the interactions among water, sanitation and hygiene at household levels, it is interesting to learn whether the water service levels correspond positively with the level of sanitation facilities and hygiene behaviours.

The chosen method is the Spearman's rank-order correlation coefficient. It is aimed to demonstrate the degree of relationship between tested variables. The Spearman's correlation coefficient specifically tests if there is an underlying monotonic relationship between two variables. There are two types of monotonic relationships: positive correlation and negative correlation. The former simply means that an increasing value of one variable is always accompanied by an increasing value of the other. Conversely, the latter means that an increasing value of one variable is accompanied by decrease in the other (Sheskin, 2003a). The correlation coefficient is denoted by r_s. The range of r_s lies between -1 to 1, whereby the absolute value of r_s indicates the strength of the relationship, the closer the value to zero, the weaker the relationship and vice versa. The method of computation described in Sheskin (2003a) is used in the following analysis. For a complete overview of the method, readers are referred to the book.

The correlation coefficients are computed for the hazard score datasets of the two study sites. For each site, three correlation coefficients are computed namely to test the relationships between the water source hazard scores and sanitation scores, water source hazard scores and hygiene scores, and lastly between sanitation and hygiene scores. Complete tabled datasets used in the computation can be found in Appendix E. A summary of the test statistics is presented in the Table 4.9. In addition, a small part of the datasets is presented in order to illustrate the computation methods.

In Table 4.8 column 2 the hazard scores for water sources were put together. The next column indicates the ranks (R_x) assigned for the scores from the lowest to the highest. Column 4 indicates the sanitation scores, similarly followed by R_y which is its rank-orders. In the event that the scores were tied, an average rank order shall be given. For example, subject 47, 72 and 90 have an equal score of 0.625 for source hazards, this leads to assigning them at the 6th rank derived from the average of 5, 6 and 7 placements in their original sequences. In the subsequent column, the difference between the rank-orders was computed and indicated as d. The last column computes the squared difference scores.

Table 4.8 – A part of the Spearman's rank order datasets for correlations of source and sanitation scores in Laos

Subject	Mean hazard ratio	R_x – source	Sanitation	R_y – Sanitation	$d=R_x-R_y$	d^2
18	0.363	1	10	21.5	-20.5	420.25
34	0.597	2	11	28.5	-26.5	702.25
109	0.607	3	12	70	-67	4489
92	0.613	4	12	70	-66	4356
47	0.625	6	7	8	-2	4
72	0.625	6	12	70	-64	4096
90	0.625	6	12	70	-64	4096
24	0.631	8	6	3.5	4.5	20.25
19	0.649	9.5	9	16.5	-7	49
37	0.649	9.5	9	16.5	-7	49
25	0.667	12	10	21.5	-9.5	90.25
41	0.667	12	8	12	0	0
89	0.667	12	12	70	-58	3364
*	...	...	...	...	...	...

**) continued to Appendix E Table E.1*

In Table 4.9, the first column consists of several terms that are used in the computation. The first term is simply the sum of the d^2 computed in the last column of Table 4.8. This value is used to compute the initial r_s using the following equation:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)} \qquad \textit{Equation 4-1}$$

Substituting the $\sum d^2$ and n to the equation, the third row of the entry table can be computed.

Given the frequent occurrence of tied ranks, the initial r_s has to be corrected. Details on the correction methods are referred to Sheskin (2003a). The correction involves the following set of equations:

$$T_x = \sum_{i=1}^{s}\left(t_{i_{(x)}}^3 - t_{i_{(x)}}\right) \qquad \textit{Equation 4-2}$$

$$T_y = \sum_{i=1}^{s}\left(t_{i_{(y)}}^3 - t_{i_{(y)}}\right) \qquad \textit{Equation 4-3}$$

$$\sum x^2 = \frac{n^3-n-T_x}{12} \qquad \textit{Equation 4-4}$$

$$\sum y^2 = \frac{n^3-n-T_y}{12} \qquad \textit{Equation 4-5}$$

$$r_{s_c} = \frac{\sum x^2+\sum y^2-\sum d^2}{2\sqrt{\sum x^2 \sum y^2}} \qquad \textit{Equation 4-6}$$

Where, $t_{i(x)}$ represents the number of X scores that are tied for a given rank and $t_{i(y)}$, the number of Y scores that are tied. Equations 4-1 and 4-2 indicate that for each set of tied rank, the number of ties in the set is subtracted from the cube of the number itself and the values obtained are subsequently summed. For example, if in the entire X datasets there are 3 sets of ties which consist of 2, 3 and 4 ties, the following computation for T_x is performed:

$$T_x = \sum_{i=1}^{s}\left(t_{i_{(x)}}^3 - t_{i_{(x)}}\right) = [(2^3-2)] + [(3^3-3)] + [(4^3-4)] = 90$$

The same principle is uses in computing T_y. Subsequently, the computed values of T_x and T_y (fourth and fifth rows Table 4.19) can be substituted to equation 4-3 and 4-4 to obtain $\sum x^2$ and $\sum y^2$ shown in the next two rows. Finally the tie-corrected r_s values may be computed and can be seen in the final row of Table 4.9.

From the table of critical values for Spearman's Rho which can be found in Appendix J, the critical r_s values for the corresponding n samples can be found. The critical values were consulted for n=100 as the maximum n in the table since all of the n in the analysis exceeded this value. The one-tailed level of significance was used because it is hypothesised that there would be positive monotonic relationships between the variables. The critical r_s at 0.05, 0.025 and 0.01 levels are 0.165, 0.197, 0.233.

Table 4.9 – Test statistic summary for hazard score Spearman's correlation coefficients

	n	r_s	r_s**-corrected**	**p**
Laos				
Source vs. Sanitation	107	0.577	0.233	<0.01
Source vs. Hygiene	107	0.427	0.139	ns
Sanitation vs. Hygiene	121	0.766	0.708	<0.01
Thailand				
Source vs. Sanitation	116	0.251	0.232	<0.025
Source vs. Hygiene	116	0.273	0.136	ns
Sanitation vs. Hygiene	118	0.325	0.202	<0.025

The results indicate that sanitation and hygiene in Laos are relatively strongly correlated with each other. The rest of the correlation coefficients only indicate weak positive relationships. Comparing the tie-corrected r_s with the critical $r_{s\text{-}0.05}$ and $r_{s\text{-}0.025}$ only the source vs. hygiene correlations are not significant. Taking a higher significance level of 0.01, only source vs. sanitation and sanitation vs. hygiene in Laos are significant. Source vs. sanitation in Thailand is just short of being significant at this level.

The strong correlation between sanitation and hygiene scores in Laos can be attributed to the association between ownership of private toilets and hand washing practice shown in Figure 3-23. It indicates that in Laos, poor sanitation facilities would normally means poor hand washing practices. This is especially true when open defecation is practiced and no hand washing facilities may be found close-by. In Thailand the association is much less apparent, although still positively correlated. Interestingly, the Thai site was exhibiting higher level of sanitation facilities and hygiene behaviours. Nevertheless, it seems that the variability in the maintenance level of the sanitation facilities may not be associated with the hand washing practices. To illustrate this, there can be either a case where a toilet facility was found to be under-maintained although the household has good hand washing practice or vice versa.

The lack of association between water source and hygiene practices indicates that there are no consistent patterns of correlations between the two hazards. There may be cases where better water source (less potential for faecal contamination at source) were used and concurrently the households may not practice good hand washing practices, or vice versa. For the former case, recontamination of drinking water due to unhygienic hand-water contact may be an issue, assuming that the household drinking water practices are unimproved (multiple handling, wide mouthed containers, scooping, etc.).

With regards to the source-sanitation correlations, in general there are slightly stronger positive correlations as compared to source-hygiene. This means that there are more instances where less hazardous source was found together with relatively better sanitation facilities. However, given the weak association, it does indicate high variability in the study population. Again, there may be cases where relatively good water source is under the influence of poor sanitation. Whether or not contamination does occur as a consequence, depends on other factors such as the proximity of the faecal contamination to the water source or the related hand washing and water handling practices. In Laos, where sanitation and hygiene are strongly associated, this may indicate a higher likelihood that contamination would occur.

In general the datasets obtained in Laos were more significant than those collected in Thailand. After correction, the correlation coefficients in the Lao datasets were significantly reduced. This is due to the large numbers of tied-ranks corresponding with the assessment of the Sang Tieng dug well, which was used concurrently by almost 80% of the study population. Lastly, the number of test performed for the source-sanitation and source-hygiene correlations were less than the sanitation-hygiene. This is due to the exclusion of bottled water users, for which no water source assessment was made. The original population size in Laos was 121, equivalent to the number of test performed for sanitation-hygiene correlation. Whereas in Thailand, originally there were 119 households, however 1 household was not checked for its toilet facility since the owner was absence during the time of visit.

5 Second-phase research methodology

In line with the research objectives, microbial water quality analysis with *E. coli* as faecal indicator organism is desirable. First of all, it serves as a proxy to health impacts. Secondly, the microbial water quality data can be used to validate the hazard classification systems. Typically, water quality data are used in conjunction with the hazard assessment, where the water quality test detects severity of contamination, the latter serves to clarify relevant risk factors in the event of contamination. At last, the microbial water quality analysis was also performed to compare a new *E. coli* quantification method to a standard method.

In the coming sections, the methodologies used in the microbial water analysis and the related sampling strategy employed during the final fieldwork phase in June 2012 are presented.

5.1 Materials and methods

Two methods were used for microbial quality analysis of the water samples, a standardized IDEXX Colisure Quanti-tray 2000 method and a new Most Probable Number (MPN) method, the CBT. These methods were appropriate for the study setting where basic laboratory facilities were absent. They offer relatively simple and rapid enumeration of faecal indicator organisms in the water samples. The new CBT method is still in developmental stage hence a comparative study with a standardized method was desirable. This is achieved by statistically comparing the quantification results from the two methods. For each method, duplicate analysis of the water samples were performed which meant that at any given time four water samples were collected from each sampling point (Figure 5-1).

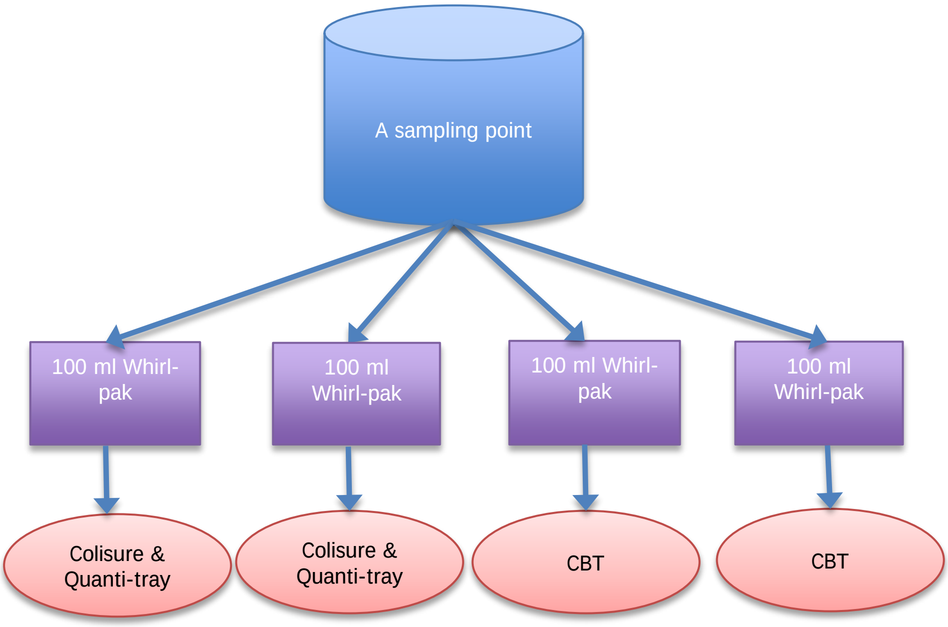


Figure 5-1 – Sampling and analysis scheme at each water point

The daily water sampling routine required the following consumables & equipment:

- NASCO Whirl-pak, 100 ml
- Lightproof insulated cooling box
- Melting ice / ice packs

As identified from the preliminary study in Januar-February, no use of disinfectant for drinking water sources was reported. Chlorine was reportedly added to the piped water supply in Waileum, Thailand. However this water source is unanimously used only for non-drinking purposes. Thus, the disposable sampling bags without thiosulphate from the NASCO Whirl-pak lines were used. Disposable bags were preferred in this study due to the absence of basic laboratory facilities in the study area. The bags have write-on and stand-up features allowing for ease of sample identification and analysis. The 100 ml volume also corresponds with the sample amount needed for detection of total coliforms or *E. coli* using the two proposed MPN methods. The total amount of bags available for the experiments were 1500 bags. In total 1098 samples were collected during the entire study period.

Lightproof insulated cooling box and melting ice/ ice packs were required to store and transport collected water samples from study site to the analysis location. Several houses or water sources were sampled sequentially during the course of five to six working hours per day. This implies that there was a time gap between sampling and analysis. In general, WHO recommends that the gap should not exceed 6 hours and 24 hours is the absolute maximum. Immediately after collection, water samples have to be preserved in the ice filled cooler box (1 – 4°C) and kept cool until analysis is to be performed.

The first analytical method, the standard total coliforms and E. coli quantification using IDEXX Colisure & Quanti-Tray 2000 required the following consumables & equipment:

- IDEXX Colisure snap pack, 100 ml
- IDEXX Quanti-Trays 2000
- IDEXX Quanti-Tray sealer 2X
- Rubber tray
- Incubator
- Portable UV lamp

In total, 600 modules of Colisure and Quanti-Trays 2000 were ordered from IDEXX and 586 analysis were performed. IDEXX Colisure was selected because it provides distinctive magenta tint to the positive wells, avoiding difficulty in identification especially when water tiontsample has natural yellow colour to it (as found in Laos dug wells). Meanwhile, Quanti-Tray 2000 counts up to 2149 MPN/100 ml without dilutions. Colisure acts as culture medium for the growth of the indicator bacteria. The Colisure snap pack is first added to 100 ml of water sample until the reagent dissolves completely. Subsequently, the water sample has to be transferred to a Quanti-tray. All handling of materials has to be performed carefully to avoid contamination. Once sample is inside the Quanti-Tray, it has to be sealed using the Quanti-Tray sealer 2X. The rubber tray will hold the Quanti-Tray during the sealing process. A one-time startup period for the Quanti-Tray sealer 2X is 10 minutes and the sealing process will take approximately 15 seconds per tray. Once sealed, the Quanti-Tray is ready for incubation. An incubation period of 24 hours at 35±5°C was used. The test is definitive after 24 hours and can be read up to 48 hours. Magenta wells indicate the presence of total coliform whereas magenta/fluorescent wells indicate E. coli. Fluorescent wells can be identified by shining a UV lamp on the Quanti-Tray. The number of positive large and small wells corresponding with an MPN value can be looked up in the MPN value table provided by IDEXX.

The second method, the new CBT MPN method for *E. coli* detection required a number of consumables and equipment:

- Disposable plastic bags containing 5 internal compartments
- Chromogenic substrate culture medium units
- External plastic clip sealer
- Incubator

In total 550 modules of CBT tests were provided by the University of North Carolina (UNC), USA. The numbers of analysis performed were 512 tests. The CBT method was developed by Sobsey (2012) of UNC. The test aims to provide a simple, portable and affordable detection and quantification of faecal bacteria in water. As with Colisure, a substrate medium has to be added to 100 ml of water sample. The substrate is then allowed to dissolve for about 15 minutes, assisted with periodic swirling of the water sample. Once dissolved, the sample is transferred to a compartmentalized disposable bag. The bag consists of 5 internal compartments of different volumes (1, 3, 10, 30 and 56 ml) that give a total volume of 100 ml. Manual hand manipulation of the outside of the bag has to be performed to distribute the sample correctly to each compartment. An external plastic clip is then used to seal the bag, reducing the risk of liquid movement from one compartment to another. Without the clipper, the test can still be performed. However, extra care has to be taken in handling the bag to avoid undesirable movement of liquid. The test is preferably incubated for 20 to 24 hours at 35 to 44.5°C. In this study, the samples were incubated at about 35.5°C. A positive chamber will turn blue or blue green and a negative shows no colour change. An MPN value table may then be consulted for the observed combination of positive chambers. The maximum MPN value for five positive chambers is >47/100 ml. This result indicates high probability of water having more than 100 bacteria/100 ml.

Besides the enumeration of the targeted water samples, positive and negative controls were also provided for both methods. In microbiological analysis, controls are necessary to provide confidence in the validity of the test results. In total 11 positive and 11 negative controls were performed for IDEXX method with compliant results. For CBT, 9 analysis for each positive and negative controls were performed, also compliant. The positive controls in Laos were obtained from the highly contaminated sources. In Thailand, as such sources were not available, the positive controls were obtained by seeding tap water with cover water from a toilet bowl. Boiled water was used as the negative controls. The controls were performed about every other day during the entire sampling periods.

In addition to microbial quality, turbidity was also measured using a portable turbidimeter (HI 98713) by Hanna Instruments, USA. The measurement of turbidity was normally performed onsite. Other supplementary consumables and equipment needed were hand sanitizers, bleach solutions, permanent markers, and clean cloth.

After all the analysis was performed, the contaminated materials were disposed with the assistance of local laboratories found in closest municipal hospitals, which have agreement with the DIADEN project. The Quanti-trays were sanitized in an autoclave in the hospital laboratories prior to final disposal. As for the CBT, the contents were mixed with adequate household bleach and let to react for at least 30 minutes before the liquid was disposed to a latrine or toilet.

5.2 Sampling strategy

The main objective of the water quality analysis is to validate the quality of drinking water in the study area at both the sources and point of use. Based on the semi-quantitative hazard assessment, the study population was classified according to the hazard scores associated with their preferred drinking water sources. In order to see the influences of different water sources on household drinking water quality, for each of the predefined source categories, a number of representative household samples were chosen initially.

The rainwater sources in Thailand were classified into three major classes: poor, fair, and good and a fourth category for bottled water. For the population in Laos, the categories are simply based on the different types of water sources, overlooking the classification that resulted from the risk assessment framework. The reason was that a validation of the semi-quantitative hazard assessment method is necessary, thus excluding a particular water source from the sampling plan is not desirable at this stage. Table 5.1 and 5.2 summarise the optimum number of samples and the corresponding amount of sampling points for each source category.

Table 5.1 – Original sampling plan in Okad, Laos

Water source categories	Number of sample households	Sampling points per week	
		Source water	Household containers
Sang Tieng	10	3	10
Nong Ta Kai	1	3	1
Houay Lam Phong	2	2	2
Temple	3	2	3
Rainwater	11	11	11
Borehole	3	3	3
Farm pond	1	2	1
Private pond	1	2	1
Bottled water	11	11	-
Total	*43*	*39*	*32*

Table 5.2 – Original sampling plan in Waileum, Thailand

Water source categories	Number of sample households	Sampling points per week	
		Source water	Household containers
Rainwater - Poor	10	10	10
Rainwater - Fair	10	10	10
Rainwater - Good	10	10	10
Bottled water	2	2	-
Total	*32*	*32*	*30*

Considering the study objectives and feasibility within the available time and resources, a predetermined sample size of 10 for each category was used. However, not all categories have a population of more than 10 households. For those categories, the whole population were sampled. In Laos where rainwater and bottled water users were counted at 11, all households were included in the sampling plan. For the other categories where the total population exceeds 10 households in Thailand (refer to Table 4.10), additional criteria drawn from the sanitation and hygiene scores were applied in selecting the 10 sample households.

In Thailand, based on the frequency distribution of the scores, most households fall on the range of good to fair (score 3-8) and very poor to poor (score 0-2) for sanitation and hygiene, respectively. Thus, households that fulfil those requirements were included in the sampling plan. In Laos, most households have sanitation scores of 11-12 and hygiene scores of 4 or 6. Those falling under the two criteria were thus selected as household samples. If more than 10 households were found under these criteria, randomised sampling was applied subsequently.

Furthermore, during the actual fieldwork, the sampling strategy underwent some improvements based on the changing circumstances. The highlight was the change in drinking water sources in Laos. During the second fieldwork period in June, the rainy season had started and unexpectedly, almost every household samples which originally used unprotected dug wells had shifted to rainwater collection systems. Sampling of rainwater collection systems called for larger amounts of consumables (more sources), hence the number of systems that could be sampled were limited in order to equally distribute the available materials over the two study sites. Ultimately, 25 rainwater harvesting systems, 1 mechanical borehole, 1 handpump borehole, 10 bottled water, and 2 original sources (Sang Tieng and private pond) were sampled in Laos. In Thailand, the original sampling plan was maintained.

The sampling scheme in Table 5.1 and 5.2 is indicative of a one-period-planning. Water quality analysis was repeated twice in one-week time (the duration between the initial and the repeated sampling was three days) to account for short-term temporal variations. Besides temporal variations, spatial variations might well be present and were taken into account for unprotected dug wells and surface water by taking samples at multiple locations.

As recapped in Chapter 3, there were four identifiable dug wells in Laos, namely Sang Tieng, Nong Ta Kai, Houay Lam Phong and Temple. Sang Tieng and Nong Ta Kai were relatively larger dug wells with diameter more than 1.5 m. Whereas, Houay Lam Phong and Temple were small dug wells with diameter less than 1 m. During the rainy period however, the small dug wells were not available, as the rivers had been flowing again. In addition, the access to Nong Ta Kai was also too difficult due to rain and bad road conditions. As Nong Ta Kai was also not a main source, it was reasonable to exclude it from the sampling plan. Therefore, only Sang Tieng was sampled.

Samples from three different locations were taken in this unprotected dug wells. This was presumed as indications for spatial variations at the water source. For all types of water sources, the most relevant sampling point is the point where users would normally collect their water. Subsequently, additional sampling points were determined according to the circumstances. For examples, a sampling point at an extended depth or different entry points to the well. At least three different samples per visit were collected for Sang Tieng. For the private pond, two sampling points were allocated, even though its size was bigger, the relevance of this water source was low since only one household was reliant on it during the dry season.

For the rainwater collection systems and borehole that were privately owned, samples of the sources (rain-jars & borehole) as well as drinking water at points of consumption (household containers) were collected at each visit. Only one sampling point was allocated to both the source and the household container. This implies that a selective sampling was applied where more than one household container were present. A principal rule in selecting the container for sampling was that it should be the container that was currently in use by the family. Similar principle was applied for rain-jar sampling.

In Okad, one other water source was sampled which was the handpump borehole. This was reportedly used by one family during the preliminary visit which however had also switched to rainwater in the second fieldwork period. Nevertheless the borehole was sampled to validate the hazard assessment. One sampling point was allocated for this source.

The last category in both study sites was the bottled water users. In most cases, they used gallon-bottled water (20 litres) or lower volume bottles (0.6 – 6 litres) acted as both the water source and POU containers. Except for two households in Laos using the Tiger brand bottled water, all the samples from the other bottled water users were collected from the actual bottles used in the households. The Tiger brand bottled water was bought on separate occasions in local shops and was used in the analysis. In particular for the users of gallon-bottled water, refilling the gallon from local vendors was the common practice and thus it was more appropriate to sample from the actual bottles used in the households.

A final remark on the sampling strategy was on the simultaneous usage of multiple household containers in Thailand. Different types of container in one household which often also meant different practices in fetching water were found in Waileum. For example, a canister and bottles would be both in use. Drinking water in a canister was normally fetched by scooping whereas with bottles, drinking water was poured to cups or glasses or drank directly from the bottles. In some other cases, treated water (boiling), was consumed only by the women in the houses whereas other members of the family drank untreated water. For a selected numbers of households, additional sampling points were assigned to obtain a picture on how these differing practices would affect water quality. The results are presented in the next chapter.

6 Microbial water quality at sources and points of consumption

In this chapter the results of the microbial water quality analysis of the water samples from drinking water sources and household containers in the two study sites are presented. Due to some changes encountered in the final fieldwork, reassessment of the water sources for the rainy season period was performed and is presented in Section 6.1. The alternative water sources which do not allow for comparisons between source and POU but remain relevant to the study, were also tested for their microbial quality and the results were presented in Section 6.2.

The first analysis presented is on the observed differences in *E. coli* contents between water sources and POU containers. Subsequently, the Spearman's rank-order correlation tests was run between the microbial water quality data of the source samples and the hazard scores assigned for the water sources. Equivalent tests were also performed for the microbial water quality data of the POU samples correlated with the sanitation classes, as well as with the hygiene classes. In addition, comparisons of the various operational parameters (e.g. types of containers, treatment, covers, etc.) based on the corresponding microbial quality were also presented. Finally, comparisons of the two enumeration methods were also conducted using the ISO 17994 method.

6.1 Reassessment of water source hazards in the rainy season

Seeing that the majority of the selected household samples had altered their drinking water sources to rainwater collection systems, reassessment of the hazards presented by the new sources was carried out in Laos. The same hazard framework explained in Section 2.4.1 was used. The final scores of the water source hazards identified in the new situation are presented in the following graph. If compared with the initial scores (first fieldwork), the change of water source in the rainy season has managed to lessen the water source hazards. Nevertheless, still as much as 73% (19 out of 26) of the systems assessed were of poor quality.

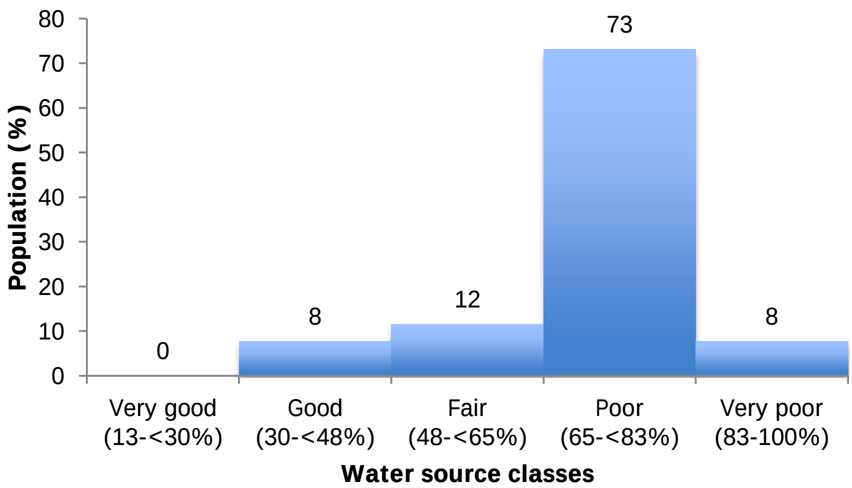


Figure 6-1 – Hazard scores of newly identified water sources in Okad, Laos during the rainy season

For the Thai site, even though the sources remain the same throughout the study period, it was decided to also reassess the water source hazard for the present conditions offsetting some circumstantial changes that may have occurred. The newly assigned scores are presented in Figure 6-16. When compared with the original scores, it appears that the new assessment has resulted in normalising the score distribution. As laid out in the Sampling strategy, equal number of houses (n=10) was selected for each of the corresponding hazard categories: Good, Fair and Poor. In this assessment, the Fair category has grown to 67% (20 out of 30), a two-fold increase. The remaining 10 households were distributed between Good and Poor categories. The changing scores were plausible given that in the dry season (first fieldwork) some of the system components were not assessed given that it was not in use (rain catchment or gutter). In addition to this, there may be changing hazard situations between the two visits.

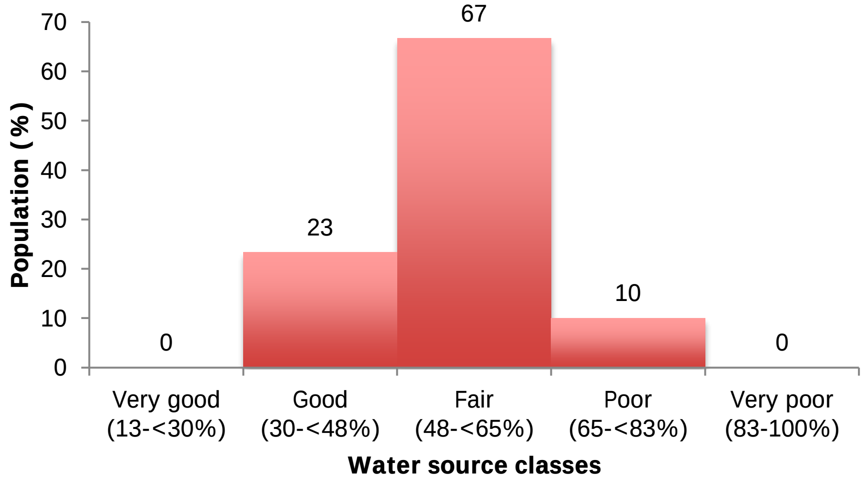


Figure 6-2 – Hazard scores for water sources in Waileum, Thailand during the rainy season

The hazard scores obtained in this reassessment shall be used in Section 6.4 to establish correlations with microbial water quality at source samples.

6.2 Microbial water quality of alternative sources

Although the biggest unprotected dug well in Loas, Sang Tieng, was not used in the rainy season, samples were still collected to measure its quality given the importance it hold in dry season. Similarly samples from the private pond and the handpump borehole were also collected. Another category of water source is also sampled, that is the bottled water. Typically, bottled water users were using their bottled water as their POU containers. As a consequence no distinction between source and POU can be made. However it remains interesting to see if the bottled water (frequently seen as of superior quality) users did consumed microbially safe water.

As explained in Chapter 5, temporal variations in the bigger water sources were addressed by collecting the samples from various spots. For Sang Tieng, there were three sampling points. The first point was at the point of entry to the well where water was normally collected from. The depth of this point was about 10 cm from the surface. The next sampling point was on the left side of the well at a depth of approximately 10 cm. The last sampling point was on an extended depth of about 30 cm. The locations of the sampling points are shown in Figure 6-3. For the private pond in the first period, two sampling points were selected. One was at the main entry point to the pond. Water was collected just at the surface of the pond given the relatively shallow pond with a depth of about 15-20 cm. The second sampling point was at the right hand side (shown in Figure 6-4) about 10 m away from the main entry point. In the second period however, considering the limited usage of the pond, this sampling point was omitted. As for the handpump borehole and the bottled water, a single sampling point was used.

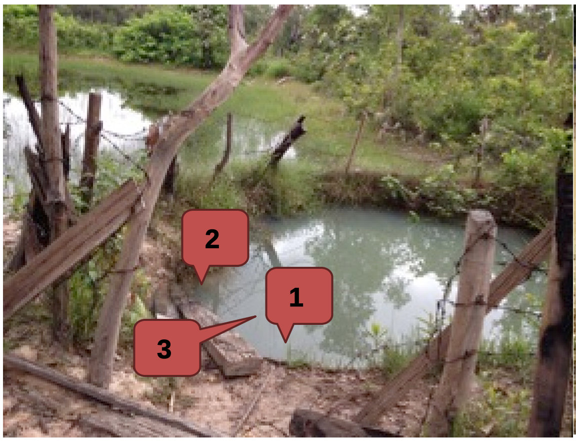


Figure 6-3 – Location of sampling points in Sang Tieng

Figure 6-4 – Location of sampling points in Private Pond

The measured microbial quality of the point sources found in Laos is compiled in the Table below. The results of the microbial water quality analysis for the bottled water users can be seen in Figure 6-5 and Figure 6-6.

Table 6.1 – Microbial quality of unprotected dug well, private pond and handpump borehole

Source	Sampling point	1st period (MPN/100 ml)	2nd period (MPN/100 ml)	Mean (MPN/100 ml)
Sang Tieng	I	207.7	179.1	193.4
	II	348.5	224.7	286.6
	III	479	170.8	324.9
	Mean	*345.1*	*191.5*	*268.3*
Private pond	I	142.8	44.2	93.5
	II	332.7	-	332.7
	Mean	*237.7*	*44.2*	*140.9*
Handpump borehole	I	2	<1	1.1

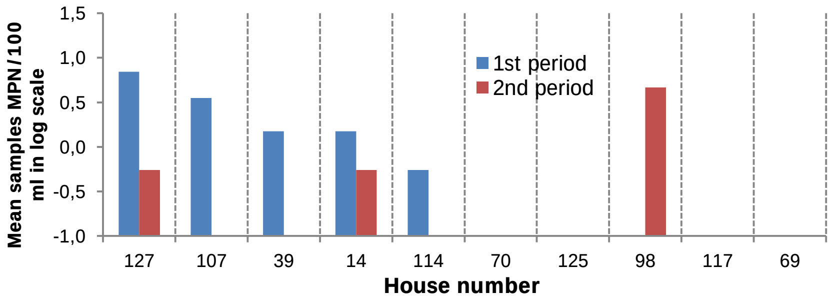


Figure 6-5 – Measured E. coli for bottled water users in Okad, Laos

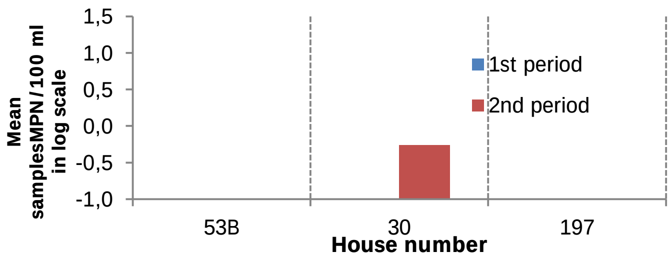


Figure 6-6 –Measured E. coli for bottled water users in Waileum, Thailand

As can be seen, the quality of the point sources was questionable, particularly for Sang Tieng and the private pond. Different sampling locations also resulted in rather different concentration of *E. coli* in the samples taken from Sang Tieng and the private pond. According to the risk classification proposed by Lloyd & Helmer (1991), Table 6.2, most of samples may be categorized as grossly contaminated for both Sang Tieng and the private pond. At the same time, although the handpump borehole can be categorised as low risk, it is still not meeting the WHO guideline that calls for undetectable *E. coli* in any 100 ml samples. The same can be said for more than half of the bottled water users in Laos, where their bottled water was not completely free from contamination (low risk). This was interesting as the contaminated samples were all either obtained via dispensing containers (fitted with spigots) or by pouring. Thus, the contamination was potentially linked with the original quality of the water or cleanliness of the spigots or container mouths. In Thailand, the contamination in House number 30 is likely to be attributable to the addition of ice by the user. The ice was bought elsewhere.

