Risk perception and health risk; towards improving drinking water management of a small island community

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ABSTRACT

A community of an island in Malaysia still uses untreated drinking water sources and is reluctant to accept chlorinated water. A water treatment plan that was installed on the island has ceased any treatment, despite routine water monitoring showing high levels of faecal coliforms. The underlying cause could include unwillingness to pay the bill, distrust in chlorine and the belief that the untreated water is safe to drink.

A systematic review was conducted on the challenges of rural drinking water supply management from source to tap to gain an overall insight on the issues faced by the local community and possible solutions. This is followed by a questionnaire survey to assess the community's perception towards risk from untreated drinking water, chlorinated water, willingness to pay the water bill and their drinking water practices. The final part involved a risk assessment to quantify the microbial health risk from the drinking water supply, by sampling the water and using quantitative microbial risk assessment approach to calculate the risk.

The review suggests that rural water interventions should be hands on with a sense of ownership, that sustainability of rural water supply system depends on reliability and user preferences, and positive management aspects include water safety plans, and a functioning committee with certain characteristics. The benefits of rural drinking water management were shown to outweigh the cost. The survey revealed factors that affect the community's perception of risk from their drinking water, perception on chlorinated water, and their drinking water practices. The risk assessment revealed the annual risk of infection from *E. coli* O157, rotavirus and cryptosporidium among adults and children exposed to untreated drinking water.

The overall findings showed the importance of community perception and the value of combining assessment of risk perception and risk quantification for rural drinking water management study.

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ACRONYMS

AFR-E	Africa Sub-region E
ANOVA	Analysis of Variance
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development)
CASP	Critical Appraisal Skills Programme
CBA	Cost Benefit Analysis
CEA	Cost Effective Analysis
CT	Cycle Threshold
DAP	Development Assistance Program
CHW	Community Health Worker
GDWQ	Guidelines for Drinking Water Quality
GPS	Global Positioning System
EAEC	Enteroaggregative *E. coli*
EHEC	Enterohaemorrhagic *E. coli*
EIEC	Enteroinvasive *E. coli*
EPEC	Enteropathogenic *E. coli*
ETEC	Enterotoxigenic *E. coli*
EPHPP	Effective Public Health Practice Project
HACCP	Hazard Analysis and Critical Control Points
IMS	Immuno-magnetic separation
JMP	Joint Monitoring Programme
MDG	Millennium Development Goal
MOH	Ministry of Health
MREC	Medical Research and Ethics Committee
NPV	Net Present Value
PVB	Present Value Benefit
PVC	Present Value Cost
PCR	Polymerase Chain Reaction
qPCR	Quantitative Real-time PCR
QAT	Quality Assessment Tool
QMRA	Quantitative Microbial Risk Assessment
Sear-D	South East Asia Sub-region D
SCBA	Social Cost Benefit Analysis
SPSS	Statistical Package for the Social Science
UEA	University of East Anglia
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
WSP	Water and Sanitation Program
WSPs	Water Safety Plans

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Chapter 1: Introduction

On an island in the east coast of Malaysia, well known internationally for its natural beauty, some 3300 plus local inhabitants are still using drinking water from untreated sources, which had consistently been shown to have high levels of total coliforms during routine monitoring (Appendix A). What makes it more mystifying is that a water treatment plant built to provide a solution to a large section of this community, has been abandoned. I came across this situation during an outbreak investigation (unrelated to the thesis) and realized that the community's problem needs investigating, and the issue is also quite relevant to Malaysia's rural drinking water management initiatives.

The country is moving towards 99% treated drinking water coverage by 2020 and available data from 2015 showed 95% coverage overall, with 97% coverage in the urban area and 93% coverage in the rural area (KeTTHA, 2016). Financing, governance and community acceptance are among the main issues and challenges in achieving this goal (Kiyu & Hardin, 1992; Saimy & Yusof, 2013). The situation on this island could provide some answers towards understanding the issues in the management of rural drinking water, and requires further attention not only for the good of the community themselves but also for the progress of the nation.

1.1 Background and rationale

The island's community are divided into several villages along the coastline, and most of these villages get their water by gravity feed through a series of pipes that connect their homes or business premises to dams built around streams in the hilly areas of the island's central region. In one village however, river water is their main source, and generators are used to pump water from the river to their homes. This village also experiences seasonal drying of the rivers and streams, resulting in disruption in water supply and causing some of the villagers there to resort to using ground water instead.

Generally, through these arrangements, the villagers can get water directly from the pipe in their homes, though the water comes without any treatment.

The main treatment advocated by health services is by boiling the water before use, with some personally choosing to use basic wound cartridge filters to help clean the water. There is however no local data to say how many actually boils water before use. During the dry season, they may need to resort to alternatives, such as getting water from alternative river sources and by making temporary piped connections.

District health officers from the mainland travel to the island twice in a year to collect water samples from several designated sampling points. These water samples routinely tested positive for the presence of faecal coliforms and not uncommonly, at high levels (Appendix A). There is continuous effort to improve the management of drinking water on the island, but the authorities seem to be facing a complex mix of social, political and economic hurdles.

To manage the quality of drinking water on the island, a water treatment plant was built by authorities in the island's main village in 2008 (Lembaga Pembangunan Tioman, 2008); however, it was not well received by the community and is currently not in operation as a water treatment facility. The reasons given vary depending on who you ask; those from local authorities would say that the villagers were not willing to pay the water bills, while the villagers would say that they dislike the taste of chlorinated water and that the chemicals may be unsafe. Some villagers argue that the natural water source is very safe even without treatment because they have not gotten sick from drinking it for generations.

To implement a strategy that will be better accepted, there is a need to understand the perception of the community about the water that they are drinking (de Franca Doria, Pidgeon, & Hunter, 2009). Do they really feel that the water is safe? Even though health education and health promotion programs have been done before, do they understand the risk? Are they really against using chlorinated water or are they just concerned about the effect on their economy?

Understanding risk perception of a community is an effective strategy towards improving drinking water management (Dupont, 2005). Understanding the villagers risk perception would be a good first step to help the authorities to develop a more effective risk communication and drinking water management strategy for the benefit of this island community and also have wider implications for other remote or rural communities facing similar issues in the country.

The second step is to conduct a risk assessment of the drinking water supply compared to the traditional drinking water standards measurement. A quantitative microbial risk assessment (QMRA) approach can be used to identify the most effective strategy in drinking water management in a community (Hunter et al., 2009). This would also be in line with the World Health Organization (WHO) Water Safety Plans approach, where drinking water management involves every level of the water supply chain (Davison et al., 2005). A quantitative health risk assessment which includes testing for the presence of specific pathogens in the water would be able to provide valuable information that is currently unavailable.

The World Health Organization (WHO) promotes the use of risk assessment together with risk management for the control of water safety in drinking water supplies in the 3rd edition of its Guidelines for Drinking-Water Quality (2004) (GDWQ) (WHO, 2004). Water safety management should no longer depend on the water supply meeting a set of measurement standards as this is not enough to ensure the public is safe from microbial contamination. They recommended that water suppliers develop and implement Water Safety Plans (WSPs) to systematically assess and manage risks.

The Malaysian government has recognized the importance of WSPs and the Ministry of Health (MOH) Malaysia has engaged WHO consultation to develop a “Strategic Action Plan for the Development and Implementation of WSPs in Malaysia”. It began implementing WSPs Pilot Projects from September 2010, followed by further plans to fully implement WSPs for rural and urban water supply in the country (MOH, 2012).

QMRA is a risk assessment tool that can be used to estimate the health risk to humans from exposure to pathogens in drinking water (Haas, Rose &

Gerba, 1999). It is very relevant to the implementation of WSPs as it can be used to provide valuable input for WSPs implementation. QMRA can be used to evaluate the components of WSPs or water management plan and identify critical points of the system, such as the required frequency of monitoring to meet certain safety level. It could help in decision making by identifying the intervention options and cost benefit ratio. Overall, QMRA is useful in achieving effective management of drinking water safety (Smeets et al., 2010).

Several studies have shown the usefulness of quantitative risk assessment in developing countries and small rural communities. Machdar (Machdar et al., 2013) applied QMRA in Accra, Ghana and found that the major contamination pathway was household storage, while disinfection of water at household level together with hygiene education was the most cost-effective intervention compared to improvement of water supply network. In another study, cost benefit analysis using Monte Carlo modelling was able to show that intervention to improve rural community water supplies was highly beneficial (Hunter et al., 2009). A study in Kampala, Uganda showed that even in developing countries with limited data, a simplified risk assessment can be conducted (Howard, Pedley & Tibatemwa, 2006).

In conducting a QMRA, the appropriate pathogens for risk assessment need to be selected. Even though there is lack of data on specific causative agents of waterborne diarrheal diseases in Malaysia, *Escherichia coli*, Giardia and Cryptosporidium has been recognised as among the most important infective agents of diarrhoea among children in developing countries (Ochoa, Salazar-Lindo & Cleary, 2004). In Malaysia, a study found *Cryptosporidium sp*. In 8 out of 76 (10.5%) waters sources (Ahmad, 1995). Another study in 2009 found the presence of Giardia and Cryptosporidium in the river waters of two recreational areas in Selangor, Malaysia (Ithoi, 2009). A study of the Langat Basin also found the presence of Cryptosporidium and Giardia in both Sungai Langat and Sungai Semenyih (Farizawati et al., 2005). In a different study 4.62% of children admitted with diarrhea in two hospitals in Malaysia were positive for cryptosporidiosis using microscopic and immunologic test methods (Rossle et al., 2012), while the prevalence of *Giardia duodenalis* infection among rural communities were found to be 19.2% (Norhayati et al., 1998).

Meanwhile *E. coli* O157:H7 has emerged as an important cause of diarrheal disease especially because it causes severe illness in young children and elderly people. Several outbreaks involving recreational water and drinking water have been reported (Hunter, 2003; Swerdlow et al., 1992; Isaacson et al., 1993). There is little information available regarding transmission of *E. coli* O157:H7 or other EHEC strains in Malaysia, but recent studies have detected *E. coli* O157:H7 in beef, raw milk and vegetables (Radu et al., 1998; Chang et al., 2012; Lye et al., 2013).

Estimation of pathogen concentration in source water is an important part of exposure assessment in QMRA. However, exposure also depends on consumption of un-boiled water and treatment efficacy (Petterson et al., 2006). Un-boiled water consumption is related to the behaviour and practice of the individual or the community. Unless the amount of water consumed and what treatments, if any, it has been subjected to is understood, a formal risk assessment cannot be undertaken.

Undertaking a risk assessment by itself is insufficient unless it leads to action that ultimately reduces the risk to consumers. Indeed, the links between risk assessment and risk management has been made explicit in several reports from the WHO (e.g. Figure 1.1).

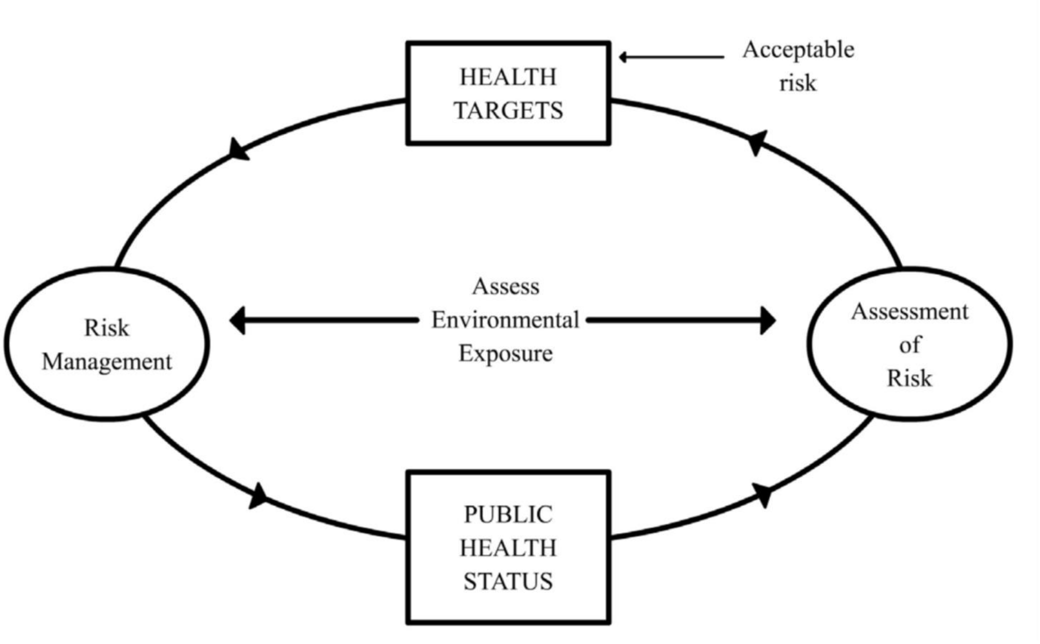

Figure 1-1 The integration of risk assessment and risk management in protecting public health (Fewtrell & Bartram, 2001)

The importance of linking risk assessment to risk management is particularly problematic when dealing with small community water supplies where individual consumers are responsible for managing or influence the management of their community water supply (Onjala, Ndiriti & Stage, 2013). If people do not know or understand the risks, then they may continue to use unsafe water sources even when safe alternatives exist. Because of this, doing a risk assessment alone is not enough, as drinking water behaviour depend a lot on the perception of risk (Anadu, 2000).

There are several relevant studies and discussion papers on the issue of risk perception and how it influences drinking water practice and choices. Nauges and Van Den Berg (2009) conducted a study in Sri Lanka which showed that the higher the perception of risk, the higher the likelihood of a household to boil or filter water before drinking. The same study discovered that a household's evaluation of risk depends on water characteristics of taste, smell and colour (organoleptics), education level and knowledge on hygiene practices.

The issue however should not be approached in a simplistic way, perceptions of water quality and health risks can be a result of many different factors, which could interact among themselves, and though many studies has investigated their relationship, it is still not completely understood (Spence & Walters, 2012; de Franca Doria, 2010; de Franca Doria et al., 2009). Other factors influencing risk perception includes perception of water chemicals, information from external source, and trust in water suppliers (de Franca Doria, 2010; de Franca Doria et al., 2009).