Table 6.2 – Risk classification based on microbial water quality

Grade	CFU/100 ml	Risk
A	0	No risk
B	1 – 10	Low risk
C	11 – 100	Intermediate to high risk
D	101 – 1000	Gross pollution; high risk
E	> 1000	Gross pollution; very high risk

(adapted from Lloyd & Helmer (1991))

6.3 Observed differences of microbial water quality at sources and points of consumption

In the following Figure 6-7, the plotted *E. coli* data for each of the house samples, excluding bottled water users, in Laos can be seen (tables can be found in Appendix F). The horizontal axis denotes the house numbers and the vertical axis represents the mean MPN/100 ml in log scale. With this scale the minimum value of -1 is equal to <1 MPN/100 ml. Undetectable *E. coli* which is <1 MPN/100 ml using the IDEXX method has to be converted to numerical values in order to enable data processing. The value 0.1 was deliberately chosen, hence -1 as the log minimum. As such, samples that contained 1 MPN/100 ml were now shown as 0 on the log scale. Except for house number 9 in the second period (a missing dark red bar indicating no measurement at the source as the family ran out of rainwater on the second visit), all the other zero values mean that 1 MPN/100 ml was measured. The blue and red colours represent the period of measurement. The measurement in Thailand is presented in a similar manner in Figure 6-8.

As can be seen from the figures below, although the majority of the samples were free from *E. coli*, apparently various degrees of contamination still took place in both study sites, starting from a relatively mild contamination up to high risk contamination. Furthermore, between the measurement periods, variations within individual households were also apparent. This is taking into account that the type of technology used was to a high degree, the same. Of course it had been also observed that the same technology might not always be adopted in exactly the same manner as it is intended to be. Subtle to obvious differences in drinking water management practices were also recorded and presented in Chapter 3.

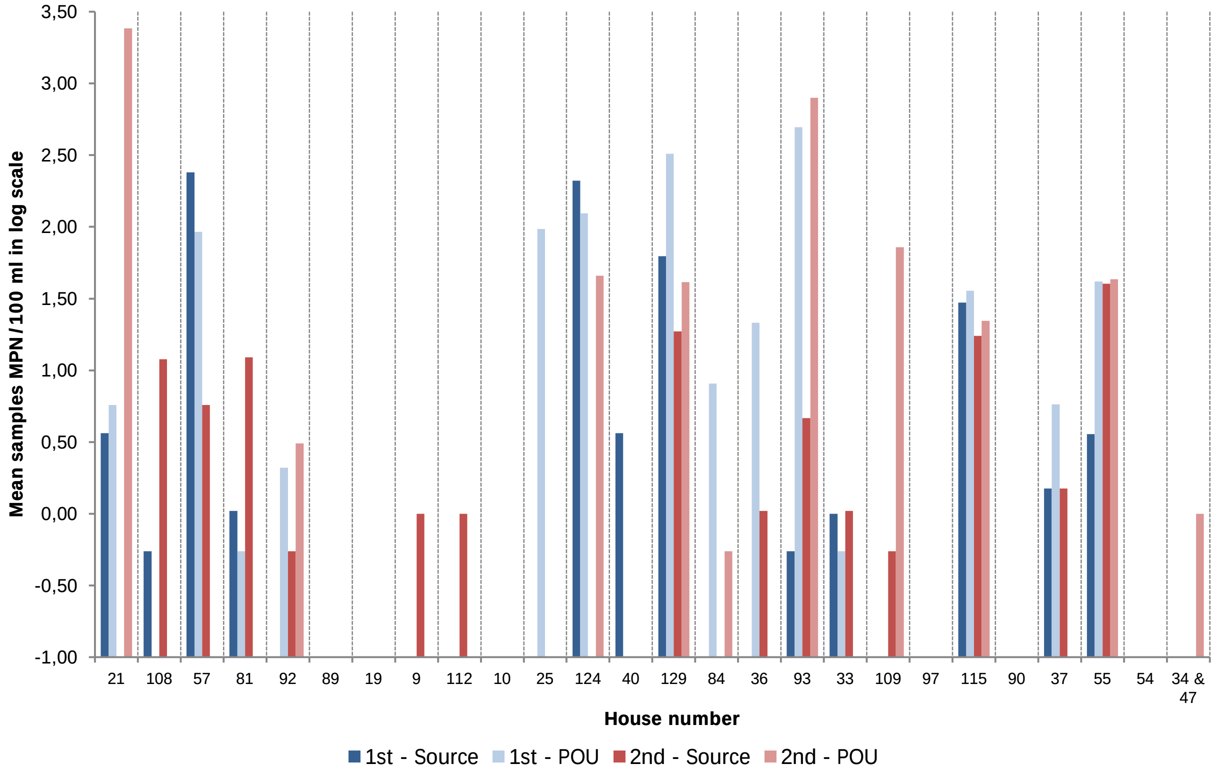


Figure 6-7 – Measured E. coli in source and POU samples in Okad, Laos

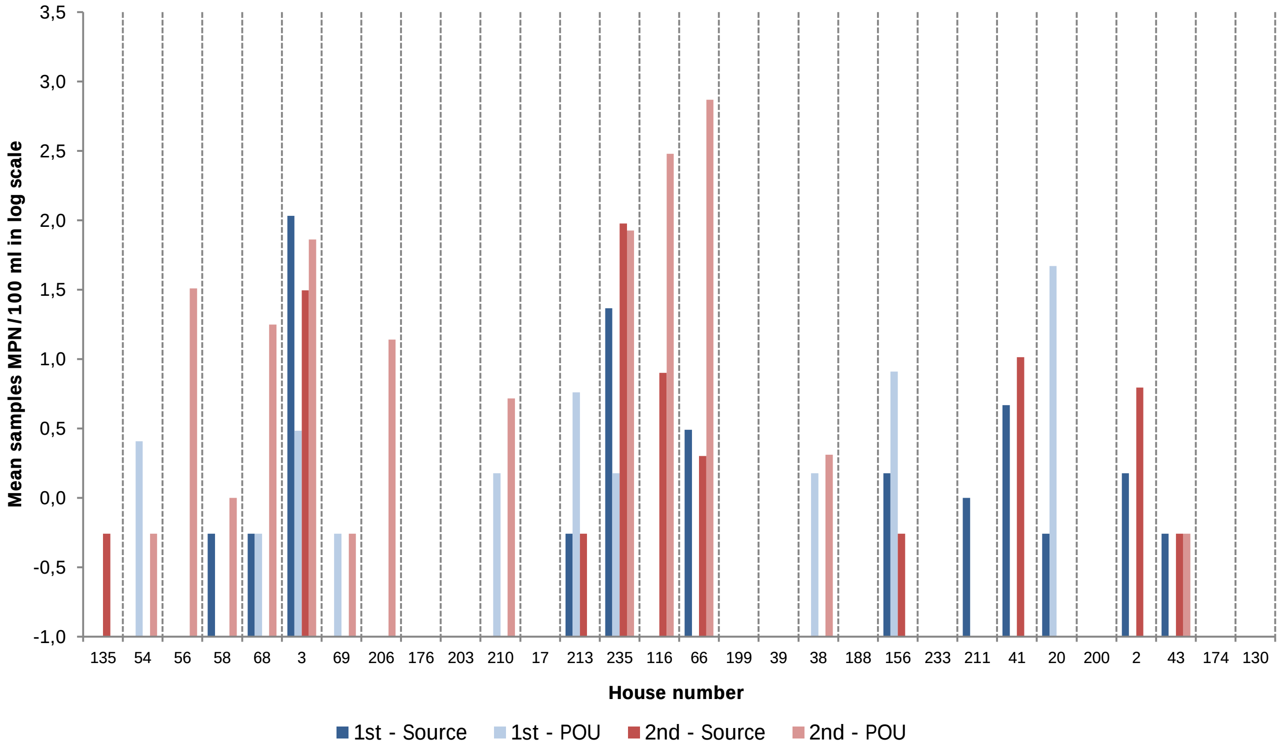


Figure 6-8 – Measured E. coli in source and POU samples in Waileum, Thailand

The changes in microbial water quality between sources and POU containers can then be calculated simply by subtracting the average MPN/100 ml measured in the samples collected from the corresponding households. The complete calculated differences can be found in Appendix F. The calculation was only possible for households that used rainwater collection systems and the borehole.

In the following two figures (Figure 6-9 and 6-10), these differences have been plotted for each household against the log MPN scales. For these graphs, missing bars indicate zero differences that can be interpreted as constant water quality between sources and POUs. The positive values indicate increasing *E. coli* counts in POU containers, which means that the source quality has deteriorated. Therefore, the negative values mean that the quality at the sources is in fact worse than at POUs indicating improvement in microbial water quality. It can be seen that even within a household, water quality changes were not consistent between the two periods.

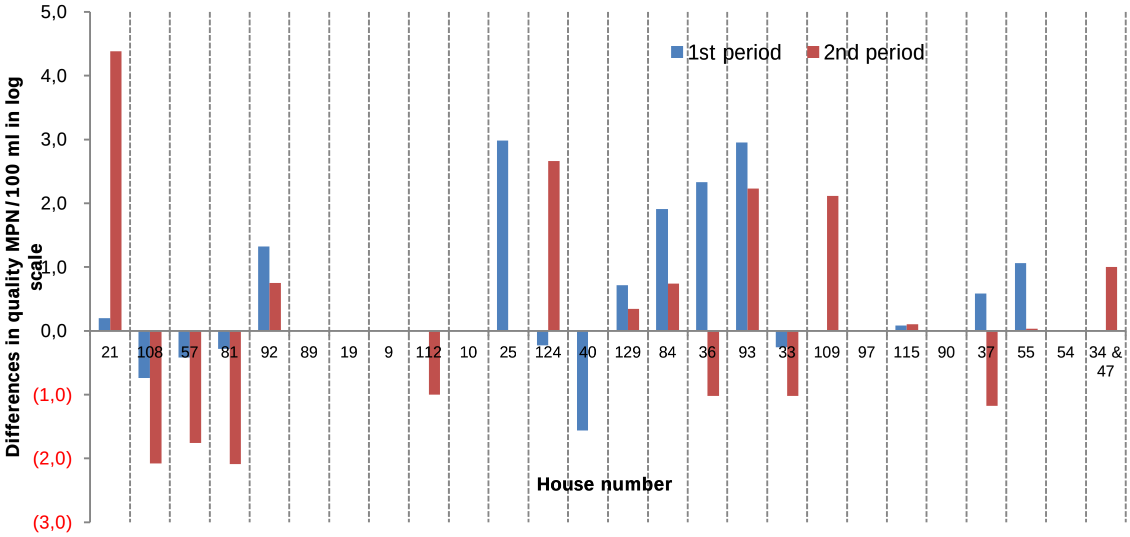


Figure 6-9 – Changes in microbial water quality between sources and POUs: Okad, Laos

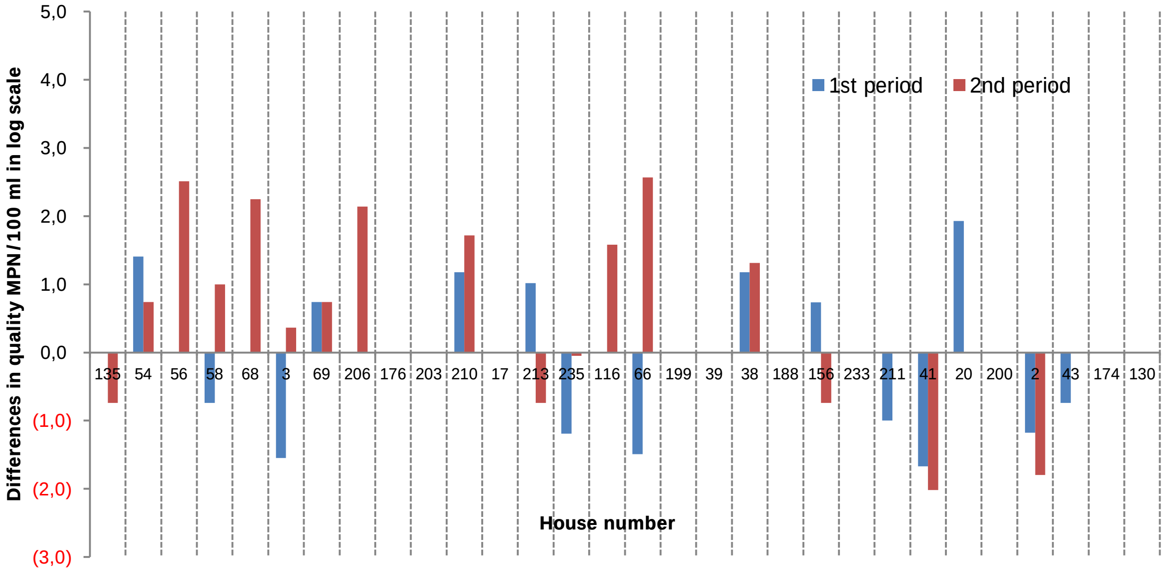


Figure 6-10 – Changes in microbial water quality between sources and POUs: Waileum, Thailand

The water quality changes detected in the samples can be summarised in terms of percentages of samples. For each of the study sites, the calculated percentages of samples that were deteriorated, constant and improved are presented in Table 6.3 and 6.4. The first and second entry rows show the percentages for the first and second measurement periods. The next row is the percentages for the whole period whereas the last row shows the percentages when the data from the two periods were averaged. By simply comparing the sheer ratio of samples that deteriorated, it cannot be concluded that there is a single pattern in water quality changes in the study sites. Improvement in water quality between sources and POUs however is consistently less than deterioration or constant quality except for the first period in Thailand (N=8 for POU<Source; N=7 for POU>Source). When comparing the results obtained in Laos, the proportions of samples that deteriorated and unchanged are quite similar. Whereas in Thailand, household samples with constant water quality were leading. This means that there is a general indication that household water handling practices in Thailand were relatively better than in Laos.

Table 6.3 – Percentages of deteriorated, constant and improved household samples in Laos

Okad Laos	**POU > Source**		**Constant**		**POU < Source**		**Total N samples**
	N	**%**	**N**	**%**	**N**	**%**	
1st period	10	38%	10	38%	6	23%	26
2nd period	10	40%	8	32%	7	28%	25
Total	*20*	*39%*	*18*	*35%*	*13*	*25%*	*51*
Average	*12*	*46%*	*7*	*27%*	*7*	*27%*	*26*

Table 6.4 – Percentages of deteriorated, constant and improved household samples in Thailand

Waileum Thailand	**POU>Source**		**Constant**		**POU<Source**		**N samples**
	N	**%**	**N**	**%**	**N**	**%**	
1st period	7	23%	15	50%	8	27%	30
2nd period	11	37%	13	43%	6	20%	30
Total	*18*	*30%*	*28*	*47%*	*14*	*23%*	*60*
Average	*12*	*40%*	*10*	*33%*	*8*	*27%*	*30*

Comparison of water quality at sources and at points of consumption may also be performed by pre-categorising the *E. coli* counts according to the classification proposed by Lloyd and Helmer seen in Table 6.2. The number of samples that fall under each category is then translated into sample percentages. The results may be seen in Figure 6-11 until Figure 6-13 for Laos and Figure 6-14 to Figure 6-16 for Thailand.

Although not remarkable, the move of the measured microbial contamination toward higher risk classes for the POU samples collected in Laos can be noticed. For instance in Figure 6-11, the proportion of samples with *E. coli* counts between 11-100 MPN/100 ml is 22% at POUs compared to 8% at sources. In Figure 6-12, a small portion of the POU samples (8% in total) has fallen under grade D and E. It has to be noted also that about half of the samples collected were of no risk category. Relatively large proportion of the source samples (about 31%) was also of low risk category. This of course is fairly in line with the technology classification that is the rainwater collection system, presumably capable of supplying safe drinking water.

In the graphs below it can be seen that a big portion of the samples collected in Thailand was of relatively acceptable quality. For the entire period, about 60% of the source and POU samples were of no risk category. The second highest portion was samples of low risk category, about 30% sources and 25% POUs. This means that about 10-15% of the samples were of intermediate to high risk. None of the samples contained *E. coli* more than 1000 MPN/100 ml. Looking at the measurement in the second period, a small trend of increasing *E. coli* counts in the POUs can be noticed. However this trend does not hold in the first period. In fact, a slight improvement in quality can be seen i.e. the proportion of POU samples having 0 MPN/100 ml is more than source sample proportion (64% against 60%).

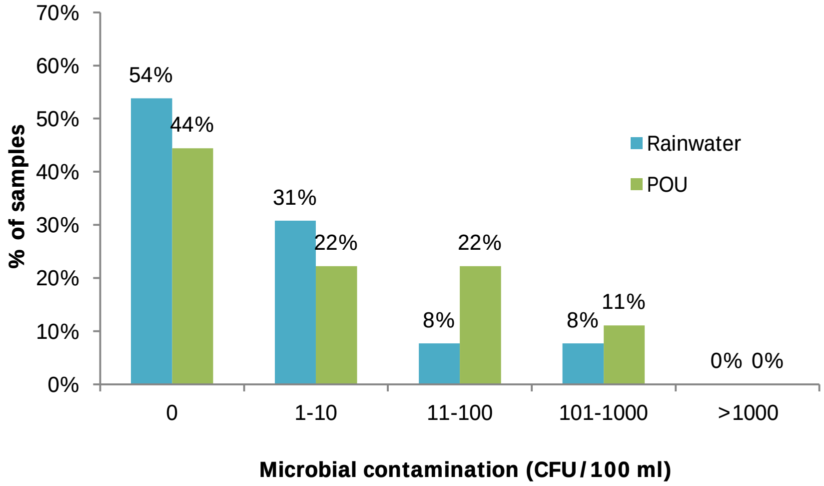


Figure 6-11 – Microbial risk classifications for sources and POUs in Laos: first period

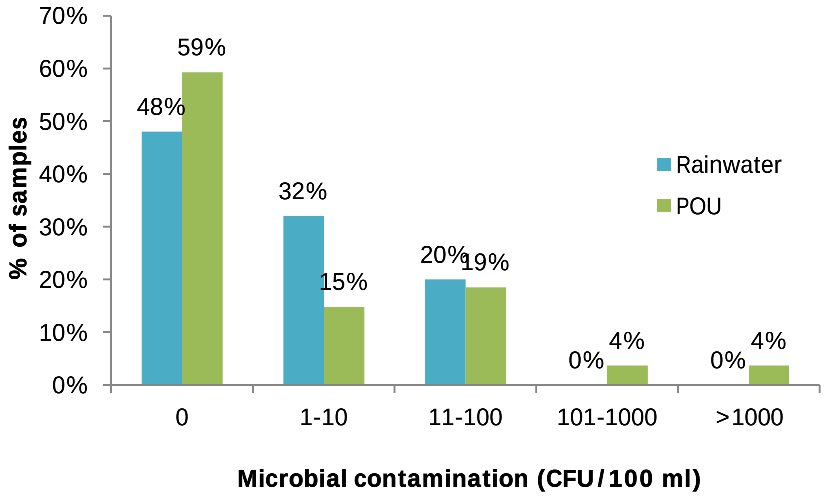


Figure 6-12 - Microbial risk classifications for sources and POUs in Laos: second period

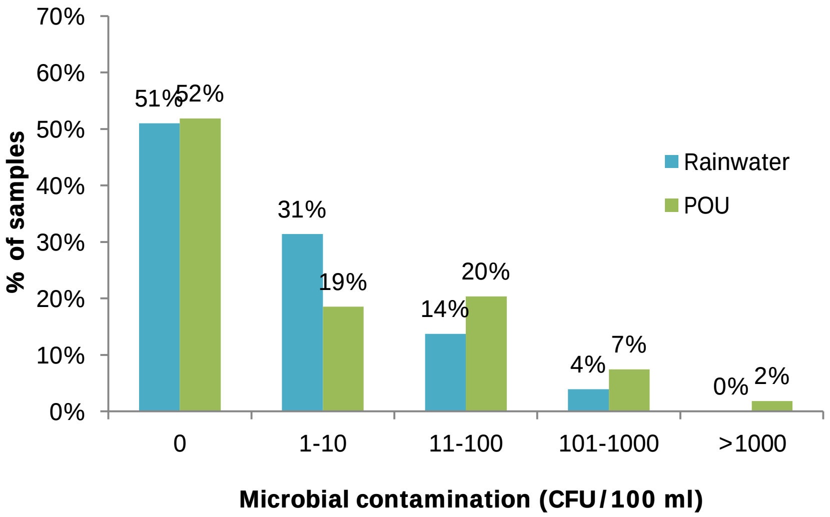


Figure 6-13 - Microbial risk classifications for sources and POUs in Laos: entire period

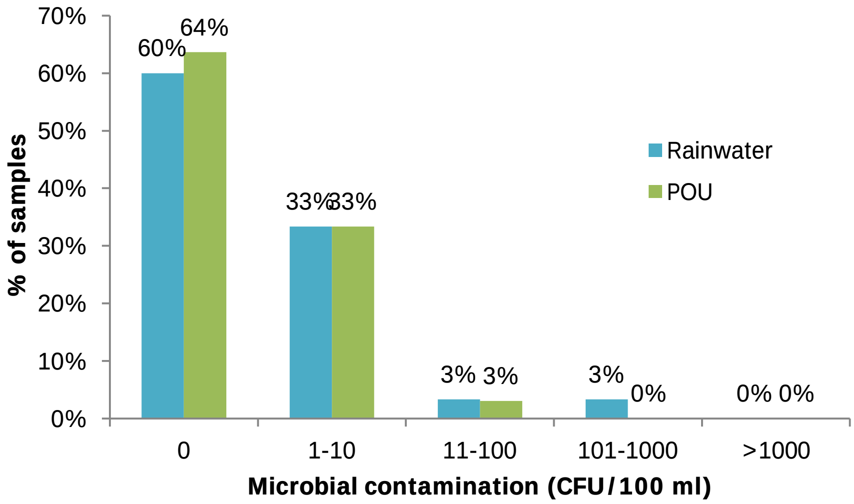


Figure 6-14 - Microbial risk classifications for sources and POUs in Thailand: first period

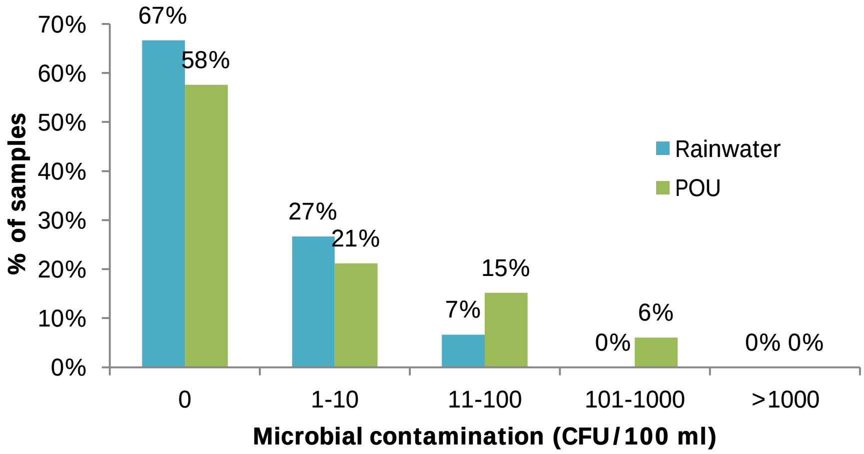


Figure 6-15 - Microbial risk classifications for sources and POUs in Thailand: second period

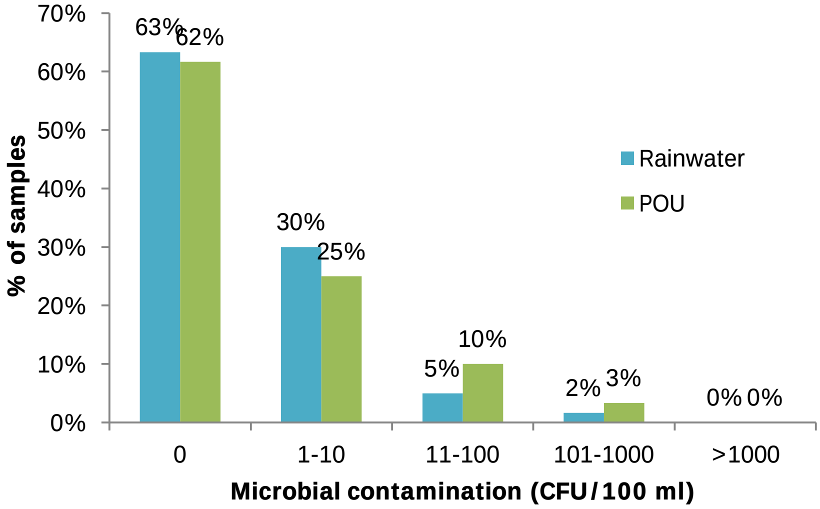


Figure 6-16 - Microbial risk classifications for sources and POUs in Thailand: entire period

When comparing the two study sites, it can be said that the water quality in the Thai village was overall better than the quality in the Lao village. This can be derived from the above analysis of the sample proportions that show a significant shift in classes between the two sites i.e. larger proportions of samples in Thailand were categorised as Grade A whereas more samples in Laos were categorised under Grade C and lower. Interestingly, the proportion of samples falling under Grade B was relatively unchanged in the two sites, especially when looking at the source quality.

A non-parametric statistical test was also carried out to analyse the differences in water quality between sources and POUs. The Wilcoxon matched-pairs signed-ranks test was the chosen method. In general this test is used to evaluate two dependent samples that may or may not originate from two different populations. In this test, the difference between the paired samples is computed and shall be tested for its significance. The method described in Sheskin (2003b) is used and for complete information reader is referred to the book.

The null hypothesis is that there is no difference between the source samples and the POU samples. The alternative hypothesis is thus whether there is significant change of microbial water quality, particularly if *E. coli* counts have been elevated, in other words the difference is hypothesised to be positive. This shall be evaluated with one tailed test.

In Table 6.5, the differences (D) computed for the samples in Laos in both periods have been compiled. The variables x_1 and x_2 used in this computation respectively correspond with the mean MPN/100 ml value of the POU sample and the source sample (provided in Appendix F). The absolute values of D are subsequently arranged in sequences from the smallest to the largest and so the rank for each D can be assigned. Tied scores receive an average rank of the original sequence. Those with zero differences are excluded from the analysis.

From here the sum of the negative (∑R–) and positive (∑R+) rankings may be calculated. In this case, ∑R+ equals to 395.5 and ∑R– equals to 165.5. Although this shows that there are more positive differences in the samples, the significance of this finding has to be tested by comparing the Wilcoxon T statistic with the tabled critical T value for n signed ranks. The T statistic obtained in this test is the smaller of the summed ranks which is 165.5. For a sample size of n=33, the critical T value at 0.05 level of significance for one-tailed test is 187 (critical values table can be found in Appendix J). The null hypothesis can be rejected if the obtained T statistic is equal to or less than the critical values. This means that apparently there is significant increase in contamination at 95% confidence interval (CI). It is also significant at 97.5% CI but failed short to be significant at 99% CI. It can be said that the tendency of increasing contamination in the Lao samples is barely consistent.

For the samples collected in Thailand shown in Table 6.6, ∑R– and ∑R+ values were respectively calculated as 206 and 302. For n equals 32, the critical T value at 0.05 level of significance is 175. This means that the obtained Wilcoxon T statistic of 206 is larger than the critical value, hence the differences observed are insignificant.

Combining the two datasets, the Wilcoxon test was repeated for n = 65 (tabled Wilcoxon ranking can be found in Appendix G). The calculated ∑R+ is 1433.5 and ∑R– is 711.5. Since the sample size is larger than the tabled critical T values, a normal approximation of the Wilcoxon T statistic is employed. The z value can be calculated using the following equation:

$$z = \frac{T - T_E}{s}$$ *Equation 6-1*

Where, the expected value of T (T_E) can be calculated as follows:

$$T_E = \frac{n(n+1)}{4}$$ *Equation 6-2*

and the standard deviation (s) is computed using this equation below:

$$s = \sqrt{\frac{n(n+1)(2n+1)}{24}}$$ *Equation 6-3*

The z value obtained is -2.36. Disregarding the minus sign, this number can be compared with z critical found in the normal distribution table (see Appendix J). The tabled critical one-tailed 0.05 and 0.01 values are $z_{.05}$ = 1.65 and $z_{.01}$ = 2.33. The null hypothesis may be rejected if at the prespecified level of significance, the absolute value of z computed is equal or greater than the critical z values. In this case, the z value of 2.36 is greater than both of the z critical which means that there is a significant difference in *E. coli* counts when comparing source samples and POU samples in both study sites. This indicates that overall deterioration of drinking water quality between source and POU prevails.

Table 6.5 – Wilcoxon ranking for the observed differences in Laos samples

Subject	**$D=X_1 - X_2$**	**Rank of |D|**	**Signed rank of |D|**
18	-0.45	2	-2
2	-0.45	2	-2
41	0.45	2	2
4	-0.5	4	-4
35	-0.9	5.5	-5.5
52	0.9	5.5	5.5
42	-0.95	7.5	-7.5
44	-0.95	7.5	-7.5
49	-1.4	9	-9
5	2	10	10
1	2.1	11	11
31	2.55	12	12
50	3	13	13
13	-3.55	14	-14
23	4.3	15	15
47	4.8	16	16
29	-5.65	17	-17
21	6.3	18	18
15	8	19	19
28	-11.85	20	-20
30	-12.2	21	-21
16	21.35	22	22
40	22.6	23	23
24	38	24	24
38	45.6	25	25
45	71.45	26	26
12	-85.7	27	-27
11	96.65	28	28
3	-147.9	29	-29
14	260.9	30	30
17	494.45	31	31
43	788.6	32	32
27	2419.5	33	33

Table 6.6 – Wilcoxon ranking for the observed differences in Thai samples

Subject	**$D=X_1 - X_2$**	**Rank of |D|**	**Signed rank of |D|**
44	-0.050	1	-1
36	0.366	2	2
21	0.735	3	3
4	-0.740	7.5	-7.5
7	0.740	7.5	7.5
28	-0.740	7.5	-7.5
31	-0.740	7.5	-7.5
32	0.740	7.5	7.5
37	0.740	7.5	7.5

Table 6.6 – Wilcoxon ranking for the observed differences in Thai samples (cont.)

Subject	$D=X_1 - X_2$	Rank of |D|	Signed rank of |D|
43	-0.740	7.5	-7.5
51	-0.740	7.5	-7.5
23	-1.000	12.5	-12.5
34	1.000	12.5	12.5
13	1.019	14	14
11	1.176	16	16
19	1.176	16	16
27	-1.176	16	-16
14	-1.191	18	-18
49	1.312	19	19
2	1.407	20	20
16	-1.491	21	-21
6	-1.549	22	-22
45	1.580	23	23
24	-1.667	24	-24
41	1.716	25	25
57	-1.796	26	-26
25	1.930	27	27
54	-2.015	28	-28
38	2.141	29	29
35	2.248	30	30
33	2.510	31	31
46	2.568	32	32

6.4 Correlations of microbial water quality with water source, sanitation and hygiene hazard scores

In this section, the correlations between microbial water quality and the hazard scores of water sources, sanitation and hygiene are described. The method used for this analysis is the non-parametric Spearman's rank-order correlation coefficient explained in Chapter 4. The new scores of water source hazards for both study sites can be found in Section 6.1. For sanitation and hygiene scores, it has been assumed that no major change would have occurred within the study period hence the initial scores assigned in Section 4.2 and 4.3 shall be used in the analysis.

The statistical tests were performed separately for the datasets obtained in Laos and Thailand. Subcategories for datasets obtained in the first sampling, second sampling and the average of both samples were also presented. The summaries of the test statistics are presented in Table 6.7 to 6.9. For information on the complete datasets used, readers are referred to Appendix H. To further illustrate the correlations, the mean *E. coli* counts in the samples were plotted against the corresponding hazard scores (Figure 6-17 toFigure 6-22).

In Table 6.7 the statistical test was performed for the *E. coli* counts in water source samples with the source hazard scores. In the subsequent tables, the statistical tests have been performed for the sanitation and hygiene scores correlated with the *E. coli* counts found in household container samples. This distinction is favoured as it is in line with the hypothesis that sanitation and hygiene may have indirectly (through handling practices) affected water quality at points of consumption.

Computed Spearman's correlation coefficients were then evaluated against the critical values for a prespecified level of significance which may be found in Appendix J. For the number of n samples indicated in each of the test statistics performed in this section, the corresponding critical r_s has been summarised in Table 6.10 for easier comparisons. The null hypothesis that no correlation between the variables exists can be rejected if the computed r_s is equal or greater than critical r_s. One-tailed test is employed as it is hypothesised that a positive monotonic relationship is expected. The strength of the relationships may be based on its divergence from zero to either directions (+1 or -1).

In Table 6.7 it can be seen that the datasets obtained in Laos display greater correlations and were significant up to 0.01 level of significance. The strength of the positive relationships was however only moderate. For the Thai datasets, no correlations can be derived. Originally, the two datasets only contain the assessment of rainwater collection systems (mainly) for the rainy season. However, in Laos the datasets from the point sources (functional only in dry season) were added and this has further fortified the correlations. It has to be noted that prior to the inclusion, the rainwater systems of Laos still exhibit relatively higher correlations as compared to those in Thailand. When these sources were excluded the correlation coefficients drop by about 20%. For these relatively unprotected point sources, the high hazard scores were consistently translated into high faecal contamination. Whereas for the rainwater harvesting systems, variability in levels of contamination as well as of the quantified hazard scores were more common. Although in Laos, it generally translates better into faecal contamination. There might be and underlying mechanisms which relates the higher incidences in Laos with the poorer sanitation or hygiene (for hygiene especially, there is comparatively more positive correlations than in Thailand although it was not significant). This reasoning however is merely indicative because the data were not statistically powerful enough for hard conclusions. With respect to the hazard score, there might be a confounding factor stemming from the equal weighting system that may not be sensitive enough to define the actual hazard level.