Rural and remote communities face problems with drinking water quality that are unique to their surroundings. This includes limited water sources that are available and limitation in water treatment facilities due to logistics or funding. These limiting factors also interplay with other sociological factors such as the attitude, perception and practices of the community in relation to drinking water. Many studies have shown the risk from drinking untreated water in rural communities (Machdar et al., 2013; Suthar, Chhimpa & Singh, 2009). People's perceptions have also been shown to impact the behaviour towards drinking water management (de Franca Doria et al., 2009; Nauges & Van Den Berg, 2009). This study would be among the first to look at both the risk perception and actual health risk from the community's exposure to their drinking water.

Studies aimed at understanding risk perceptions of a group or a community have vast policy implications. The understanding of different risk perceptions and the important factors that influence them can contribute towards the development of a more appropriate risk communication strategies and effective water management policies and programs (de França Doria, 2010; de França Doria, 2004). Though this study is focused on improving the situation of the community on the island by applying QMRA methodology and doing a risk perception assessment, the knowledge on QMRA and risk perception analysis will also be essential in the future implementation of WSPs in Malaysia.

1.2 Study Objectives

1.2.1 Main objective of the study

To evaluate the risk perception of the community towards their drinking water source, and the microbial risk of the water source towards the community, from key microbial pathogens in drinking water and to identify how better management of drinking water safety in the community could be introduced.

1.2.2 Specific objectives of the study

a) To understand how the local population perceive the safety of their drinking water and their perception towards drinking water treatment
b) To obtain quantitative estimates of the presence of key waterborne pathogens in drinking water
c) To obtain estimates of water consumption behaviour and practices amongst villages
d) To undertake QMRA to quantify risk of illness in the population within the study area from contaminated drinking water
e) To identify effective strategies of drinking water management on the island

1.3 Thesis structure

The main body of work for this thesis comprises of three different but related parts, which will be laid out in chapters 2, 3 and 4 respectively.

Chapter 2 will reveal the systematic review that was undertaken to understand some of the relevant issues involving drinking water management in rural or remote communities. The findings help to give a proper perspective of the findings in further chapters in the thesis.

Chapter 3 will discuss the finding on the perceptions of the community with regards to the health risk from their drinking water source, drinking water treated with chlorine, and drinking water practices, which is mainly based on the questionnaire survey which was conducted at the beginning of the study.

This chapter will also give more detail of the study site to provide the proper context for which to understand the findings of the survey.

Chapter 4 will proceed to look at the findings from the water sampling, depending more on data from field sampling and lab-based analysis. Though some important information will also come from the questionnaire, which, together with the lab data, will be the basis for a risk assessment approach that will be the main objective of this 4th chapter.

Following that, chapter 5 will then discuss and summarizes the findings and significance of all the three main parts of the thesis and discuss the conclusions of the study and how it will contribute to improving the community in focus and contribute to the knowledge and improvement of public health issues in general.

Chapter 2: Challenges of water supply management in rural communities; a review of literature

2.1 Background

In July 2010, a United Nations (UN) General Assembly Resolution formally recognised the right to water and sanitation, acknowledging that availability of clean drinking water and proper sanitation as essential to humans and is a basic right. This acknowledgement has provided stronger support for drinking water safety efforts which has continued to move forward under the Millennium Development Goal (MDG). Under MDG 7, Target C, the aim was to reduce by half the number of people without access to safe drinking water and basic sanitation by 2015 (from 1990 figures). According to the 2015 MDG update report by the Joint Monitoring Programme (JMP) for Water Supply and Sanitation (a joint WHO-UNICEF body that officially monitors the progress), the target for safe drinking water has been achieved in 2010, when it surpassed 88% coverage from originally only 76% coverage. The challenge continues however, as disparities remain between regions and countries, and between rural and urban populations. It is estimated that 2.6 billion people globally now has access to improved water sources, however 663 million still lack access, and the majority are from sub Saharan Africa and Southern Asia. Additionally, according to the 2015 assessment report, 96% of global urban population receive water from improved sources compared to 84% for global rural population (Unicef, 2015). Another important point to note from the MDG assessment is that the method used in identifying whether access to safe water is available in a certain area or region or not is simply based on the presence of infrastructure for improved water sources. The presence of infrastructure is often called a proxy indicator as actual information on drinking water quality and access to them is not available for every area or region, and would be too costly to gather for the purpose of the assessment.

It is a challenge to implement an effective drinking water management system in rural or remote communities, as they are limited in their capacity in managing, operating and maintaining an effective system. This limited capacity may come from both financial and technical aspect. National or local governments may have limited finance to cover the expenses of building and maintaining a proper water infrastructure in rural areas (Abui et al., 2016). In developing countries where budget must be properly balanced to cover many areas of growth, water infrastructure in rural communities may not become a priority. It may also be difficult to offset this expenditure by charging fees for the community to use the water, and governments would be more tempted to focus on other spending which would lead to immediate commercial gain. This issue of funding limitation has been discussed in a wider context of water privatisation issue in developing countries (Saner, Yiu & Khusainova, 2014). In rural context, many funders such as World Bank and UNICEF (United Nations International Children's Emergency Fund) and other NGOs have been involved in rural drinking water management; however, issues of poor funding management and corruption have been reported to be a problem (Abui et al., 2016; Sanctuary, Haller & Tropp, 2004). Communities in rural and remote area also face the issue of water scarcity, access and availability. The water source may be located at a remote, difficult to reach location, and they may also face problem of seasonal variations, with extreme wet and dry conditions (Lutz et al., 2015, Tadesse, Bosona & Gebresenbet, 2013). These problems pose further questions as to which water supply system or management approach would be the most suitable or cost effective. The community itself may be reluctant or resistant to change the water supply system. There may be entrenched beliefs and practices which can be difficult to change for communities to accept new technologies, such as the use of chlorine in water treatment (Figueroa & Kincaid, 2010).

As earlier quoted, 84% of global rural population receives water from improved water sources. Here improved sources are defined as a drinking water source that is likely to be protected from outside contamination, particularly faecal contamination, either by the nature of its construction or additionally from a physical barrier. Examples of improved water sources include piped water into dwelling, protected spring or dug wells, boreholes, or public standpipes. Unimproved sources include unprotected spring, unprotected dug wells and surface water. Improved water sources however do not always guarantee safe water. A study on water supply and household water in Peru found that 90% of households receive water from improved water sources, yet 43% of the water source and 47% of household water were found to be contaminated by faecal material (Heitzinger et al., 2015). Among improved water sources, the most reliable in term of providing uncontaminated water is piped supplies to dwellings. A meta-analysis of 45 studies looking at faecal contamination at source and household storage found that piped supplies had significantly lower probability of contamination compared to non-piped water (Shields et al., 2015). Again, according to the MDG report, even though there has been a lot of progress in the rural water supply during the MDG period, in 2015, only 1 out of 3 people in rural areas have access to piped water supply compared to 4 out of 5 people in urban areas (Unicef, 2015).

The World Health Organisation (WHO) is aware that an improved water source does not guarantee safe drinking water. It is estimated that 1.8 billion people globally are still using faecal contaminated water (Unicef, 2015). A report published in WHO Bulletin discussed three ways where improved water source can be unsafe. The first is through improper storage, as uncontaminated source water can be contaminated during storage. The second is the problem with piped water supply, where piped water may be supplied from contaminated source, or faces challenges in reliability. The third is management issues which could lead to improved sources not actually being used (Shaheed et al., 2014).

Strategies towards eliminating or reducing contamination at storage level have been studied. A lot has also been discussed on point of use treatment within the household. Engineering for Change (Goodier, 2012) listed 10 low cost technologies for household water treatment. Among them are ceramic filters, slow sand filtration, solar disinfection and chlorine. The effectiveness of these methods has been studies in various localities. In a systematic review that looked at 33 trials evaluating household level treatment to improve microbiological quality of water, they concluded that the household treatments or interventions were generally effective in preventing diarrhoea, for all ages and for the important target group of children under 5 years old. However, the review mentioned significant differences within the level of effectiveness found between these studies, suggesting that many factors may influence the effectiveness, though these factors were not able to be investigated in the review. Among interventions that were included in the review are household chlorination, flocculation and slow sand filtration (Clasen et al., 2007).

When water source is unsafe, there is an option for water treatment. The issue with applying the water treatment is again financial strength and logistics. What are the costs and how will the costs be recovered? What are the technical requirements that must be available for the system to be sustainable? WHO in a guideline publication, recommended 4 community-based water treatment systems. They provided the guideline for; storage and sedimentation system, up-flow roughing filter method, slow sand filtration technique and chlorination in piped water supply systems (WHO 2011). The Water and Sanitation Program (WSP) presented an assessment report on the use of drip chlorination and tablet chlorinators in Honduras, where each technology was found to have their advantages and disadvantages (Water, 2004). These technologies suggested by WHO and WSP are considered cost-effective for rural and small communities setting, as they do not require high technical capabilities and comparatively lower in cost to build and maintain. Of course, it must be assessed based on local context.

WHO also recognises the special challenges faced by rural communities in term of governance and management. The model that is mainly being put forward is of community management, by empowering the member of the community and involving them with the development, operation and monitoring of the water supply system (Tadesse et al., 2013). With the community being involved, a better take up rate is expected, ensuring that the whole system is more sustainable. This may not always be the case, as sustainability of a community water supply would depend on other factors than just community involvement. Knowledge of risk from uncontaminated water would influence their attitude towards water treatment or support for improved water infrastructure. Community perception can be based on their knowledge, experience, underlying beliefs or even the influence of peers or leaders in the community, and could impact on their action in relation to improved drinking water supply (Figueroa et al., 2010).

Since 2004, WHO have begun to adopt Water Safety Plans in its guidelines. Traditionally, drinking water management was reliant on routine monitoring of the drinking water supply to meet certain standards. However, this approach has been found to be inadequate to safeguard the public from the risk of consuming contaminated water. This has been shown by outbreak cases that occur even in supply system that continuously meet the required standards.

WSPs address all the steps in a drinking water supply network. According to WHO, management of water supply systems should include ensuring the safety of source waters, selective water harvesting, controlled storage, treatment prior to distribution, protection during distribution and safe storage in the household. Some circumstances also require point of use treatment. The water safety plans approach is based on a risk management approach based on Hazard Analysis and Critical Control Points (HACCP), where risk at every critical point is assessed and control measures are identified.

To assist the implementation of the WSPs in rural communities or small water supply systems, WHO has provided several different guidance papers relevant to that (WHO, 2012; WHO, 2014). The field guide outlines step by step the process of implementing water safety plans for rural water supply. The first being engagement and setting up of the team. This is followed by mapping of the supply system, then a walkthrough of the entire supply system network to identify potential hazard, risk and existing control measure. Based on these, the next step is the development and implementation of system, together with monitoring of control measures. It is also important to document every step of the process. Currently various water supply schemes or systems are employed in a rural community setting, depending on various regional or local factors.

2.2 Objectives

In view of the disparities between rural and urban drinking water management and the many issues facing rural drinking water, this study aims to review research on drinking water management or interventions in rural communities, with a specific aim to identify aspects of the management or intervention that are important in the implementation of a rural or small-communities drinking water system.

Rural drinking water management comes in many forms, they may be targeting one aspect of the supply network, such as an intervention for improving water supply, or water treatment options. Or they may be in a form of an integrated management to improve the whole system. These systems can be costly, in term of financial cost or man hours. They are implemented to achieve the target of delivering safe drinking water to the community. As such the systems or interventions need to be evaluated for their effectiveness to ensure that a good management system can be identified and replicated, and problems and weakness can be rectified or reduced. Therefore, evaluation studies are very important for public health programs. Many studies have been done to evaluate these management strategies, and some systems have been more extensively studied than others. Evaluation studies also use different outcome measures to evaluate the management systems or interventions. The most common outcome measures are water quality and health impact, while a few has looked at reliability, sustainability and cost effectiveness.

There is a need to gather the information from these evaluation studies to assist in moving forward in different areas of rural drinking water supply. There are still many communities which are looking for the right management solution that would help them to improve their drinking water supply system. As much as rural water supply and small community water systems globally share in their characteristics, there will certainly be local factors that would make certain strategies more difficult to implement. As such this review intends to expand the knowledge base on different drinking water management strategies available for rural drinking water supply.

The review will be limited to strategies that focus on management from source to tap and will not include evaluation of point of use interventions, unless they include an evaluation of overall management or source intervention analysis. This review will also avoid studies that only focus on the evaluation of impact based on pathogen reduction or on diarrhoea as these has been widely covered in previous systematic reviews and meta-analysis, unless it forms a part of a more integrated evaluation.

2.3 Methods

2.3.1 Search strategy

Three online databases, OVID, Web of Science and Cochrane Library were searched for studies which evaluated rural drinking water or small-community water supply managements. In the search strategy, an initially broad search was done for 4 groups of key terms, including all relevant sub headers, and then matching the results to yield the relevant papers. The 4 grouped key terms were “evaluation or assessment”, “management or intervention”, “drinking water or water supply”, and “rural or small communities”. This was then followed by systematically excluding papers after reviewing the title, then the abstracts, and finally the full paper to select the papers based on the selection and exclusion criteria. Bibliographies of the selected articles were further searched for additional relevant papers that were again assessed by the same criteria.

2.3.2 Selection and exclusion criteria

2.3.2.1 Study design:

To include papers which evaluated interventions that are not commonly looked at or new methods of evaluation, the search was not limited to any specific study design. However, the study must be able to provide; 1) a clear description of the intervention being studied and 2) a clear description of the evaluation method used. The review had included quasi experimental, case studies, cross sectional studies and longitudinal studies.

2.3.2.2 Intervention or management scope:

The scope covers management of rural or small community water supply system between source to tap. The definition of rural or small community water supply can vary between countries or regions, often defined in term of relation to urban areas or in the size of the water supply population. The interest is more in the characteristics of the water supply and this fits with the definition of rural water supply in German Federal Ministry for Economic Cooperation and Development Environmental Handbook (BMZ, 1996) and definition of small scale water supply in WHO guiding document on small scale water supply in the pan-European region (WHO, 2011). Papers which only reviewed point of use water treatment evaluation studies were excluded from selection. If they also include source to tap management system, they will be included with focus on the source to tap relevant findings. Studies which do not clearly mentions whether these were conducted in rural or small community settings will be evaluated on the characteristics to see if it bears similarity to a rural or small community settings. Studies that are selected may look at specific intervention points in a water supply system or a comprehensive evaluation of a management strategy.

2.3.2.3 Outcome measure:

The review is interested in a wide range of outcome measures which may help identify factors that work in rural drinking water management. This includes outcome measures of functionality and sustainability against factors that may impact them, such as the characteristics of drinking water management (eg; water committee, source of funding, collection of fees) and costs. However, studies evaluating only the health impact or water quality of different types of improved water sources, which has been analysed in much larger systematic reviews, were excluded from this study. Studies that focused only on chemical risk such as arsenic would also be excluded from the study.

All papers that were selected were then assessed for their quality, and the characteristics and key findings of the study were identified and categorised.

2.3.3 Study appraisal

The quality of the studies was assessed using several tools as reference. The tools were loosely adapted in view of the mixed characteristics of many of the studies selected in this review. For cross sectional and longitudinal studies, the NIH Quality Assessment Tool was used, for mixed method, quasi experimental studies both the Critical Appraisal Skills Programme (CASP) tool and Quality Assessment Tool (QAT) from Effective Public Health Practice Project (EPHPP) were used as reference.

2.4 Results

Initial search yielded 1173 results. After going through the titles, papers that are clearly not relevant to the subject of study were removed. This resulted in a list of 93 papers. After going through the abstracts of the 93 papers, the list was reduced further based on the inclusion and exclusion criteria set in the methodology. This included papers which were clearly described in the abstract as having only health outcome or water quality outcome. The list of papers was then shortlisted to 20 papers. The full text of the 20 papers were acquired, and after reading through the full article, 9 papers had to be excluded for various reasons explained in Table 2.1, leaving 11 papers that were found to fit the criteria. The search was also expanded by looking for relevant references in the selected papers and as a result, 4 more papers were found that could be included in the study. In total 15 papers were included for this review (Figure 2.1).

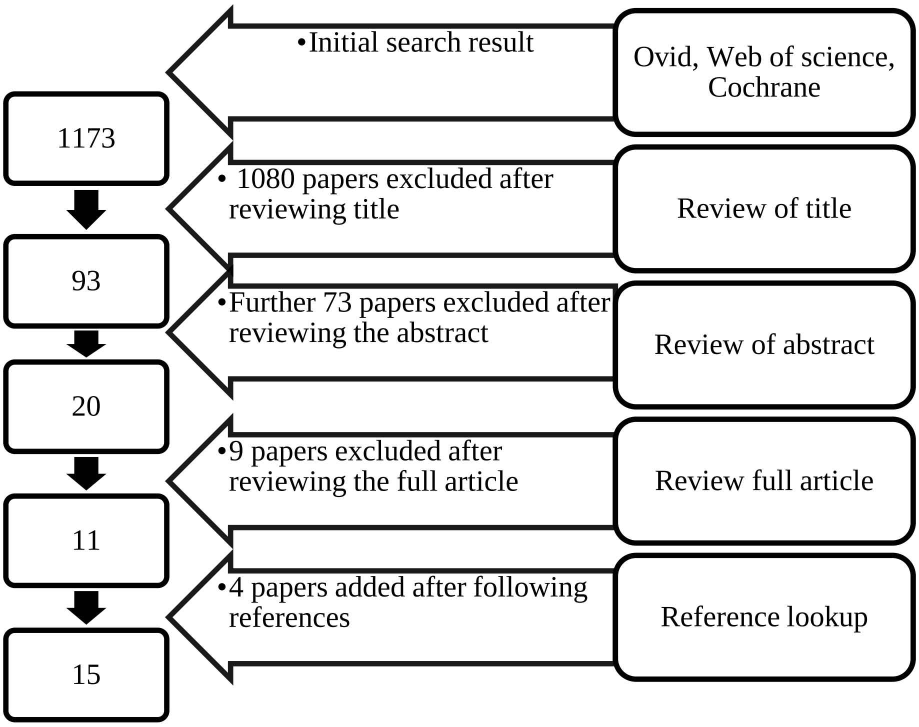

Figure 2-1 Article selection flow chart

Table 2.1 List of excluded papers and reason for exclusion

Papers	Reason excluded
Murthy BM, Girijamma AR and Bejankiwar RS. 2004. Development of an evaluation criteria for rural water supply and environmental sanitation program in project and non-project villages--a case study. Journal of Environmental Science & Engineering 46 (1): 41-8.	Case study focused on development of evaluation criteria
Swistock BR, Clemens S, Sharpe WE and Rummel S. 2013. Water quality and management of private drinking water wells in Pennsylvania. Journal of Environmental Health 75 (6): 60-6.	A description of water quality without evaluation
Postma J, Butterfield PW, Odom-Maryon T, Hill W and Butterfield PG. 2011. Rural children's exposure to well water contaminants: implications in light of the American Academy of Pediatrics' recent policy statement. Journal of the American Academy of Nurse Practitioners 23 (5): 258-65.	A review of current status rather than a study on impact of management
Checkley W, Gilman RH, Black RE, Epstein LD, Cabrera L, Sterling CR and Moulton LH. 2004. Effect of water and sanitation on childhood health in a poor Peruvian peri-urban community. Lancet 363 (9403): 112-8.	Evaluation done on health impact only
Hunter PR, Zmirou-Navier D and Hartemann P. 2009. Estimating the impact on health of poor reliability of drinking water interventions in developing countries. Science of the Total Environment 407 (8): 2621-4.	Outcome measure of health benefit based on probability of pathogen infection.
Harvey PA. 2011. Zero subsidy strategies for accelerating access to rural water and sanitation services. Water Science & Technology 63 (5): 1037-43.	A description of strategies rather than actual evaluation
Opryszko MC, Guo Y, MacDonald L, MacDonald L, Kiihl S and Schwab KJ. 2013. Impact of water-vending kiosks and hygiene education on household drinking water quality in rural Ghana. American Journal of Tropical Medicine & Hygiene 88 (4): 651-60.	Only provide water quality outcome
Arnold M, VanDerslice JA, Taylor B, Benson S, Allen S, Johnson M, Kiefer J, et al. 2013. Drinking water quality and source reliability in rural Ashanti region, Ghana. Journal of Water & Health 11 (1): 161-72.	Only provide water quality outcome
Brown J, Hien VT, McMahan L, Jenkins MW, Thie L, Liang K, Printy E and Sobsey MD. 2013. Relative benefits of on-plot water supply over other 'improved' sources in rural Vietnam. Tropical Medicine & International Health 18 (1): 65-74.	Water quality and diarrhoeal outcome only

From the 15 papers, 3 are cross sectional studies, 2 case studies, 2 longitudinal studies, 3 quasi experimental and 5 papers using cost effectiveness or cost benefit analysis modelling. Selected studies included 11 different countries. Ethiopia, Liberia, Sierra Leone, South Africa, Tanzania and Uganda from African region, Bolivia from South Americas, New Hampshire and Mexico in North Americas and Bangladesh and India from South Asia.

Most of the studies were looking at community managed improved water supply, however there are two studies that include community-based water treatment system, and one study that involved private rural water supply. Almost all types of improved water supply technology are included in the 15 selected studies. There are 31, 094 different water points of various type or technology studied in the selected papers, these mainly comes from two research papers which used available water point mapping data. Water point mapping is a program originally tested by Wateraid in Malawi in 2002, but has now been applied in several African countries. The program assigns every improved water source point with global positioning system (GPS) data, and collects other information such as ownership, functionality, and management issues that is merged with the GPS data, allowing each of this water points to be mapped with important data on functionality attached to them. If a village has 5 tubewells for example, then each tubewell is a single water point.

Characteristics and descriptive statistics of the 15 articles are summarized in Table 2.2 below.

Table 2.2 Characteristics of the 15 selected articles

Study	Location	Study design	Study quality	Type of water management system	Water supply technology covered	Number of water supply	Communities involved	Respondents involved	Intervention or management studied	Outcome measure
Alexander et al. 2015	Ethiopia	Cross sectional	Moderate	Improved rural community water supply	Deep well, handpump, protected spring	89	89	NS	Community water schemes	Functionality status, score, governance characteristics
deWilde et al. 2008	Guerrero, Mexico	Longitudinal study	Moderate	Community based water treatment	UVwaterworks purification system	21	21	NS	Community water treatment	Technical status, use by community
Eder et al. 2012	Bolivia	Quasi experimental	Strong	Community water systems	NS	NR	14	316 individuals 66 households	Development assistance program	Status and sustainability of water systems
Foster et al. 2013	Liberia, Sierra Leone, Uganda	Cross sectional	Strong	Community managed water supply	Borehole and shallow/hand dug handpump	25061	NS	NR	Community managed handpumps	Functionality status, governance characteristics
Gupta et al. 2012	Tamil Nadu, India	Quasi experimental	Strong	Rural water supply	NS	NR	2	225 household	Community Health Worker Program	Knowledge, seeking treatment, use of ORT
Jimenez et al. 2011	Tanzania	Cross sectional	Moderate	Improved rural water supply	Handpumps, motorised pumps, gravity fed	5921	NS	NR	Community water schemes	Functionality rate, management factors
Mahmud et al. 2007	Bangladesh	Case study	Strong	Rural water supply	All type except gravity fed	NS	82	NS	Water safety plans	Sanitary risk, tool effectiveness
Majuru et al. 2012	Limpopo, South Africa	Quasi experimental	Strong	Rural small community water supply	Handpump, water tank, holding tank, small scale plant	2	3	114 households	Water supply upgrade	Volume collected per capita, distance from source

Table 2.2 Characteristics of the 15 selected articles (cont.)

Minamoto et al. 2012	Bangladesh	Longitudinal study	Strong	Rural water supply	Tubewell	NS	4	550 children	Education program	Tubewell ownership, knowledge level
Paul et al. 2015	Tuftonboro, New Hampshire	Case study	Moderate	Private rural water supply	Private wells	NS	1	NR	Water testing campaign	Sample collection rate
Cameron et al. 2011	Limpopo, South Africa	CBA	Strong	Small scale water supply	NS	NS	1	NS	Small scale water supply	Capital cost, maintenance cost, cost benefit, CBA
Clasen et al. 2007	Afr-C, Sear-D	CEA	Strong	Rural water supply	Dugwell, borehole, communal standpost	NS	NS	NR	Rural water supply system	Costs, DALYSs, cost per DALY CEA
Hunter et al. 2009	Amr-A, Eur-A, Eur-B, Eur-C, Wpr-A	CBA	Strong	Rural community water supply	NS	NS	NS	NR	Small Community water supply	Capital cost, maintenance cost, cost benefit, CBA
Jeuland et al. 2009	Africa, South Asia	CBA	Strong	Rural community water supply	Deep well with public handpumps	NS	NS	NR	Deep wells with public handpumps, biosand filter, community vaccination, school vaccination	Costs, benefits
Pattanayak et al. 2010	Maharashtra, India	Quasi experimental impact evaluation	Strong	Rural community water supply	NS	NS	242	9500 household	Large scale program for community water supply	Illness cost, coping cost, cost savings

NS – Not specified. Where the information is not clearly specified in the article.

NR – Not relevant. Where the information is not relevant to the study

The selected papers covered various aspect of rural water supply management and intervention, and it would be easier to describe the result from these various aspects.

Eder, Gupta and Minamoto each looked at the effectiveness of community education intervention programs in promoting a sustainable change in behaviour and practice in drinking water safety in rural communities. Eder in his study found that the functional status of community water systems (condition of intake, collection and storage tanks, distribution networks, and pipes, water quantity and quality) was 42% higher in communities that were involved in a Development Assistance Program (DAP) compared to the control communities. The program employed learning by doing strategy to promote the implementation of community and household level water facilities. The DAP intervention community were also 30% more likely to sustain the system (based on the state of repair and maintenance) compared to control. Gupta however, followed up a Community Health Worker (CHW) program, and found that though knowledge on drinking water contamination has increased in the intervention community, there was no real improvement in positive behaviour (decision to treat water, hand washing and use of oral rehydration therapy) compared to control community. Minamoto on the other hand, found that both knowledge (worm transmission and illness that it causes) and practice (use of latrine and using clean water from tubewell in cooking and washing food) improved immediately after health education program to improve water supply, sanitation and knowledge on intestinal helminths. Tubewell ownership increased 18.7% in intervention communities with higher percentage of correct answers to knowledge questions. After 5 years however, only the positive practice is maintained, where tubewell ownership in the intervention communities were still higher compare to ownership before the program started, but knowledge score actually worsened (though not significantly), showing lack of sustainability of the knowledge gained.

deWilde and Majuru both described in some ways how an improved technology does not necessarily give the intended result. deWilde looked at the implementation of an ultraviolet purification-based community treatment system. On 5-year post installation follow up, all study villages (with or without UV Waterworks installed) had reported an average 25% fewer cases of diarrhoea per week in children under 5 compared to cases 2 years prior to installation of the system. In looking at the performance of the system however only 8 of the 21 systems installed were technically functioning. The study however found no correlation between the non-functioning system with organizational capacity, physical capacity or financial capacity. The study further noted that from the 21 communities with UV waterworks, only 3 communities has a substantial portion (>50% household) using the system. The study concluded that the system was not functioning because communities do no prefer to use them over other source of water available.

Majuru's study investigated two communities in Vhembe, Limpopo, that are having their water service upgraded by the local government and found that the upgraded systems were beneficial when they did work, but poor reliability had a detrimental effect on water supply to the community. In the first community, drilled wells with handpumps were upgraded to a pumped groundwater water holding tank with piped network to communal taps. The second community had received monthly water supply from a local municipality tanker and has been upgraded to a small-scale treatment plant that treats water from a river, stores it in elevated tanks and distribute the water via pipes to communal water taps. The improved water service systems (termed as basic services) provided better benchmark results compared to the previous water service systems (termed as rudimentary service), provided they are operational. The benchmark was based on WHO guidelines and included acceptable minimum distance from water source (500 metres) and acceptable per capita water collection (15 litres per capita per day). During non-operational period of basic services however, the amount of water collected was effectively reduced by 5.19 litres per capita per day (lcd) ($p<0.001$, 95% CI 4.06-6.31), while overall people have to go further to access water, as the difference in distance to source between no service and basic service was 639 metres ($p<0.001$, 95% CI 560-718).

Mahmud (2007) described the success of the implementation of water safety plans in the development and management of small water supplies in rural communities in Bangladesh, involving various communities and water point technologies, citing the importance of having simple tools, such as the pictorial community monitoring tools and ongoing surveillance. Another study, by Paul detailed a successful water testing campaign in Tuftonboro, New Hampshire for private owned wells testing. The campaign involved multiple approaches, including an awareness drive (presentation by experts to community selectboard, news articles and distribution of information by mail), and employment of voluntary sample collectors who aided in collecting and sending samples, resulting in a marked increase in delivered water samples. 285 samples were collected in two sampling periods in 2012 and 2013, compared to 83 samples tested in the previous six years.