For the sanitation scores in Laos with n=37, the critical values for n=40 are consulted. It can be seen that for the first period, it is just short of being significant at 0.05 level. In the case of Thai datasets in the first period (n=33) compared to the critical values for n=35, it is significant at 0.05 level. For the other periods, the correlations are insignificant. Weak positive monotonic relationships were found in all of the datasets analysed. A positive correlation between the two parameters is expected to indicate poor sanitation as a possible driver in determining contamination event at household POU.

The results shown in Table 6.9 on hygiene scores indicate that no correlations may be derived from the hygiene scores and the *E. coli* counts found in the household POU containers. The lack of correlation can be argued similarly as for sanitation hazard. In addition, it has to be remarked that the assessment of the hygiene indicator, hand washing, was largely based on questionnaire results (no actual observation of hand washing practices was conducted, although supporting elements such as hand washing facilities and provision of soap were checked) which may not fully reflect the actual situations.

Finally, it is quite likely that the relationships are affected by the variability in the microbial data. The short-term sampling period provides a snapshot of water quality variations in time, however it may not suffice to illustrate the pattern of water quality in longer term.

Table 6.7 – Spearman's correlation coefficients for E. coli counts of water source samples with water source hazard scores

Source E. coli vs. Water source score				
	n	**r_s**	**r_s-corrected**	**p**
Laos				
1st period	29	0.483	0.450	<0.01
2nd period	28	0.567	0.543	<0.01
Average	29	0.510	0.496	<0.01
Thailand				
1st period	30	0.060	-0.062	ns
2nd period	30	0.249	0.115	ns
Average	30	0.033	-0.053	ns

Table 6.8 – Spearman's correlation coefficients for E. coli counts of household POU samples with sanitation scores

POU E. coli vs. Sanitation score				
	n	**r_s**	**r_s-corrected**	**p**
Laos				
1st period	37	0.380	0.240	ns
2nd period	37	0.377	0.162	ns
Average	37	0.352	0.226	ns
Thailand				
1st period	33	0.422	0.323	<0.05
2nd period	33	0.122	0.006	ns
Average	33	0.265	0.211	ns

Table 6.9 – Spearman's correlation coefficients for E. coli counts of household POU samples with hygiene scores

Source E. coli vs. Hygiene score				
	n	**rs**	**rs-corrected**	**p**
Laos				
1st period	37	0.284	0.216	ns
2nd period	37	0.210	0.179	ns
Average	37	0.150	0.117	ns
Thailand				
1st period	33	0.460	-0.018	ns
2nd period	33	0.301	-0.068	ns
Average	33	0.350	0.018	ns

Table 6.10 – Critical Spearman's correlation coefficients for selected n samples

	One-tailed level of significance		
n	**0.05**	**0.025**	**0.01**
28	0.317	0.375	0.440
29	0.312	0.368	0.433
30	0.306	0.362	0.425
35	0.283	0.335	0.394
40	0.264	0.313	0.368

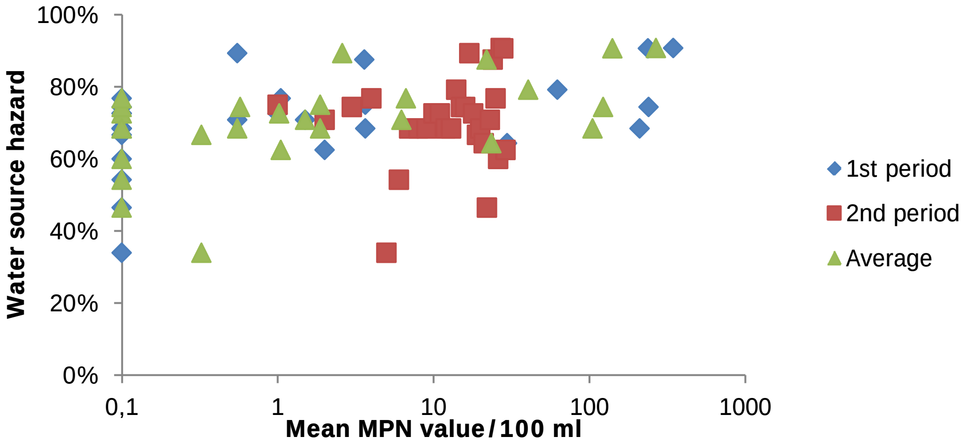


Figure 6-17 – Plotted Source E. coli counts vs. Water source hazard score in Laos

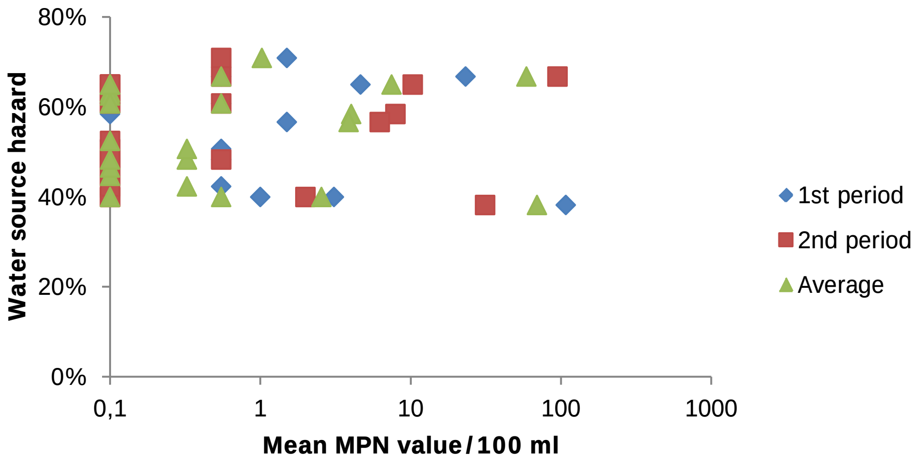


Figure 6-18 – Plotted Source E. coli counts vs. Water source hazard score in Thailand

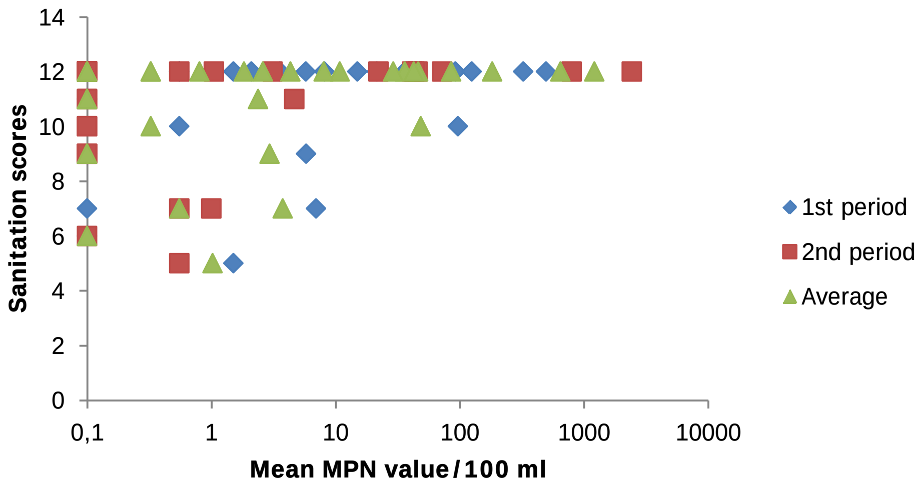


Figure 6-19 – Plotted POU E. coli counts vs. Sanitation scores in Laos

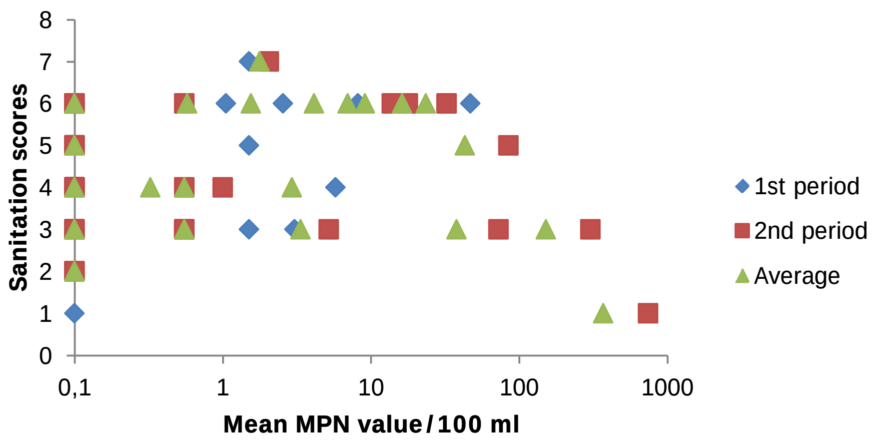


Figure 6-20 – Plotted POU E. coli counts vs. Sanitation scores in Thailand

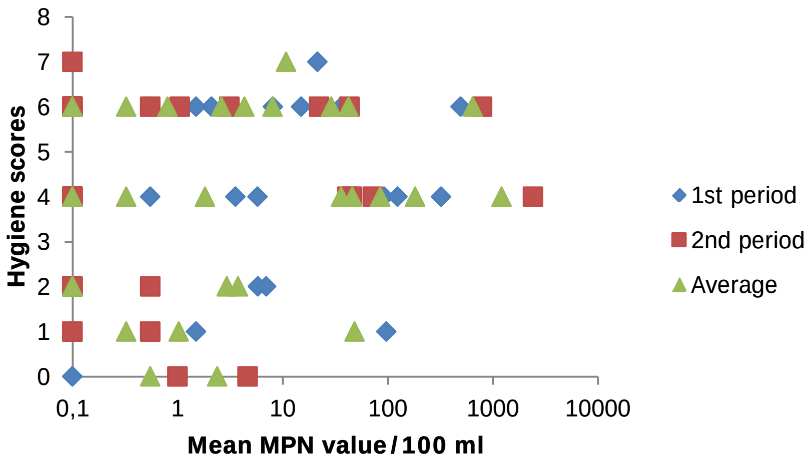


Figure 6-21 – Plotted POU E. coli counts vs. Hygiene scores in Laos

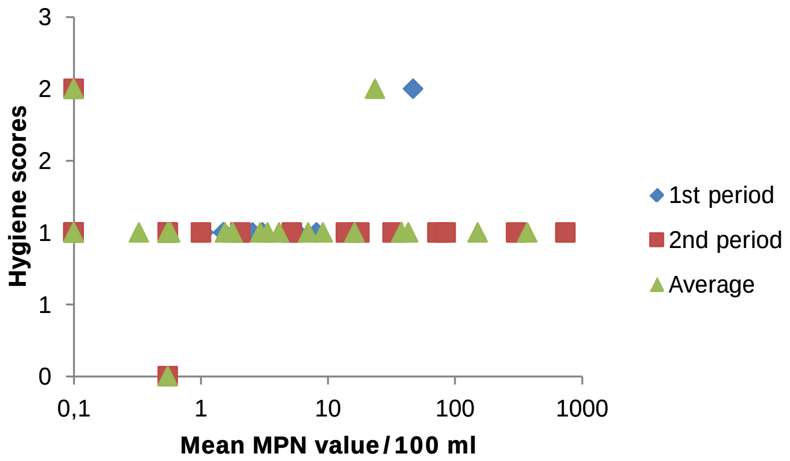


Figure 6-22 – Plotted POU E. coli counts vs. Hygiene scores in Thailand

6.5 Comparing microbial water quality in relations with various operational parameters

For some of the operational parameters that were observed during the house visits, a basic comparison is made to see if there is a significant indication of correlation between microbial water quality and the corresponding handling practices. For all the identifiable variables, mean *E. coli* counts were calculated which can be seen in Table 6.11 and 6.12 for Laos and Thailand, respectively. For comparison purpose, the composite mean *E. coli* values were graphed accompanied with the calculated standard errors (SE). Graphical representations for the datasets obtained in Laos can be seen from Figure 6-23 to Figure 6-28. Similarly, the datasets obtained in Thailand were presented in Figure 6-29 to Figure 6-34.

Table 6.11 – Mean E. coli counts for identifiable operational variables in Okad, Laos

Laos		1st period				2nd period				Composite			
Parameters	**Variables**	**Mean**	**STDEV**	**n**	**SE**	**Mean**	**STDEV**	**n**	**SE**	**Mean**	**STDEV**	**n**	**SE**
Types of POU containers	Thermos canister	0,27	1,43	16	0,36	-0,39	1,07	15	0,28	-0,05	1,30	31	0,23
	Wide bowl	0,76	0,00	1	0,00	-	-	-	-	0,76	0,00	1	0,00
	Plastic gallon	-0,21	0,88	10	0,28	-0,22	1,30	9	0,43	-0,21	1,07	19	0,25
	Plastic jug	0,51	1,25	7	0,47	0,18	1,15	7	0,44	0,35	1,17	14	0,31
	Glass jug	-1,00	0,00	1	0,00	-1,00	0,00	1	0,00	-1,00	0,00	2	0,00
	Plastic bottle	-1,00	0,00	2	0,00	-1,00	0,00	2	0,00	-1,00	0,00	4	0,00
Cover	Well covered	0,07	1,23	33	0,21	-0,15	1,29	33	0,22	-0,04	1,26	66	0,15
	Uncovered	0,83	1,12	3	0,65	-0,81	0,37	4	0,19	-0,11	1,12	7	0,42
	Insufficient cover	-1,00	0,00	1	0,00	-	-	-	-	-1,00	0,00	1	0,00
Modes of collection	Scoop	0,30	1,39	17	0,34	-0,16	1,40	16	0,35	0,08	1,40	33	0,24
	Pour	0,07	1,19	11	0,36	-0,25	1,07	11	0,32	-0,09	1,12	22	0,24
	Tap	-0,25	0,93	9	0,31	-1,00	0,00	1	0,00	-0,33	0,90	10	0,29
Transfer devices	Cup with handle	0,33	1,29	20	0,29	-0,31	1,19	11	0,36	0,10	1,27	31	0,23
	Cup without handle	-0,56	0,76	3	0,44	0,46	2,53	3	1,46	-0,05	1,76	6	0,72
	Jug	0,32	1,28	8	0,45	-0,08	1,13	9	0,38	0,11	1,18	17	0,29
	Tap	-0,46	1,09	4	0,54	-0,30	1,25	10	0,40	-0,34	1,17	14	0,31
	Bottle	-1,00	0,00	2	0,00	-1,00	0,00	2	0,00	-1,00	0,00	4	0,00
State of cleanliness	Dirty	0,30	1,22	25	0,24	0,05	1,40	23	0,29	0,18	1,30	48	0,19
	Clean	-0,32	1,17	12	0,34	-0,67	0,75	14	0,20	-0,51	0,96	26	0,19
Treatment	No treatment	0,04	1,19	33	0,21	-0,21	1,27	35	0,21	-0,08	1,23	68	0,15
	Boiling	0,55	1,60	4	0,80	-0,50	0,71	2	0,50	0,20	1,39	6	0,57

Table 6.12 – Mean E. coli counts for identifiable operational variables in Waileum, Thailand

Thailand		1st period				2nd period				Composite			
Parameters	**Variables**	**Mean**	**STDEV**	**n**	**SE**	**Mean**	**STDEV**	**n**	**SE**	**Mean**	**STDEV**	**n**	**SE**
Types of POU containers	Thermos canister	-0,67	0,51	5	0,23	-0,31	0,55	4	0,28	-0,51	0,53	9	0,18
	Plastic gallon	-0,35	0,00	1	0,00	-1,00	0,00	1	-	-0,35	0,00	1	0,00
	Plastic jug	-0,50	0,00	1	0,00	1,25	0,00	1	0,00	0,37	1,24	2	0,87
	Plastic bottle	-0,62	0,66	21	0,14	-0,13	1,35	22	0,29	-0,37	1,09	43	0,17
	Earthen jar	0,27	1,34	3	0,77	-0,43	0,98	3	0,57	-0,08	1,12	6	0,46
	Pot	-1,00	0,00	2	0,00	-1,00	0,00	2	0,00	-1,00	0,00	4	0,00
Cover	Well covered	-0,54	0,71	32	0,13	-0,19	1,20	32	0,21	-0,37	1,00	64	0,12
	Insufficient cover	-1,00	0,00	1	0,00	-1,00	0,00	1	-	-1,00	0,00	1	0,00
Modes of collection	Scoop	-0,32	0,95	8	0,33	-0,06	0,83	7	0,31	-0,20	0,87	15	0,22
	Pour	-0,64	0,62	25	0,12	-0,26	1,28	26	0,25	-0,44	1,02	51	0,14
Transfer devices	Cup with handle	-0,32	0,95	8	0,33	-0,06	0,83	7	0,31	-0,20	0,87	15	0,22
	Cup without handle	-0,67	0,46	2	0,33	-1,00	0,00	1	0,00	-0,78	0,38	3	0,22
	Bottle	-0,60	0,67	20	0,15	-0,19	1,35	21	0,30	-0,39	1,08	41	0,17
	Other	-0,75	0,35	2	0,25	-0,44	1,12	4	0,56	-0,54	0,90	6	0,37
State of cleanliness	Dirty	-0,71	0,53	8	0,19	0,03	1,35	13	0,37	-0,25	1,15	21	0,25
	Clean	-0,53	0,49	57	0,07	-0,37	1,09	20	0,24	-0,49	0,69	77	0,08
Treatment	No treatment	-0,55	0,73	29	0,14	-0,15	1,26	28	0,24	-0,36	1,04	57	0,14
	Boiling	-1,00	0,00	2	0,00	-1,00	0,00	3	0,00	-1,00	0,00	5	0,00

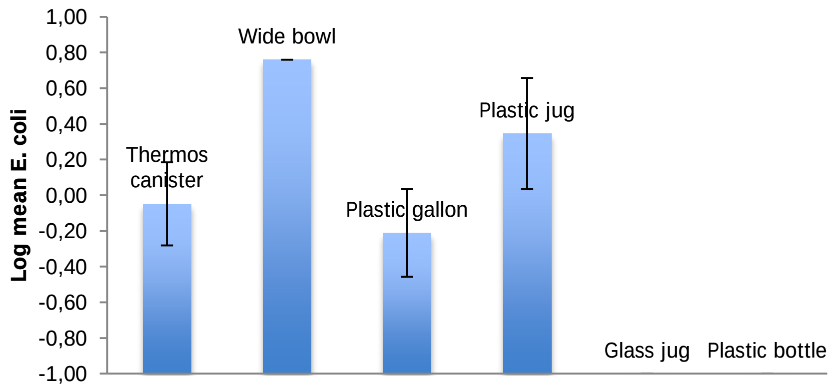


Figure 6-23 – Comparison of mean E. coli counts for various types of POU containers in Okad, Laos

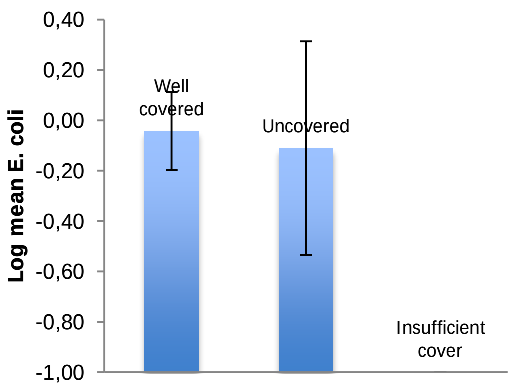


Figure 6-24 - Comparison of mean E. coli counts for container covers in Okad, Laos

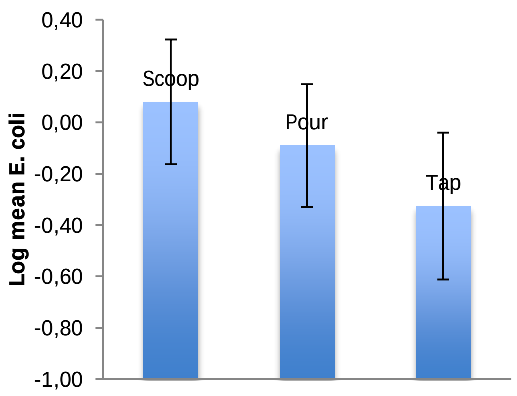


Figure 6-25 - Comparison of mean E. coli counts for various modes of drinking water collection in Okad, Laos

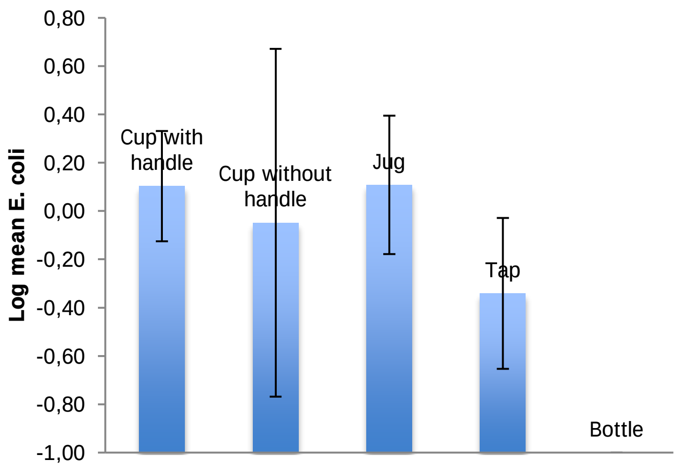


Figure 6-26 - Comparison of mean E. coli counts for various types of transfer devices in Okad, Laos

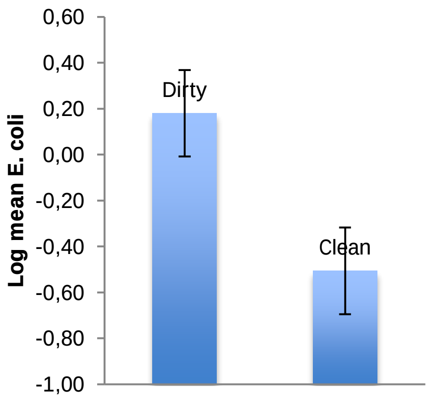


Figure 6-27 - Comparison of mean E. coli counts for different state of cleanliness in Okad, Laos

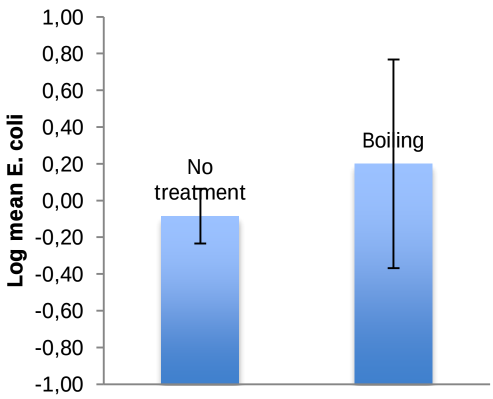


Figure 6-28 - Comparison of mean E. coli counts for treatment status in Okad, Laos

As can be seen from the figures above, there are some indications that the various operational parameters were affecting water quality differently. For the different types of POU containers, the data suggest that mean *E. coli* counts in glass jug (n=2) and plastic bottle (n=4) were significantly lower than the other container types. The lack of contamination can be also attributed to the water source since, all of glass jugs and plastic bottles were used by the users who reportedly used bottled water. As with the wide bowl, it provided much contaminated water. However since there was only one sample, the significance cannot be measured.

For the sufficiency of cover, no significant relationship was found. It may seem that insufficient cover provided significantly better water, but this is because only 1 sample was collected and thus may not be representative. The samples with insufficient cover was also much less (n=7) compared to the well covered containers (n=66).

With regards to the modes of collection there is an interesting pattern (not statistically significant) where *E. coli* counts decrease in the following order: scoop, pour and tap. The three modes are associated with decreasing hand contacts (note: pour and tap are equal in this respect).

The effect of different transfer devices used in extracting water was also not significantly different. Although there is an indication that water collected via tap is of better quality compare to those collected with cup with handle. Again here, the use of bottle water is associated with significantly better water quality.

Looking at the state of cleanliness, it also suggests that clean containers were significantly related with lower *E. coli* counts. Cleanliness of containers was assessed by observing the general appearances of the containers from dirt, accumulated sediments, or small animals inside the containers.

It appears that treatment in Laos did not improve water quality. Only one out of five households show improvement after boiling, whereas the remaining 4 households experienced deteriorating water quality. This is very likely due to recontamination since boiled water was kept in thermos canisters that require scooping, thus potentially introducing hand contacts. It may also be possible that the subsequent containers were not clean, water may have been mixed or boiling was not performed well. During sampling, the water presented was also of room temperature (unlike those sampled in Thailand where boiling was performed).

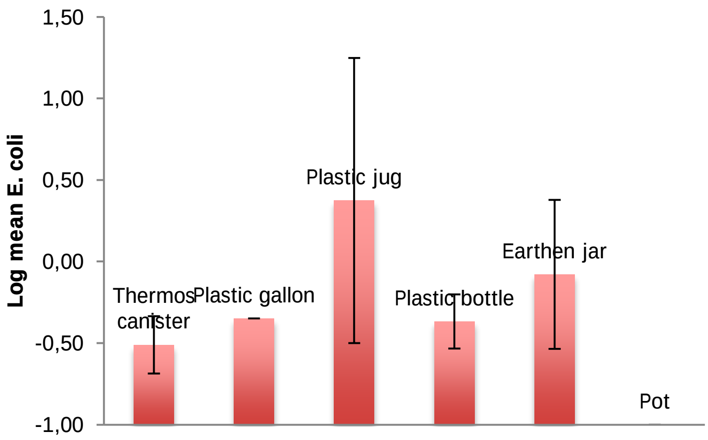


Figure 6-29 - Comparison of mean E. coli counts for various types of POU containers in Waileum, Thailand

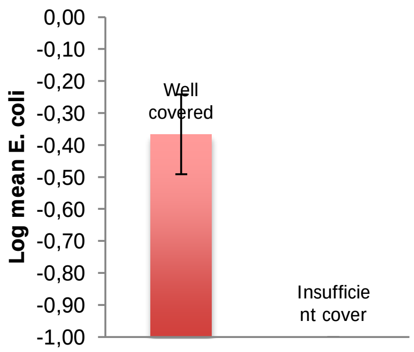


Figure 6-30 - Comparison of mean E. coli counts for container covers in Waileum, Thailand

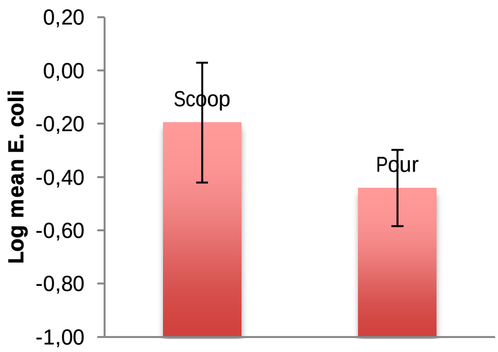


Figure 6-31 - Comparison of mean E. coli counts for various various modes of drinking water collection in Waileum, Thailand

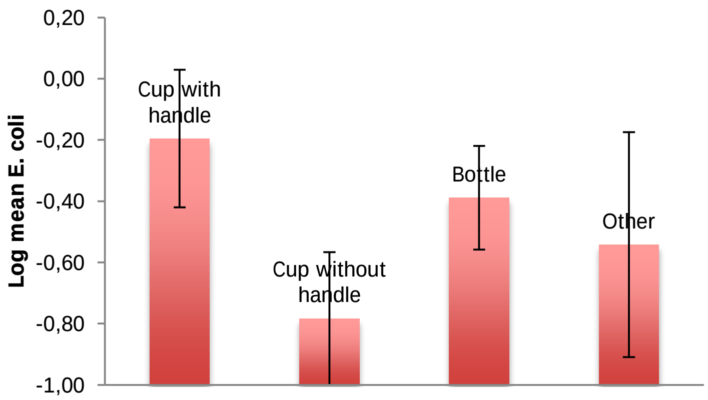


Figure 6-32 - Comparison of mean E. coli counts for various types of transfer devices in Waileum, Thailand

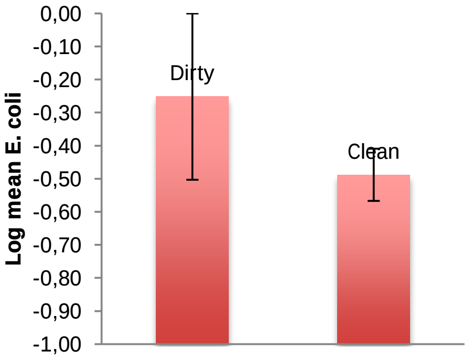


Figure 6-33 - Comparison of mean E. coli counts for different state of cleanliness in Waileum, Thailand

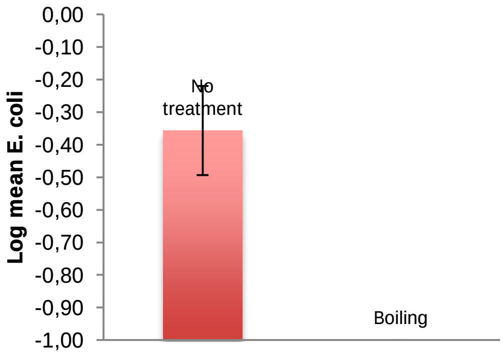


Figure 6-34 - Comparison of mean E. coli counts for treatment status in Waileum, Thailand

For the types of POU containers in Thailand, they appear to have no significant effect on drinking water quality, except for the pot which is actually attributable to treatment efficacy, as those pots were used for boiling.

As for container covers, in fact only one household was recorded with insufficient cover, thus statistical comparison for this parameter is not possible.

Again for the modes of collection, although not significant, there is a certain decreasing pattern of faecal contamination associated with decreasing hand contacts.

Interestingly for the transfer device category, cup without handle may be significantly be associated with lower *E. coli* counts compared to using cup with handle or bottle. This is rather counterintuitive as cup without handle is presumed as allowing more hand contacts.

For the state of cleanliness, the pattern shown was not statistically significant. On the other hand, boiling in the Thai site did ensure good water quality.

Overall, there is a consistent (although weak) pattern in both sites that modes of collection may be associated with water quality. In both sites, the efficacy of container cover was not conclusive. Types of transfer devices were also not significantly affecting water quality, except for the cup without handle (in comparison with cup with handle) in Thailand. The state of cleanliness is indicative of water quality (significant in Laos and weak pattern in Thailand). Treatment of water is only significant in Thailand. In Laos it appears that boiling had no effect. It was plausible that recontamination of the treated water occurred in Laos. During sampling, the Thai samples were presented boiling hot and poured from the boilers whereas the Laos samples were of room temperature and were scooped out from their POU containers.

6.6 Comparing the methods: CBT vs. IDEXX

To compare the two MPN methods used in this research, the evaluation method described in ISO 17994:2004 shall be used. The ISO method provides a framework of comparisons of the average relative differences against chosen criteria of equivalence (ISO, 2004).

In a simple positive and negative detection table, the numbers of samples that are detected as equally positive (++) or equally negative (--) as well as unequal (+- or -+) for the two enumeration methods are shown (Table 6.13).

Table 6.13 – Numbers of samples corresponding with positive and/or negative detections

Methods	**CBT**	
Quanti-tray 2000	**+**	**-**
+	93	15
-	22	118

In Table 6.14, the eligible samples have been analysed for their relative differences. Samples that were detected at zero counts for both methods (--) or were larger than countable ranges for either method are excluded from the analysis. The relative difference (x_i) may be calculated with Equation 6-4 or Equation 6-5 depending on the types of datasets. Equation 6-4 is used when the both methods give non-zero MPN counts (a_i, b_i) whereas Equation 6-5 is used when one of the methods give zero count ((a_i, 0) or (0, b_i)).

$$x_i = [ln(a_i) - ln(b_i)] \times 100\%$$ *Equation 6-4*

$$x_i = ln(a_i + 1) \times 100\%$$ or $$x_i = -ln(b_i + 1) \times 100\%$$
Equation 6-5

Subsequently the mean relative difference (x') can be calculated according to the equation below:

$$x' = \frac{\sum x_i}{n}$$ *Equation 6-6*

where n is simply the number of samples analysed. The standard deviation (s) may then be computed using a conventional formula (Equation 6-7). The expanded uncertainty (U) is next derived from the standard error ($s_{x'}$) multiplied by a coverage factor, k equals 2. The final evaluation is based on the resulting confidence interval computed using Equation 6-10.

$$s = \sqrt{\frac{\sum (x_i - x')^2}{n-1}}$$ *Equation 6-7*

$$s_{x'} = \frac{s}{\sqrt{n}}$$ *Equation 6-8*

$$U = ks_{x'} = \frac{2s}{\sqrt{n}}$$ *Equation 6-9*

Lower limit: $x_L = x' - U$

Upper limit: $x_H = x' + U$

Equation 6-10

Table 6.14 – Sample relative differences: comparison of CBT and Quanti-tray 2000

Number	**Sample code**	**MPN CBT**	**MPN IDEXX**	**Xi**
89	BW1	<0.1	1	-69.31
111	RW15	<0.1	1	-69.31
133	POU21	<0.1	1	-69.31
10	RW5	<0.1	1	-69.31
50	RW25	<0.1	1	-69.31
55	RW23	<0.1	1	-69.31
59	RW28	<0.1	1	-69.31
66	RW1	<0.1	1	-69.31
104	BW2	<0.1	1	-69.31
14	RW3	<0.1	1.5	-91.63
22	POU11	<0.1	1.5	-91.63
36	HP1	<0.1	2	-109.86
104	RW10/POU7	<0.1	2	-109.86
139	RW26B	<0.1	2	-109.86
85	POU19	<0.1	2.05	-111.51
105	POU8	48.3	43.25	11.04
99	POU5	48.3	22.15	77.96

69	POU8	40.45	13.85	107.18

Table 6.14 – Sample relative differences: comparison of CBT and Quanti-tray 2000 (cont.)