Three studies looked at water system functionality and governance characteristics such as the role of water committees, fee collections and expenditure. Functionality of these water points were either defined broadly in terms of regular water availability and day to day use by the community or in more detail, including water flow rate, drainage and construction quality. Jimenez looked at functionality of handpumps in Tanzania and found that functionality is linked to water committees having meeting, income and expenditure, especially at supra regional and regional level. At district level, expenditure is the main aspect of significance in water system functionality. Alexander studied water schemes in rural Ethiopia, and though they did not found significant difference in management practice between functional and non-functional water points, when the functionality was given a scoring instead of just a yes or no value, the analysis revealed significant differences between functionality score with management aspects of having regular meetings, good record keeping, financial audits, monthly fee and caretaker compensation (Table 2.3). It was also interesting for the study to find a significant inverse relationship between functionality score and whether the community was consulted about location of water point before it was set up. Foster studied a large database of community managed handpumps in Liberia, Sierra Leone and Uganda and found significant relationship between functionality and regular committee meetings, revenue collection, distance from spare parts and distance from capital (Table 2.3).

Table 2.3 Summary of significant findings from Foster and Alexander

Foster (2013): Logistic regression for non-functionality of water point			
Outcome Variable categorized by country	**OR**	**95% CI**	**P value**
Longer age of water point			
Liberia	1.17	1.12-1.22	**P < 0.001**
Sierra Leone	1.14	1.11-1.17	**P < 0.001**
Uganda	1.16	1.14-1.18	**P < 0.001**
Water point type: Borehole instead of hand-dug well			
Liberia	0.89	0.71-1.12	0.332
Sierra Leone	0.84	0.68-1.03	**0.008**
Uganda	0.48	0.44-0.52	**P < 0.001**
Water point installed by NGO instead of government			
Liberia	1.37	0.80-2.34	0.249
Sierra Leone	0.65	0.54-0.78	**P < 0.001**
Uganda	1.62	1.44-1.82	**P < 0.001**
Water committee not having regular meeting			
Uganda	2.80	2.55-3.08	**P < 0.001**
Water committee not having training			
Uganda	1.30	1.19-1.42	**P < 0.001**
No female in key committee position			
Uganda	1.61	1.47-1.75	**P < 0.001**
Committee without revenue collection			
Liberia	1.53	1.26-1.85	**P < 0.001**
Sierra Leone	1.81	1.47-2.23	**P < 0.001**
Uganda	3.31	3.03-3.60	**P < 0.001**

Table 2.3 Summary of significant findings from Foster and Alexander (cont.)

Outcome Variable categorized by country	**OR**	**95% CI**	**P value**
No regular servicing of system			
Uganda	2.85	2.61-3.12	**P < 0.001**
Longer distance from spare parts			
Sierra Leone	1.95	1.56-2.43	**P < 0.001**
Longer distance from capital			
Liberia	1.11	1.08-1.14	**P < 0.001**
Sierra Leone	1.09	1.05-1.13	**P < 0.001**
Uganda	1.12	1.09-1.15	**P < 0.001**
Poor perception of water quality			
Liberia	2.82	2.35-3.38	**P < 0.001**
Sierra Leone	2.86	2.35-3.47	**P < 0.001**
Alexander et al.: Mean difference of functional water points scoring (higher score means better functionality)			
Outcome variable	***β***	**CI**	**P**
Community consulted about location	-1.40	-2.60 - -0.19	**0.02**
Committee has regular meetings	1.27	0.20-2.33	**0.02**
Good record keeping	2.60	0.72-4.42	**0.01**
Periodic financial audit	2.69	1.44-4.22	**< 0.01**
Caretaker	1.82	0.46-3.17	**0.01**
Caretaker receives compensation	1.30	0.17-2.42	**0.03**
Committee can do minor repairs	3.00	1.03-4.96	**0.01**

Five papers in this review focus on economic evaluation, using either cost effectiveness or cost benefit analysis to evaluate rural water systems.

Clasen calculated regional cost-effectiveness for non-piped source and household interventions in two WHO epidemiological sub-regions, Afr-E and Sear-D of developing countries. The non-piped source interventions included in the calculation are dug wells, boreholes and community stand posts. The source interventions were found to be highly cost-effective in Afr-E and cost-effective in Sear-D. They remain cost effective even after sensitivity testing at low effectiveness estimate.

Hunter et al. estimated the cost and benefit of small water supply interventions in five developed WHO epidemiological sub-regions. The study adapted various definitions of small supplies as they differ between countries, and includes for example; small and very small community supplies, and private wells. They calculated the cost of interventions (improving or repairing failing water supplies to standard, and the cost of maintaining them). They could show that for each of these sub-regions, the benefits of intervention significantly outweigh the costs.

Jeuland compared the cost benefit of two water interventions (deep borehole with public hand pump and biosand filters point of use treatment) and two vaccination strategies (community-based and targeted school-based), including their combinations. The study found that economic benefits are more in favour of the two improved water supply interventions and targeted cholera vaccination. The study also noted that vaccination program is not justified when water intervention has been implemented, especially when the water intervention is biosand filters. Water intervention is still beneficial even after vaccination has been applied in a community as they yield many other benefits, such as saving time for collecting water.

Pattanayak estimated the economic benefits of a large-scale government project (backed by The World Bank) of community driven water supply improvement in four districts in Maharashtra, India. In this program, the community worked together to improve their water supply, choosing a system that best benefits them and applying for government involvement. The community pays 10% of the capital cost and 100% of the operational and maintenance cost of the system. It was a 5-year program that was implemented in about 2800 villages in 26 districts. From a sample of 242 villages in four of the districts, the study found that the average household could save as much as 7 usd per month in coping cost (time spent collecting water, time spent going to the toilet, cost of treating water and cost of storing water) and that poorer households stand to benefit more.

Cameron conducted social cost benefit analysis (SCBA) of small scale drinking water intervention using data collected from a village in Limpopo. The study is based on a case study in Folovhowde, Limpopo, involving an intervention to upgrade the groundwater community drinking water supply system of the village. Based on the collected data the study calculated a Present Value Benefit (PVB) of R 34 million and Present Value Cost (PVC) of R 11 million. SCBA analysis produced a Net Present Value (NPV) of R 11 million and a PVB/PVC ratio of 3.1. This showed that the intervention was justified in monetary terms.

2.5 Discussion

The findings from this systematic review have provided information on various aspects of rural water management. The mix of research methodology, outcome measure and type of data collected does not allow us to conduct an aggregation of the results or meta-analysis, but some of the studies are similar and some support the findings of other studies. The systematic review could also have benefitted from a local database search of research done in similar regions, such as a search in South East Asian journals or in grey literature which could provide data from smaller scale but relevant studies. This can perhaps be done in the future with a larger collaborative effort and focus on systematic review, but was not achievable within the limitation of the current study.

Targeting knowledge, attitude and practice or behaviour change through education or empowerment is a well-used strategy in promoting the implementation of public health programs. It can however be complicated to achieve the desired effect, depending, among others, on the subject matter, the community background and the difference in approach. Knowledge does not always translate to practice, so various approaches need to be tried to achieve a better result. The findings of the studies from Eder, Gupta and Minamoto are valuable to understand these dynamics in the context of rural communities and rural drinking water supply. These studies evaluated 3 different approaches in the context of education intervention that has been used in rural water supply setting, a Community Health Worker program (CHW), a Development Assistance Program (DAP) and another study on a more conventional health education program.

Eder and Minamoto both found that changes in practice (water supply maintenance) were maintained after follow-up, however, Gupta discovered that only knowledge remains but practice (seeking treatment and taking oral rehydration therapy) was not sustained. One way to explain this is by looking at the type of intervention programs. Eder and Minamoto both studied programs that involved more community participation in building the water supply system. Minamoto, for example, measured tube well ownership, where the tube wells were built by the community themselves, while Eder measures maintenance of water and sanitation infrastructure that again was built by the community with support in the form of education and training from external party. This suggests that the more involved the community is in a program the more the positive practice in related to it can be sustained. Indeed, Minamoto found that at follow up practice was still higher than baseline, but knowledge and house cleanliness had dropped from immediate post intervention period (endline). Gupta on the other hand focuses on behaviour changes of treating water at home and taking oral rehydration salts. Community engagement in the CHW program studied by Gupta was limited, as selected villagers are trained as CHWs and mainly trained to promote healthy drinking water practices and education activities among the villagers. This shows that behaviour changes are very complex and would take more involvement than just education to achieve a sustainable change.

Paul in their private water testing study had showed how campaigns can be successful to promote positive practice. However, how it sustains the positive practice needs to be considered. They described the underlying barriers to water testing (eg: lack of awareness, testing schedules, financial costs), and during the campaign these barriers were quite effectively reduced. There was an awareness campaign coupled with volunteers doing sample collection for the two-year period of the program. It would need to be further investigated how this had influenced further practice of water testing after the program, whether changes have been made to have a permanent solution to reduce the barriers or not.

In Mahmud's study, it was encouraging to discover the success of water safety plans model in the development and implementation of rural water supplies, since WSPs are being implemented more widely, and this include in countries like Malaysia, where many safe drinking water supply issues comes from rural or remote areas. Though the study was not able to evaluate the community tools in a quantitative manner, it has provided valuable feedback nonetheless from rural communities. One issue it noted was in the low action on record keeping, where 58% of system caretakers did not maintain a proper record chart. As record keeping is important for a continuous system improvement, it would useful to study this further, perhaps looking at the differences between caretaker background, whether this has any influence. One possibility is to try and develop a more user-friendly method, but again the issue itself need to be investigated further.

Majuru and deWilde showed how systems can be ineffective. There are many issues with the implementation of UVwaterworks in the community. deWilde concluded the failure is due to user preference. It is probably understandable as the community had access to different water supply. This is one of the issues in many rural areas, especially among the poorer communities. There are villages in rural areas which have been provided with piped water supply, but continue to maintain their own groundwater borehole or dug well supply. It has not been adequately discussed as to how much health risk the community in deWilde's study is exposed to in the light of having several sources of water.

3 papers discussed functionality of water treatment system in relation to management practice and financial factors. Two studies are large scale using available water point mapping database, though I was only able to get detailed data on the relationship with functionality with management practice in the study by Foster. Foster reviewed large amount of data and could show many factors that are associated with the functionality status of a rural water supply point. However, it has to depend on what available variables or information that have been collected in that national water point mapping survey. Alexander directly studied 82 water schemes and though initially could not find a significant relationship, when the functionality was detailed further and given a scoring, they were able to show some interesting findings, for example when they showed that consulting a community on water schemes location may not result in a more sustainable water scheme, but the opposite of it instead.

Alexander's study may lack the power in term of amount of water points studied, but could show differences by being more detailed in its collection of the water point characteristics and evaluation. To offer a detailed evaluation however it would be difficult to depend on available local data, as most likely it would not contain the necessary details required. Thus, it seems one is left with the choice of conducting a large research but with baseline information on characteristics or a smaller research but with more characteristics collected. This however shows that a localized study can work well if one can identify properly the variables that are important in that local setting.

The findings from these three studies agree in certain aspects. Mainly a working water committee with regular revenue give positive outcome towards sustainability. Access to technical support (distance to spare parts, committee can do minor repair, distance from capital) also helps a system to be more sustainable. Foster, with a large database found that presence of female in key position of water committee is important for sustainability, while Alexander found that good record keeping is important. Foster also noted that community perception of water quality plays an important role in the acceptance of the water treatment system. If they perceive that the quality of treated water is good, they would be more likely to support the system, making it more sustainable.

The five economic assessment studies included in this review looked at rural water supply but in different settings. Clasen evaluated intervention in developing WHO sub-regions while Hunter did so in developed WHO sub-regions. Pattanayak reported on a large-scale water supply program coordinated by the local government. Cameron and Pattanayak used data collected in the field compared to other studies which are based on available data in literature. However, these studies all showed positive outcome in term of the economic value of rural water intervention. Furthermore, most of the studies consider their calculation conservative in term of cost benefit as each study has their own limitation in which cost benefit that they considered in their analysis. Another point of note mentioned by Clasen is “who pays for the intervention”. This is an important question on the ground since the suggested models for rural water supply all require payment from the community. A sustainable community water supply model requires the community to partially pay for the capital cost and to pay for the service. A government water supply model would also certainly require revenue collection, and what more a private water supply model.

2.6 Conclusions

Even though this systematic review was not able to aggregate data to further substantiate the validity of the findings on the characteristics of a successful intervention, it has managed to provide input to various available approaches, discuss its weaknesses and strengths.

An intervention which involves the community in a hands-on approach, giving ownership or a sense of ownership is more likely to succeed than education and awareness alone. Ownership is expected to last longer than knowledge, at least when involving adults. Understanding the barriers, and removing them, effectively increases the targeted response that you are looking for.

Rural drinking water intervention's effectiveness depends on more than establishing infrastructure or having technical capabilities; among key factors is the reliability of the system and community preferences.

In term of rural community water management, important factors include presence of a caretaker, trained and working water committee with regular meeting, audit and record keeping, available revenue, presence of female in key positions, and again perception of the water quality itself. While in terms of an overall approach, WSPs have been found to be promising for application in rural or small water supply setting, with further evaluation of the tools that are available.

Studies on cost effectiveness and cost benefit analyses has consistently showed the economic benefit of developing rural drinking water supplies, but in term of local implementation, important questions, such as cost recovery within a government or organisation with limited available funding still remains.

These review findings are very relevant with the issues concerning the study population, and need to be taken in to consideration in the final conclusions of the whole study (Chapter 5). Also, some aspects noted in this review, specifically on user preferences and issue of cost will be explored further in the next chapter using a different methodology.

Chapter 3: Community perception of risk from their untreated drinking water supply and perception of chlorinated water

3.1 Background

The subject of study, briefly mentioned in the main introduction chapter (Chapter 1), is a small island community on the east coast of Malaysia, which is using untreated water as their source of water for drinking and food preparation. This fact alone is not entirely surprising since as a country, Malaysia is still working towards achieving safe water access to all, with many rural and remote areas still presenting a challenge. The story of Tioman however, is twice as interesting, since in this community, a water treatment plant has already been built for the community (in 2008), but has been more or less abandoned. Below, I will go into further detail to define the community and the problem regarding their drinking water supply.

3.1.1 The site

This study will be conducted on the Island of Tioman, which is under the state of Pahang. Pahang is one of the 14 states in Malaysia, consisting of a large territory situated on the east coast of West Malaysia (Figure 3.1). Tioman Island itself, though administratively falls under Pahang, geographically, lies closer to the coast of the state of Johor, which is just south of Pahang (Figure 3.1). There are two jetties from the mainland which are used to get to the island, the main, more popular jetty in Mersing, Johor, which is about 50 kilometres away, and the second one being Tanjung Gemok, Pahang, which is about 60 kilometres away. For better perspective, these jetties are about 4-5 hours' drive from Kuala Lumpur, Malaysia's capital. Then, from these jetties, it takes a further 2-hour ride by ferry to get to Tioman Island (Figure 3.1 Tioman Island: located on the east coast of West Malaysia).

Figure 3-1 Tioman Island: located on the east coast of West Malaysia

The island span is about 130 sq. kilometres. With the longest stretch of about 20 kilometres from north to south and longest width of 8 kilometres east to west, the island is shaped somewhat like a pear (Figure 3.2). The central part of the island consists of hilly terrains and dense vegetation. All the villages lie on the west or east coastal side of the island, where getting from one village to another requires travel by boat (though trekking routes can usually be found through the hill and trees for the adventurous), and only Kampung Juara and Air Batang are connected by some form of road to the main village of Tekek. There used to be a flight service from Subang, near Kuala Lumpur, via a chartered flight, but the operation by Berjaya Air has been suspended in 2014, and it is currently unclear when such service will be made available again.

Figure 3-2 Tioman Island map

3.1.2 The people

According to a 2014 report (Lembaga Pembangunan Tioman, 2014), the 3300 plus population (Table 3.1) living along the coastal areas of the island, can be grouped into 8 different villages, namely Tekek (the main and largest village), Air Batang, Salang, Genting, Paya, Lanting and Mukut on the western coast, and Juara on the eastern coast (Figure 3.2 Tioman Island map).

Table 3.1 Tioman population data

Villages	Household	Resident
Salang	36	279
Air Batang and Tekek	459	2092
Paya, Genting and Lanting	86	435
Mukut	41	225
Juara	62	283
Total	**687**	**3314**
Source: Tioman Development Board Annual Report, 2014		

The village of Tekek is the main or central village of the island, located on the western coast. It is connected by road to Juara, which lies on the eastern coast of the island, allowing travel between the two villages by car, pickup trucks and motorbikes, albeit via a steep road up and down as it crosses through the middle of the island, which is the peak hilly part of the island (Figure 3.3). Tekek is also partially connected to Air Batang, just towards the north of it, by road, as the road from Tekek stops just a few hundred metres from Air Batang, replaced by a paved stairs and walkway around a cove (Figure 3.4). Getting to other villages from Tekek requires travel by sea route, usually by motorboats or ferry boats (Figure 3.2). Tekek has an airport, a clinic, a mosque, a primary and a secondary school, and several government and private offices and housing quarters. To the south of Tekek, is the largest resort in Tioman, which is called Tioman Berjaya Resort.

Figure 3-3 The road that connects Tekek to Juara on the other side of the island

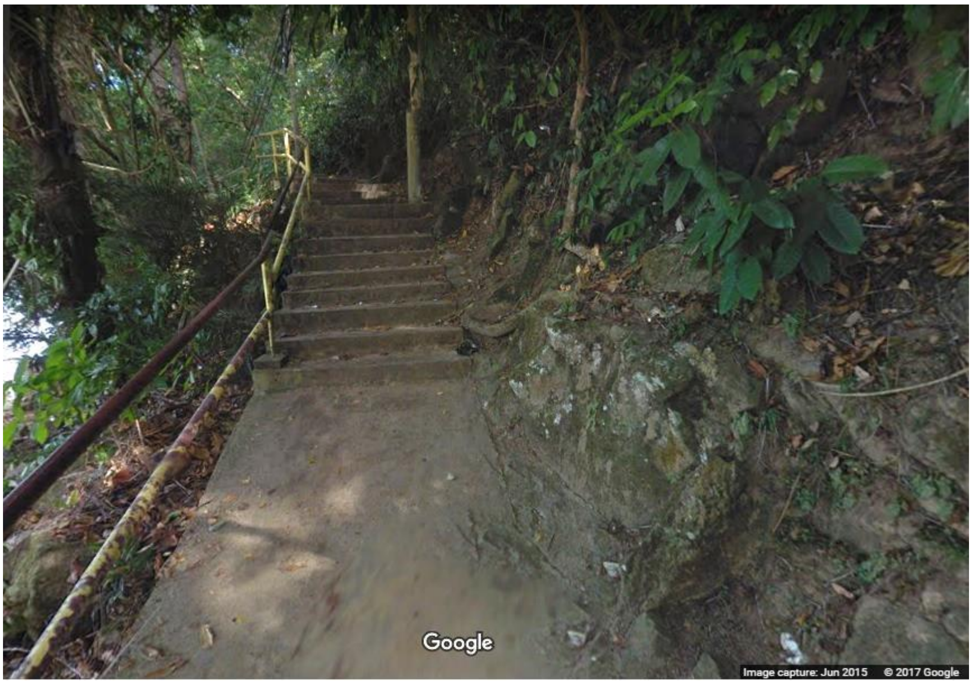

Figure 3-4 Need to climb around a cove to get from Tekek to Air Batang. Image downloaded from Google Map on 15 August 2017.

Air Batang, which lies towards the north of Tekek (Figure 3.2), is a small village compared to Tekek, where there are no big roads, just a small paved single lane pathway, big enough for a 3-wheel motorbike, the main vehicle for transporting goods between people there. Towards the south of the village one can climb a paved stairwell and path towards Tekek, making it somewhat more easily accessible from the main village compared to some of the other villages. Despite the small size, it plays a key role when discussing the issue of water supply, because it is located between Tekek and another village further north, Salang which often faces the problem of water scarcity in the dry seasons (Figure 3.2).

Salang, though is moderate in size, is known for having a good reputation among tourists. However, geographically, it is relatively far from a hilly central region, so most of it water comes from surface water from comparatively low-lying rivers in the inland. Because of this, it often suffers from low water supply during the dry months. One of the solution that has long been suggested but has yet to be implemented were to build water supply pipes from Tekek to supply water to Salang, however these pipes has to go through the village of Air Batang, and this requires their permission and agreement as it involves placing these pipes on land that belongs to the people of Air Batang (Lembaga Pembangunan Tioman, 2014).

Then towards the south of the main village of Tekek, the most notable village would be Genting, one of the more famous villages among tourists, mostly for those coming from Singapore, Malaysia’s neighbour to the south. Close to it are smaller villages of Paya, Lanting and Mukut. Finally, to the east of Tekek, there is Juara, famous for beautiful beaches and a turtle sanctuary. It is the only village that lies on the east coast of Tioman (Figure 3.2). It is however connected to Tekek, the main village via a road that was built across the central hilly part of the island.

3.1.3 The Water

According to the Assistant Environmental Health Officer who was working at the health clinic in Tekek, the population of Tioman mainly consume water from gravity feed systems, build by the authorities and supplied through a network of pipes. The authority in charge of supplying water is Jabatan Bekalan Air (JBA) Tioman, or translated to english as Tioman Water Supply Department. In the past, workers along with the help of the locals, would identify the source of water in the high hills in the central region of the island, mainly large streams, and build a dam around the water source (Figure 3.5). Pipes were then connected from these water sources to the houses in the villages. Each village normally has one of these dams in the hills built for them. There is no treatment being applied, and water is supplied directly to the houses. These are the official dams, supplying to both the local and tourist chalets, however, there are other smaller, private connections that some of the chalet operators may have made to get more water to their customers. These private connections are normally just pipes that goes into the ground near spring water and does not normally involves any kind of dam being built. In the village of Salang however, local residents mainly depend on river water and ground water (Figure 3.6, 3.7 & 3.8). The location of the village somehow meant that geographically, there is only low-lying river that is available for them as a main water source. As such they do not have a gravity fed system supplying water; instead pumps are used to pump water up from the river, and to the houses in distribution pipes.

Tioman Island experiences periods of heavy rains from October to March (Figure 3.10), and during sunny periods, Salang will experience drying of river beds. To counter this, the people in the village, with the help of the authorities have resorted to using ground water via boreholes as an alternative source (Figure 3.6, 3.7 & 3.8). As much more work and machinery is required to build a groundwater source there a limited number of these groundwater sources available in Salang, mainly providing to the southern part of the village.

The authorities completed building a water treatment plant in Tekek in 2010, with the objective of providing treated water to the island, starting from the main village, but it has stopped treating the water, and is currently only acting as a reservoir of the water collected form the gravity feed dam, before supplying the water to everyone in the village through pipes to house taps

(Figure 3.9). It was also to be used as source of water supply to the village of Salang, however to date the authorities has not been able to gain approval from the villagers from Air Batang to build pipes in their land to supply water from the treatment plant (reservoir) in Tekek to Salang.

Figure 3-5 Kampung Juara gravity feed dam (drinking water source)

Figure 3-6 River or surface water source for Salang during wet season

Figure 3-7 The same river as above during dry season

Figure 3-8 One of the boreholes in Salang, a relief during dry season

Figure 3-9 Mostly abandoned water treatment plant in Tekek

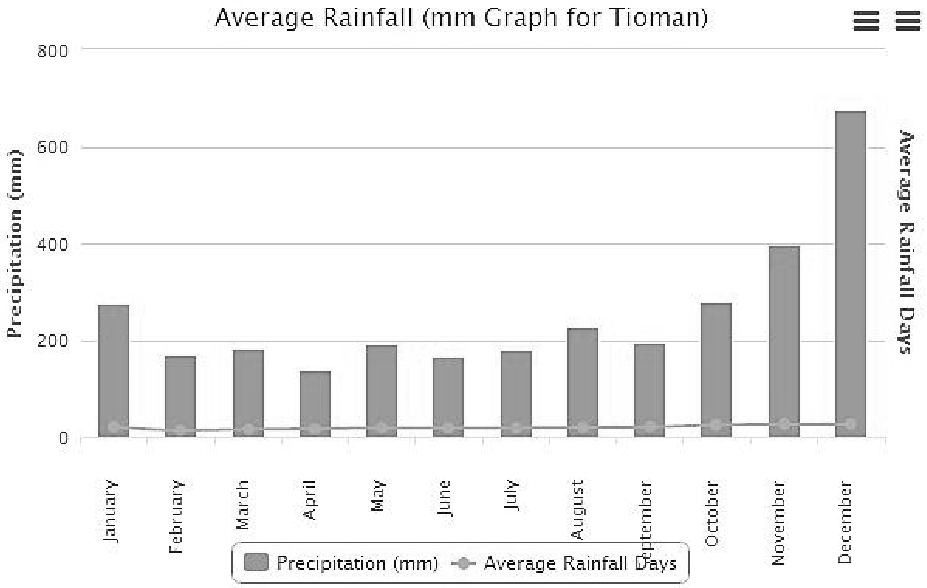

Figure 3-10 Tioman Annual Precipitations and Rainfall Days (Source: World Weather Online, 2014)

3.1.4 The perception

From an initial visit that was conducted before the start of this study, I discovered several underlying issues related to the problem of providing safe drinking water supply in Tioman from informal conversations with clinic staff, health inspectors, boatmen, ordinary villagers and other government officers. There were many different and opposing viewpoints about water supply issues. The main talking points included the abandoned water treatment plant and chlorination of drinking water. I managed to identify and group them into three main points; i) risk perception of their drinking water supply, ii) perception of water treated with chlorine and iii) practices related to drinking water.

3.1.4.1 Perception of risk from untreated drinking water source

The main point given by the locals when discussing the need for water treatment was that the water supply that they are using is perfectly safe for direct consumption. They would argue that they have been consuming the water for years without any ill effect to themselves or to their family members. Because of this, they do not feel they need to receive treated water, moreover pay for it. These was categorized under the issue of risk perception.

3.1.4.2 Perception of chlorine or water treated with chlorine

The second main point, felt largely linked to the perception of water treated with chlorine, including willingness to pay the water bill. The water treatment option that the authorities tried to implement in Tioman but so far has failed, and that they are still planning to implement in the future, is similar to countrywide water treatment method, which is by building a chlorinated water treatment plant, supplying the water through pipes direct to the taps in the houses, and charging usage bills to the consumers via water meters. In Tioman, the mention of chlorinated water would bring about comments of how chlorinated water does not taste nice compared to natural water, and how the chemicals could be dangerous instead of beneficial.

3.1.4.3 Practices related to drinking water

Finally, the third main important point regarding the problem that the community is facing with their water, is related to their own drinking water practices. It included the practice of treating the water that they use for drinking and the practice of drinking water direct from tap. These issues are important to be investigated since they are related to the community's perception of their drinking water source, and is important in the understanding of the actual exposure of the community to untreated drinking water.

These three areas are the main points being raised by the different stakeholders. How much of these factors play a role, how common is it among the locals, these can only be made clear by further investigation. Since, as have been discussed in the introductory chapter, these perception issues play a role in how much people are going to accept and support an intervention, including drinking water supply management (Dupont, 2005; de França Doria et al., 2009), there is a need to identify the issue more clearly, perhaps quantitatively to help in a systematic approach in solving this drinking water supply issue.

To answer these questions, this study used a risk perception framework model adapted from the thesis by de Franca Doria as baseline (de França Doria, 2004). Though de Franca Doria's framework was focused on identifying the important factors that play a role in the perception of water quality and risk (Figure 3.11), I have adapted the framework to investigate the factors (eg: organoleptics, demographics) that influence risk perception and water treatment perception in this small island community and how risk perception affects their attitude and actions regarding drinking water consumption and drinking water treatment (Figure 3.12).