Number	Sample code	MPN CBT	MPN IDEXX	Xi
63	POU22	30.95	21.45	36.66
122	RW23	30.95	18.7	50.38
135	POU19	30.95	45.7	-38.97
49	POU25	30.95	46.8	-41.35
37	RW10/POU7	30.95	15	72.43
87	RW1	30.95	11.95	95.16
92	RW14	30.95	94.95	-112.10
103	POU4	30.95	72	-84.43
20	POU1	28.95	5.75	161.64
15	POU2	20.85	2.55	210.13
129	BW9	15.35	4.65	119.42
102	RW8	13.6	17.35	-24.35
90	RW15	13.6	7.95	53.69
9	BW1	13.6	6.95	67.13
16	POU6.1	13.6	5.8	85.22
29	RW14	13.6	23.3	-53.84
38	POU19	13.6	1.5	220.46
106	RW11	13.6	40.25	-108.50
118	POU20	13.6	41.3	-111.08
73	PN1/1	13.6	44.15	-117.75
21	RW4	11.6	3.65	115.63
106	RW24	11.35	10.35	9.22
132	RW24	11	<1	248.49
137	RW13	9.6	5.75	51.26
12	BW3	9.4	3.55	97.38
119	RW14	9.15	12.3	-29.58
26	POU13	9.15	5.75	46.46
48	RW24	9.15	4.65	67.69
33	RW11	9.15	3.6	93.28
18	BW5	9.15	1.5	180.83
42	POU21	8.5	8.15	4.20
33	RW16	4.7	3.1	41.62
11	POU6	4.7	3.05	43.24
43	RW21	4.7	1.5	114.21
57	RW27	4.7	1.5	114.21
82	BW5	4.7	1	154.76
79	POU2	4.7	1	154.76
97	RW13	4.7	1	154.76
17	BW4	4.05	1.5	99.33
28	POU14	4.05	1.5	99.33
94	RW6	3.65	4.65	-24.21
75	POU4	3.65	1	129.47
45	RW15	3.6	<1	152.61
40	RW14	3.4	2	53.06
59	POU21	3.2	8.1	-92.87
126	RW19	2.95	1	108.18
35	POU9	2.6	<1	128.09
5	RW1	2.4	1	87.55
19	BW6	2.4	1	87.55
76	POU2	2.4	<1	122.38
93	POU2	2.4	<1	122.38
42	POU12	2.3	4.1	-57.81
41	RW20	2.3	<1	119.39
109	POU21	2.05	<1	111.51

107	POU9	2	<1	109.86

Table 6.14 – Sample relative differences: comparison of CBT and Quanti-tray 2000 (cont.)

Number	Sample code	MPN CBT	MPN IDEXX	Xi
78	RW10	2	<1	109.86
69	RW26B	1.5	1	40.55
116	RW28	1.5	1	40.55
54	POU17	1.5	<1	91.63
4	RW2	1.5	<1	91.63
109	POU12	1.5	3.1	-72.59
27	RW13	1.35	1	30.01
1	BW1	1.35	2	-39.30
96	POU13	1.35	<1	85.44
80	RW3	1.3	1.5	-14.31
101	RW7	1.2	1	18.23
110	RW21	1.2	1	18.23
117	RW20	1.2	<1	78.85
4	POU1.1	1.1	<1	74.19
87	POU17	1	<1	69.31
41	POU11	0.8	1	-22.31
9	POU5	0.8	1	-22.31
115	POU28	0.8	1	-22.31
52	RW19	0.8	<1	58.78
61	RW29	0.8	<1	58.78
121	RW23	0.8	<1	58.78
25	RW6	0.65	1	-43.08
8	RW4	0.65	1	-43.08
46	BW2	0.65	1	-43.08
71	POU7	0.65	1	-43.08
81	BW4	0.65	<1	50.08
130	POU22	0.65	<1	50.08
39	RW19	0.65	<1	50.08
131	RW25	0.65	2	-112.39
94	RW16	0.65	2	-112.39

Calculated mean relative difference for these samples is 28.5% with a total n of 103. The standard deviation of the samples is 89.4, thus the expanded uncertainty amounts to 17.6 which gives a lower limit of 10.8 and an upper limit of 46.1. Comparing the mean relative difference with the U value, it appears that the U is less than 28.5% which means that the samples produced significant difference. It has to be taken into considerations that the CBT and the Quanti-tray have a different level of sensitivity in enumerating *E. coli.* The CBT with 5 compartments allow for only 32 combinations of the MPN (maximum detection limit >100 MPN/100 ml). On the other hand the Quanti-tray 2000 method allows for 49 times 48 MPN combinations with maximum detection limit of >2419 MPN/100 ml. This discrepancy is not covered by the current comparison method.

7 Discussions

To address the study objective, the hazard classification framework of the study population coupled with the microbial water quality analysis using *E. coli* as indicator organism have been presented and analysed accordingly. The main findings and their implications on the study objective are discussed in the following section.

The main results of the first study phase were the general characteristics of the study population according to their water supply system, sanitation facilities and hygiene behaviours (Chapter 3) which culminates with a more specific characterisations based on the identified hazard classes (Chapter 4). The general overview of the study population reveals an expected discrepancy between the two study sites where as a whole the Thai site exhibited greater access to improved drinking water sources (particularly in the dry season), better sanitation facilities and hand washing practices. The large part of the Lao study population was reliant on an unimproved water source in the dry season that is the unprotected dug wells. Two things are particularly interesting with respect to the choice of drinking water source in Laos. First of all, the majority of the population in the study site in Laos did own a private improved water source, the mechanical borehole. However, it was not preferred for use as drinking water due to the unpalatable taste. The perceptions of locals to what may be considered as “good” drinking water appears to be more affected by the taste of water as opposed to the visual appearance (the dug well water was visibly turbid). Secondly, during the final fieldwork in the rainy season, it was found out that the population in Laos had changed their source to rainwater. Instead of one main source, the population was reliant on two water sources in different seasons. This certainly points to variability of drinking water quality throughout the year, given that the dug well was grossly contaminated compared to rainwater (as confirmed by the microbial analysis in the final fieldwork). Although not explored within the scope of this study, multiple types of sources (with different hazards) could also pose as a confounding factor in monitoring effort that is based on water service level classification, which typically characterise a population based on a single water source.

In the rainy season where the population in both study sites were concurrently using rainwater, it was also found that the types of the rainwater collection systems that were installed in both villages differed considerably. In Thailand, the systems had more permanent structures as indicated by larger rain-jars (2000 litres-jar as opposed to most common 200 litres-jar in Laos), fixed gutters and some piping systems to convey the rainwater from its catchment to the rain-jars. The systems in Laos on the other hand, were typically a set up of the household storage containers (also used to store well water during dry season), detached sheets of corrugated iron as the catchment, or alternatively, house roof would serve as a catchment without any guttering or piping systems in place. The fact that the rainwater collections systems were implemented in different manner in the study sites further suggests that a monitoring effort that relies heavily on mere technology types may not adequately characterise the potentially different hazard levels presented by the discrete systems.

Subsequently, the characteristics of the household water management were also described. It was found that a wide range of household containers was in used in both study sites. Within a household, multiple numbers and types containers were also commonly found. Most of the household containers were wide-mouthed allowing for hand-water contact. This was supported by the relatively greater proportions of the population that reportedly “scooped’ out their water for drinking as compared with “pouring”. Furthermore, boiling as the only reported method of treatment was performed by limited numbers of households. On the whole, the household water management practices give indications of unsafe handling which may potentially compromise water quality at point of consumption.

As mentioned before, the Lao population was found to be less improved in terms of sanitation facilities and hygiene practices compared to the Thai population. About 7 out of 10 people in the Lao site practiced open defecation. This was also associated with poor hand washing practices. Overall, the mode of hand washing that was most frequently reported is only with water, which is less reliable than washing with soap.

The descriptions of the water supply system, sanitation facilities, and hand washing practices of the study population were limited by the methods used. In general, more in depth overview on the water supply system was provided given its direct implication on drinking water quality.

Following the general observations, the semi-quantitative hazard assessment framework has been applied to classify the hazard levels identified at the water source and sanitation facilities and the hazard related with hand washing practices. The assessment framework for the water source is principally based on the hazard diagnostic tool developed by the WHO, that is the sanitary inspection procedure. Basically, the sanitary inspection is a rapid assessment tool that is based on identification of faults in the system that may potentially introduce contaminants (in this work, faecal contamination is of main interest) to the water supply system. During the two fieldwork periods, sanitary inspection was carried out for all relevant water sources. A few of the minor water sources were excluded due to logistical limitations. In the dry season, the majority of the water sources in Laos have been classified as very poor. Whereas during the rainy season, where about 30% of the original population was sampled, the reassessment of the water sources reveals improvement in the hazard scores. This was mainly attributed to the shift to rainwater collection systems. In Thailand, during the dry season, about 60% of the water source was assessed as having moderate hazard levels. A relatively similar pattern was observed during the rainy season. The hazard assessment framework shows that although the rainwater systems may be categorised as improved (the JMP indicator), when the discrete systems were inspected, varying hazard levels were found to be present. The classification of the sanitation facilities were pretty much in line with the general characteristics of the population, where sanitation was found to be very poor in Laos and was significantly better in Thailand. For the hand washing practice, again it was found that the Thai site was better.

The poor sanitation and hygiene levels in Laos site turns out to be strongly associated when the statistical analysis was made. In fact it is the only correlation that is robust. This was primarily attributed to the lack of hand washing after open defecation (since hand washing facilities were frequently not available close-by). The correlation between source and hygiene was the weakest and insignificant. This means that there is high variability when comparing source quality and hand washing practice. Different combinations of hazards may exist, not excluding cases where the combination of good water quality and poor hygiene may provide ground for recontamination of water at POU. Source and sanitation was positively correlated ($p<0.01$ for Laos and $p<0.025$ for Thailand) but was also markedly weak. Similar to the source-hygiene correlation, there is also rather high variability between the two components. There is unspecified likelihood that poor sanitation may affect water quality negatively. It would be particularly exaggerated if in combination with poor hygiene, which is quite likely in Laos.

More generally, the lack of correlations between water source and sanitation/hygiene hazards may be due to other unaccounted factors. Even though these risk factors are together interlinked in the disease transmission pathways, their hazard components may be quite independently shaped by different perceptions, values, traditions, education levels, economic status, or other social factors of the users.

When the water source hazard scores were subsequently correlated with the microbial water quality data found in the water source samples, a positive moderate correlation was found significant for the Lao datasets (not in the Thai datasets). The lack of sensitivity in the Thai datasets may point to the main limitation of the scoring system especially when the water source is more improved with functional physical protection or lack of apparent contaminants. Discerning faecal contamination via overall score of the system's faults become increasingly inaccurate. One of the underlying assumptions in the water source hazard scoring was the equal weighting for all hazard components which may not necessarily reflect the actual conditions. It is likely that one or more hazard components are more crucial in determining the occurrence of contamination. Finally, the rainwater harvesting systems as the most assessed systems, are typically owned privately and thus are limited to contamination at household levels, which may be relatively less constant compared to other contamination sources found at communal water sources (e.g. farm animals, agricultural activities, runoffs, underground seepage, etc.).

Another important element that may affect the comparison is the variability of the microbial water quality. The short-term sampling period provides a snapshot of water quality variations in time, however it may not suffice to illustrate the pattern of water quality in longer term. It has been observed that water quality within a household may vary from time to time. The variation in space attributed to non-uniform dispersal of microorganisms in water may also affect the detection.

The lack of correlation between the sanitation/hygiene status and POU water quality is reasonable. Firstly, it has to be noted that in this study framework, sanitation and hygiene act as secondary drivers, which underpin direct contamination caused by handling practices, thus the correlations may not be so apparent. Specifically concerning the hygiene status, the assessed parameters were limited to hand washing practices. Although this was suggested by Trevett et al. (2005) as a key risk factor, the lack of direct quantification of other relevant parameters specifically those that relate to hygienic water handling practices, may have reduced the sensitivity of this analysis. Alternatively, it can also be argued that the relationships that exist may not be linearly explained due to the complex interactions that determine the occurrence of recontamination.

More practically, there can also be a confounding factor due to the data collection method especially with regard to the hand washing behaviours. There are two inputs to the scoring system: the household questionnaire and the spot observation. The spot observation however did not directly document hand washing practices but used proxies such as availability of soap or hand washing facility. Hence the scored hand washing after toilet, before food and mode of hand washing relied on the answers of the respondents which in some cases may not truly reflect the actual practices (reluctance in disclosing personal information).

Additionally, the possibility of incorporating the microbial water quality data as an input to the water source assessment framework was not carried out in this study. Typically, there is a feedback mechanism between the sanitary inspection and water quality test. Future efforts can be made to consolidate the datasets.

The findings with respect to water quality at the different sources are in line with previous works, notably the RADWQ results by JMP in which it was similarly found that improved sources were delivering water of variable quality (WHO/UNICEF, 2011). In Thailand where more rainwater harvesting systems were used year-round and where the systems were better equipped technically, the overall water quality at supply points tended to be superior to the system in Laos where the systems are typically used intermittently.

With respect to the quality at point of consumption, it was found that the water quality significantly deteriorated between source and POU, especially in Laos. In Thailand the deterioration was insignificant. But when overall datasets were analysed, the deterioration remains significant. As shown in many studies (discussed in Section 1.3), deterioration is commonly found between source and POU particularly in cases where manual collection, transport and storage are involved. In general, the patterns of water quality changes are also inconsistent. The proportions of samples that undergo deterioration, remain constant, and improved are 39%, 35% and 25%, respectively. Inconsistent pattern of change was similarly found in a study in Northern Nigeria (Onabolu et al., 2011). Deterioration was also not exclusively found in certain households which has been reported elsewhere (Trevett et al., 2004). Improved water quality was similarly found in study by (VanDerslice and Briscoe, 1993) in about 16% of the samples. Trevett et al. proposed plausible explanations that is bacteria die off or incomplete pictures of household drinking water management practices.

To see which of the various household water management practices may signify higher levels of faecal contamination, simple statistical comparisons were performed in Section 6.5. The results suggest that there are weak (statistically not significant) patterns that decreasing hand contacts (from different modes of water extraction: scoop, pour, tap) can be associated with lower faecal contamination. Treatment (boiling) was found to be also affected negatively by water handling practices (in Laos), probably due to recontamination of the water after boiling. This was similarly reported by Oswald et al. (2007). BOiling was effective in Thailand as there was no additional handling (boiled water was kept in kettles). In Laos, cleanliness of containers was significantly associated with lower faecal contamination. Both the types of containers and types of transfer devices did not indicate significant effects on water quality. However, this may be due to the limited numbers of samples especially when the variables are more numerous. Covering the containers was also not effective, in contrast with the conclusion of the systematic meta-analysis by Wright et al. (2004). But it was in line with a number of studies (Mertens et al., 1990, Lindskog and Lindskog, 1988, VanDerslice and Briscoe, 1993) where no correlation was drawn between drinking water quality and container cover.

Finally the comparison of the CBT with Quanti-tray using the ISO method suggests that there is significant difference in the enumerated *E. coli* concentration. It is important to consider that the two methods have different sensitivity levels with Quanti-tray offering much wider combinations of MPN counts. The discrepancy was not accounted in the comparison which may reduce the sensitivity of the test. It is highly recommended that the datasets obtained in this study be pooled with the UNC database for more statistical power.

8 Conclusions and recommendations

In general the results suggest minor indication that the refined classification systems may provide better characterisations of the water supply system based on faecal contamination hazards as a more tangible quantification of health impacts. This was supported by the moderate positive correlation between water quality data at sources and hazard classifications in Laos. With respect to the water quality at POU, the sanitation and hygiene related hazards were not sufficiently indicative. Looking at the results of the POU water quality comparisons based on various handling practices, it can be concluded that some of the parameters (e.g. modes of fetching, cleanliness, and treatment) have the potentials to be used as a more direct indicator of water quality. Lastly, the issue of water quality deterioration from source to POU was not insignificant, particularly where sanitation and hygiene practices were less developed, as shown with the considerably greater recontamination incidences in Laos.

The current model requires further modifications, for example the model can be improved by incorporating weighted criteria based on reliable knowledge of the relative importance of the different components. To establish the relative importance of the hazard components, the microbial water quality data can be used in conjunction with the results of the sanitary inspection to verify certain risk factors. Given the variability of the observed water quality, collection of more datasets on microbial water quality are likely to provide better understanding on the long term patterns instead of the short term variability. To approximate the water quality at POU, the classification system can be improved by incorporating the household water management variables as a primary hazard combined with the existing hand washing and sanitation status as the secondary proxy. This complementary hazard assessment for water handling practices and its relation to the sanitation facilities and hygiene behaviour classes needs to be explored further and validated with microbial water quality data. Overall, the framework has to be validated with health impact (disease incidences from DIADEN project).

To guarantee safe drinking water quality from source to POU, proper methods of collection, transport, storage and extraction are needed particularly when hand-water contact is likely to occur. Even when water was treated (boiled), handling practices played important role in determining the final water quality. Overall, understanding the relative importance of the various drinking water management practices is also interesting in order to narrow down intervention efforts. Future research may also be directed on gaining more comprehensive understandings on the effects of the variables on water quality as an aggregated factor. In addition, it should be clarified whether the mechanisms are universally applicable in different settings or if they are governed by general underlying factors such as economic conditions, education levels, community awareness, etc.

Comparing the quality at supply points in Laos, it is recommended that the use of unprotected dug wells be limited as it is at higher risks of contamination compared to rainwater and boreholes. However this requires considerable efforts for the community as for the most part, the current storage systems in Laos are not large enough for year-round drinking water storage. Thus, it is recommended that the water quality data be compared to the related health impacts. It is particularly interesting to see if there are significant differences when more contaminated water is consumed. A permanent system that allow for better technical specifications, as found in Thailand, is also able to deliver better water quality.

Lastly it is reiterated that although safe drinking water is the highlight of this research, in practice the inference has been based on the commonly accepted assumption that the microbial indicator *E. coli* is a good indicator for health risks. Direct measures of health impacts were not feasible in this study but it is part of the larger DIADEN study. Future data consolidations are highly recommended. The use of the indicator organism serves its purpose in demonstrating the level of contamination.

List of references

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Annexes

Annex A Household questionnaires

	General information	Answers
1.	Form No:	
2.	Name of interviewer:	
3.	Interviewer telephone:	
4.	Respondent telephone:	
5.	GPS:	[N:.......................... E:..........................]
6.	House No:	[............./.............]
7.	Date (dd/mm/yy):	[........./........./201...]
8.	Country:	o 1. Thailand o 2. Laos
9.	Village:	o 1. Ban Waileum o 2. Okad
I.	**Socio-demographic profile**	**Answers**
1.	No of families in HH:	o 1. One o 2. Two o 3. Three o 4. Four
2.	No of people living in HH:	
3.	No of children <5 years old in HH:	
II.	**Drinking water**	**Answers**
4.	How much drinking water is consumed per person per day? (on average)	o 1. <1 liter o 2. 1 liter – 2 liters o 3. > 2 liters
5.	What is the <u>main source</u> of drinking water for members of your household? *(select just one that he drinks most)*	o 1. Piped water into dwelling *Q10* o 2. Piped water into yard/plot *Q10* o 3. Public tap/standpipe *Q15* o 4. Tube well/borehole *Q15* o 5. Protected dug well *Q15* o 6. Unprotected dug well *Q15* o 7. Protected spring *Q15* o 8. Unprotected spring *Q15* o 9. Rainwater *Q24* o 10. Cart with small drum/tank *Q26* o 11. Tanker-truck *Q26* o 12. Surface water *Q15* o 13. Bottled water o 14. Other, ...
6.	If <u>piped water</u> is supplied, do you know where it originated?	o 1. Yes *Q11* o 2. No
7.	If yes, what is the source water for the tap?	o 1. Lake o 2. River o 3. Well o 4. Spring o 5. Other, ...
8.	If possible, prompt for location:	[..]
9.	Is the piped water able to provide water continuously at satisfactory quantity?	o 1. Yes o 2. No *Q14*
10.	If no, how often is it not working? *Q27*	o 1. Everyday o 2. .... times / week o 3. .... times / month
11.	If <u>public tap, well, spring, or surface water</u> is used, what is the distance from house?	o 1. ≤500 m o 2. 500-1000 m o 3. >1000 m
12.	If possible, prompt for location:	[..]
13.	How long is one trip (back and forth) to collect water?	o 1. < 5 min o 2. 5-10 mins o 3. 10-30 mins o 4. >30 mins
14.	How often do you go for water collection?	o 1. Everyday o 2. .... times / week o 3. .... times / month
15.	How much water do you collect each time? (on average)	o 1. < 10 liters o 2. 10 - 20 liters o 3. 20-30 liters o 4. 30-40 liters o 5. 40-50 liters o 6. >50 liters
16.	What kind of container do you use to collect drinking water from the source?	o 1. Plastic bucket o 2. Metallic drum o 3. Jerry can o 4. Jar o 2. Other, ...
17.	Do you have something to cover/ close the container while transporting the water?	o 1. Yes o 2. No
18.	Do you use the container for anything else?	o 1. Yes *Q23* o 2. No

19.	If yes, what else do you use it for? *Q27*	o 1. Washing clothes o 2. Bathing o 3. Carrying foodstuffs	o 4. Collect drinking water o 5. Other, ...
20.	If <u>rainwater</u> is used, how do you collect it?	o 1. From roof runoff to rainwater tank o 2. From surface runoff (paved) to underground tank o 3. From surface runoff (unpaved) to underground tank o 4. Other, ...	
21.	How do you collect water from the rainwater tank? *Q27*	o 1. Using tap o 2. Sucking it out with hose	o 3. Scoop out with container / scooper o 4. Other, ...
22.	If a <u>cart or tanker truck</u> supplies the water, do you know where the water originated?	o 1. Yes, (ask for location: ....) o 2. No	
23.	Do you always have enough drinking water from the main source (all the year)?	o 1. Yes o 2. No *Q28 & Q29*	
24.	If no, in which season is water inadequate?	o 1. In rainy season o 2. In dry season	
25.	If no, what is your <u>alternative source</u> of drinking water?	o 1. Piped water into dwelling o 2. Piped water into yard/plot o 3. Public tap/standpipe o 4. Tube well/borehole o 5. Protected dug well o 6. Unprotected dug well o 7. Protected spring	o 8. Unprotected spring o 9. Rainwater o 10. Cart with small drum/tank o 11. Tanker-truck o 12. Surface water o 13. Bottled water o 14. Other, ...
26.	Do you store drinking water in <u>household containers</u>? *(keep water in any container for drinking purpose)*	o 1. Yes *Q31* o 2. No *Q37*	
27.	How often do you clean your drinking water containers?	o 1. Everyday o 2. .... times / week o 3. .... times / month	o 4. .... times / year o 5. Other, ... o 6. Don't know
28.	If yes, do you clean with soap or other disinfectant?	o 1. Yes o 2. No	
29.	How do you fetch water from the container to drink?	o 1. Pour it out o 2. Scoop it out	o 3. Both o 4. Other, ...
30.	If you scoop it out, what do you use for scooping?	o 1. Cup with handle o 2. Cup without handle	o 3. Ladle o 4. Other, ...
31.	Is the scooper mentioned used for other purpose?	o 1. Yes o 2. No	
32.	If yes, what else do you use it for?	[..]	
33.	Do you <u>treat</u> your drinking water in any way?	o 1. Yes *Q38* o 2. No *Q41*	
34.	If yes, which treatment do you use?	o 1. Boiling o 2. Adding bleach/chlorine o 3. Strain it through a cloth o 4. Water filter (ceramic, sand, etc.)	o 5. Solar disinfection o 6. Let it stand and settle o 7. Other, ... o 2. Don't know
35.	How often do you treat your water?	o 1. Always o 2. Sometimes	
36.	If sometimes, specify the reason for treating the water:	o 1. Water looks dirty o 2. Somebody is sick	o 3. Bleach/chlorine is available o 4. Other, ...
III.	**Sanitation & Hygiene**	**Answers**	
61.	Do you have your own toilet facility in your house?	o 1. Yes *Q67* o 2. No *Q66*	
62.	If no, where do members of the household go to toilet?	o 1. Bush o 2. Farm fields	o 3. Refuse dump o 4. Other, ...
63.	If yes, what kinds of toilet facility do members of your household use?	o 1. Flush toilet to: o a. piped sewer system o b. septic tank o c. pit latrine o d. elsewhere o e. unknown place/not sure/DK o 2. Ventilated improved pit latrine	o 3. Pit latrine with slab o 4. Pit latrine without slab/open pit o 5. Composting toilet o 6. Bucket o 7. Hanging toilet/latrine o 8. Other, ...

64.	If pit or septic tank is used, how is it emptied?	o 1. Manually o 2. Central sewage disposal unit (suction pump or tanker with vacuum pump) o 3. Never	
65.	If pit or septic tank is used, how often is it emptied?	o 1. .... Times/ year	
66.	Do you share this facility with other households?	o 1. Yes *Q69* o 2. No *Q70*	
67.	If yes, how many households use this toilet facility?	o 1. [...........] households o 2. DK	
68.	Can any member of the public use this toilet?	o 1. Yes o 2. No	o 3. DK
69.	How do you dispose of stool from babies and children who do not use toilet?	o 1. Put/rinsed into toilet/latrine o 2. Put/rinsed into drain or ditch o 3. Thrown into garbage	o 4. Buried o 5. Left in the open o 6. Other, ...
70.	Do you usually wash your hands after the toilet?	o 1. Yes o 2. No	o 3. Sometimes
71.	Do you usually wash your hands before eating?	o 1. Yes o 2. No	o 3. Sometimes
72.	If yes, what do you usually wash your hands with?	o 1. With soap o 2. With water only	o 3. Both

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Annex B Sanitary inspection

	General information	Answers	
1.	Form No:	[...]	
2.	Name of inspector:	Signature:	
3.	Inspector telephone:	[...]	
4.	Water authority/community representative:	Signature:	
7.	Date (dd/mm/yy):	[........./........./201...]	
8.	Country:	o 1. Thailand	o 2. Laos
9.	Village:	o 1. Ban Waileum	o 2. Okad
5.	GPS:	[N:...	E:...]
6.	Type of water source:	o 1. Piped water into dwelling o 2. Piped water into yard/plot o 3. Public tap/standpipe o 4. Tube well/borehole o 5. Protected dug well o 6. Unprotected dug well o 7. Protected spring	o 8. Unprotected spring o 9. Rainwater o 10. Cart with small drum/tank o 11. Tanker-truck o 12. Surface water o 13. Bottled water o 14. Other, ...
7.	House number if piped into dwelling/yard:	[...]	
8.	Describe the system adequately in terms of dimensions, materials, equipment, construction elements, and other relevant physical & explanatory information about the source, treatment, transportation/distribution, storage and usage:		
9.	Intended use of the water: • Primary • Secondary • Tertiary	 [...] [...] [...]	

I.	Rainwater collection	Answers 1. Yes	2. No	3. NA	Comments
1.	Is there any visible contamination of the roof catchment area (plants, dirt, or excreta)?	o	o	o	
2.	Are the guttering channels that collect water dirty?	o	o	o	
3.	Is there any deficiency in the filter box at the tank inlet (e.g. lacks fine gravel)?	o	o	o	
4.	Is there any other point of entry to the tank that is not properly covered?	o	o	o	
5.	Is there any defect in the walls or top of the tank (e.g. cracks) that could let water in?	o	o	o	
6.	Is the tap leaking or otherwise defective?	o	o	o	
7.	Is the concrete floor under the tap defective or	o	o	o	

	dirty?			
8.	Is the water collection area inadequately drained?	o	o	o
9.	Is there any source of pollution around the tank or water collection area (e.g. excreta)?	o	o	o
10.	Is a bucket in use and left in a place where it may become contaminated?	o	o	o
II.	**Unprotected dug well**	**1. Yes**	**2. No**	**3. NA**
1.	Is there a latrine within 10 m of the well?	o	o	o
2.	Is the nearest latrine on higher ground than the well?	o	o	o
3.	Is there any other source of pollution (e.g. animal excreta, rubbish) within 10m of the well?	o	o	o
4.	Is the drainage poor, causing stagnant water within 2m of the well?	o	o	o
5.	Is there a faulty drainage channel? Is it broken, permitting ponding?	o	o	o
6.	Is the wall (parapet) around the well inadequate, allowing surface water to enter the well?	o	o	o
7.	Is the concrete floor less than 1m wide around the well?	o	o	o
8.	Are the walls of the well inadequately sealed at any point for 3 m below ground?	o	o	o
9.	Are there any cracks in the concrete floor around the well which could permit water to enter the well?	o	o	o
10.	Are the rope and bucket left in such a position that they may become contaminated?	o	o	o
11.	Does the installation require fencing?	o	o	o
III.	**Borehole**	**1. Yes**	**2. No**	**3. NA**
1.	Is there a latrine within 10 m of the hand pump?	o	o	o
2.	Is the nearest latrine on higher ground than the hand-pump?	o	o	o
3.	Is there any other source of pollution (e.g. animal excreta, rubbish, surface water) within 10m of the hand-pump?	o	o	o
4.	Is the drainage poor, causing stagnant water within 2m of the hand-pump?	o	o	o
5.	Is it broken, permitting ponding? Does it need cleaning?	o	o	o
6.	Is the hand-pump drainage channel faulty?	o	o	o
7.	Is the fencing around the hand-pump inadequate, allowing animals in?	o	o	o
8.	Is the concrete floor less than 1m wide all around the hand-pump?	o	o	o
9.	Is there any ponding on the concrete floor around the hand-pump?	o	o	o
10.	Are there any cracks in the concrete floor around the hand-pump which could permit water to enter the well?	o	o	o
11.	Is the hand-pump loose at the point of attachment to the base so that water could enter the casing?	o	o	o

Annex C Spot observations

Spot observations		Form number	
Date		House number	

	Sanitation facility	Answer	Options
1	Toilet type		1. Squat flush; 2. Sit flush
2	NDW container in toilet		1.Cement tank; 2.Bucket; 3.Big earthen jar; 4.Small earthen jar
3	Scooper		1.Yes; 2.No
4	Other remarks:		

	Toilet inspection	Answer	Remarks
1	The toilet appears to be used by the family		
2	Any member of HH still do open defecation		
3	Toilet door is broken or missing		
4	Toilet door is closed		
5	Toilet walls are clean		
6	Toilet floor is clean		
7	Toilet smells badly		
8	Toilet seat is clean		
9	There is toilet cover		
10	There are flies around toilet		
11	The ground around the toilet is muddy		
12	There are hand washing facilities near the toilet		
13	There is soap provided for hand washing after toilet use		
	Other remarks		

	Household drinking water system	Answer	Options
1	System observed		1. HH storage tank; 2. Rain tank; 3.Bottled water; 4.POU receptacle; 5.Borehole
2	Number of storage:		
3	Type of tanks		1.Very big earthen jar; 2.Big earthen jar; 3.Metallic drum; 4.Small earthen jar; 5.Plastic drum
4	Ground area		1.Earth/soil; 2.Wood structure
5	Type of lid		1.CI;2.Mosq net;3.Cloth;4.Plastic;5.Wood plank;6.Metal lid;7.Bucket;8.Water proof cloth;9.Bucket_a.with securing band; b.without
	Lid category		1. Single; 2. Multiple

6	Sufficiency of lid		1.Sufficient; 2.Insufficient
7	Scooper information		1.Outside; 2.Inside
8	Water turbidity		1.Turbid; 2.Relatively clear
9	POU water receptacles		1.Plastic gallon; 2.Thermos canister; 3.Small earthen jar; 4.Plastic jugs; 5.Plastic bucket
10	Specific location of receptacles		1.Table; 2.On top of storage tank; 3.Earth; 4.Cemented floor; 5.Wood structure
	Location of receptacle		1..Outside; 2.Inside; 3.Under shade; 4.Partially under shade
11	Presence of animals in house compounds		
12	Other remarks:		
13	Picture reference number:		
I	***Storage tanks/house receptacle***	**Answer**	**Options**
1	Can contaminants (e.g soil) enter the tank during filling?		
2	Does the tank lack a cover?		
4	Is there stagnant water around the tank?		
5	The ground around water storage facility is muddy?		
6	Water storage facility is easily accessible to children		
7	Water storage facility looks dirty from outside?		
8	Where is the container for DW located?		(1.Outside; 2.Inside;3.Under shade;4.Partially under shade)
9	Number of DW containers found & used at present?		
10	Number of DW containers covered with lid?		
11	Location of covered DW containers?		

Annex D Summary of hazard scores: water sources, sanitation facilities and hygiene behaviours in Laos and Thailand

Table D.1 – A summary of water source, sanitation and hygiene scores in Laos

Okad, Laos										
	House number	Form	Water source assessment				Sanitation assessment		Hygiene assessment	
			Water source	Alternative	Mean hazard ratio	Class	Score	Class	Score	Class
1	36	1	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
2	20	2	Sang Tieng	-	91%	Very poor	11	Poor	4	Fair
3	23	3	Sang Tieng	-	91%	Very poor	11	Poor	4	Fair
4	28	5	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
5	14	7	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
6	34	8	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
7	8	10	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
8	19	11	Sang Tieng	-	91%	Very poor	8	Fair	2	Good
9	41	12	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
10	43	13	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
11	47	15	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
12	32	16	Sang Tieng	-	91%	Very poor	11	Poor	4	Fair
13	22	20	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
14	5	21	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
15	30	22	Sang Tieng	-	91%	Very poor	12	Very poor	7	Poor
16	61	23	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
17	63	26	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
18	2	27	Sang Tieng	-	91%	Very poor	9	Fair	3	Good
19	33	28	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
20	53	29	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
21	54	30	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
22	35	31	Sang Tieng	-	91%	Very poor	9	Fair	4	Fair
23	58	32	Sang Tieng	-	91%	Very poor	12	Very poor	2	Good
24	51	35	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
25	52	36	Sang Tieng	-	91%	Very poor	12	Very poor	7	Poor
26	36	38	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
27	4	40	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
28	14	42	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
29	13	43	Sang Tieng	-	91%	Very poor	6	Good	0	Very good
30	NA	44	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
31	43	45	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
32	44	48	Sang Tieng	-	91%	Very poor	8	Fair	2	Good
33	58	49	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
34	NA	50	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
35	NA	51	Sang Tieng	-	91%	Very poor	11	Poor	4	Fair
36	28	53	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
37	NA	56	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
38	13	57	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
39	11	58	Sang Tieng	-	91%	Very poor	10	Fair	1	Very good
40	15	59	Sang Tieng	-	91%	Very poor	6	Good	0	Very good
41	52	60	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
42	17	62	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
43	33	71	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
44	26	73	Sang Tieng	-	91%	Very poor	8	Fair	2	Good
45	50	74	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
46	12	75	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
47	21	76	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
48	NA	77	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
49	NA	82	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor

50	21	84	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
51	61	85	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
52	17	86	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
53	23	87	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
54	24	88	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
55	4	91	Sang Tieng	-	91%	Very poor	7	Fair	1	Very good
56	24	94	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
57	44	95	Sang Tieng	-	91%	Very poor	12	Very poor	7	Poor
58	31	97	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
59	3	99	Sang Tieng	-	91%	Very poor	10	Fair	2	Good
60	1	100	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
61	40	101	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
62	50	102	Sang Tieng	-	91%	Very poor	10	Fair	4	Fair
63	57	103	Sang Tieng	-	91%	Very poor	11	Poor	6	Poor
64	57	104	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
65	NA	105	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
66	55	106	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
67	49	108	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
68	45	110	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
69	22	111	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
70	59	116	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
71	41	119	Sang Tieng	-	91%	Very poor	10	Fair	2	Good
72	61	120	Sang Tieng	-	91%	Very poor	7	Fair	0	Very good
73	35	121	Sang Tieng	-	91%	Very poor	8	Fair	2	Good
74	46	122	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
75	48	123	Sang Tieng	-	91%	Very poor	12	Very poor	6	Poor
76	60	124	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
77	32	126	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
78	15	128	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
79	45	129	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
80	9	130	Sang Tieng	-	91%	Very poor	12	Very poor	4	Fair
81	NA	80	Temple	At the field	91%	Very poor	12	Very poor	6	Poor
82	39	81	Temple	Rainwater	91%	Very poor	12	Very poor	6	Poor
83	38	115	Temple	Unprotected dug well	91%	Very poor	12	Very poor	6	Poor
84	29	54	Nong Ta Kai	Bottled water	81%	Poor	6	Good	2	Good
85	1	9	Houay Lam Phong	-	93%	Very poor	11	Poor	4	Fair
86	NA	78	Houay Lam Phong	-	93%	Very poor	12	Very poor	4	Fair
103	66	33	Private pond	-	91%	Very poor	12	Very poor	4	Fair
104	19	93	Farm pond	Unprotected dug well	97%	Very poor	12	Very poor	6	Poor
87	10	4	Rainwater	Unprotected dug well	91%	Very poor	12	Very poor	4	Fair
88	12	6	Rainwater	Unprotected dug well	91%	Very poor	12	Very poor	4	Fair
89	40	17	Rainwater	Unprotected dug well	91%	Very poor	11	Poor	1	Very good
99	NA	96	Rainwater	Sang Tieng	91%	Very poor	6	Good	3	Good
102	59	113	Rainwater	Sang Tieng	91%	Very poor	6	Good	2	Good
90	39	18	Rainwater	Unprotected dug well	36%	Good	10	Fair	1	Very good
91	2	19	Rainwater	Unprotected dug well	65%	Fair	9	Fair	2	Good
92	42	24	Rainwater	Unprotected dug well	63%	Fair	6	Good	2	Good
93	38	25	Rainwater	Unprotected dug well	67%	Poor	10	Fair	1	Very good

94	52	37	Rainwater	-	65%	Fair	9	Fair	2	Good
95	42	41	Rainwater	Unprotected dug well	67%	Poor	8	Fair	6	Poor
96	6	89	Rainwater	Unprotected dug well	67%	Poor	12	Very poor	6	Poor
97	26	90	Rainwater	-	63%	Fair	12	Very poor	6	Poor
98	5	92	Rainwater	-	61%	Fair	12	Very poor	6	Poor
100	16	109	Rainwater	Sang Tieng	61%	Fair	12	Very poor	4	Fair
101	10	112	Rainwater	-	79%	Poor	12	Very poor	4	Fair
105	67	34	Borehole	-	60%	Fair	11	Poor	4	Fair
106	68	47	Borehole	-	63%	Fair	7	Fair	0	Very good
107	NA	72	Handpump borehole	-	63%	Fair	12	Very poor	6	Poor
108	54	14	Bottled water	-	-	-	5	Good	1	Very good
109	55	39	Bottled water	-	-	-	12	Very poor	6	Poor
110	27	55	Bottled water	-	-	-	12	Very poor	6	Poor
111	NA	69	Bottled water	-	-	-	11	Poor	2	Good
112	NA	70	Bottled water	-	-	-	9	Fair	2	Good
113	53	98	Bottled water	-	-	-	11	Poor	0	Very good
114	60	107	Bottled water	-	-	-	12	Very poor	4	Fair
115	59	114	Bottled water	-	-	-	10	Fair	1	Very good
116	NA	117	Bottled water	Rainwater	-	-	12	Very poor	6	Poor
117	8	125	Bottled water	-	-	-	9	Fair	2	Good
118	64	127	Bottled water	-	-	-	7	Fair	2	Good
119	37	79	Other	Sang Tieng	-	-	12	Very poor	6	Poor
120	31	83	Other	Rainwater	-	-	12	Very poor	4	Fair
121	64	46	Other	Borehole	-	-	12	Very poor	6	Poor

Table D.2 – A summary of water source, sanitation and hygiene scores in Thailand

Waileum, Thailand								
	House number	**Water source assessment**			**Sanitation assessment**		**Hygiene assessment**	
		Water source	**Mean hazard ratio**	**Class**	**Score**	**Class**	**Score**	**Class**
1	203	Rainwater	52%	Fair	3	Good	1	Very good
2	63	Rainwater	54%	Fair	3	Good	2	Good
3	135	Rainwater	67%	Poor	4	Good	1	Very good
4	54	Rainwater	48%	Fair	6	Good	1	Very good
5	55	Rainwater	65%	Fair	7	Fair	1	Very good
6	61	Rainwater	63%	Fair	7	Fair	0	Very good
7	6	Rainwater	65%	Fair	5	Good	0	Very good
8	60	Rainwater	65%	Fair	7	Fair	1	Very good
9	59	Rainwater	65%	Fair	4	Good	1	Very good
10	58	Rainwater	56%	Fair	4	Good	1	Very good
11	67	Rainwater	65%	Fair	4	Good	2	Good
12	69	Rainwater	44%	Good	3	Good	1	Very good
13	3	Rainwater	44%	Good	3	Good	1	Very good
14	76	Rainwater	48%	Fair	3	Good	1	Very good
15	2	Rainwater	44%	Good	2	Very good	1	Very good
16	138	Rainwater	48%	Fair	4	Good	1	Very good
17	141	Rainwater	52%	Fair	4	Good	1	Very good
18	211	Rainwater	44%	Good	2	Very good	1	Very good
19	68	Rainwater	52%	Fair	6	Good	1	Very good
20	64	Rainwater	65%	Fair	4	Good	1	Very good
21	206	Rainwater	46%	Good	6	Good	1	Very good
22	200	Rainwater	57%	Fair	4	Good	1	Very good
23	299	Rainwater	58%	Fair	7	Fair	1	Very good
24	229	Rainwater	52%	Fair	2	Very good	0	Very good
25	159	Rainwater	61%	Fair	4	Good	1	Very good

26	210	Rainwater	67%	Poor	3	Good	1	Very good
27	17	Rainwater	68%	Poor	3	Good	1	Very good
28	11	Rainwater	65%	Fair	2	Very good	1	Very good
29	183	Rainwater	68%	Poor	4	Good	2	Good
30	235	Rainwater	68%	Poor	5	Good	1	Very good
31	70	Rainwater	52%	Fair	3	Good	1	Very good
32	213	Rainwater	68%	Poor	4	Good	1	Very good
33	117	Rainwater	56%	Fair	5	Good	1	Very good
34	176	Rainwater	48%	Fair	4	Good	1	Very good
35	53b	Rainwater	40%	Good	6	Good	1	Very good
36	193/127	Rainwater	61%	Fair	3	Good	1	Very good
37	222	Rainwater	65%	Fair	3	Good	1	Very good
38	165	Rainwater	67%	Poor	7	Fair	2	Good
39	27	Rainwater	67%	Poor	2	Very good	2	Good
40	116	Rainwater	65%	Fair	3	Good	1	Very good
41	207	Rainwater	52%	Fair	3	Good	1	Very good
42	205	Rainwater	52%	Fair	7	Fair	1	Very good
43	230	Rainwater	54%	Fair	3	Good	2	Good
44	199	Rainwater	52%	Fair	3	Good	1	Very good
45	66	Rainwater	44%	Good	1	Very good	1	Very good
46	218	Rainwater	54%	Fair	6	Good	1	Very good
47	204	Rainwater	48%	Fair	3	Good	1	Very good
48	188	Rainwater	54%	Fair	5	Good	1	Very good
49	173	Rainwater	54%	Fair	5	Good	1	Very good
50	180	Rainwater	65%	Fair	4	Good	1	Very good
51	47	Rainwater	65%	Fair	5	Good	1	Very good
52	39	Rainwater	67%	Poor	5	Good	1	Very good
53	49	Rainwater	54%	Fair	7	Fair	1	Very good
54	38	Rainwater	40%	Good	7	Fair	1	Very good
55	162	Rainwater	65%	Fair	2	Very good	1	Very good
56	124	Rainwater	67%	Poor	7	Fair	2	Good
57	233	Rainwater	67%	Poor	5	Good	1	Very good
58	160	Rainwater	65%	Fair	5	Good	2	Good
59	164	Rainwater	54%	Fair	9	Fair	1	Very good
60	56	Rainwater	52%	Fair	6	Good	1	Very good
61	57	Rainwater	67%	Poor	7	Fair	4	Fair
62	72	Rainwater	65%	Fair	3	Good	0	Very good
63	219	Rainwater	54%	Fair	4	Good	0	Very good
64	14	Rainwater	65%	Fair	7	Fair	2	Good
65	195	Rainwater	54%	Fair	6	Good	0	Very good
66	155	Rainwater	52%	Fair	4	Good	0	Very good
67	142	Rainwater	65%	Fair	7	Fair	1	Very good
68	20	Rainwater	32%	Good	6	Good	2	Good
69	92	Rainwater	67%	Poor	7	Fair	1	Very good
70	172	Rainwater	52%	Fair	6	Good	0	Very good
71	34	Rainwater	67%	Poor	7	Fair	0	Very good
72	227	Rainwater	65%	Fair	5	Good	2	Good
73	29	Rainwater	54%	Fair	7	Fair	2	Good
74	130	Rainwater	46%	Good	2	Very good	2	Good
75	28	Rainwater	67%	Poor	8	Fair	1	Very good
76	113	Rainwater	67%	Poor	8	Fair	4	Fair
77	16	Rainwater	54%	Fair	6	Good	2	Good
78	240	Rainwater	67%	Poor	4	Good	0	Very good
79	21	Rainwater	54%	Fair	9	Fair	1	Very good
80	212	Rainwater	54%	Fair	8	Fair	1	Very good

81	242	Rainwater	54%	Fair	7	Fair	2	Good
82	194	Rainwater	67%	Poor	9	Fair	2	Good
83	182	Rainwater	54%	Fair	3	Good	1	Very good
84	43	Rainwater	67%	Poor	4	Good	1	Very good
85	126	Rainwater	67%	Poor	7	Fair	1	Very good
86	4	Rainwater	67%	Poor	11	Poor	4	Fair
87	90	Rainwater	63%	Fair	6	Good	2	Good
88	196	Rainwater	67%	Poor	8	Fair	1	Very good
89	48	Rainwater	54%	Fair	7	Fair	2	Good
90	44	Rainwater	54%	Fair	6	Good	1	Very good
91	42	Rainwater	54%	Fair	5	Good	2	Good
92	226	Rainwater	24%	Very good	7	Fair	1	Very good
93	41	Rainwater	67%	Poor	5	Good	1	Very good
94	174	Rainwater	44%	Good	4	Good	2	Good
95	36	Rainwater	67%	Poor	8	Fair	1	Very good
96	129	Rainwater	52%	Fair	4	Good	1	Very good
97	220	Rainwater	63%	Fair	5	Good	1	Very good
98	37	Rainwater	50%	Fair	7	Fair	1	Very good
99	31	Rainwater	67%	Poor	5	Good	1	Very good
100	148	Rainwater	67%	Poor	2	Very good	1	Very good
101	185	Rainwater	67%	Poor	7	Fair	2	Good
102	156	Rainwater	67%	Poor	6	Good	1	Very good
103	303	Rainwater	52%	Fair	5	Good	1	Very good
104	202	Rainwater	67%	Poor	8	Fair	1	Very good
105	189	Rainwater	54%	Fair	6	Good	1	Very good
106	5	Rainwater	54%	Fair	6	Good	2	Good
107	9	Rainwater	67%	Poor	9	Fair	1	Very good
108	163	Rainwater	54%	Fair	4	Good	2	Good
109	50	Rainwater	54%	Fair	6	Good	1	Very good
110	295	Rainwater	67%	Poor	7	Fair	2	Good
111	52	Rainwater	65%	Fair	2	Very good	1	Very good
112	297	Rainwater	65%	Fair	8	Fair	1	Very good
113	52/1	Rainwater	52%	Fair	4	Good	1	Very good
114	45	Rainwater	67%	Poor	6	Good	2	Good
115	7	Rainwater	45%	Good	6	Good	2	Good
116	291	Rainwater	44%	Good	4	Good	0	Very good
117	30	Bottled water	-	-	3	Good	0	Very good
118	197	Bottled water	-	-	6	Good	1	Very good

Annex E Spearman's statistical tests to correlate water source hazard, sanitation and hygiene scores

Table E.1 Spearman's test for water source vs. sanitation scores - Laos

	Mean hazard ratio	Rx - source	Sanitation	Ry - Sanitation	d=Rx-Ry	d^2
18	0.363	1	10	21.5	-20.5	420.25
34	0.597	2	11	28.5	-26.5	702.25
109	0.607	3	12	70	-67	4489
92	0.613	4	12	70	-66	4356
47	0.625	6	7	8	-2	4
72	0.625	6	12	70	-64	4096
90	0.625	6	12	70	-64	4096
24	0.631	8	6	3.5	4.5	20.25
19	0.649	9.5	9	16.5	-7	49
37	0.649	9.5	9	16.5	-7	49
25	0.667	12	10	21.5	-9.5	90.25
41	0.667	12	8	12	0	0
89	0.667	12	12	70	-58	3364
112	0.792	14	12	70	-56	3136
54	0.807	15	6	3.5	11.5	132.25
33	0.906	16	12	70	-54	2916
4	0.907	60.5	12	70	-9.5	90.25
6	0.907	60.5	12	70	-9.5	90.25
17	0.907	60.5	11	28.5	32	1024
96	0.907	60.5	6	3.5	57	3249
113	0.907	60.5	6	3.5	57	3249
80	0.907	60.5	12	70	-9.5	90.25
81	0.907	60.5	12	70	-9.5	90.25
115	0.907	60.5	12	70	-9.5	90.25
1	0.907	60.5	12	70	-9.5	90.25
2	0.907	60.5	11	28.5	32	1024
3	0.907	60.5	11	28.5	32	1024
5	0.907	60.5	12	70	-9.5	90.25
7	0.907	60.5	12	70	-9.5	90.25
8	0.907	60.5	12	70	-9.5	90.25
10	0.907	60.5	12	70	-9.5	90.25
11	0.907	60.5	8	12	48.5	2352.25
12	0.907	60.5	12	70	-9.5	90.25
13	0.907	60.5	12	70	-9.5	90.25
15	0.907	60.5	12	70	-9.5	90.25
16	0.907	60.5	11	28.5	32	1024
20	0.907	60.5	12	70	-9.5	90.25
21	0.907	60.5	12	70	-9.5	90.25
22	0.907	60.5	12	70	-9.5	90.25
23	0.907	60.5	12	70	-9.5	90.25
26	0.907	60.5	12	70	-9.5	90.25
27	0.907	60.5	9	16.5	44	1936
28	0.907	60.5	12	70	-9.5	90.25
29	0.907	60.5	12	70	-9.5	90.25
30	0.907	60.5	12	70	-9.5	90.25
31	0.907	60.5	9	16.5	44	1936
32	0.907	60.5	12	70	-9.5	90.25
35	0.907	60.5	12	70	-9.5	90.25
36	0.907	60.5	12	70	-9.5	90.25
38	0.907	60.5	12	70	-9.5	90.25
40	0.907	60.5	12	70	-9.5	90.25
42	0.907	60.5	12	70	-9.5	90.25

43	0.907	60.5	6	3.5	57	3249
44	0.907	60.5	12	70	-9.5	90.25
45	0.907	60.5	12	70	-9.5	90.25
48	0.907	60.5	8	12	48.5	2352.25
49	0.907	60.5	12	70	-9.5	90.25
50	0.907	60.5	12	70	-9.5	90.25
51	0.907	60.5	11	28.5	32	1024
53	0.907	60.5	12	70	-9.5	90.25
56	0.907	60.5	12	70	-9.5	90.25
57	0.907	60.5	12	70	-9.5	90.25
58	0.907	60.5	10	21.5	39	1521
59	0.907	60.5	6	3.5	57	3249
60	0.907	60.5	12	70	-9.5	90.25
62	0.907	60.5	12	70	-9.5	90.25
71	0.907	60.5	12	70	-9.5	90.25
73	0.907	60.5	8	12	48.5	2352.25
74	0.907	60.5	12	70	-9.5	90.25
75	0.907	60.5	12	70	-9.5	90.25
76	0.907	60.5	12	70	-9.5	90.25
77	0.907	60.5	12	70	-9.5	90.25
82	0.907	60.5	12	70	-9.5	90.25
84	0.907	60.5	12	70	-9.5	90.25
85	0.907	60.5	12	70	-9.5	90.25
86	0.907	60.5	12	70	-9.5	90.25
87	0.907	60.5	12	70	-9.5	90.25
88	0.907	60.5	12	70	-9.5	90.25
91	0.907	60.5	7	8	52.5	2756.25
94	0.907	60.5	12	70	-9.5	90.25
95	0.907	60.5	12	70	-9.5	90.25
97	0.907	60.5	12	70	-9.5	90.25
99	0.907	60.5	10	21.5	39	1521
100	0.907	60.5	12	70	-9.5	90.25
101	0.907	60.5	12	70	-9.5	90.25
102	0.907	60.5	10	21.5	39	1521
103	0.907	60.5	11	28.5	32	1024
104	0.907	60.5	12	70	-9.5	90.25
105	0.907	60.5	12	70	-9.5	90.25
106	0.907	60.5	12	70	-9.5	90.25
108	0.907	60.5	12	70	-9.5	90.25
110	0.907	60.5	12	70	-9.5	90.25
111	0.907	60.5	12	70	-9.5	90.25
116	0.907	60.5	12	70	-9.5	90.25
119	0.907	60.5	10	21.5	39	1521
120	0.907	60.5	7	8	52.5	2756.25
121	0.907	60.5	8	12	48.5	2352.25
122	0.907	60.5	12	70	-9.5	90.25
123	0.907	60.5	12	70	-9.5	90.25
124	0.907	60.5	12	70	-9.5	90.25
126	0.907	60.5	12	70	-9.5	90.25
128	0.907	60.5	12	70	-9.5	90.25
129	0.907	60.5	12	70	-9.5	90.25
130	0.907	60.5	12	70	-9.5	90.25
9	0.925	105.5	11	28.5	77	5929
78	0.925	105.5	12	70	35.5	1260.25
93	0.969	107	12	70	37	1369

Table E.2 Spearman's test for water source vs. hygiene scores - Laos

	Mean hazard ratio	Rx - source	Hygiene	Ry - hygiene	d=Rx-Ry	d^2
18	0.363	1	1	7	-6	36
34	0.597	2	4	48	-46	2116
109	0.607	3	4	48	-45	2025
92	0.613	4	6	88.5	-84.5	7140.25
47	0.625	6	0	2.5	3.5	12.25
72	0.625	6	6	88.5	-82.5	6806.25
90	0.625	6	6	88.5	-82.5	6806.25
24	0.631	8	2	15.5	-7.5	56.25
19	0.649	9.5	2	15.5	-6	36
37	0.649	9.5	2	15.5	-6	36
25	0.667	12	1	7	5	25
41	0.667	12	6	88.5	-76.5	5852.25
89	0.667	12	6	88.5	-76.5	5852.25
112	0.792	14	4	48	-34	1156
54	0.807	15	2	15.5	-0.5	0.25
33	0.906	16	4	48	-32	1024
4	0.907	60.5	4	48	12.5	156.25
6	0.907	60.5	4	48	12.5	156.25
17	0.907	60.5	1	7	53.5	2862.25
96	0.907	60.5	3	22.5	38	1444
113	0.907	60.5	2	15.5	45	2025
80	0.907	60.5	6	88.5	-28	784
81	0.907	60.5	6	88.5	-28	784
115	0.907	60.5	6	88.5	-28	784
1	0.907	60.5	4	48	12.5	156.25
2	0.907	60.5	4	48	12.5	156.25
3	0.907	60.5	4	48	12.5	156.25
5	0.907	60.5	4	48	12.5	156.25
7	0.907	60.5	4	48	12.5	156.25
8	0.907	60.5	4	48	12.5	156.25
10	0.907	60.5	6	88.5	-28	784
11	0.907	60.5	2	15.5	45	2025
12	0.907	60.5	6	88.5	-28	784
13	0.907	60.5	4	48	12.5	156.25
15	0.907	60.5	6	88.5	-28	784
16	0.907	60.5	4	48	12.5	156.25
20	0.907	60.5	6	88.5	-28	784
21	0.907	60.5	4	48	12.5	156.25
22	0.907	60.5	7	106	-45.5	2070.25
23	0.907	60.5	4	48	12.5	156.25
26	0.907	60.5	4	48	12.5	156.25
27	0.907	60.5	3	22.5	38	1444
28	0.907	60.5	4	48	12.5	156.25
29	0.907	60.5	4	48	12.5	156.25
30	0.907	60.5	4	48	12.5	156.25
31	0.907	60.5	4	48	12.5	156.25
32	0.907	60.5	2	15.5	45	2025
35	0.907	60.5	4	48	12.5	156.25
36	0.907	60.5	7	106	-45.5	2070.25
38	0.907	60.5	4	48	12.5	156.25
40	0.907	60.5	4	48	12.5	156.25
42	0.907	60.5	6	88.5	-28	784
43	0.907	60.5	0	2.5	58	3364
44	0.907	60.5	6	88.5	-28	784
45	0.907	60.5	4	48	12.5	156.25

48	0.907	60.5	2	15.5	45	2025
49	0.907	60.5	6	88.5	-28	784
50	0.907	60.5	6	88.5	-28	784
51	0.907	60.5	4	48	12.5	156.25
53	0.907	60.5	4	48	12.5	156.25
56	0.907	60.5	4	48	12.5	156.25
57	0.907	60.5	4	48	12.5	156.25
58	0.907	60.5	1	7	53.5	2862.25
59	0.907	60.5	0	2.5	58	3364
60	0.907	60.5	6	88.5	-28	784
62	0.907	60.5	6	88.5	-28	784
71	0.907	60.5	4	48	12.5	156.25
73	0.907	60.5	2	15.5	45	2025
74	0.907	60.5	6	88.5	-28	784
75	0.907	60.5	6	88.5	-28	784
76	0.907	60.5	4	48	12.5	156.25
77	0.907	60.5	4	48	12.5	156.25
82	0.907	60.5	6	88.5	-28	784
84	0.907	60.5	6	88.5	-28	784
85	0.907	60.5	6	88.5	-28	784
86	0.907	60.5	4	48	12.5	156.25
87	0.907	60.5	6	88.5	-28	784
88	0.907	60.5	6	88.5	-28	784
91	0.907	60.5	1	7	53.5	2862.25
94	0.907	60.5	6	88.5	-28	784
95	0.907	60.5	7	106	-45.5	2070.25
97	0.907	60.5	6	88.5	-28	784
99	0.907	60.5	2	15.5	45	2025
100	0.907	60.5	6	88.5	-28	784
101	0.907	60.5	4	48	12.5	156.25
102	0.907	60.5	4	48	12.5	156.25
103	0.907	60.5	6	88.5	-28	784
104	0.907	60.5	4	48	12.5	156.25
105	0.907	60.5	4	48	12.5	156.25
106	0.907	60.5	4	48	12.5	156.25
108	0.907	60.5	4	48	12.5	156.25
110	0.907	60.5	4	48	12.5	156.25
111	0.907	60.5	4	48	12.5	156.25
116	0.907	60.5	6	88.5	-28	784
119	0.907	60.5	2	15.5	45	2025
120	0.907	60.5	0	2.5	58	3364
121	0.907	60.5	2	15.5	45	2025
122	0.907	60.5	4	48	12.5	156.25
123	0.907	60.5	6	88.5	-28	784
124	0.907	60.5	4	48	12.5	156.25
126	0.907	60.5	4	48	12.5	156.25
128	0.907	60.5	4	48	12.5	156.25
129	0.907	60.5	4	48	12.5	156.25
130	0.907	60.5	4	48	12.5	156.25
9	0.925	105.5	4	48	57.5	3306.25
78	0.925	105.5	4	48	57.5	3306.25
93	0.969	107	6	88.5	18.5	342.25

Table E.3 Spearman's test for sanitation vs. hygiene scores – Laos

	Sanitation	Rx	Hygiene	Ry - hygiene	d=Rx-Ry	d^2
18	10	26	1	9	17	289
34	11	34.5	4	56	-21.5	462.25
109	12	80.5	4	56	24.5	600.25
92	12	80.5	6	100	-19.5	380.25
47	7	9.5	0	3	6.5	42.25

72	12	80.5	6	100	-19.5	380.25
90	12	80.5	6	100	-19.5	380.25
24	6	4.5	2	20.5	-16	256
19	9	19.5	2	20.5	-1	1
37	9	19.5	2	20.5	-1	1
25	10	26	1	9	17	289
41	8	14	6	100	-86	7396
89	12	80.5	6	100	-19.5	380.25
112	12	80.5	4	56	24.5	600.25
54	6	4.5	2	20.5	-16	256
33	12	80.5	4	56	24.5	600.25
4	12	80.5	4	56	24.5	600.25
6	12	80.5	4	56	24.5	600.25
17	11	34.5	1	9	25.5	650.25
96	6	4.5	3	29.5	-25	625
113	6	4.5	2	20.5	-16	256
80	12	80.5	6	100	-19.5	380.25
81	12	80.5	6	100	-19.5	380.25
115	12	80.5	6	100	-19.5	380.25
1	12	80.5	4	56	24.5	600.25
2	11	34.5	4	56	-21.5	462.25
3	11	34.5	4	56	-21.5	462.25
5	12	80.5	4	56	24.5	600.25
7	12	80.5	4	56	24.5	600.25
8	12	80.5	4	56	24.5	600.25
10	12	80.5	6	100	-19.5	380.25
11	8	14	2	20.5	-6.5	42.25
12	12	80.5	6	100	-19.5	380.25
13	12	80.5	4	56	24.5	600.25
15	12	80.5	6	100	-19.5	380.25
16	11	34.5	4	56	-21.5	462.25
20	12	80.5	6	100	-19.5	380.25
21	12	80.5	4	56	24.5	600.25
22	12	80.5	7	120	-39.5	1560.25
23	12	80.5	4	56	24.5	600.25
26	12	80.5	4	56	24.5	600.25
27	9	19.5	3	29.5	-10	100
28	12	80.5	4	56	24.5	600.25
29	12	80.5	4	56	24.5	600.25
30	12	80.5	4	56	24.5	600.25
31	9	19.5	4	56	-36.5	1332.25
32	12	80.5	2	20.5	60	3600
35	12	80.5	4	56	24.5	600.25
36	12	80.5	7	120	-39.5	1560.25
38	12	80.5	4	56	24.5	600.25
40	12	80.5	4	56	24.5	600.25
42	12	80.5	6	100	-19.5	380.25
43	6	4.5	0	3	1.5	2.25
44	12	80.5	6	100	-19.5	380.25
45	12	80.5	4	56	24.5	600.25
48	8	14	2	20.5	-6.5	42.25
49	12	80.5	6	100	-19.5	380.25
50	12	80.5	6	100	-19.5	380.25
51	11	34.5	4	56	-21.5	462.25
53	12	80.5	4	56	24.5	600.25
56	12	80.5	4	56	24.5	600.25
57	12	80.5	4	56	24.5	600.25
58	10	26	1	9	17	289

59	6	4.5	0	3	1.5	2.25
60	12	80.5	6	100	-19.5	380.25
62	12	80.5	6	100	-19.5	380.25
71	12	80.5	4	56	24.5	600.25
73	8	14	2	20.5	-6.5	42.25
74	12	80.5	6	100	-19.5	380.25
75	12	80.5	6	100	-19.5	380.25
76	12	80.5	4	56	24.5	600.25
77	12	80.5	4	56	24.5	600.25
82	12	80.5	6	100	-19.5	380.25
84	12	80.5	6	100	-19.5	380.25
85	12	80.5	6	100	-19.5	380.25
86	12	80.5	4	56	24.5	600.25
87	12	80.5	6	100	-19.5	380.25
88	12	80.5	6	100	-19.5	380.25
91	7	9.5	1	9	0.5	0.25
94	12	80.5	6	100	-19.5	380.25
95	12	80.5	7	120	-39.5	1560.25
97	12	80.5	6	100	-19.5	380.25
99	10	26	2	20.5	5.5	30.25
100	12	80.5	6	100	-19.5	380.25
101	12	80.5	4	56	24.5	600.25
102	10	26	4	56	-30	900
103	11	34.5	6	100	-65.5	4290.25
104	12	80.5	4	56	24.5	600.25
105	12	80.5	4	56	24.5	600.25
106	12	80.5	4	56	24.5	600.25
108	12	80.5	4	56	24.5	600.25
110	12	80.5	4	56	24.5	600.25
111	12	80.5	4	56	24.5	600.25
116	12	80.5	6	100	-19.5	380.25
119	10	26	2	20.5	5.5	30.25
120	7	9.5	0	3	6.5	42.25
121	8	14	2	20.5	-6.5	42.25
122	12	80.5	4	56	24.5	600.25
123	12	80.5	6	100	-19.5	380.25
124	12	80.5	4	56	24.5	600.25
126	12	80.5	4	56	24.5	600.25
128	12	80.5	4	56	24.5	600.25
129	12	80.5	4	56	24.5	600.25
130	12	80.5	4	56	24.5	600.25
9	11	34.5	4	56	-21.5	462.25
78	12	80.5	4	56	24.5	600.25
93	12	80.5	6	100	-19.5	380.25
14	5	1	1	9	-8	64
39	12	80.5	6	100	-19.5	380.25
55	12	80.5	6	100	-19.5	380.25
69	11	34.5	2	20.5	14	196
70	9	19.5	2	20.5	-1	1
98	11	34.5	0	3	31.5	992.25
107	12	80.5	4	56	24.5	600.25
114	10	26	1	9	17	289
117	12	80.5	6	100	-19.5	380.25
125	9	19.5	2	20.5	-1	1
127	7	9.5	2	20.5	-11	121
79	12	80.5	6	100	-19.5	380.25
83	12	80.5	4	56	24.5	600.25
46	12	80.5	6	100	-19.5	380.25

Table E.4 Spearman's test for water source vs. sanitation scores – Thailand

	Source hazard	Rx - source	Sanitation	Ry - Sanitation	d=Rx-Ry	d^2
203	0.523809524	27.5	3	19	8.5	72.25
63	0.541666667	45.5	3	19	26.5	702.25
135	0.666666667	98.5	4	38.5	60	3600
54	0.482142857	17	6	73.5	-56.5	3192.25
55	0.648809524	75	7	93.5	-18.5	342.25
61	0.630952381	65	7	93.5	-28.5	812.25
6	0.648809524	75	5	57	18	324
60	0.648809524	75	7	93.5	-18.5	342.25
59	0.648809524	75	4	38.5	36.5	1332.25
58	0.55952381	57.5	4	38.5	19	361
67	0.648809524	75	4	38.5	36.5	1332.25
69	0.44047619	8	3	19	-11	121
3	0.44047619	8	3	19	-11	121
76	0.482142857	17	3	19	-2	4
2	0.44047619	8	2	6	2	4
138	0.482142857	17	4	38.5	-21.5	462.25
141	0.523809524	27.5	4	38.5	-11	121
211	0.44047619	8	2	6	2	4
68	0.523809524	27.5	6	73.5	-46	2116
64	0.648809524	75	4	38.5	36.5	1332.25
206	0.458333333	13.5	6	73.5	-60	3600
200	0.56547619	59	4	38.5	20.5	420.25
299	0.577380952	60	7	93.5	-33.5	1122.25
229	0.523809524	27.5	2	6	21.5	462.25
159	0.607142857	61.5	4	38.5	23	529
210	0.666666667	98.5	3	19	79.5	6320.25
17	0.68452381	114.5	3	19	95.5	9120.25
11	0.648809524	75	2	6	69	4761
183	0.68452381	114.5	4	38.5	76	5776
235	0.68452381	114.5	5	57	57.5	3306.25
70	0.523809524	27.5	3	19	8.5	72.25
213	0.68452381	114.5	4	38.5	76	5776
117	0.55952381	57.5	5	57	0.5	0.25
176	0.482142857	17	4	38.5	-21.5	462.25
53b	0.404761905	3.5	6	73.5	-70	4900
193/127	0.607142857	61.5	3	19	42.5	1806.25
222	0.648809524	75	3	19	56	3136
165	0.666666667	98.5	7	93.5	5	25
27	0.666666667	98.5	2	6	92.5	8556.25
116	0.648809524	75	3	19	56	3136
207	0.523809524	27.5	3	19	8.5	72.25
205	0.523809524	27.5	7	93.5	-66	4356
230	0.541666667	45.5	3	19	26.5	702.25
199	0.523809524	27.5	3	19	8.5	72.25
66	0.44047619	8	1	1	7	49
218	0.541666667	45.5	6	73.5	-28	784
204	0.482142857	17	3	19	-2	4
188	0.541666667	45.5	5	57	-11.5	132.25
173	0.541666667	45.5	5	57	-11.5	132.25
180	0.648809524	75	4	38.5	36.5	1332.25
47	0.648809524	75	5	57	18	324
39	0.666666667	98.5	5	57	41.5	1722.25
49	0.541666667	45.5	7	93.5	-48	2304
38	0.404761905	3.5	7	93.5	-90	8100
162	0.648809524	75	2	6	69	4761