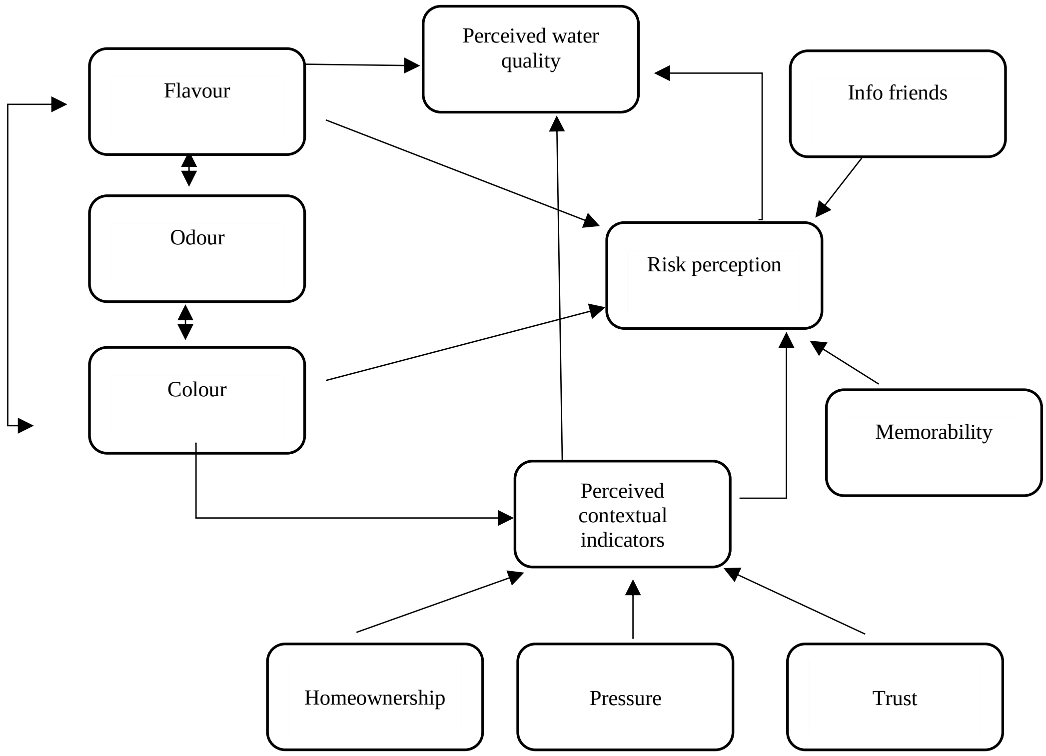

Figure 3-11 Model of factors affecting drinking water risk perception (de Franca Doria, 2004)

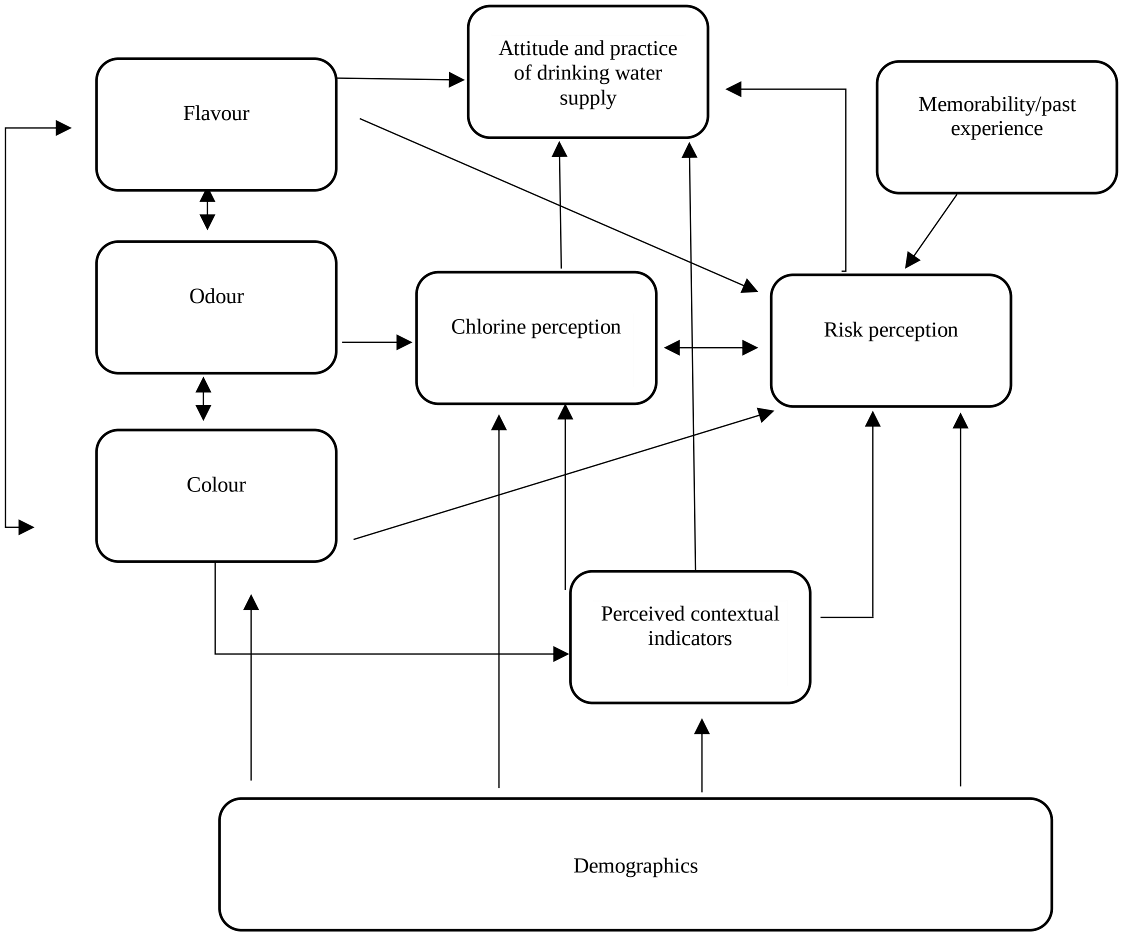

Figure 3-12 Model of factors affecting drinking water risk perception, chlorine perception, attitude and practice (modified from de Franca Doria, 2004)

3.2 Hypotheses

Risk perception of the respondent of their drinking water source may be influenced by several sociodemographic factors, including age, gender, education level, income level, household factors, traditional customs and beliefs and which village he or she lives in (Omar, 2016; de Franca Doria, 2010; Anadu, 2000; Grondin & Levallois, 1999).

- An older person may for example be immune to waterborne illness and feels no harm can come from the untreated drinking water. In term of gender a woman may be more protective and be more perceptive to information about risk or illness among her children.

- As respondent does not necessarily live alone, but with family or other members of the household, it is possible that the respondent's perception may also be influenced. Household factors that may be important include highest education level in household, since a family with a highly-educated person may be influenced by that person in term of drinking water perception. Also, there is a need to consider highest household income, because for one, the respondent may not be the main income earner, and the income earner may have more say on the household, and secondly, the highest household income may reflect the economic status of the household better than the income of the head of the household.

- Household size or number of people living in the household may also be an important factor, since if there are issues like water shortages, water supply fees and people with large family will be more affected by it.

- Since a person's perception may be linked to local customs and belief, one of the ways to look out for that effect is by identifying whether the respondent had been born in Tioman, or from somewhere else. Also, considering as local customs can be learned, it would be good to see if perception is influenced by how long the respondent has lived in the house. Another way of looking at this is by looking at the house ownership question, which can differentiate between those that own houses or those living in staff quarters, where a higher percentage would be people coming from outside of the island to work there.

- As the villages on the island has different characteristics which are relevant to the issue of drinking water supply, it would be interesting to see whether there is an effect of village of respondent on perception.

Previous studies have shown that risk perception may be influenced by perceived water quality, such as taste, colour and odour (Nauges & Van Den Berg, 2009). Other perceived input that may affect risk perception includes contextual perception such as a person's perception on water supply reliability or water pressure (de Franca Doria et al., 2009). It is important to assess how much these factors play a role in shaping the respondents' risk perception.

In this study, there is also interest in the relationship between perception and drinking water practices such as whether the respondent drink direct from tap water and whether drinking water source is treated before use (Nauges & Van De Berg, 2009; Anadu, 2000). The study will assess how these attitude and practices are influenced by sociodemographic factors, perception of the water supply and risk perception.

The study is also interested in looking at attitude, perception on chlorine and willingness to pay for treated water supply, and how other perception and sociodemographic factors of the respondent influence them.

3.3 Objectives

- To identify the factors associated with risk perception of the respondents towards their drinking water source.
- To identify the factors associated with chlorine attitude and perception among the respondents and their willingness to pay for water treatment with chlorine.
- To identify the factors associated with drinking water practices among the respondents.

3.4 Methodology

The study was conducted using survey questionnaire and convenience sampling of the study population. The questionnaire was administered via face to face interview of each household selected for the study.

3.4.1 Ethical considerations

Since the study used a questionnaire to collect information from respondents, it required ethical approval to ensure ethical considerations had been met. The study had received ethical approval from both the University of East Anglia (UEA) General Research Ethics Committee (Appendix B) and from the Medical Research and Ethics Committee (MREC), Ministry of Health, Malaysia (Appendix C).

3.4.2 Questionnaire:

The questionnaire was designed to collect information on the villagers' perception of the drinking water supply, their behaviour and consumption pattern. It was developed in English (Appendix D) and then translated to Malay for the actual survey (Appendix E).

The questionnaire consisted of 4 sections; the first section is on consumption pattern and is primarily designed to derive quantitative exposure data for use in subsequent QMRA. The second section asks their perception on their drinking water supply, its quality and risk and their views about their supply's current management. The third section asks the consumption pattern of a child 5 years or below. The last section of the questionnaire is concerned with identification of the socio-economic status of the household.

The perception questions are based on a previous PhD thesis which studied people's perception of their drinking water supply (de Franca Doria, 2004). Questions on consumption and behaviour are also based on established questionnaires on water consumption pattern (WHO & UNICEF, 2006; Few et al., 2009). de Franca Doria's study framework included several categories that are linked to each other, towards understanding factors that have an impact in perception of water quality, risk perception and behaviour. These factors were constructed into questionnaire items to gather the information from his study population.

That questionnaire had been adapted to fit this study's objective and setting. This study managed to use the framework and questionnaire on perception produced by de Franca Doria (2004) as its baseline model. Since that model had been tested thoroughly in his study, it is a reliable model to be adapted by this research to discover possible relationships and to try and answer the research questions that this study is interested in. The perception component and their relevant questions that have been included in the questionnaire is listed in Table 3.2.

Table 3.2 Model component and relevant questionnaire items

Perception model component	**Questionnaire items/questions**
Colour	• I am happy with the colour of my tap water
Odour	• I am happy with the odour of my tap water
Flavour	• I am happy with the taste of my tap water
Perceived contextual indicators	• I am satisfied with the water pressure in my house • The water supply system in my village is highly reliable • Bottled water is too expensive • It is easy to buy and install a water filter in your home
Information from family or friends	• One of my friends, family members, or myself was ill possibly due to tap water
Risk perception	• The water supply to my house is safe to drink without any treatment • It is safe to drink from a tap fitted with a water filter • There are health risks associated with drinking tap water in my house
Chlorine perception	• Drinking water treated with chlorine have a bad taste or smell • Drinking water treated with chlorine have chemicals that are dangerous to health • Drinking water treated with chlorine is safe and good for health • Drinking water treated with chlorine is too expensive • Drinking water treated with chlorine should be supplied to all

A pilot survey was done on 10 households in Tekek. The pilot survey had helped to identify the best approaches for the interviewers when facing different situations in the field. The results from the pilot survey were included into the main survey.

3.4.3 Sampling

Because of time and resource limitation, 4 out of the 8 main villages on the island were chosen, with a total of 557 households in the 4 villages.

Based on a 2014 Tioman Development Agency annual report data (Lembaga Pembangunan Tioman, 2014), there are 8 villages on the island consisting of 687 households. This study was conducted in 4 of the 8 villages on the island, which according to the report, consist of 557 households' altogether; 459 in Tekek and Air Batang, 36 in Juara and 62 in Salang. Based on these figures, all 557 households in the 4 selected villages were to be invited to be interviewed. From calculation, assuming that there is only a 70% compliance rate (i.e. about 400 respondents), this would be adequate to estimate a prevalence with standard error of no more than 0.025 in the least precise scenario or substantially less in better scenarios. This number of participants would also be sufficient for correlation analysis between variables with Alpha = 0.05, Power = 0.8 and correlation coefficient >0.15. Again, this would be sufficient for both the QMRA and the risk perception analyses.

This background data on household is however not entirely accurate, which was only discovered at the start of the survey, as many houses had become abandoned houses, due to people moving out of the villages, and we could see previous census stickers on them, but no one was currently living there. The survey team also discovered that 190 households in Tekek consist of staff living quarters for Berjaya Tioman Resort. They were initially included in the study, but from the survey interviews, it was realised that the staff quarters are receiving drinking water from private water supply from Berjaya Tioman Resort. Since this fall outside the study scope it was decided to exclude the 190 staff quarters from the study, resulting in a substantial loss of sample size.

The main village, Tekek was selected because it has the largest number of households. Air Batang and Juara were selected because of logistical reason, as they can be reached by land transport from the main village Tekek, reducing the need for traveling via boat. The fourth village, Salang was selected because compared to other villages, its main water source is from low lying rivers (other villages depend on gravity feed dam), and due to the problem of water shortage, they also depend on ground water sources.

Every household in the selected villages who are receiving water from the main drinking water supply were to be included in the study, provided that they consented to be interviewed. Only one adult per household were interviewed. The adult was also asked to answer a second part of the questionnaire about one child aged 5 years or below in the household, if any. This cut off age is selected because it is this age group that are most susceptible to waterborne illness and they are not at a school going age, allowing a better estimate on their consumption by their guardian.

9 medical lab technologists, and 1 attendant with various experiences in environmental health fieldwork and health survey from Environmental Health Research Centre, Institute for Medical Research, Ministry of Health, Malaysia (collaborating institution in the study) were selected and trained to conduct the interview. It was a 3-day training by the principal investigator on the objective, scope and concept of the questionnaire and the overall study, where the interviewers practiced applying the questionnaire to other staff of the research centre. In the field, a pilot survey of 10 households was conducted at the start of fieldwork, where interviewer's technique and interviewee's responses were noted for any communication or language issues. There were no major changes to the questionnaire required from the pilot study and the pilot study results were incorporated into the main study. The interview took about 30-45 minutes to be completed per household. The survey questionnaire was applied once at the beginning of the study, which was conducted from the 3rd to the 10th of September 2014.

There was no systematic household numbering on the island, so we had to create our own numbering system using stickers. Some houses were remote and hidden requiring guide by local clinic staff. Due to time and logistical limitation, the survey team were unable to conduct all the interviews at specific times in the day (for example after working hours). However, for every household where no one or no adult was present, we made sure to return a second time after working hours.