124	0.666666667	98.5	7	93.5	5	25
233	0.666666667	98.5	5	57	41.5	1722.25
160	0.648809524	75	5	57	18	324
164	0.541666667	45.5	9	113.5	-68	4624
56	0.523809524	27.5	6	73.5	-46	2116
57	0.666666667	98.5	7	93.5	5	25
72	0.648809524	75	3	19	56	3136
219	0.541666667	45.5	4	38.5	7	49
14	0.648809524	75	7	93.5	-18.5	342.25
195	0.541666667	45.5	6	73.5	-28	784
155	0.523809524	27.5	4	38.5	-11	121
142	0.648809524	75	7	93.5	-18.5	342.25
20	0.321428571	2	6	73.5	-71.5	5112.25
92	0.666666667	98.5	7	93.5	5	25
172	0.523809524	27.5	6	73.5	-46	2116
34	0.666666667	98.5	7	93.5	5	25
227	0.648809524	75	5	57	18	324
29	0.541666667	45.5	7	93.5	-48	2304
130	0.458333333	13.5	2	6	7.5	56.25
28	0.666666667	98.5	8	108	-9.5	90.25
113	0.666666667	98.5	8	108	-9.5	90.25
16	0.541666667	45.5	6	73.5	-28	784
240	0.666666667	98.5	4	38.5	60	3600
21	0.541666667	45.5	9	113.5	-68	4624
212	0.541666667	45.5	8	108	-62.5	3906.25
242	0.541666667	45.5	7	93.5	-48	2304
194	0.666666667	98.5	9	113.5	-15	225
182	0.541666667	45.5	3	19	26.5	702.25
43	0.666666667	98.5	4	38.5	60	3600
126	0.666666667	98.5	7	93.5	5	25
4	0.666666667	98.5	11	116	-17.5	306.25
90	0.625	63.5	6	73.5	-10	100
196	0.666666667	98.5	8	108	-9.5	90.25
48	0.541666667	45.5	7	93.5	-48	2304
44	0.541666667	45.5	6	73.5	-28	784
42	0.541666667	45.5	5	57	-11.5	132.25
226	0.238095238	1	7	93.5	-92.5	8556.25
41	0.666666667	98.5	5	57	41.5	1722.25
174	0.44047619	8	4	38.5	-30.5	930.25
36	0.666666667	98.5	8	108	-9.5	90.25
129	0.523809524	27.5	4	38.5	-11	121
220	0.625	63.5	5	57	6.5	42.25
37	0.5	20	7	93.5	-73.5	5402.25
31	0.666666667	98.5	5	57	41.5	1722.25
148	0.666666667	98.5	2	6	92.5	8556.25
185	0.666666667	98.5	7	93.5	5	25
156	0.666666667	98.5	6	73.5	25	625
303	0.523809524	27.5	5	57	-29.5	870.25
202	0.666666667	98.5	8	108	-9.5	90.25
189	0.541666667	45.5	6	73.5	-28	784
5	0.541666667	45.5	6	73.5	-28	784
9	0.666666667	98.5	9	113.5	-15	225
163	0.541666667	45.5	4	38.5	7	49
50	0.541666667	45.5	6	73.5	-28	784
295	0.666666667	98.5	7	93.5	5	25
52	0.648809524	75	2	6	69	4761
297	0.648809524	75	8	108	-33	1089
52/1	0.523809524	27.5	4	38.5	-11	121
45	0.666666667	98.5	6	73.5	25	625
7	0.452380952	12	6	73.5	-61.5	3782.25
291	0.44047619	8	4	38.5	-30.5	930.25

Table E.5 Spearman's test for water source vs. hygiene scores – Laos

	Source hazard	Rx - source	Hygiene	Ry - hygiene	d=Rx-Ry	d^2
203	0.523809524	27.5	1	49.5	-22	484
63	0.541666667	45.5	2	100.5	-55	3025
135	0.666666667	98.5	1	49.5	49	2401
54	0.482142857	17	1	49.5	-32.5	1056.25
55	0.648809524	75	1	49.5	25.5	650.25
61	0.630952381	65	0	6	59	3481
6	0.648809524	75	0	6	69	4761
60	0.648809524	75	1	49.5	25.5	650.25
59	0.648809524	75	1	49.5	25.5	650.25
58	0.55952381	57.5	1	49.5	8	64
67	0.648809524	75	2	100.5	-25.5	650.25
69	0.44047619	8	1	49.5	-41.5	1722.25
3	0.44047619	8	1	49.5	-41.5	1722.25
76	0.482142857	17	1	49.5	-32.5	1056.25
2	0.44047619	8	1	49.5	-41.5	1722.25
138	0.482142857	17	1	49.5	-32.5	1056.25
141	0.523809524	27.5	1	49.5	-22	484
211	0.44047619	8	1	49.5	-41.5	1722.25
68	0.523809524	27.5	1	49.5	-22	484
64	0.648809524	75	1	49.5	25.5	650.25
206	0.458333333	13.5	1	49.5	-36	1296
200	0.56547619	59	1	49.5	9.5	90.25
299	0.577380952	60	1	49.5	10.5	110.25
229	0.523809524	27.5	0	6	21.5	462.25
159	0.607142857	61.5	1	49.5	12	144
210	0.666666667	98.5	1	49.5	49	2401
17	0.68452381	114.5	1	49.5	65	4225
11	0.648809524	75	1	49.5	25.5	650.25
183	0.68452381	114.5	2	100.5	14	196
235	0.68452381	114.5	1	49.5	65	4225
70	0.523809524	27.5	1	49.5	-22	484
213	0.68452381	114.5	1	49.5	65	4225
117	0.55952381	57.5	1	49.5	8	64
176	0.482142857	17	1	49.5	-32.5	1056.25
53b	0.404761905	3.5	1	49.5	-46	2116
193/127	0.607142857	61.5	1	49.5	12	144
222	0.648809524	75	1	49.5	25.5	650.25
165	0.666666667	98.5	2	100.5	-2	4
27	0.666666667	98.5	2	100.5	-2	4
116	0.648809524	75	1	49.5	25.5	650.25
207	0.523809524	27.5	1	49.5	-22	484
205	0.523809524	27.5	1	49.5	-22	484
230	0.541666667	45.5	2	100.5	-55	3025
199	0.523809524	27.5	1	49.5	-22	484
66	0.44047619	8	1	49.5	-41.5	1722.25
218	0.541666667	45.5	1	49.5	-4	16
204	0.482142857	17	1	49.5	-32.5	1056.25
188	0.541666667	45.5	1	49.5	-4	16
173	0.541666667	45.5	1	49.5	-4	16
180	0.648809524	75	1	49.5	25.5	650.25
47	0.648809524	75	1	49.5	25.5	650.25
39	0.666666667	98.5	1	49.5	49	2401
49	0.541666667	45.5	1	49.5	-4	16
38	0.404761905	3.5	1	49.5	-46	2116

162	0.648809524	75	1	49.5	25.5	650.25
124	0.666666667	98.5	2	100.5	-2	4
233	0.666666667	98.5	1	49.5	49	2401
160	0.648809524	75	2	100.5	-25.5	650.25
164	0.541666667	45.5	1	49.5	-4	16
56	0.523809524	27.5	1	49.5	-22	484
57	0.666666667	98.5	4	115	-16.5	272.25
72	0.648809524	75	0	6	69	4761
219	0.541666667	45.5	0	6	39.5	1560.25
14	0.648809524	75	2	100.5	-25.5	650.25
195	0.541666667	45.5	0	6	39.5	1560.25
155	0.523809524	27.5	0	6	21.5	462.25
142	0.648809524	75	1	49.5	25.5	650.25
20	0.321428571	2	2	100.5	-98.5	9702.25
92	0.666666667	98.5	1	49.5	49	2401
172	0.523809524	27.5	0	6	21.5	462.25
34	0.666666667	98.5	0	6	92.5	8556.25
227	0.648809524	75	2	100.5	-25.5	650.25
29	0.541666667	45.5	2	100.5	-55	3025
130	0.458333333	13.5	2	100.5	-87	7569
28	0.666666667	98.5	1	49.5	49	2401
113	0.666666667	98.5	4	115	-16.5	272.25
16	0.541666667	45.5	2	100.5	-55	3025
240	0.666666667	98.5	0	6	92.5	8556.25
21	0.541666667	45.5	1	49.5	-4	16
212	0.541666667	45.5	1	49.5	-4	16
242	0.541666667	45.5	2	100.5	-55	3025
194	0.666666667	98.5	2	100.5	-2	4
182	0.541666667	45.5	1	49.5	-4	16
43	0.666666667	98.5	1	49.5	49	2401
126	0.666666667	98.5	1	49.5	49	2401
4	0.666666667	98.5	4	115	-16.5	272.25
90	0.625	63.5	2	100.5	-37	1369
196	0.666666667	98.5	1	49.5	49	2401
48	0.541666667	45.5	2	100.5	-55	3025
44	0.541666667	45.5	1	49.5	-4	16
42	0.541666667	45.5	2	100.5	-55	3025
226	0.238095238	1	1	49.5	-48.5	2352.25
41	0.666666667	98.5	1	49.5	49	2401
174	0.44047619	8	2	100.5	-92.5	8556.25
36	0.666666667	98.5	1	49.5	49	2401
129	0.523809524	27.5	1	49.5	-22	484
220	0.625	63.5	1	49.5	14	196
37	0.5	20	1	49.5	-29.5	870.25
31	0.666666667	98.5	1	49.5	49	2401
148	0.666666667	98.5	1	49.5	49	2401
185	0.666666667	98.5	2	100.5	-2	4
156	0.666666667	98.5	1	49.5	49	2401
303	0.523809524	27.5	1	49.5	-22	484
202	0.666666667	98.5	1	49.5	49	2401
189	0.541666667	45.5	1	49.5	-4	16
5	0.541666667	45.5	2	100.5	-55	3025
9	0.666666667	98.5	1	49.5	49	2401
163	0.541666667	45.5	2	100.5	-55	3025
50	0.541666667	45.5	1	49.5	-4	16
295	0.666666667	98.5	2	100.5	-2	4
52	0.648809524	75	1	49.5	25.5	650.25
297	0.648809524	75	1	49.5	25.5	650.25
52/1	0.523809524	27.5	1	49.5	-22	484
45	0.666666667	98.5	2	100.5	-2	4
7	0.452380952	12	2	100.5	-88.5	7832.25

291	0.44047619	8	0	6	2	4

Table E.6 Spearman's test for sanitation vs. hygiene scores – Thailand

	Sanitation	Rx - Sanitation	Ry - hygiene	d=Rx-Ry	d^2
203	3	19.5	51	-31.5	992.25
63	3	19.5	102.5	-83	6889
135	4	39.5	51	-11.5	132.25
54	6	75	51	24	576
55	7	95.5	51	44.5	1980.25
61	7	95.5	6.5	89	7921
6	5	58	6.5	51.5	2652.25
60	7	95.5	51	44.5	1980.25
59	4	39.5	51	-11.5	132.25
58	4	39.5	51	-11.5	132.25
67	4	39.5	102.5	-63	3969
69	3	19.5	51	-31.5	992.25
3	3	19.5	51	-31.5	992.25
76	3	19.5	51	-31.5	992.25
2	2	6	51	-45	2025
138	4	39.5	51	-11.5	132.25
141	4	39.5	51	-11.5	132.25
211	2	6	51	-45	2025
68	6	75	51	24	576
64	4	39.5	51	-11.5	132.25
206	6	75	51	24	576
200	4	39.5	51	-11.5	132.25
299	7	95.5	51	44.5	1980.25
229	2	6	6.5	-0.5	0.25
159	4	39.5	51	-11.5	132.25
210	3	19.5	51	-31.5	992.25
17	3	19.5	51	-31.5	992.25
11	2	6	51	-45	2025
183	4	39.5	102.5	-63	3969
235	5	58	51	7	49
70	3	19.5	51	-31.5	992.25
213	4	39.5	51	-11.5	132.25
117	5	58	51	7	49
176	4	39.5	51	-11.5	132.25
53b	6	75	51	24	576
193/127	3	19.5	51	-31.5	992.25
222	3	19.5	51	-31.5	992.25
165	7	95.5	102.5	-7	49
27	2	6	102.5	-96.5	9312.25
116	3	19.5	51	-31.5	992.25
207	3	19.5	51	-31.5	992.25
205	7	95.5	51	44.5	1980.25
230	3	19.5	102.5	-83	6889
199	3	19.5	51	-31.5	992.25
66	1	1	51	-50	2500
218	6	75	51	24	576
204	3	19.5	51	-31.5	992.25
188	5	58	51	7	49
173	5	58	51	7	49
180	4	39.5	51	-11.5	132.25
47	5	58	51	7	49
39	5	58	51	7	49
49	7	95.5	51	44.5	1980.25

38	7	95.5	51	44.5	1980.25
162	2	6	51	-45	2025
124	7	95.5	102.5	-7	49
233	5	58	51	7	49
160	5	58	102.5	-44.5	1980.25
164	9	115.5	51	64.5	4160.25
56	6	75	51	24	576
57	7	95.5	117	-21.5	462.25
72	3	19.5	6.5	13	169
219	4	39.5	6.5	33	1089
14	7	95.5	102.5	-7	49
195	6	75	6.5	68.5	4692.25
155	4	39.5	6.5	33	1089
142	7	95.5	51	44.5	1980.25
20	6	75	102.5	-27.5	756.25
92	7	95.5	51	44.5	1980.25
172	6	75	6.5	68.5	4692.25
34	7	95.5	6.5	89	7921
227	5	58	102.5	-44.5	1980.25
29	7	95.5	102.5	-7	49
130	2	6	102.5	-96.5	9312.25
28	8	110	51	59	3481
113	8	110	117	-7	49
16	6	75	102.5	-27.5	756.25
240	4	39.5	6.5	33	1089
21	9	115.5	51	64.5	4160.25
212	8	110	51	59	3481
242	7	95.5	102.5	-7	49
194	9	115.5	102.5	13	169
182	3	19.5	51	-31.5	992.25
43	4	39.5	51	-11.5	132.25
126	7	95.5	51	44.5	1980.25
4	11	118	117	1	1
90	6	75	102.5	-27.5	756.25
196	8	110	51	59	3481
48	7	95.5	102.5	-7	49
44	6	75	51	24	576
42	5	58	102.5	-44.5	1980.25
226	7	95.5	51	44.5	1980.25
41	5	58	51	7	49
174	4	39.5	102.5	-63	3969
36	8	110	51	59	3481
129	4	39.5	51	-11.5	132.25
220	5	58	51	7	49
37	7	95.5	51	44.5	1980.25
31	5	58	51	7	49
148	2	6	51	-45	2025
185	7	95.5	102.5	-7	49
156	6	75	51	24	576
303	5	58	51	7	49
202	8	110	51	59	3481
189	6	75	51	24	576
5	6	75	102.5	-27.5	756.25
9	9	115.5	51	64.5	4160.25
163	4	39.5	102.5	-63	3969
50	6	75	51	24	576
295	7	95.5	102.5	-7	49
52	2	6	51	-45	2025
297	8	110	51	59	3481
52/1	4	39.5	51	-11.5	132.25
45	6	75	102.5	-27.5	756.25

7	6	75	102.5	-27.5	756.25
291	4	39.5	6.5	33	1089
30	3	19.5	6.5	13	169
197	6	75	51	24	576

Annex F Water quality data of collected samples and computed differences between source and point of consumption

Table F.1 Water quality data in Laos – first period

No	House number	WATER SOURCE					POU				Difference POU-Source	
		Type	Code	1st period (MPN/100 ml)			Code	1st period (MPN/100 ml)			1st period	
				Log mean	Mean	STD		Log mean	Mean	STD	Mean MPN/100 ml	Log mean
1	21	Rainwater	RW4	0.56	3.65	3.75	POU1	0.8	5.75	2.33	*2.1*	*0.20*
2	108	Rainwater	RW1	-0.26	0.55	0.64	POU1.1	-1.0	<1	0.00	*(0.5)*	*(0.74)*
3	57	Rainwater	RW13	2.38	240.05	50.13	POU10	2.0	92.15	5.30	*(147.9)*	*(0.42)*
4	81	Rainwater	RW14	0.02	1.05	1.34	POU11	-0.3	0.55	0.64	*(0.5)*	*(0.28)*
5	92	Rainwater	RW15	-1.00	<1	0.00	POU12	0.3	2.1	2.83	*2.0*	*1.32*
6	89	Rainwater	RW16	-1.00	<1	0.00	POU13	-1.0	<1	0.00	*0.0*	*0.00*
7	19	Rainwater	RW17	-1.00	<1	0.00	POU14	-1.0	<1	0.00	*0.0*	*0.00*
8	9	Rainwater	RW18	-1.00	<1	0.00	POU15	-1.0	<1	0.00	*0.0*	*0.00*
9	112	Rainwater	RW19	-1.00	<1	0.00	POU16	-1.0	<1	0.00	*0.0*	*0.00*
10	10	Rainwater	RW20	-1.00	<1	0.00	POU17	-1.0	<1	0.00	*0.0*	*0.00*
11	25	Rainwater	RW21	-1.00	<1	0.00	POU18	2.0	96.75	22.42	*96.7*	*2.99*
12	124	Rainwater	RW22	2.32	210.05	36.56	POU19	2.1	124.35	12.80	*(85.7)*	*(0.23)*
13	40	Rainwater	RW4	0.56	3.65	3.75	POU2	-1.0	<1	0.00	*(3.6)*	*(1.56)*
14	129	Rainwater	RW23	1.79	62.35	13.22	POU20	2.5	323.25	123.53	*260.9*	*0.71*
15	84	Rainwater	RW24	-1.00	<1	0.00	POU21	0.9	8.1	5.66	*8.0*	*1.91*
16	36	Rainwater	RW25	-1.00	<1	0.00	POU22	1.3	21.45	0.21	*21.4*	*2.33*
17	93	Rainwater	RW6	-0.26	0.55	0.64	POU3	2.7	495	119.36	*494.5*	*2.95*
19	33	Rainwater	RW26B	0.00	1	0.00	POU3B	-0.3	0.55	0.64	*(0.5)*	*(0.26)*
20	109	Rainwater	RW7	-1.00	<1	0.00	POU4	-1.0	<1	0.00	*0.00*	*0.00*
21	97	Rainwater	RW2	-1.00	<1	0.00	POU4.1	-1.0	<1	0.00	*0.0*	*0.00*
22	115	Rainwater	RW8	1.47	29.65	15.20	POU5	1.6	35.95	0.64	*6.3*	*0.08*
23	90	Rainwater	RW9	-1.00	<1	0.00	POU6	-1.0	<1	0.00	*0.0*	*0.00*
24	37	Rainwater	RW3	0.18	1.5	0.71	POU6.1	0.8	5.8	2.40	*4.3*	*0.59*
25	55	Rainwater	RW11	0.56	3.6	0.71	POU8	1.6	41.6	4.53	*38.0*	*1.06*
26	54	Rainwater	RW12	-1.00	<1	0.00	POU9	-1.0	<1	0.00	*0.0*	*0.00*
27	72	Rainwater	RW10/POU7	1.18	15	0.71	RW10/POU7	1.2	15	0.71	*0.0*	*0.00*
28	34 & 47	Borehole	MB1	-1.00	<1	0.00	POU2.1	-1.0	<1	0.00	*0.0*	*0.00*
29	127	Bottled water	-				BW1	0.8	6.95	4.03	-	
30	107	Bottled water	-				BW3	0.6	3.55	0.78	-	
31	39	Bottled water	-				BW4	0.2	1.5	0.71	-	
32	14	Bottled water	-				BW5	0.2	1.5	0.71	-	
33	114	Bottled water	-				BW6	-0.3	0.55	0.64	-	
34	70	Bottled water	-				BW7	-1.0	<1	0.00	-	
35	125	Bottled water	-				BW8	-1.0	<1	0.00	-	
36	98	Bottled water	-				BW9	-1.0	<1	0.00	-	
37	117	Bottled water	-				TGH	-1.0	<1	0.00	-	
38	69	Bottled water	-				TGH	-1.0	<1	0.00	-	

Table F.2 Water quality data in Laos – second period

No	House number	WATER SOURCE					POU				Difference POU-Source	
		Type	Code	2nd period (MPN/100 ml)			Code	2nd period (MPN/100 ml)			2nd period	
				Log mean	Mean	STD		Log mean	Mean	STD	Mean MPN/100 ml	Diff log mean
1	21	Rainwater	RW4	-1.0	<1	0.00	POU1	3.4	>2419.6	0.00	*>2420*	*4.38*
2	108	Rainwater	RW1	1.1	11.95	9.55	POU1.1	-1.0	<1	0.00	*(12)*	*(2.08)*
3	57	Rainwater	RW13	0.8	5.75	0.78	POU10	-1.0	<1	0.00	*(6)*	*(1.76)*
4	81	Rainwater	RW14	1.1	12.3	5.37	POU11	-1.0	<1	0.00	*(12)*	*(2.09)*
5	92	Rainwater	RW15	-0.3	0.55	0.64	POU12	0.5	3.1	2.97	*3*	*0.75*
6	89	Rainwater	RW16	-1.0	<1	0.00	POU13	-1.0	<1	0.00	*0*	*0.00*
7	19	Rainwater	RW17	-1.0	<1	0.00	POU14	-1.0	<1	0.00	*0*	*0.00*

8	9	Rainwater	RW18	-	-	-	POU15	-1.0	<1	0.00	-	-
9	112	Rainwater	RW19	0.0	1	0.00	POU16	-1.0	<1	0.00	*(1)*	*(1.00)*
10	10	Rainwater	RW20	-1.0	<1	0.00	POU17	-1.0	<1	0.00	*0*	*0.00*
11	25	Rainwater	RW21	-1.0	<1	0.00	POU18	-1.0	<1	0.00	*0*	*0.00*
12	124	Rainwater	RW22	-1.0	<1	0.00	POU19	1.7	45.7	0.99	*46*	*2.66*
13	40	Rainwater	RW4	-1.0	<1	0.00	POU2	-1.0	<1	0.00	*0*	*0.00*
14	129	Rainwater	RW23	1.3	18.7	9.33	POU20	1.6	41.3	8.20	*23*	*0.34*
15	84	Rainwater	RW24	-1.0	<1	0.00	POU21	-0.3	0.55	0.64	*0*	*0.74*
16	36	Rainwater	RW25	0.0	1.05	1.34	POU22	-1.0	<1	0.00	*(1)*	*(1.02)*
17	93	Rainwater	RW6	0.7	4.65	0.78	POU3	2.9	793.25	32.74	*789*	*2.23*
19	33	Rainwater	RW26B	0.0	1.05	1.34	POU3B	-1.0	<1	0.00	*(1)*	*(1.02)*
20	109	Rainwater	RW7	-0.3	0.55	0.64	POU4	1.9	72	4.10	*71*	*2.12*
21	97	Rainwater	RW2	-1.0	<1	0.00	POU4.1	-1.0	<1	0.00	*0*	*0.00*
22	115	Rainwater	RW8	1.2	17.35	1.91	POU5	1.3	22.15	2.47	*5*	*0.11*
23	90	Rainwater	RW9	-1.0	<1	0.00	POU6	-1.0	<1	0.00	*0*	*0.00*
24	37	Rainwater	RW3	0.2	1.5	0.71	POU6.1	-1.0	<1	0.00	*(1)*	*(1.18)*
25	55	Rainwater	RW11	1.6	40.25	7.42	POU8	1.6	43.25	3.18	*3*	*0.03*
26	54	Rainwater	RW12	-1.0	<1	0.00	POU9	-1.0	<1	0.00	*0*	*0.00*
27	72	Rainwater	RW10/POU7	0.0	1.05	1.34	RW10/POU7	0.0	1.05	1.34	*0*	*0.00*
28	34 & 47	Borehole	MB1	-1.0	<1	0.00	POU2.1	0.0	1	0.00	*1*	*1.00*
29	127	Bottled water	-				BW1	-0.3	0.55	0.64	-	
30	107	Bottled water	-				BW3	-1.0	<1	0.00	-	
31	39	Bottled water	-				BW4	-1.0	<1	0.00	-	
32	14	Bottled water	-				BW5	-0.3	0.55	0.64	-	
33	114	Bottled water	-				BW6	-1.0	<1	0.00	-	
34	70	Bottled water	-				BW7	-1.0	<1	0.00	-	
35	125	Bottled water	-				BW8	-1.0	<1	0.00	-	
36	98	Bottled water	-				BW9	0.7	4.65	0.78	-	
37	117	Bottled water	-				TGH	-1.0	<1	0.00	-	
38	69	Bottled water	-				TGH	-1.0	<1	0.00	-	

Table F.3 Water quality data in Laos – averaged counts

No	House number	WATER SOURCE					POU				Difference POU-Source	
		Type	Code	Average			Code	Average			Whole period	
				Mean	Log mean	STD		Log mean	Mean	STD	Mean MPN/100 ml	Diff log mean
1	21	Rainwater	RW4	1.88	0.27	2.98	POU1	3.08	1212.68	1393.64	*1210.8*	*2.8*
2	108	Rainwater	RW1	6.25	0.80	8.59	POU1.1	-1.00	0.10	0.00	*(6.2)*	*(1.8)*
3	57	Rainwater	RW13	122.90	2.09	138.34	POU10	1.66	46.13	53.23	*(76.8)*	*(0.4)*
4	81	Rainwater	RW14	6.68	0.82	7.24	POU11	-0.49	0.33	0.45	*(6.4)*	*(1.3)*
5	92	Rainwater	RW15	0.33	-0.49	0.45	POU12	0.41	2.60	2.44	*2.3*	*0.9*
6	89	Rainwater	RW16	<1	-1.00	0.00	POU13	-1.00	0.10	0.00	*0.0*	*0.0*
7	19	Rainwater	RW17	<1	-1.00	0.00	POU14	-1.00	0.10	0.00	*0.0*	*0.0*
8	9	Rainwater	RW18	<1	-1.00	0.00	POU15	-1.00	0.10	0.00	*0.0*	*0.0*
9	112	Rainwater	RW19	0.55	-0.26	0.52	POU16	-1.00	0.10	0.00	*(0.5)*	*(0.7)*
10	10	Rainwater	RW20	<1	-1.00	0.00	POU17	-1.00	0.10	0.00	*0.0*	*0.0*
11	25	Rainwater	RW21	<1	-1.00	0.00	POU18	1.69	48.43	57.28	*48.3*	*2.7*
12	124	Rainwater	RW22	105.08	2.02	123.04	POU19	1.93	85.03	46.01	*(20.1)*	*(0.1)*
13	40	Rainwater	RW4	1.88	0.27	2.98	POU2	-1.00	0.10	0.00	*(1.8)*	*(1.3)*
14	129	Rainwater	RW23	40.53	1.61	26.88	POU20	2.26	182.28	177.79	*141.8*	*0.7*
15	84	Rainwater	RW24	<1	-1.00	0.00	POU21	0.64	4.33	5.46	*4.2*	*1.6*
16	36	Rainwater	RW25	0.58	-0.24	0.95	POU22	1.03	10.78	12.33	*10.2*	*1.3*
17	93	Rainwater	RW6	2.60	0.41	2.44	POU3	2.81	644.13	186.43	*641.5*	*2.4*
19	33	Rainwater	RW26B	1.03	0.01	0.78	POU3B	-0.49	0.33	0.45	*(0.7)*	*(0.5)*
20	109	Rainwater	RW7	0.33	-0.49	0.45	POU4	1.56	36.05	41.58	*35.7*	*2.0*
21	97	Rainwater	RW2	<1	-1.00	0.00	POU4.1	-1.00	0.10	0.00	*0.0*	*0.0*
22	115	Rainwater	RW8	23.50	1.37	11.34	POU5	1.46	29.05	8.10	*5.6*	*0.1*
23	90	Rainwater	RW9	<1	-1.00	0.00	POU6	-1.00	0.10	0.00	*0.0*	*0.0*
24	37	Rainwater	RW3	1.50	0.18	0.58	POU6.1	0.47	2.95	3.57	*1.5*	*0.3*
25	55	Rainwater	RW11	21.93	1.34	21.59	POU8	1.63	42.43	3.33	*20.5*	*0.3*
26	54	Rainwater	RW12	<1	-1.00	0.00	POU9	-1.00	0.10	0.00	*0.0*	*0.0*

27	72	Rainwater	RW10/POU7	8.03	0.90	8.10	RW10/POU7	0.90	8.03	8.10	*0.0*	*0.0*
28	34 & 47	Borehole	MB1	<1	-1.00	0.00	POU2.1	-0.26	0.55	0.52	*0.5*	*0.7*
29	127	Bottled water	-				BW1	0.57	3.75	4.38		
30	107	Bottled water	-				BW3	0.26	1.83	2.04		
31	39	Bottled water	-				BW4	-0.10	0.80	0.91		
32	14	Bottled water	-				BW5	0.01	1.03	0.78		
33	114	Bottled water	-				BW6	-0.49	0.33	0.45		
34	70	Bottled water	-				BW7	-1.00	0.10	0.00		
35	125	Bottled water	-				BW8	-1.00	0.10	0.00		
36	98	Bottled water	-				BW9	0.38	2.38	2.67		
37	117	Bottled water	-				TGH	-1.00	0.10	0.00		
38	69	Bottled water	-				TGH	-1.00	0.10	0.00		

Table F.4 – Water quality data in Thailand – first period

No	House number	WATER SOURCE					POU					Difference POU-Source	
		Type	Code	1st period			Code	1st period				1st period	
				Log Mean	MEAN	STD		Log Mean	MEAN	STD	Turbidity (NTU)	Mean MPN/100 ml	Diff log mean
1	135	Rainwater	RW1	-1,0	<1	0,6	POU1	-1,0	<1	0,6	*0,8*	*0,0*	*0,0*
2	54	Rainwater	RW2	-1,0	<1	0,6	POU2	0,4	2,55	1,6	*0,4*	*2,5*	*1,4*
3	56	Rainwater	RW3	-1,0	<1	0,6	POU3	-1,0	<1	0,6	*0,4*	*0,0*	*0,0*
4	58	Rainwater	RW4	-0,3	0,55	0,6	POU4	-1,0	<1	0,6	*0,4*	*(0,5)*	*(0,7)*
5	68	Rainwater	RW5	-0,3	0,55	0,6	POU5	-0,3	0,55	1,0	*0,5*	*0,0*	*0,0*
6	3	Rainwater	RW6	2,0	107,9	52,1	POU6	0,5	3,05	1,8	*0,6*	*(104,9)*	*(1,5)*
7	69	Rainwater	RW7	-1,0	<1	0,6	POU7	-0,3	0,55	1,0	*0,6*	*0,5*	*0,7*
8	206	Rainwater	RW8	-1,0	<1	0,6	POU8	-1,0	<1	0,6	*0,6*	*0,0*	*0,0*
9	176	Rainwater	RW9	-1,0	<1	0,6	POU9	-1,0	<1	0,6	*0,2*	*0,0*	*0,0*
10	203	Rainwater	RW10	-1,0	<1	0,6	POU10	-1,0	<1	0,6	*0,5*	*0,0*	*0,0*
11	210	Rainwater	RW11	-1,0	<1	0,6	POU11	0,2	1,5	1,0	*0,3*	*1,4*	*1,2*
12	17	Rainwater	RW12	-1,0	<1	0,6	POU12	-1,0	<1	0,6	*0,6*	*0,0*	*0,0*
13	213	Rainwater	RW13	-0,3	0,55	0,6	POU13	0,8	5,75	4,0	*0,4*	*5,2*	*1,0*
14	235	Rainwater	RW14	1,4	23,3	12,6	POU14	0,2	1,5	0,7	*0,6*	*(21,8)*	*(1,2)*
15	116	Rainwater	RW15	-1,0	<1	0,6	POU15	-1,0	<1	0,6	*0,4*	*0,0*	*0,0*
16	66	Rainwater	RW16	0,5	3,1	1,3	POU16	-1,0	<1	0,6	*0,7*	*(3,0)*	*(1,5)*
17	199	Rainwater	RW17	-1,0	<1	0,6	POU17	-1,0	<1	0,6	*0,7*	*0,0*	*0,0*
18	39	Rainwater	RW18	-1,0	<1	0,6	POU18	-1,0	<1	0,6	*0,4*	*0,0*	*0,0*
19	38	Rainwater	RW19	-1,0	<1	0,6	POU19	0,2	1,5	0,7	*0,4*	*1,4*	*1,2*
20	188	Rainwater	RW20	-1,0	<1	0,6	POU20	-1,0	<1	0,6	*2,1*	*0,0*	*0,0*
21	156	Rainwater	RW21	0,2	1,5	1,0	POU21	0,9	8,15	4,8	*0,6*	*6,7*	*0,7*
22	233	Rainwater	RW22	-1,0	<1	0,6	POU22	-1,0	<1	0,6	*0,6*	*0,0*	*0,0*
23	211	Rainwater	RW23	0,0	1	0,5	POU23	-1,0	<1	0,6	*0,7*	*(0,9)*	*(1,0)*
24	41	Rainwater	RW24	0,7	4,65	1,9	POU24	-1,0	<1	0,6	*0,9*	*(4,6)*	*(1,7)*
25	20	Rainwater	RW25	-0,3	0,55	1,0	POU25	1,7	46,8	22,2	*0,8*	*46,3*	*1,9*
26	200	Rainwater	RW26	-1,0	<1	0,6	POU26	-1,0	<1	0,6	*0,8*	*0,0*	*0,0*
27	2	Rainwater	RW27	0,2	1,5	1,0	POU27	-1,0	<1	0,6	*0,6*	*(1,4)*	*(1,2)*
28	43	Rainwater	RW28	-0,3	0,55	1,0	POU28	-1,0	<1	0,6	*0,9*	*(0,5)*	*(0,7)*
29	174	Rainwater	RW29	-1,0	<1	0,6	POU29	-1,0	<1	0,6	*0,7*	*0,0*	*0,0*
30	130	Rainwater	RW30	-1,0	<1	0,6	POU30	-1,0	<1	0,6	*0,7*	*0,0*	*0,0*
31	53B	Bottled water	-	-	-	-	BW1	0,0	1,05	1,0	*0,6*	-	-
32	30	Bottled water	-	-	-	-	BW2	-0,3	0,55	0,6	*0,4*	-	-
33	197	Bottled water	-	-	-	-	BW3	-1,0	<1	0,6	*0,3*	-	-