In the end there was a total of 351 premises that were considered as households in the 4 villages (Tekek-237, Juara-62, Air Batang-29, Salang-23). The team managed to interview 218 respondents from 351 households, giving a 62% respond rate interviewed (Table 3.3).

Table 3.3 Interview response rate by village

Village	Response (%)
Tekek	141 (59)
Juara	38 (61)
Air Batang	21 (72)
Salang	18 (78)

Non-respondents were due to no occupants or adults being present even after a second visit, and households which refused to answer the questionnaire. Reasons for refusal included too busy, having the same opinion as the head of the family (even though living in different household), and saying that the study has no benefit for them (despite our attempt to explain the possible benefits)

3.4.4 Statistical analysis

SPSS statistical software version 23 was used to analyse the data. Composite variables were constructed when necessary from the available socio-demographic data to output other relevant socio-economic status variables such as highest education level and highest income level in household (Table 3.4). Composite variables of material wealth were also constructed from questions on property ownership (Table 3.4). Descriptive analysis of the respondents and household were conducted to reflect the demographic characteristics of the study population, the drinking water practice and the perception variables (Table 3.4). Where necessary, factor analysis with Equamax rotation were conducted to reduce the number of dependent variables according to the research questions or perception categories being investigated. Univariate analysis of factors influencing the dependent variables were then conducted. Those independent factors with significance of $p<0.1$ from univariate analysis were selected for multiple logistic regression analysis. Factors which remain significant at $p<0.05$ were identified and used in the stepwise backward elimination method to build the best model that describes the relationship between the factors and outcome. Factors which are close to significance are also retained if it has a considerable role in the model.

Table 3.4 List of dependent and independent variables

Independent variable
Respondent and household sociodemographics
Respondent gender (M/F)
Respondent age
Respondent age group
Respondent place of birth
Respondent home address
Respondent education level
Respondent employment status
Respondent income level
Respondent years in the house
Number of people in household
Highest education level in the household
Highest income level in the household
House build type
House condition
House ownership status
Material score
Organoleptics
I am happy with the colour of my tap water
I am happy with the odour of my tap water
I am happy with the taste of my tap water
Contextual perception
I am satisfied with the water pressure in my house
The water supply system in my village is highly reliable
Bottled water is too expensive
It is easy to buy and install a water filter in your home

Table 3.4 List of dependent and independent variables (cont.)

External input from family or friends
One of my friends, family members, or myself was ill possibly due to tap water
Dependent variable
Risk perception of drinking water
The water supply to my house is safe to drink without any treatment
It is safe to drink from a tap fitted with a water filter
There are health risks associated with drinking tap water in my house
Perception of water treated with chlorine
Drinking water treated with chlorine have a bad taste or smell
Drinking water treated with chlorine have chemicals that are dangerous to health
Drinking water treated with chlorine is safe and good for health
Drinking water treated with chlorine is too expensive
Drinking water treated with chlorine should be supplied to all
Are you willing to pay for water treated with chlorine by authorities (Y/N)
Drinking water attitude and practice
Do you treat the water in any way before drinking? (Y/N)
Do you ever drink water direct from tap? (Y/N)

3.5 Results

Below are the findings from the questionnaire survey, including the sociodemographic data, the respondent's perception on health risk from untreated drinking water source, perception and attitude on water treated with chlorine, drinking water behaviour and practice, and results from univariate regression analysis, multiple regression analysis and factorial analysis.

3.5.1 Study population characteristics

The questionnaires were applied to interview respondents (the person answering the questionnaire) for data about themselves and about the household that they are living in (general household information and information about others living in the household). A description of the respondents' and the households' socio-demographic characteristics is in Table 3.5 below. The survey only interviewed those who are age 13 and above, so respondent characteristics are only among the adults. Data on all members of the household included all ages. There are almost the same numbers of female and male respondents, with about equal distribution of age except for the oldest age group. 35% of respondents have primary or lower education, and another 40% with secondary level education. However, income level is quite evenly distributed among the respondents, between 16-24% at each income level. Looking at other aspects of socioeconomic characteristics, only 1.4% of respondents lived in a poorly built house, and 0.9% lived in heavily degraded house condition. In term of drinking water source, 88% of the interviewed household receive water from the main dam or river, 3% from tube wells, 2% from spring, and 3% used bottled water.

Table 3.5 Socio-demographic characteristics of study respondents and households

	Respondent (%)	Household (%)
Gender: Female	113 (51.8)	429 (49.9)
Male	105 (48.2)	431 (50.1)
Age (Years): 0-5	-	85 (9.2)
6-12	-	116 (12.6)
13-30	46 (21.1)	304 (33)
31-40	57 (26.1)	152 (16.5)
41-50	45 (20.6)	123 (13.4)
51-60	46 (21.1)	83 (9.0)
61 or >	24 (11.0)	56 (6.1)
Education level:		
Didn't finish or start	10 (4.6)	123 (13.8)
Primary level	68 (31.2)	243 (27.2)
Secondary level	91 (41.7)	411 (46.1)
Tertiary level	49 (22.5)	115 (12.9)
Income level:		
<1000	46 (21.5)	449 (53.3)
1000-1999	51 (23.8)	104 (12.3)
2000-2999	47 (22.0)	156 (18.5)
3000-3999	35 (16.4)	66 (7.2)
4000 or >	35 (16.4)	68 (8.1)
Village: Air Batang	21 (9.6)	
Juara	38 (17.4)	
Salang	18 (8.3)	
Tekek	141 (64.7)	
House build: Solid	176 (81.5)	
Semi solid	34 (15.7)	
Poorly build	3 (1.4)	
House condition:		
Good	160 (74.1)	
Lightly degraded	54 (25)	
Heavily degraded	2 (0.9)	
Main drinking water source:		
Piped from dam/river	192 (88.1)	
Piped from tube well	7 (3.2)	
Piped from spring	5 (2.3)	
Bottled water	7 (3.2)	

3.5.2 Factors influencing risk perception of drinking water

Which factors influence the respondent's risk perception towards the drinking water source is one of the three main questions or objectives in this chapter. Below is a descriptive overview of the dependent variables under the category of risk perception of drinking water, followed by factor analysis and regression analysis.

3.5.2.1 Overview of respondent's risk perception of the drinking water source.

To evaluate the respondents' risk perception of their water supply, the survey provided three statements or questions in the questionnaire, and asked the respondents to mark whether they agree with the statement. The response is in Likert scale form, where score 1 means completely disagree and score 7 means completely agreeing with the statement. A summary of the respondent's score for the three questions can be seen in Figure 3.13 to 3.15.

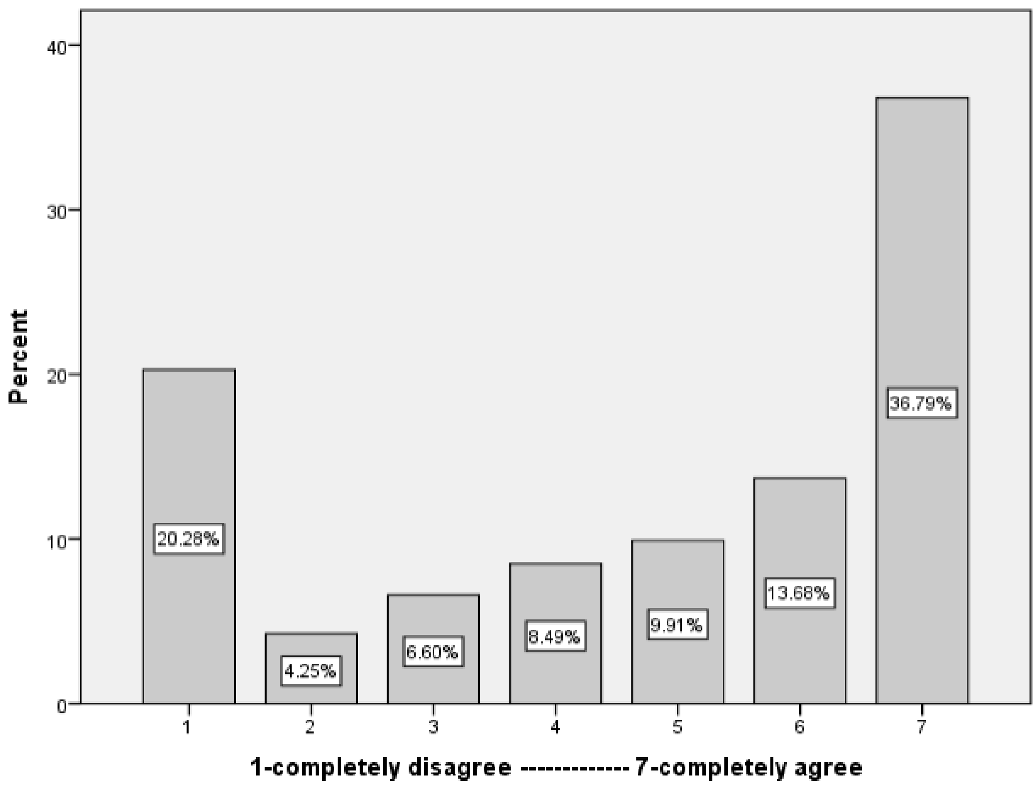

Figure 3-13 Water supply is safe to drink without treatment

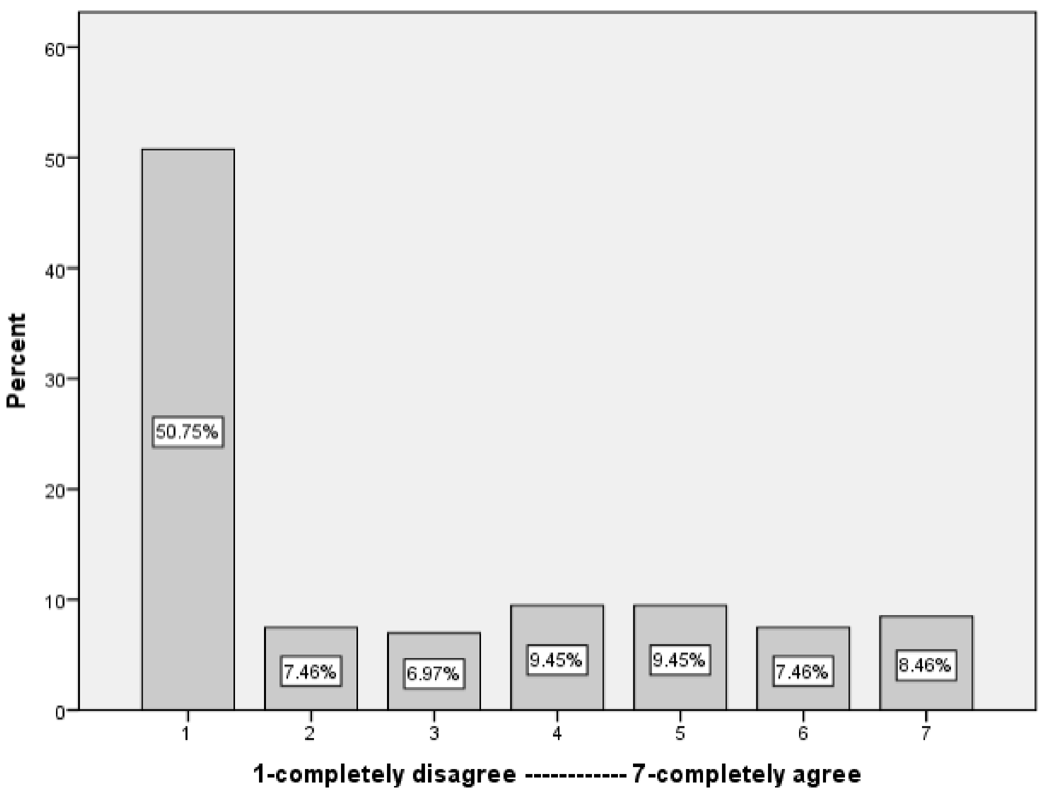

Figure 3-14 There are health risks associated with drinking tap water

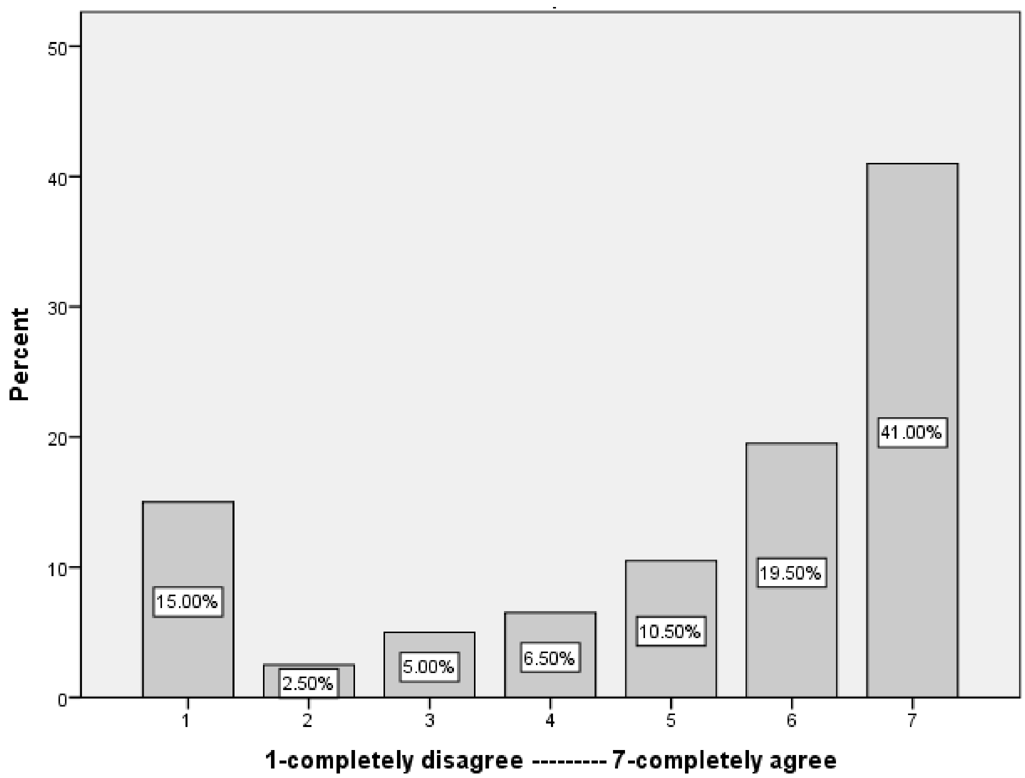

Figure 3-15 It is safe to drink from tap with water filter

Overall, looking at the respond to the three risk perception statements of drinking water variables, more villagers feel that their untreated drinking water source is safe for consumption. There is some split among the respondents in two of the questions, regarding the water being safe to drink without treatment, and it is safe to drink from taps with water filters. However, on the other hand, they are quite in agreement that there are no health risks from their untreated water.