Table F.5 – Water quality data in Thailand – second period

No	House number	WATER SOURCE					POU			Difference POU-Source	
		Type	Code	2nd period			2nd period			2nd period	
				Log Mean	MEAN	STD	Log Mean	MEAN	STD	Mean MPN/100 ml	Diff log mean
1	135	Rainwater	RW1	-0,3	0,55	1,0	-1,0	<1	0,6	*(0,5)*	*(0,7)*
2	54	Rainwater	RW2	-1,0	<1	0,6	-0,3	0,55	1,0	*0,5*	*0,7*
3	56	Rainwater	RW3	-1,0	<1	0,6	1,5	32,35	17,7	*32,3*	*2,5*
4	58	Rainwater	RW4	-1,0	<1	0,6	0,0	1	0,5	*0,9*	*1,0*

5	68	Rainwater	RW5	-1,0	<1	0,6	1,2	17,7	8,1	*17,6*	*2,2*
6	3	Rainwater	RW6	1,5	31,3	15,8	1,9	72,65	34,9	*41,4*	*0,4*
7	69	Rainwater	RW7	-1,0	<1	0,6	-0,3	0,55	1,0	*0,5*	*0,7*
8	206	Rainwater	RW8	-1,0	<1	0,6	1,1	13,85	6,3	*13,8*	*2,1*
9	176	Rainwater	RW9	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
10	203	Rainwater	RW10	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
11	210	Rainwater	RW11	-1,0	<1	0,6	0,7	5,2	2,7	*5,1*	*1,7*
12	17	Rainwater	RW12	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
13	213	Rainwater	RW13	-0,3	0,55	0,6	-1,0	<1	0,6	*(0,5)*	*(0,7)*
14	235	Rainwater	RW14	2,0	94,95	48,1	1,9	84,55	45,7	*(10,4)*	*(0,1)*
15	116	Rainwater	RW15	0,9	7,95	3,7	2,5	302,55	148,4	*294,6*	*1,6*
16	66	Rainwater	RW16	0,3	2	0,8	2,9	739,75	407,5	*737,8*	*2,6*
17	199	Rainwater	RW17	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
18	39	Rainwater	RW18	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
19	38	Rainwater	RW19	-1,0	<1	0,6	0,3	2,05	1,2	*2,0*	*1,3*
20	188	Rainwater	RW20	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
21	156	Rainwater	RW21	-0,3	0,55	0,6	-1,0	<1	0,6	*(0,5)*	*(0,7)*
22	233	Rainwater	RW22	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
23	211	Rainwater	RW23	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
24	41	Rainwater	RW24	1,0	10,35	5,9	-1,0	<1	0,6	*(10,3)*	*(2,0)*
25	20	Rainwater	RW25	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
26	200	Rainwater	RW26	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
27	2	Rainwater	RW27	0,8	6,25	3,1	-1,0	<1	0,6	*(6,2)*	*(1,8)*
28	43	Rainwater	RW28	-0,3	0,55	0,6	-0,3	0,55	0,6	*0,0*	*0,0*
29	174	Rainwater	RW29	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
30	130	Rainwater	RW30	-1,0	<1	0,6	-1,0	<1	0,6	*0,0*	*0,0*
31	53B	Bottled water	-	-	-	-	-1,0	<1	0,6	-	-
32	30	Bottled water	-	-	-	-	-0,3	0,55	0,6	-	-
33	197	Bottled water	-	-	-	-	-1,0	<1	0,6	-	-

Table F.6 – Water quality data in Thailand – averaged counts

No	House number	WATER SOURCE					POU			Difference POU-Source	
		Type	Code	Whole period			Whole period			Whole period	
				Log mean	MEAN	STD	Log mean	MEAN	STD	Mean MPN/100 ml	Diff log mean
1	135	Rainwater	RW1	-0,6	0,325	0,5	-1,0	<1	0,0	*(0)*	*(0,4)*
2	54	Rainwater	RW2	-1,0	<1	0,0	0,1	1,55	1,8	*1*	*1,1*
3	56	Rainwater	RW3	-1,0	<1	0,0	0,3	16,225	21,2	*16*	*1,3*
4	58	Rainwater	RW4	-0,6	0,325	0,5	-0,5	0,55	0,5	*0*	*0,1*
5	68	Rainwater	RW5	-0,6	0,325	0,5	0,5	9,125	9,9	*9*	*1,1*
6	3	Rainwater	RW6	1,8	69,6	45,4	1,2	37,85	40,4	*(32)*	*(0,6)*
7	69	Rainwater	RW7	-1,0	<1	0,0	-0,3	0,55	0,5	*0*	*0,7*
8	206	Rainwater	RW8	-1,0	<1	0,0	0,1	6,975	8,0	*7*	*1,1*
9	176	Rainwater	RW9	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
10	203	Rainwater	RW10	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
11	210	Rainwater	RW11	-1,0	<1	0,0	0,4	3,35	2,4	*3*	*1,4*
12	17	Rainwater	RW12	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
13	213	Rainwater	RW13	-0,3	0,55	0,5	-0,1	2,925	3,9	*2*	*0,1*
14	235	Rainwater	RW14	1,7	59,125	41,9	1,1	43,025	49,3	*(16)*	*(0,6)*
15	116	Rainwater	RW15	0,0	4,025	4,6	0,7	151,325	178,0	*147*	*0,8*
16	66	Rainwater	RW16	0,4	2,55	0,6	0,9	369,925	439,4	*367*	*0,5*
17	199	Rainwater	RW17	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
18	39	Rainwater	RW18	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
19	38	Rainwater	RW19	-1,0	<1	0,0	0,2	1,775	1,0	*2*	*1,2*
20	188	Rainwater	RW20	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
21	156	Rainwater	RW21	0,0	1,025	0,8	0,0	4,125	5,7	*3*	*(0,0)*
22	233	Rainwater	RW22	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
23	211	Rainwater	RW23	-0,5	0,55	0,5	-1,0	<1	0,0	*(0)*	*(0,5)*
24	41	Rainwater	RW24	0,8	7,5	4,1	-1,0	<1	0,0	*(7)*	*(1,8)*
25	20	Rainwater	RW25	-0,6	0,325	0,5	0,3	23,45	27,1	*23*	*1,0*
26	200	Rainwater	RW26	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*

27	2	Rainwater	RW27	0,5	3,875	3,3	-1,0	<1	0,0	*(4)*	*(1,5)*
28	43	Rainwater	RW28	-0,3	0,55	0,5	-0,6	0,325	0,5	*(0)*	*(0,4)*
29	174	Rainwater	RW29	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
30	130	Rainwater	RW30	-1,0	<1	0,0	-1,0	<1	0,0	*0*	*0,0*
31	53B	Bottled water	-	-	-		-0,5	0,575	1,0	-	-
32	30	Bottled water	-	-	-		-0,3	0,55	0,5	-	-
33	197	Bottled water	-	-	-		-1,0	<1	0,0	-	-

Annex G Wilcoxon tests for observed differences between sources and points of consumption – combined datasets

Table G.1 – Wilcoxon tests for observed differences between sources and POUs for combined datasets

	Number	Difference	Absolute	Rank	Signed Rank
8	37	-0.95	0.950	18.5	-18.5
12	23	-1	1.000	20.5	-20.5
13	56	1	1.000	20.5	20.5
14	24	1.019305155	1.019	22	22
15	57	1.176091259	1.176	24	24
16	25	1.176091259	1.176	24	24
17	58	-1.176091259	1.176	24	-24
18	26	-1.191264662	1.191	26	-26
19	59	1.311753861	1.312	27	27
9	5	-1.4	1.400	28	-28
20	27	1.40654018	1.407	29	29
21	60	-1.491361694	1.491	30	-30
22	28	-1.548721605	1.549	31	-31
23	61	1.580430029	1.580	32	32
24	29	-1.667452953	1.667	33	-33
25	62	1.716003344	1.716	34	34
26	30	-1.795880017	1.796	35	-35
27	63	1.929883164	1.930	36	36
10	6	2	2.000	37	37
28	31	-2.01494035	2.015	38	-38
11	38	2.1	2.100	39	39
29	64	2.141449773	2.141	40	40
30	32	2.247973266	2.248	41	41
31	65	2.509874285	2.510	42	42
12	39	2.55	2.550	43	43
32	33	2.568054978	2.568	44	44
13	7	3	3.000	45	45
14	8	-3.55	3.550	46	-46
15	40	4.3	4.300	47	47
16	41	4.8	4.800	48	48
17	9	-5.65	5.650	49	-49
18	42	6.3	6.300	50	50
19	10	8	8.000	51	51
20	43	-11.85	11.850	52	-52
21	11	-12.2	12.200	53	-53
22	44	21.35	21.350	54	54
23	12	22.6	22.600	55	55
24	45	38	38.000	56	56
25	13	45.6	45.600	57	57
26	46	71.45	71.450	58	58
27	14	-85.7	85.700	59	-59
28	47	96.65	96.650	60	60
29	15	-147.9	147.900	61	-61
30	48	260.9	260.900	62	62
31	16	494.45	494.450	63	63
32	49	788.6	788.600	64	64
33	17	2419.5	2419.500	65	65

Annex H Spearman's tests for correlating hazard scores with water quality

Table H.1 Spearman's test for water source scores and microbial quality of source samples – Laos

		1st period		2nd period		Whole period		Hazard assessment	Likelihood	1st period			2nd period			Whole period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean			Ry - Source	d=Rx-Ry	d^2	Ry - Source	d=Rx-Ry	d^2	Ry - Source	d=Rx-Ry	d^2
21	RW4	3.65	21.5	0.1	6.5	1.88	17.5	75%	Poor	21	0.5	0.25	20	-13.5	182.25	21	-3.5	12.25
108	RW1	0.55	15.5	11.95	21	6.25	20	71%	Poor	13.5	2	4	12.5	8.5	72.25	13.5	6.5	42.25
57	RW13	240.05	26	5.75	20	122.90	26	74%	Poor	19	7	49	18	2	4	19	7	49
81	RW14	1.05	18	12.3	22	6.68	21	77%	Poor	22.5	-4.5	20.25	21.5	0.5	0.25	22.5	-1.5	2.25
92	RW15	0.1	7.5	0.55	13.5	0.33	11.5	34%	Good	1	6.5	42.25	1	12.5	156.25	1	10.5	110.25
89	RW16	0.1	7.5	0.1	6.5	0.10	5.5	54%	Fair	3	4.5	20.25	3	3.5	12.25	3	2.5	6.25
19	RW17	0.1	7.5	0.1	6.5	0.10	5.5	68%	Poor	9.5	-2	4	9	-2.5	6.25	9.5	-4	16
9	RW18	0.1	7.5	-	-	0.10	5.5	68%	Poor	9.5	-2	4	-	-	-	9.5	-4	16
112	RW19	0.1	7.5	1	15	0.55	13	68%	Poor	9.5	-2	4	9	6	36	9.5	3.5	12.25
10	RW20	0.1	7.5	0.1	6.5	0.10	5.5	73%	Poor	16	-8.5	72.25	15	-8.5	72.25	16	-10.5	110.25
25	RW21	0.1	7.5	0.1	6.5	0.10	5.5	73%	Poor	16	-8.5	72.25	15	-8.5	72.25	16	-10.5	110.25
124	RW22	210.05	25	0.1	6.5	105.08	25	68%	Poor	9.5	15.5	240.25	9	-2.5	6.25	9.5	15.5	240.25
40	RW4	3.65	21.5	0.1	6.5	1.88	17.5	68%	Poor	9.5	12	144	9	-2.5	6.25	9.5	8	64
129	RW23	62.35	24	18.7	24	40.53	24	79%	Poor	24	0	0	23	1	1	24	0	0
84	RW24	0.1	7.5	0.1	6.5	0.10	5.5	74%	Poor	19	-11.5	132.25	18	-11.5	132.25	19	-13.5	182.25
36	RW25	0.1	7.5	1.05	16.5	0.58	14	74%	Poor	19	-11.5	132.25	18	-1.5	2.25	19	-5	25
93	RW6	0.55	15.5	4.65	19	2.60	19	89%	Very poor	26	-10.5	110.25	25	-6	36	26	-7	49
33	RW26B	1	17	1.05	16.5	1.03	15	73%	Poor	16	1	1	15	1.5	2.25	16	-1	1
109	RW7	0.1	7.5	0.55	13.5	0.33	11.5	67%	Poor	6	1.5	2.25	6	7.5	56.25	6	5.5	30.25
97	RW2	0.1	7.5	0.1	6.5	0.10	5.5	68%	Poor	9.5	-2	4	9	-2.5	6.25	9.5	-4	16
115	RW8	29.65	23	17.35	23	23.50	23	64%	Fair	5	18	324	5	18	324	5	18	324
90	RW9	0.1	7.5	0.1	6.5	0.10	5.5	46%	Good	2	5.5	30.25	2	4.5	20.25	2	3.5	12.25
37	RW3	1.5	19	1.5	18	1.50	16	71%	Poor	13.5	5.5	30.25	12.5	5.5	30.25	13.5	2.5	6.25
55	RW11	3.6	20	40.25	25	21.93	22	88%	Very poor	25	-5	25	24	1	1	25	-3	9

54	RW12	0.1	7.5	0.1	6.5	0.10	5.5	77%	Poor	22.5	-15	225	21.5	-15	225	22.5	-17	289
34 & 47	MB1	0.1	7.5	0.1	6.5	0.10	5.5	60%	Fair	4	3.5	12.25	4	2.5	6.25	4	1.5	2.25
											0	*1705.5*		*0*	*1469.5*		*0*	*1737.5*

Table H.2 Spearman's test for sanitation scores and microbial quality of POU samples - Laos

		1st period		2nd period		Whole period		Sanitation assessment		1st period			2nd period			Whole period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean	Score	Class	Ry - sanitation	d=Rx-Ry	d^2	Ry - sanitation	d=Rx-Ry	d^2	Ry - sanitation	d=Rx-Ry	d^2
21	POU1	5.75	25	2419.6	37	1212.68	37	12	Very poor	25.5	-0.5	0.25	25.5	11.5	132.25	25.5	11.5	132.25
108	POU1.1	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
57	POU10	92.15	33	0.1	12	46.13	32	12	Very poor	25.5	7.5	56.25	25.5	-13.5	182.25	25.5	6.5	42.25
81	POU11	0.55	19	0.1	12	0.33	16	12	Very poor	25.5	-6.5	42.25	25.5	-13.5	182.25	25.5	-9.5	90.25
92	POU12	2.1	23	3.1	29	2.60	23	12	Very poor	25.5	-2.5	6.25	25.5	3.5	12.25	25.5	-2.5	6.25
89	POU13	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
19	POU14	0.1	9	0.1	12	0.10	7.5	9	Fair	6.5	2.5	6.25	6.5	5.5	30.25	6.5	1	1
9	POU15	0.1	9	0.1	12	0.10	7.5	11	Poor	12	-3	9	12	0	0	12	-4.5	20.25
112	POU16	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
10	POU17	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
25	POU18	96.75	34	0.1	12	48.43	33	10	Fair	9.5	24.5	600.25	9.5	2.5	6.25	9.5	23.5	552.25
124	POU19	124.35	35	45.7	34	85.03	34	12	Very poor	25.5	9.5	90.25	25.5	8.5	72.25	25.5	8.5	72.25
40	POU2	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
129	POU20	323.25	36	41.3	32	182.28	35	12	Very poor	25.5	10.5	110.25	25.5	6.5	42.25	25.5	9.5	90.25
84	POU21	8.1	28	0.55	25	4.33	26	12	Very poor	25.5	2.5	6.25	25.5	-0.5	0.25	25.5	0.5	0.25
36	POU22	21.45	30	0.1	12	10.78	28	12	Very poor	25.5	4.5	20.25	25.5	-13.5	182.25	25.5	2.5	6.25
93	POU3	495	37	793.25	36	644.13	36	12	Very poor	25.5	11.5	132.25	25.5	10.5	110.25	25.5	10.5	110.25
33	POU3B	0.55	19	0.1	12	0.33	16	12	Very poor	25.5	-6.5	42.25	25.5	-13.5	182.25	25.5	-9.5	90.25
109	POU4	0.1	9	72	35	36.05	30	12	Very poor	25.5	-16.5	272.25	25.5	9.5	90.25	25.5	4.5	20.25
97	POU4.1	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324

115	POU5	35.95	31	22.15	31	29.05	29	12	Very poor	25.5	5.5	30.25	25.5	5.5	30.25	25.5	3.5	12.25
90	POU6	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
37	POU6.1	5.8	26	0.1	12	2.95	24	9	Fair	6.5	19.5	380.25	6.5	5.5	30.25	6.5	17.5	306.25
55	POU8	41.6	32	43.25	33	42.43	31	12	Very poor	25.5	6.5	42.25	25.5	7.5	56.25	25.5	5.5	30.25
54	POU9	0.1	9	0.1	12	0.10	7.5	6	Good	2	7	49	2	10	100	2	5.5	30.25
34 & 47	POU2.1	0.1	9	1	27	0.55	18	7	Fair	3.5	5.5	30.25	3.5	23.5	552.25	3.5	14.5	210.25
72	RW10/POU7	15	29	1.05	28	8.03	27	12	Very poor	25.5	3.5	12.25	25.5	2.5	6.25	25.5	1.5	2.25
127	BW1	6.95	27	0.55	25	3.75	25	7	Fair	3.5	23.5	552.25	3.5	21.5	462.25	3.5	21.5	462.25
107	BW3	3.55	24	0.1	12	1.83	21	12	Very poor	25.5	-1.5	2.25	25.5	-13.5	182.25	25.5	-4.5	20.25
39	BW4	1.5	21.5	0.1	12	0.80	19	12	Very poor	25.5	-4	16	25.5	-13.5	182.25	25.5	-6.5	42.25
14	BW5	1.5	21.5	0.55	25	1.03	20	5	Good	1	20.5	420.25	1	24	576	1	19	361
114	BW6	0.55	19	0.1	12	0.33	16	10	Fair	9.5	9.5	90.25	9.5	2.5	6.25	9.5	6.5	42.25
70	BW7	0.1	9	0.1	12	0.10	7.5	9	Fair	6.5	2.5	6.25	6.5	5.5	30.25	6.5	1	1
125	BW8	0.1	9	0.1	12	0.10	7.5	9	Fair	6.5	2.5	6.25	6.5	5.5	30.25	6.5	1	1
98	BW9	0.1	9	4.65	30	2.38	22	11	Poor	12	-3	9	12	18	324	12	10	100
117	TGH	0.1	9	0.1	12	0.10	7.5	12	Very poor	25.5	-16.5	272.25	25.5	-13.5	182.25	25.5	-18	324
69	TGH	0.1	9	0.1	12	0.10	7.5	11	Poor	12	-3	9	12	0	0	12	-4.5	20.25

Table H.3 Spearman's test for hygiene scores and microbial quality of POU samples – Laos

		1st period		2nd period		Whole period		Hygiene assessment		1st period			2nd period			1st period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean	Score	Class	Ry - hygiene	d=Rx-Ry	d^2	Ry - hygiene	d=Rx-Ry	d^2	Ry - hygiene	d=Rx-Ry	d^2
21	POU1	5.75	25	2419.6	37	1212.68	37	4	Fair	18	7	49	18	19	361	18	19	361
108	POU1.1	0.1	9	0.1	12	0.10	7.5	4	Fair	18	-9	81	18	-6	36	18	-10.5	110.25
57	POU10	92.15	33	0.1	12	46.13	32	4	Fair	18	15	225	18	-6	36	18	14	196
81	POU11	0.55	19	0.1	12	0.33	16	6	Poor	30	-11	121	30	-18	324	30	-14	196
92	POU12	2.1	23	3.1	29	2.60	23	6	Poor	30	-7	49	30	-1	1	30	-7	49
89	POU13	0.1	9	0.1	12	0.10	7.5	6	Poor	30	-21	441	30	-18	324	30	-22.5	506.25
19	POU14	0.1	9	0.1	12	0.10	7.5	2	Good	9	0	0	9	3	9	9	-1.5	2.25
9	POU15	0.1	9	0.1	12	0.10	7.5	4	Fair	18	-9	81	18	-6	36	18	-10.5	110.25

112	POU16	0.1	9	0.1	12	0.10	7.5	4	Fair	18	-9	81	18	-6	36	18	-10.5	110.25
10	POU17	0.1	9	0.1	12	0.10	7.5	6	Poor	30	-21	441	30	-18	324	30	-22.5	506.25
25	POU18	96.75	34	0.1	12	48.43	33	1	Very good	4	30	900	4	8	64	4	29	841
124	POU19	124.35	35	45.7	34	85.03	34	4	Fair	18	17	289	18	16	256	18	16	256
40	POU2	0.1	9	0.1	12	0.10	7.5	4	Fair	18	-9	81	18	-6	36	18	-10.5	110.25
129	POU20	323.25	36	41.3	32	182.28	35	4	Fair	18	18	324	18	14	196	18	17	289
84	POU21	8.1	28	0.55	25	4.33	26	6	Poor	30	-2	4	30	-5	25	30	-4	16
36	POU22	21.45	30	0.1	12	10.78	28	7	Poor	37	-7	49	37	-25	625	37	-9	81
93	POU3	495	37	793.25	36	644.13	36	6	Poor	30	7	49	30	6	36	30	6	36
33	POU3B	0.55	19	0.1	12	0.33	16	4	Fair	18	1	1	18	-6	36	18	-2	4
109	POU4	0.1	9	72	35	36.05	30	4	Fair	18	-9	81	18	17	289	18	12	144
97	POU4.1	0.1	9	0.1	12	0.10	7.5	6	Poor	30	-21	441	30	-18	324	30	-22.5	506.25
115	POU5	35.95	31	22.15	31	29.05	29	6	Poor	30	1	1	30	1	1	30	-1	1
90	POU6	0.1	9	0.1	12	0.10	7.5	6	Poor	30	-21	441	30	-18	324	30	-22.5	506.25
37	POU6.1	5.8	26	0.1	12	2.95	24	2	Good	9	17	289	9	3	9	9	15	225
55	POU8	41.6	32	43.25	33	42.43	31	6	Poor	30	2	4	30	3	9	30	1	1
54	POU9	0.1	9	0.1	12	0.10	7.5	2	Good	9	0	0	9	3	9	9	-1.5	2.25
34 & 47	POU2.1	0.1	9	1	27	0.55	18	0	Very good	1.5	7.5	56.25	1.5	25.5	650.25	1.5	16.5	272.25
72	RW10/POU7	15	29	1.05	28	8.03	27	6	Poor	30	-1	1	30	-2	4	30	-3	9
127	BW1	6.95	27	0.55	25	3.75	25	2	Good	9	18	324	9	16	256	9	16	256
107	BW3	3.55	24	0.1	12	1.83	21	4	Fair	18	6	36	18	-6	36	18	3	9
39	BW4	1.5	21.5	0.1	12	0.80	19	6	Poor	30	-8.5	72.25	30	-18	324	30	-11	121
14	BW5	1.5	21.5	0.55	25	1.03	20	1	Very good	4	17.5	306.25	4	21	441	4	16	256
114	BW6	0.55	19	0.1	12	0.33	16	1	Very good	4	15	225	4	8	64	4	12	144
70	BW7	0.1	9	0.1	12	0.10	7.5	2	Good	9	0	0	9	3	9	9	-1.5	2.25
125	BW8	0.1	9	0.1	12	0.10	7.5	2	Good	9	0	0	9	3	9	9	-1.5	2.25
98	BW9	0.1	9	4.65	30	2.38	22	0	Very good	1.5	7.5	56.25	1.5	28.5	812.25	1.5	20.5	420.25
117	TGH	0.1	9	0.1	12	0.10	7.5	6	Poor	30	-21	441	30	-18	324	30	-22.5	506.25
69	TGH	0.1	9	0.1	12	0.10	7.5	2	Good	9	0	0	9	3	9	9	-1.5	2.25

Table H.4 Spearman's test for water source scores and microbial quality of source samples – Thailand

		1st period		2nd period		Whole period		Hazard assessment	Likelihood	1st period			2nd period			Whole period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean			Ry - Source	d=Rx-Ry	d^2	Ry - Source	d=Rx-Ry	d^2	Ry - Source	d=Rx-Ry	d^2
135	RW1	0.1	9.5	0.55	22.5	0.33	18.5	48%	Fair	9.5	0	0	9.5	13	169	9.5	9	81
54	RW2	0.1	9.5	0.1	10.5	0.10	8.5	40%	Good	3	6.5	42.25	3	7.5	56.25	3	5.5	30.25
56	RW3	0.1	9.5	0.1	10.5	0.10	8.5	63%	Fair	19.5	-10	100	19.5	-9	81	19.5	-11	121
58	RW4	0.55	21	0.1	10.5	0.33	18.5	48%	Fair	9.5	11.5	132.25	9.5	1	1	9.5	9	81
68	RW5	0.55	21	0.1	10.5	0.33	18.5	51%	Fair	12	9	81	12	-1.5	2.25	12	6.5	42.25
3	RW6	107.9	30	31.3	29	69.60	30	38%	Good	1	29	841	1	28	784	1	29	841
69	RW7	0.1	9.5	0.1	10.5	0.10	8.5	63%	Fair	21.5	-12	144	21.5	-11	121	21.5	-13	169
206	RW8	0.1	9.5	0.1	10.5	0.10	8.5	48%	Fair	9.5	0	0	9.5	1	1	9.5	-1	1
176	RW9	0.1	9.5	0.1	10.5	0.10	8.5	63%	Fair	21.5	-12	144	21.5	-11	121	21.5	-13	169
203	RW10	0.1	9.5	0.1	10.5	0.10	8.5	45%	Good	6	3.5	12.25	6	4.5	20.25	6	2.5	6.25
210	RW11	0.1	9.5	0.1	10.5	0.10	8.5	65%	Fair	25	-15.5	240.25	25	-14.5	210.25	25	-16.5	272.25
17	RW12	0.1	9.5	0.1	10.5	0.10	8.5	65%	Fair	25	-15.5	240.25	25	-14.5	210.25	25	-16.5	272.25
213	RW13	0.55	21	0.55	22.5	0.55	22	61%	Fair	17	4	16	17	5.5	30.25	17	5	25
235	RW14	23.3	29	94.95	30	59.13	29	67%	Poor	28.5	0.5	0.25	28.5	1.5	2.25	28.5	0.5	0.25
116	RW15	0.1	9.5	7.95	27	4.03	27	58%	Fair	15	-5.5	30.25	15	12	144	15	12	144
66	RW16	3.1	27	2	25	2.55	25	40%	Good	3	24	576	3	22	484	3	22	484
199	RW17	0.1	9.5	0.1	10.5	0.10	8.5	52%	Fair	13	-3.5	12.25	13	-2.5	6.25	13	-4.5	20.25
39	RW18	0.1	9.5	0.1	10.5	0.10	8.5	65%	Fair	25	-15.5	240.25	25	-14.5	210.25	25	-16.5	272.25
38	RW19	0.1	9.5	0.1	10.5	0.10	8.5	63%	Fair	19.5	-10	100	19.5	-9	81	19.5	-11	121
188	RW20	0.1	9.5	0.1	10.5	0.10	8.5	65%	Fair	25	-15.5	240.25	25	-14.5	210.25	25	-16.5	272.25
156	RW21	1.5	25.5	0.55	22.5	1.03	24	71%	Poor	30	-4.5	20.25	30	-7.5	56.25	30	-6	36
233	RW22	0.1	9.5	0.1	10.5	0.10	8.5	61%	Fair	17	-7.5	56.25	17	-6.5	42.25	17	-8.5	72.25
211	RW23	1	24	0.1	10.5	0.55	22	40%	Good	3	21	441	3	7.5	56.25	3	19	361
41	RW24	4.65	28	10.35	28	7.50	28	65%	Fair	25	3	9	25	3	9	25	3	9
20	RW25	0.55	21	0.1	10.5	0.33	18.5	42%	Good	5	16	256	5	5.5	30.25	5	13.5	182.25
200	RW26	0.1	9.5	0.1	10.5	0.10	8.5	46%	Good	7	2.5	6.25	7	3.5	12.25	7	1.5	2.25

2	RW27	1.5	25.5	6.25	26	3.88	26	57%	Fair	14	11.5	132.25	14	12	144	14	12	144
43	RW28	0.55	21	0.55	22.5	0.55	22	67%	Poor	28.5	-7.5	56.25	28.5	-6	36	28.5	-6.5	42.25
174	RW29	0.1	9.5	0.1	10.5	0.10	8.5	61%	Fair	17	-7.5	56.25	17	-6.5	42.25	17	-8.5	72.25
130	RW30	0.1	9.5	0.1	10.5	0.10	8.5	48%	Fair	9.5	0	0	9.5	1	1	9.5	-1	1

Table H.5 Spearman's test for sanitation scores and microbial quality of POU samples – Thailand

		1st period		2nd period		Whole period		Sanitation assessment		1st period			2nd period			Whole period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean	Score	Class	Ry - sanitation	d=Rx-Ry	d^2	Ry - sanitation	d=Rx-Ry	d^2	Ry - sanitation	d=Rx-Ry	d^2
135	POU1	0.1	11	0.1	10	0.10	8	4	Good	16	-5	25	16	-6	36	16	-8	64
54	POU2	2.55	29	0.55	21.5	1.55	21	6	Good	28.5	0.5	0.25	28.5	-7	49	28.5	-7.5	56.25
56	POU3	0.1	11	32.35	29	16.23	28	6	Good	28.5	-17.5	306.25	28.5	0.5	0.25	28.5	-0.5	0.25
58	POU4	0.1	11	1	24	0.55	18	4	Good	16	-5	25	16	8	64	16	2	4
68	POU5	0.55	23	17.7	28	9.13	27	6	Good	28.5	-5.5	30.25	28.5	-0.5	0.25	28.5	-1.5	2.25
3	POU6	3.05	30	72.65	30	37.85	30	3	Good	8.5	21.5	462.25	8.5	21.5	462.25	8.5	21.5	462.25
69	POU7	0.55	23	0.55	21.5	0.55	18	3	Good	8.5	14.5	210.25	8.5	13	169	8.5	9.5	90.25
206	POU8	0.1	11	13.85	27	6.98	26	6	Good	28.5	-17.5	306.25	28.5	-1.5	2.25	28.5	-2.5	6.25
176	POU9	0.1	11	0.1	10	0.10	8	4	Good	16	-5	25	16	-6	36	16	-8	64
203	POU10	0.1	11	0.1	10	0.10	8	3	Good	8.5	2.5	6.25	8.5	1.5	2.25	8.5	-0.5	0.25
210	POU11	1.5	27	5.2	26	3.35	24	3	Good	8.5	18.5	342.25	8.5	17.5	306.25	8.5	15.5	240.25
17	POU12	0.1	11	0.1	10	0.10	8	3	Good	8.5	2.5	6.25	8.5	1.5	2.25	8.5	-0.5	0.25
213	POU13	5.75	31	0.1	10	2.93	23	4	Good	16	15	225	16	-6	36	16	7	49
235	POU14	1.5	27	84.55	31	43.03	31	5	Good	22	5	25	22	9	81	22	9	81
116	POU15	0.1	11	302.55	32	151.33	32	3	Good	8.5	2.5	6.25	8.5	23.5	552.25	8.5	23.5	552.25
66	POU16	0.1	11	739.75	33	369.93	33	1	Very good	1	10	100	1	32	1024	1	32	1024
199	POU17	0.1	11	0.1	10	0.10	8	3	Good	8.5	2.5	6.25	8.5	1.5	2.25	8.5	-0.5	0.25
39	POU18	0.1	11	0.1	10	0.10	8	5	Good	22	-11	121	22	-12	144	22	-14	196
38	POU19	1.5	27	2.05	25	1.78	22	7	Fair	33	-6	36	33	-8	64	33	-11	121

188	POU20	0.1	11	0.1	10	0.10	8	5	Good	22	-11	121	22	-12	144	22	-14	196
156	POU21	8.15	32	0.1	10	4.13	25	6	Good	28.5	3.5	12.25	28.5	-18.5	342.25	28.5	-3.5	12.25
233	POU22	0.1	11	0.1	10	0.10	8	5	Good	22	-11	121	22	-12	144	22	-14	196
211	POU23	0.1	11	0.1	10	0.10	8	2	Very good	3	8	64	3	7	49	3	5	25
41	POU24	0.1	11	0.1	10	0.10	8	5	Good	22	-11	121	22	-12	144	22	-14	196
20	POU25	46.8	33	0.1	10	23.45	29	6	Good	28.5	4.5	20.25	28.5	-18.5	342.25	28.5	0.5	0.25
200	POU26	0.1	11	0.1	10	0.10	8	4	Good	16	-5	25	16	-6	36	16	-8	64
2	POU27	0.1	11	0.1	10	0.10	8	2	Very good	3	8	64	3	7	49	3	5	25
43	POU28	0.1	11	0.55	21.5	0.33	16	4	Good	16	-5	25	16	5.5	30.25	16	0	0
174	POU29	0.1	11	0.1	10	0.10	8	4	Good	16	-5	25	16	-6	36	16	-8	64
130	POU30	0.1	11	0.1	10	0.10	8	2	Very good	3	8	64	3	7	49	3	5	25
53B	BW1	1.05	25	0.1	10	0.58	20	6	Good	28.5	-3.5	12.25	28.5	-18.5	342.25	28.5	-8.5	72.25
30	BW2	0.55	23	0.55	21.5	0.55	18	3	Good	8.5	14.5	210.25	8.5	13	169	8.5	9.5	90.25
197	BW3	0.1	11	0.1	10	0.10	8	6	Good	28.5	-17.5	306.25	28.5	-18.5	342.25	28.5	-20.5	420.25

Table H.6 Spearman's test for hygiene scores and microbial quality of POU samples – Thailand

		1st period		2nd period		Whole period		Hygiene assessment		1st period			2nd period			1st period		
House	Code	Mean"	Rx - mean	Mean"	Rx - mean	Mean"	Rx - mean	Score	Class	Ry - hygiene	d=Rx-Ry	d^2	Ry - hygiene	d=Rx-Ry	d^2	Ry - hygiene	d=Rx-Ry	d^2
135	POU1	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
54	POU2	2.55	29	0.55	21.5	1.55	21	1	Very good	16	13	169	16	5.5	30.25	16	5	25
56	POU3	0.1	11	32.35	29	16.23	28	1	Very good	16	-5	25	16	13	169	16	12	144
58	POU4	0.1	11	1	24	0.55	18	1	Very good	16	-5	25	16	8	64	16	2	4
68	POU5	0.55	23	17.7	28	9.13	27	1	Very good	16	7	49	16	12	144	16	11	121
3	POU6	3.05	30	72.65	30	37.85	30	1	Very good	16	14	196	16	14	196	16	14	196
69	POU7	0.55	23	0.55	21.5	0.55	18	1	Very good	16	7	49	16	5.5	30.25	16	2	4
206	POU8	0.1	11	13.85	27	6.98	26	1	Very good	16	-5	25	16	11	121	16	10	100
176	POU9	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
203	POU10	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
210	POU11	1.5	27	5.2	26	3.35	24	1	Very good	16	11	121	16	10	100	16	8	64

17	POU12	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
213	POU13	5.75	31	0.1	10	2.93	23	1	Very good	16	15	225	16	-6	36	16	7	49
235	POU14	1.5	27	84.55	31	43.03	31	1	Very good	16	11	121	16	15	225	16	15	225
116	POU15	0.1	11	302.55	32	151.33	32	1	Very good	16	-5	25	16	16	256	16	16	256
66	POU16	0.1	11	739.75	33	369.93	33	1	Very good	16	-5	25	16	17	289	16	17	289
199	POU17	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
39	POU18	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
38	POU19	1.5	27	2.05	25	1.78	22	1	Very good	16	11	121	16	9	81	16	6	36
188	POU20	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
156	POU21	8.15	32	0.1	10	4.13	25	1	Very good	16	16	256	16	-6	36	16	9	81
233	POU22	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
211	POU23	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
41	POU24	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
20	POU25	46.8	33	0.1	10	23.45	29	2	Good	32	1	1	32	-22	484	32	-3	9
200	POU26	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
2	POU27	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64
43	POU28	0.1	11	0.55	21.5	0.33	16	1	Very good	16	-5	25	16	5.5	30.25	16	0	0
174	POU29	0.1	11	0.1	10	0.10	8	2	Good	32	-21	441	32	-22	484	32	-24	576
130	POU30	0.1	11	0.1	10	0.10	8	2	Good	32	-21	441	32	-22	484	32	-24	576
53B	BW1	1.05	25	0.1	10	0.58	20	1	Very good	16	9	81	16	-6	36	16	4	16
30	BW2	0.55	23	0.55	21.5	0.55	18	0	Very good	1	22	484	1	20.5	420.25	1	17	289
197	BW3	0.1	11	0.1	10	0.10	8	1	Very good	16	-5	25	16	-6	36	16	-8	64

Annex I Raw data of microbial samples using IDEXX and CBT methods

Table I.1 Sample raw data Laos

Number	Sample code	Average CBT	Average IDEXX
1	ST1	>100	207.7
2	ST2	>100	348.5
3	ST3	>100	478.95
6	MB1	<0.1	<1
7	POU2.1	<0.1	<1
8	POU3A	<0.1	<1
10	PN1/1	>100	142.8
11	PN1/2	>100	332.65
13	RW2	<0.1	<1
15	POU4.1	<0.1	<1
22	RW5	<0.1	<1
23	POU2	<0.1	<1
24	POU3	>100	495
27	RW7	<0.1	<1
30	POU6	<0.1	<1
31	RW9	<0.1	<1
32	RW12	<0.1	<1
43	POU13	<0.1	<1
44	POU14	<0.1	<1
46	RW16	<0.1	<1
47	POU15	<0.1	<1
48	RW17	<0.1	<1
49	RW18	<0.1	<1
50	BW7	<0.1	<1
51	BW8	<0.1	<1
53	POU16	<0.1	<1
56	RW21	<0.1	<1
57	RW20	<0.1	<1
58	BW9	<0.1	<1
60	POU20	>100	323.25
61	POU19	>100	124.35
62	RW22	>100	210.05
64	RW24	<0.1	<1
66	RW25	<0.1	<1
67	TGH	<0.1	<1
68	CONTROL -	<0.1	<1
75	CONTROL +	>100	202
77	MB1	<0.1	<1
78	RW2	<0.1	<1
83	BW3	<0.1	<1
84	POU6	<0.1	<1
88	POU1.1	<0.1	<1
90	BW6	<0.1	<1
92	POU1	>100	>2419.6
95	RW5	<0.1	<1
96	HP1	<0.1	<1
97	POU3	>100	793.25
98	RW9	<0.1	<1
100	POU6	<0.1	<1
108	RW12	<0.1	<1
110	POU13	<0.1	<1
112	POU15	<0.1	<1
113	POU14	<0.1	<1
114	RW17	<0.1	<1
115	BW8	<0.1	<1
116	RW16	<0.1	<1
120	POU11	<0.1	<1
121	BW7	<0.1	<1
123	RW21	<0.1	<1
124	POU18	<0.1	<1
125	POU16	<0.1	<1
127	POU17	<0.1	<1

134	RW22	<0.1	<1
136	POU10	<0.1	<1
79	POU4.1	<0.1	<1
41	POU11	0.8	1
80	RW3	1.3	1.5
101	RW7	1.2	1
25	RW6	0.65	1
69	RW26B	1.5	1
81	BW4	0.65	<1
130	POU22	0.65	<1
52	RW19	0.8	<1
89	BW1	<0.1	1
111	RW15	<0.1	1
133	POU21	<0.1	1
4	POU1.1	1.1	<1
94	RW6	3.65	4.65
117	RW20	1.2	<1
131	RW25	0.65	2
5	RW1	2.4	1
14	RW3	<0.1	1.5
19	BW6	2.4	1
40	RW14	3.4	2
54	POU17	1.5	<1
109	POU12	1.5	3.1
42	POU12	2.3	4.1
36	HP1	<0.1	2
104	RW10/POU7	<0.1	2
107	POU9	2	<1
139	RW26B	<0.1	2
126	RW19	2.95	1
76	POU2	2.4	<1
93	POU2	2.4	<1
35	POU9	2.6	<1
17	BW4	4.05	1.5
119	RW14	9.15	12.3
55	POU18	>100	96.75
45	RW15	3.6	<1
82	BW5	4.7	1
102	RW8	13.6	17.35
137	RW13	9.6	5.75
59	POU21	3.2	8.1
105	POU8	48.3	43.25
33	RW11	9.15	3.6
12	BW3	9.4	3.55
9	BW1	13.6	6.95
18	BW5	9.15	1.5
16	POU6.1	13.6	5.8
38	POU10	>100	92.15
21	RW4	11.6	3.65
63	POU22	30.95	21.45
129	BW9	15.35	4.65
132	RW24	11	<1
122	RW23	30.95	18.7
135	POU19	30.95	45.7
37	RW10/POU7	30.95	15
87	RW1	30.95	11.95
20	POU1	28.95	5.75
99	POU5	48.3	22.15
106	RW11	13.6	40.25
118	POU20	13.6	41.3
73	PN1/1	13.6	44.15
65	RW23	>100	62.35
103	POU4	30.95	72
34	POU8	>100	41.6

29	POU5	>100	35.95
28	RW8	>100	29.65
91	RW4	>100	<1

Table I.2 Sample raw data Thailand

Number	Sample code	Average CBT	Average IDEXX
2	POU1	<0.1	<1
3	RW1	<0.1	<1
5	POU3	<0.1	<1
6	RW3	<0.1	<1
7	POU4	<0.1	<1
12	RW6	>100	107.9
14	RW7	<0.1	<1
16	POU8	<0.1	<1
17	RW8	<0.1	<1
18	POU9	<0.1	<1
19	RW9	<0.1	<1
20	POU10	<0.1	<1
21	RW10	<0.1	<1
23	RW11	<0.1	<1
24	POU12	<0.1	<1
25	RW12	<0.1	<1
30	POU15	<0.1	<1
31	RW15	<0.1	<1
32	POU16	<0.1	<1
34	POU17	<0.1	<1
35	RW17	<0.1	<1
36	POU18	<0.1	<1
37	RW18	<0.1	<1
40	POU20	<0.1	<1
44	POU22	<0.1	<1
45	RW22	<0.1	<1
47	POU24	<0.1	<1
51	POU26	<0.1	<1
52	RW26	<0.1	<1
53	C+	>100	547.5
54	POU23	<0.1	<1
56	POU27	<0.1	<1
58	POU28	<0.1	<1
60	POU29	<0.1	<1
62	BW3	<0.1	<1
63	POU30	<0.1	<1
64	RW30	<0.1	<1
65	POU1	<0.1	<1
67	POU9	<0.1	<1
68	RW9	<0.1	<1
70	RW8	<0.1	<1
72	RW7	<0.1	<1
76	RW4	<0.1	<1
77	POU10	<0.1	<1
80	RW2	<0.1	<1
82	RW3	<0.1	<1
83	POU18	<0.1	<1
84	RW18	<0.1	<1
86	RW19	<0.1	<1
88	RW17	<0.1	<1
89	POU15	>100	302.55
93	POU16	>100	739.75
95	BW1	<0.1	<1
98	POU12	<0.1	<1
99	RW12	<0.1	<1
101	RW11	<0.1	<1
102	POU25	<0.1	<1
103	RW25	<0.1	<1
105	POU24	<0.1	<1
107	POU22	<0.1	<1

108	RW22	<0.1	<1
111	POU20	<0.1	<1
112	RW20	<0.1	<1
113	POU30	<0.1	<1
114	RW30	<0.1	<1
117	POU29	<0.1	<1
118	RW29	<0.1	<1
119	BW3	<0.1	<1
120	POU23	<0.1	<1
9	POU5	0.8	1
115	POU28	0.8	1
110	RW21	1.2	1
8	RW4	0.65	1
46	BW2	0.65	1
71	POU7	0.65	1
27	RW13	1.35	1
42	POU21	8.5	8.15
116	RW28	1.5	1
39	RW19	0.65	<1
1	BW1	1.35	2
61	RW29	0.8	<1
121	RW23	0.8	<1
10	RW5	<0.1	1
50	RW25	<0.1	1
55	RW23	<0.1	1
59	RW28	<0.1	1
66	RW1	<0.1	1
104	BW2	<0.1	1
87	POU17	1	<1
106	RW24	11.35	10.35
96	POU13	1.35	<1
94	RW16	0.65	2
22	POU11	<0.1	1.5
4	RW2	1.5	<1
33	RW16	4.7	3.1
11	POU6	4.7	3.05
78	RW10	2	<1
85	POU19	<0.1	2.05
109	POU21	2.05	<1
41	RW20	2.3	<1
28	POU14	4.05	1.5
75	POU4	3.65	1
43	RW21	4.7	1.5
57	RW27	4.7	1.5
26	POU13	9.15	5.75
79	POU2	4.7	1
97	RW13	4.7	1
48	RW24	9.15	4.65
90	RW15	13.6	7.95
29	RW14	13.6	23.3
38	POU19	13.6	1.5
91	POU14	>100	84.55
49	POU25	30.95	46.8
15	POU2	20.85	2.55
69	POU8	40.45	13.85
73	POU6	>100	72.65
92	RW14	30.95	94.95
81	POU3	>100	32.35
74	RW6	>100	31.3

Annex J Statistical tables for various critical test statistic values

Table A1 Table of the Normal Distribution

z	$p(\mu$ to $z)$	$p(z$ to tail)	ordinate
.00	.0000	.5000	.3989
.01	.0040	.4960	.3989
.02	.0080	.4920	.3989
.03	.0120	.4880	.3988
.04	.0160	.4840	.3986
.05	.0199	.4801	.3984
.06	.0239	.4761	.3982
.07	.0279	.4721	.3980
.08	.0319	.4681	.3977
.09	.0359	.4641	.3973
.10	.0398	.4602	.3970
.11	.0438	.4562	.3965
.12	.0478	.4522	.3961
.13	.0517	.4483	.3956
.14	.0557	.4443	.3951
.15	.0596	.4404	.3945
.16	.0636	.4364	.3939
.17	.0675	.4325	.3932
.18	.0714	.4286	.3925
.19	.0753	.4247	.3918
.20	.0793	.4207	.3910
.21	.0832	.4168	.3902
.22	.0871	.4129	.3894
.23	.0901	.4090	.3885
.24	.0948	.4052	.3876
.25	.0987	.4013	.3867
.26	.1026	.3974	.3857
.27	.1064	.3936	.3847
.28	.1103	.3897	.3836
.29	.1141	.3859	.3825
.30	.1179	.3821	.3814
.31	.1217	.3783	.3802
.32	.1255	.3745	.3790
.33	.1293	.3707	.3778
.34	.1331	.3669	.3765
.35	.1368	.3632	.3752
.36	.1406	.3594	.3739
.37	.1443	.3557	.3725
.38	.1480	.3520	.3712
.39	.1517	.3483	.3697
.40	.1554	.3446	.3683
.41	.1591	.3409	.3668
.42	.1628	.3372	.3653
.43	.1664	.3336	.3637
.44	.1700	.3300	.3621
.45	.1736	.3264	.3605
.46	.1772	.3228	.3589
.47	.1808	.3192	.3572
.48	.1844	.3156	.3555
.49	.1879	.3121	.3538
.50	.1915	.3085	.3521
.51	.1950	.3050	.3503
.52	.1985	.3015	.3485
.53	.2019	.2981	.3467
.54	.2054	.2946	.3448
.55	.2088	.2912	.3429
.56	.2123	.2877	.3410
.57	.2157	.2843	.3391
.58	.2190	.2810	.3372
.59	.2224	.2776	.3352
.60	.2257	.2743	.3332
.61	.2291	.2709	.3312
.62	.2324	.2676	.3292
.63	.2357	.2643	.3271
.64	.2389	.2611	.3251
.65	.2422	.2578	.3230
.66	.2454	.2546	.3209
.67	.2486	.2514	.3187
.68	.2517	.2483	.3166
.69	.2549	.2451	.3144
.70	.2580	.2420	.3123
.71	.2611	.2389	.3101
.72	.2642	.2358	.3079
.73	.2673	.2327	.3056
.74	.2704	.2296	.3034
.75	.2734	.2266	.3011
.76	.2764	.2236	.2989
.77	.2794	.2206	.2966
.78	.2823	.2177	.2943
.79	.2852	.2148	.2920
.80	.2881	.2119	.2897
.81	.2910	.2090	.2874
.82	.2939	.2061	.2850
.83	.2967	.2033	.2827
.84	.2995	.2005	.2803
.85	.3023	.1977	.2780
.86	.3051	.1949	.2756
.87	.3078	.1922	.2732
.88	.3106	.1894	.2709
.89	.3133	.1867	.2685

Table A1 Table of the Normal Distribution (continued)

z	p(μ to z)	p(z to tail)	ordinate
.90	.3159	.1841	.2661
.91	.3186	.1814	.2637
.92	.3212	.1788	.2613
.93	.3238	.1762	.2589
.94	.3264	.1736	.2565
.95	.3289	.1711	.2541
.96	.3315	.1685	.2516
.97	.3340	.1660	.2492
.98	.3365	.1635	.2468
.99	.3389	.1611	.2444
1.00	.3413	.1587	.2420
1.01	.3438	.1562	.2396
1.02	.3461	.1539	.2371
1.03	.3485	.1515	.2347
1.04	.3508	.1492	.2323
1.05	.3531	.1469	.2299
1.06	.3554	.1446	.2275
1.07	.3577	.1423	.2251
1.08	.3599	.1401	.2227
1.09	.3621	.1379	.2203
1.10	.3643	.1357	.2179
1.11	.3665	.1335	.2155
1.12	.3686	.1314	.2131
1.13	.3708	.1292	.2107
1.14	.3729	.1271	.2083
1.15	.3749	.1251	.2059
1.16	.3770	.1230	.2036
1.17	.3790	.1210	.2012
1.18	.3810	.1190	.1989
1.19	.3830	.1170	.1965
1.20	.3849	.1151	.1942
1.21	.3869	.1131	.1919
1.22	.3888	.1112	.1895
1.23	.3907	.1093	.1872
1.24	.3925	.1075	.1849
1.25	.3944	.1056	.1826
1.26	.3962	.1038	.1804
1.27	.3980	.1020	.1781
1.28	.3997	.1003	.1758
1.29	.4015	.0985	.1736
1.30	.4032	.0968	.1714
1.31	.4049	.0951	.1691
1.32	.4066	.0934	.1669
1.33	.4082	.0918	.1447
1.34	.4099	.0901	.1626

z	p(μ to z)	p(z to tail)	ordinate
1.35	.4115	.0885	.1604
1.36	.4131	.0869	.1582
1.37	.4147	.0853	.1561
1.38	.4162	.0838	.1539
1.39	.4177	.0823	.1518
1.40	.4192	.0808	.1497
1.41	.4207	.0793	.1476
1.42	.4222	.0778	.1456
1.43	.4236	.0764	.1435
1.44	.4251	.0749	.1415
1.45	.4265	.0735	.1394
1.46	.4279	.0721	.1374
1.47	.4292	.0708	.1354
1.48	.4306	.0694	.1334
1.49	.4319	.0681	.1315
1.50	.4332	.0668	.1295
1.51	.4345	.0655	.1276
1.52	.4357	.0643	.1257
1.53	.4370	.0630	.1238
1.54	.4382	.0618	.1219
1.55	.4394	.0606	.1200
1.56	.4406	.0594	.1182
1.57	.4418	.0582	.1163
1.58	.4429	.0571	.1145
1.59	.4441	.0559	.1127
1.60	.4452	.0548	.1109
1.61	.4463	.0537	.1092
1.62	.4474	.0526	.1074
1.63	.4484	.0516	.1057
1.64	.4495	.0505	.1040
1.65	.4505	.0495	.1023
1.66	.4515	.0485	.1006
1.67	.4525	.0475	.0989
1.68	.4535	.0465	.0973
1.69	.4545	.0455	.0957
1.70	.4554	.0446	.0940
1.71	.4564	.0436	.0925
1.72	.4573	.0427	.0909
1.73	.4582	.0418	.0893
1.74	.4591	.0409	.0878
1.75	.4599	.0401	.0863
1.76	.4608	.0392	.0848
1.77	.4616	.0384	.0833
1.78	.4625	.0375	.0818
1.79	.4633	.0367	.0804

Table A1 Table of the Normal Distribution (continued)

z	$p(\mu$ to $z)$	$p(z$ to tail)	ordinate	z	$p(\mu$ to $z)$	$p(z$ to tail)	ordinate
1.80	.4641	.0359	.0790	2.25	.4878	.0122	.0317
1.81	.4649	.0351	.0775	2.26	.4881	.0119	.0310
1.82	.4656	.0344	.0761	2.27	.4884	.0116	.0303
1.83	.4664	.0336	.0748	2.28	.4887	.0113	.0297
1.84	.4671	.0329	.0734	2.29	.4890	.0110	.0290
1.85	.4678	.0322	.0721	2.30	.4893	.0107	.0283
1.86	.4686	.0314	.0707	2.31	.4896	.0104	.0277
1.87	.4693	.0307	.0694	2.32	.4898	.0102	.0270
1.88	.4699	.0301	.0681	2.33	.4901	.0099	.0264
1.89	.4706	.0294	.0669	2.34	.4904	.0096	.0258
1.90	.4713	.0287	.0656	2.35	.4906	.0094	.0252
1.91	.4719	.0281	.0644	2.36	.4909	.0091	.0246
1.92	.4726	.0274	.0632	2.37	.4911	.0089	.0241
1.93	.4732	.0268	.0620	2.38	.4913	.0087	.0235
1.94	.4738	.0262	.0608	2.39	.4916	.0084	.0229
1.95	.4744	.0256	.0596	2.40	.4918	.0082	.0224
1.96	.4750	.0250	.0584	2.41	.4920	.0080	.0219
1.97	.4756	.0244	.0573	2.42	.4922	.0078	.0213
1.98	.4761	.0239	.0562	2.43	.4925	.0075	.0208
1.99	.4767	.0233	.0551	2.44	.4927	.0073	.0203
2.00	.4772	.0228	.0540	2.45	.4929	.0071	.0198
2.01	.4778	.0222	.0529	2.46	.4931	.0069	.0194
2.02	.4783	.0217	.0519	2.47	.4932	.0068	.0189
2.03	.4788	.0212	.0508	2.48	.4934	.0066	.0184
2.04	.4793	.0207	.0498	2.49	.4936	.0064	.0180
2.05	.4798	.0202	.0488	2.50	.4938	.0062	.0175
2.06	.4803	.0197	.0478	2.51	.4940	.0060	.0171
2.07	.4808	.0192	.0468	2.52	.4941	.0059	.0167
2.08	.4812	.0188	.0459	2.53	.4943	.0057	.0163
2.09	.4817	.0183	.0449	2.54	.4945	.0055	.0158
2.10	.4821	.0179	.0440	2.55	.4946	.0054	.0155
2.11	.4826	.0174	.0431	2.56	.4948	.0052	.0151
2.12	.4830	.0170	.0422	2.57	.4949	.0051	.0147
2.13	.4834	.0166	.0413	2.58	.4951	.0049	.0143
2.14	.4838	.0162	.0404	2.59	.4952	.0048	.0139
2.15	.4842	.0158	.0396	2.60	.4953	.0047	.0136
2.16	.4846	.0154	.0387	2.61	.4955	.0045	.0132
2.17	.4850	.0150	.0379	2.62	.4956	.0044	.0129
2.18	.4854	.0146	.0371	2.63	.4957	.0043	.0126
2.19	.4857	.0143	.0363	2.64	.4959	.0041	.0122
2.20	.4861	.0139	.0355	2.65	.4960	.0040	.0119
2.21	.4864	.0136	.0347	2.66	.4961	.0039	.0116
2.22	.4868	.0132	.0339	2.67	.4962	.0038	.0113
2.23	.4871	.0129	.0332	2.68	.4963	.0037	.0110
2.24	.4875	.0125	.0325	2.69	.4964	.0036	.0107

Table A1 Table of the Normal Distribution (continued)

z	$p(\mu$ to $z)$	$p(z$ to tail)	ordinate	z	$p(\mu$ to $z)$	$p(z$ to tail)	ordinate
2.70	.4965	.0035	.0104	3.15	.4992	.0008	.0028
2.71	.4966	.0034	.0101	3.16	.4992	.0008	.0027
2.72	.4967	.0033	.0099	3.17	.4992	.0008	.0026
2.73	.4968	.0032	.0096	3.18	.4993	.0007	.0025
2.74	.4969	.0031	.0093	3.19	.4993	.0007	.0025
2.75	.4970	.0030	.0091	3.20	.4993	.0007	.0024
2.76	.4971	.0029	.0088	3.21	.4993	.0007	.0023
2.77	.4972	.0028	.0086	3.22	.4994	.0006	.0022
2.78	.4973	.0027	.0084	3.23	.4994	.0006	.0022
2.79	.4974	.0026	.0081	3.24	.4994	.0006	.0021
2.80	.4974	.0026	.0079	3.25	.4994	.0006	.0020
2.81	.4975	.0025	.0077	3.26	.4994	.0006	.0020
2.82	.4976	.0024	.0075	3.27	.4995	.0005	.0019
2.83	.4977	.0023	.0073	3.28	.4995	.0005	.0018
2.84	.4977	.0023	.0071	3.29	.4995	.0005	.0018
2.85	.4978	.0022	.0069	3.30	.4995	.0005	.0017
2.86	.4979	.0021	.0067	3.31	.4995	.0005	.0017
2.87	.4979	.0021	.0065	3.32	.4995	.0005	.0016
2.88	.4980	.0020	.0063	3.33	.4996	.0004	.0016
2.89	.4981	.0019	.0061	3.34	.4996	.0004	.0015
2.90	.4981	.0019	.0060	3.35	.4996	.0004	.0015
2.91	.4982	.0018	.0058	3.36	.4996	.0004	.0014
2.92	.4982	.0018	.0056	3.37	.4996	.0004	.0014
2.93	.4983	.0017	.0055	3.38	.4996	.0004	.0013
2.94	.4984	.0016	.0053	3.39	.4997	.0003	.0013
2.95	.4984	.0016	.0051	3.40	.4997	.0003	.0012
2.96	.4985	.0015	.0050	3.41	.4997	.0003	.0012
2.97	.4985	.0015	.0048	3.42	.4997	.0003	.0012
2.98	.4986	.0014	.0047	3.43	.4997	.0003	.0011
2.99	.4986	.0014	.0046	3.44	.4997	.0003	.0011
3.00	.4987	.0013	.0044	3.45	.4997	.0003	.0010
3.01	.4987	.0013	.0043	3.46	.4997	.0003	.0010
3.02	.4987	.0013	.0042	3.47	.4997	.0003	.0010
3.03	.4988	.0012	.0040	3.48	.4997	.0003	.0009
3.04	.4988	.0012	.0039	3.49	.4998	.0002	.0009
3.05	.4989	.0011	.0038	3.50	.4998	.0002	.0009
3.06	.4989	.0011	.0037	3.51	.4998	.0002	.0008
3.07	.4989	.0011	.0036	3.52	.4998	.0002	.0008
3.08	.4990	.0010	.0035	3.53	.4998	.0002	.0008
3.09	.4990	.0010	.0034	3.54	.4998	.0002	.0008
3.10	.4990	.0010	.0033	3.55	.4998	.0002	.0007
3.11	.4991	.0009	.0032	3.56	.4998	.0002	.0007
3.12	.4991	.0009	.0031	3.57	.4998	.0002	.0007
3.13	.4991	.0009	.0030	3.58	.4998	.0002	.0007
3.14	.4992	.0008	.0029	3.59	.4998	.0002	.0006

Table A1 Table of the Normal Distribution (continued)

z	p(μ to z)	p(z to tail)	ordinate
3.60	.4998	.0002	.0006
3.61	.4998	.0002	.0006
3.62	.4999	.0001	.0006
3.63	.4999	.0001	.0005
3.64	.4999	.0001	.0005
3.65	.4999	.0001	.0005
3.66	.4999	.0001	.0005
3.67	.4999	.0001	.0005
3.68	.4999	.0001	.0005
3.69	.4999	.0001	.0004
3.70	.4999	.0001	.0004
3.71	.4999	.0001	.0004
3.72	.4999	.0001	.0004
3.73	.4999	.0001	.0004
3.74	.4999	.0001	.0004
3.75	.4999	.0001	.0004
3.76	.4999	.0001	.0003
3.77	.4999	.0001	.0003
3.78	.4999	.0001	.0003
3.79	.4999	.0001	.0003

z	p(μ to z)	p(z to tail)	ordinate
3.80	.4999	.0001	.0003
3.81	.4999	.0001	.0003
3.82	.4999	.0001	.0003
3.83	.4999	.0001	.0003
3.84	.4999	.0001	.0003
3.85	.4999	.0001	.0002
3.86	.4999	.0001	.0002
3.87	.4999	.0001	.0002
3.88	.4999	.0001	.0002
3.89	1.0000	.0000	.0002
3.90	1.0000	.0000	.0002
3.91	1.0000	.0000	.0002
3.92	1.0000	.0000	.0002
3.93	1.0000	.0000	.0002
3.94	1.0000	.0000	.0002
3.95	1.0000	.0000	.0002
3.96	1.0000	.0000	.0002
3.97	1.0000	.0000	.0002
3.98	1.0000	.0000	.0001
3.99	1.0000	.0000	.0001
4.00	1.0000	.0000	.0001

Table A18 Table of Critical Values for Spearman's Rho

	One–tailed level of significance			
	.05	.025	.01	.005
	Two–tailed level of significance			
	.10	.05	.02	.01
n				
4	1.000	–	–	–
5	.900	1.000	1.000	–
6	.829	.886	.943	1.000
7	.714	.786	.893	.929
8	.643	.738	.833	.881
9	.600	.700	.783	.833
10	.564	.648	.745	.794
11	.536	.618	.709	.755
12	.503	.587	.671	.727
13	.484	.560	.648	.703
14	.464	.538	.622	.675
15	.443	.521	.604	.654
16	.429	.503	.582	.635
17	.414	.485	.566	.615
18	.401	.472	.550	.600
19	.391	.460	.535	.584
20	.380	.447	.520	.570
21	.370	.435	.508	.556
22	.361	.425	.496	.544
23	.353	.415	.486	.532
24	.344	.406	.476	.521
25	.337	.398	.466	.511
26	.331	.390	.457	.501
27	.324	.382	.448	.491
28	.317	.375	.440	.483
29	.312	.368	.433	.475
30	.306	.362	.425	.467
35	.283	.335	.394	.433
40	.264	.313	.368	.405
45	.248	.294	.347	.382
50	.235	.279	.329	.363
60	.214	.255	.300	.331
70	.190	.235	.278	.307
80	.185	.220	.260	.287
90	.174	.207	.245	.271
100	.165	.197	.233	.257

Table A5 Table of Critical *T* Values for Wilcoxon's Signed-Ranks and Matched-Pairs Signed-Ranks Test

	One-tailed level of significance .05	.025	.01	.005
	Two-tailed level of significance .10	**.05**	**.02**	**.01**
n				
5	0	–	–	–
6	2	0	–	–
7	3	2	0	–
8	5	3	1	0
9	8	5	3	1
10	10	8	5	3
11	13	10	7	5
12	17	13	9	7
13	21	17	12	9
14	25	21	15	12
15	30	25	19	15
16	35	29	23	19
17	41	34	27	23
18	47	40	32	27
19	53	46	37	32
20	60	52	43	37
21	67	58	49	42
22	75	65	55	48
23	83	73	62	54
24	91	81	69	61
25	100	89	76	68
26	110	98	84	75
27	119	107	92	83

	One-tailed level of significance .05	.025	.01	.005
	Two-tailed level of significance .10	**.05**	**.02**	**.01**
n				
28	130	116	101	91
29	140	126	110	100
30	151	137	120	109
31	163	147	130	118
32	175	159	140	128
33	187	170	151	138
34	200	182	162	148
35	213	195	173	159
36	227	208	185	171
37	241	221	198	182
38	256	235	211	194
39	271	249	224	207
40	286	264	238	220
41	302	279	252	233
42	319	294	266	247
43	336	310	281	261
44	353	327	296	276
45	371	343	312	291
46	389	361	328	307
47	407	378	345	322
48	426	396	362	339
49	446	415	379	355
50	466	434	397	373

Annex K Turbidity measurement

Figure K.1 Turbidity measurement in Laos samples

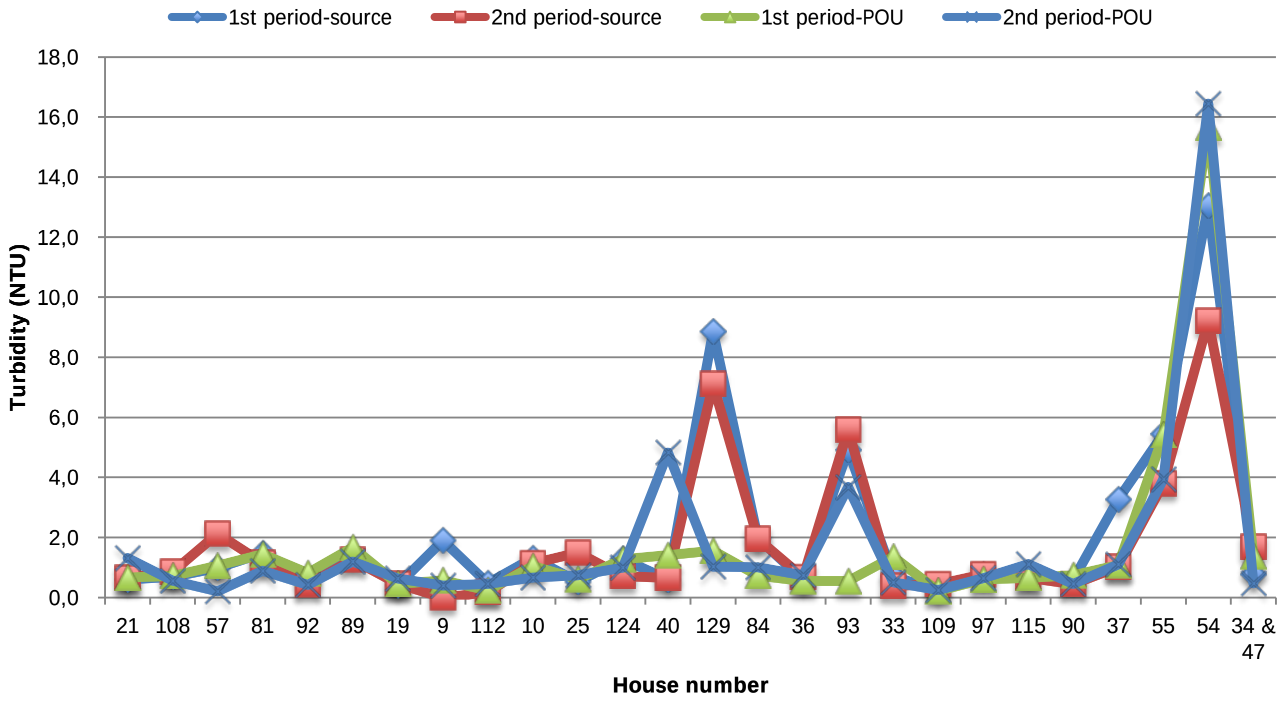

Figure K.2 Turbidity measurement in Thai samples