3.5.2.2 Factorial analysis of drinking water risk perception

As there are three variables for evaluation of risk perception with different responses, factorial analysis was conducted to see if it could reduce the outcome variable and help with the understanding of the factors that play a role in risk perception amongst the community. The factorial analysis constructed one new variable that strongly correlates with the 3 different risk perception variables (Table 3.6).

Table 3.6 Factor analysis component for drinking water risk perception

Component Matrix[a]

	Component 1
Water supply is safe	.787
Safe to drink tap with filter	.761
Drink tap water health risk	-.662

Extraction Method: Principal Component Analysis.
a. 1 components extracted.

The new component or variable can be described as low risk perception score, as higher value of the score means lower risk perception.

ANOVA test and simple linear regression was then conducted on the new variable with the independent variables.

From these univariate analyses, it was found that the new variable, lower risk perception score, produced significant result when tested with age group, education level, income level, respondent's village, born in same village, I am happy with colour, I am happy with odour, water supply is reliable and years respondents has lived in the house (Table 3.7).

From these results multiple linear regression analysis was conducted using generalized linear model procedure in SPSS to identify the best fit model for explaining the factors that influence higher values on low risk perception score. By manually conducting stepwise backward elimination, it was possible to produce a best fit model that included respondent age group, income level, village, I am happy with odour and water supply is reliable (Table 3.8). The model produced a likelihood ratio Chi-square of 116.465 ($p<0.001$).

Table 3.7 ANOVA and regression of low risk perception score (component 1)

		Sum of Squares	Df	Mean Square	F	Sig.
Age group	Between Groups	20.054	4	5.013	5.514	<0.001
	Within Groups	160.946	177	.909		
	Total	181.000	181			
Respondent education level	Between Groups	24.672	3	8.224	9.364	<0.001
	Within Groups	156.328	178	.878		
	Total	181.000	181			
Respondent income level	Between Groups	13.281	4	3.320	3.522	.009
	Within Groups	164.060	174	.943		
	Total	177.341	178			
Village	Between Groups	39.662	3	13.221	16.650	<0.001
	Within Groups	141.338	178	.794		
	Total	181.000	181			
Born in same village	Between Groups	10.698	2	5.349	5.622	.004
	Within Groups	170.302	179	.951		
	Total	181.000	181			
Happy with colour	Between Groups	43.743	6	7.290	9.295	<0.001
	Within Groups	137.257	175	.784		
	Total	181.000	181			
Happy with odour	Between Groups	47.640	6	7.940	10.419	<0.001
	Within Groups	133.360	175	.762		
	Total	181.000	181			
Water supply is reliable	Between Groups	28.613	6	4.769	5.520	<0.001
	Within Groups	149.467	173	.864		
	Total	178.080	179			
		R square	B			Sig.
Years lived in the house		0.157	0.19			<0.001

Table 3.8 Best fit model for low risk perception score (component 1)

Variables/factors		B	Standard error	Significance
Age group	13-30	-.921	.2294	
	31-40	-.603	.2194	
	41-50	-.603	.2165	
	51-60	-.166	.2186	
	> 60	0		<0.001
Income	<1000	.510	.2036	
	1000-1999	.477	.1999	
	2000-2999	.419	.1859	
	3000-3999	.216	.2024	
	4000 or >	0		0.070
Village	Air Batang	.801	.2075	
	Juara	.582	.1651	
	Salang	.628	.2508	
	Tekek	0		<0.001
Happy with odour	1	-1.511	.3644	
	2	-1.583	.3614	
	3	-.142	.3203	
	4	-.359	.2176	
	5	-.459	.1937	
	6	-.562	.1764	
	7	0		<0.001
Water supply reliable	1	-.217	.1959	
	2	.095	.2757	
	3	.164	.2502	
	4	.303	.2036	
	5	.407	.2112	
	6	.212	.1860	
	7	0		0.094

3.5.3 Factors influencing perception and attitude towards water treated with chlorine

Perception on water treated with chlorine is another important question in this study. Here the analysis result of the questionnaire questions on perception and attitude towards water treated with chlorine will be described. This includes a question on willingness to pay for water treated with chlorine.

3.5.3.1 Overview of perception and attitude towards water treated with chlorine

Below are the overall responses using three of the main questions used to assess the respondents' perception and attitude towards water treated with chlorine. To the question "Does drinking water treated with chlorine has a bad taste or smell?", 71% of the respondents said 'Yes' (Figure 3.16).

To the question "Should water treated with chlorine be supplied to all?", only about 32% people agreed and said 'Yes' (Figure 3.17).

When asked for willingness to pay for water treated with chlorine supplied by the authorities, 49% said 'Yes' (Figure 3.18).

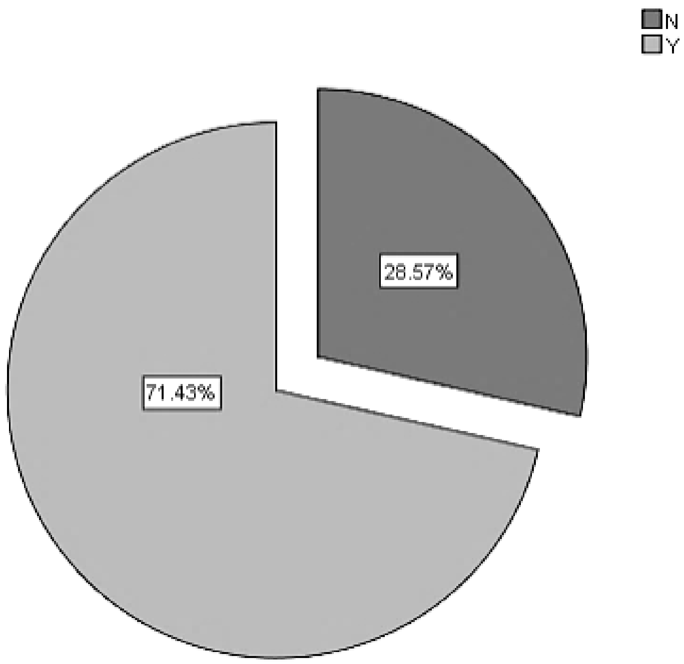

Figure 3-16 Drinking water treated with chlorine has a bad taste or smell

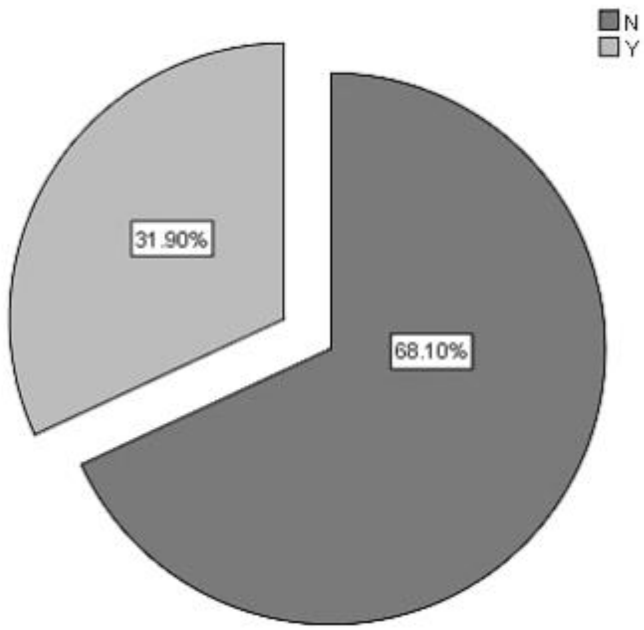

Figure 3-17 Drinking water treated with chlorine should be supplied to all

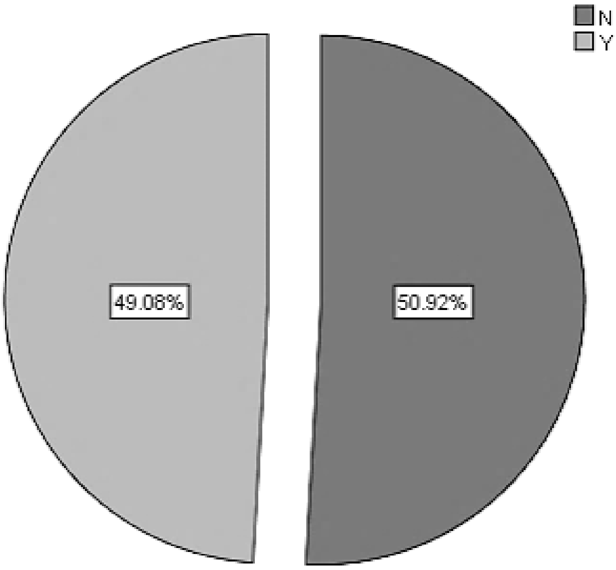

Figure 3-18 Willingness to pay for water treated with chlorine supplied by the authorities

Looking at the distribution of score for the three questions, it appears that around 70% of the people in Tioman are not in favour of water treated with chlorine. Interestingly however this does not translate to the same response to the question on willingness to pay, as almost half of the people responded that they are willing to pay for water treated with chlorine supplied by the authorities.

3.5.3.2 Factorial analysis to describe overall relationship between perception and attitude towards water treated with chlorine

In the survey, there were a total of 6 variables that were used to evaluate perception and attitude towards water treated with chlorine. Using factorial analysis, they were reduced to help with the interpretation of the results.

Factorial analysis with equamax rotation produced two components that can explain the 6 different factors. The first component is positive perception towards water treated with chlorine. The second component is negative perception towards water treated with chlorine (Table 3.9).

Table 3.9 Factorial analysis for drinking water treated with chlorine component 1 and 2

Rotated Component Matrix[a]

	Component	
	1	2
Chlorine has bad taste smell yes or no	-.100	.773
Chlorine chemical danger yes or no	-.076	.773
Chlorine good for health yes or no	.731	-.087
Chlorine too expensive yes or no	.074	.665
Chlorinated water for all yes or no	.875	-.034
Willingness to pay yes or no	.620	.024

Extraction Method: Principal Component Analysis.
Rotation Method: Equamax with Kaiser Normalization.
a. Rotation converged in 3 iterations.

ANOVA and linear regression analysis were conducted on these two new dependant variables, positive chlorine perception (component 1) and negative chlorine perception (component 2). The first new variable on chlorine, which is positive chlorine perception, were significant for education level, income level, village, born in same village, status of house ownership, happy with colour, happy with odour, happy with taste, water supply reliable, and number of years the respondent has lived in the house (Table 3.10).

The negative perception on chlorine variable were significant for age group, easy to buy and install water filter, family or friend has been ill due to drinking water, safe to drink from tap with filter and drinking from tap is associated with health risk (Table 3.11).

Using generalized linear modelling in SPSS a best fit model was calculated for the significant variables in explaining the change in positive chlorine perception variable. The result was a best fit model which included respondent's status of house ownership, I am happy with colour and water supply is reliable (Table 3.12). The model likelihood ratio chi-square is 85.263 ($p<0.001$).

The same analysis was done for negative chlorine perception and using stepwise backward elimination and removing for relationships that were not meaningful, the best fit model included factors of family or friend has been ill due to drinking water and it is safe to drink from tap with filter (Table 3.13). The model likelihood ratio chi-square is however only 32.833 ($P<0.001$)

Table 3.10 ANOVA and linear regression for positive chlorine perception

		Sum of Squares	Df	Mean Square	F	Sig.
Respondent education level	Between Groups	11.038	3	3.679	3.829	.011
	Within Groups	197.962	206	.961		
	Total	209.000	209			
Respondent income level	Between Groups	12.070	4	3.017	3.170	.015
	Within Groups	191.310	201	.952		
	Total	203.379	205			
Village	Between Groups	19.941	3	6.647	7.243	<0.001
	Within Groups	189.059	206	.918		
	Total	209.000	209			
Born in same village	Between Groups	14.966	2	7.483	7.983	<0.001
	Within Groups	194.034	207	.937		
	Total	209.000	209			
Status of house ownership	Between Groups	19.405	3	6.468	7.024	<0.001
	Within Groups	187.871	204	.921		
	Total	207.277	207			
Happy with colour	Between Groups	46.194	6	7.699	9.558	<0.001
	Within Groups	162.712	202	.806		
	Total	208.905	208			
Happy with odour	Between Groups	28.537	6	4.756	5.326	<0.001
	Within Groups	180.369	202	.893		
	Total	208.905	208			

Table 3.10 ANOVA and linear regression for positive chlorine perception (cont.)

Happy with taste	Between Groups Within Groups Total	38.844 166.161 205.005	6 199 205	6.474 .835	7.753	<0.001
Water supply is reliable	Between Groups Within Groups Total	36.557 170.634 207.191	6 200 206	6.093 .853	7.141	<0.001
		R square	B			Sig.
Years lived in the house		0.042	-0.10			0.003

Table 3.11 ANOVA for negative chlorine perception

		Sum of Squares	Df	Mean Square	F	Sig.
Respondent age group	Between Groups	12.100	4	3.025	3.149	0.015
	Within Groups	196.900	205	.960		
	Total	209.000	209			
Easy to buy and install water filter	Between Groups	20.615	6	3.436	3.566	0.002
	Within Groups	148.364	154	.963		
	Total	168.979	160			
Family or friend ill due to drinking water	Between Groups	16.985	6	2.831	3.159	0.006
	Within Groups	155.011	173	.896		
	Total	171.995	179			
Safe to drink from tap with filter	Between Groups	14.124	6	2.354	2.473	0.025
	Within Groups	177.036	186	.952		
	Total	191.160	192			
Drinking from tap is associated with health risk	Between Groups	12.786	6	2.131	2.263	0.039
	Within Groups	176.081	187	.942		
	Total	188.867	193			

Table 3.12 Best fit model for positive chlorine perception

Variable/factors		B	Standard error	Significance
Status of house ownership	Own	-.177	.1641	
	Rented	.307	.1956	
	Family/friend	1.375	.6045	
	Staff quarters	0		0.003
I am happy with colour	1	.627	.3574	
	2	.870	.4391	
	3	1.408	.2889	
	4	.128	.1778	
	5	.116	.1883	
	6	-.251	.1721	
	7	0		<0.001
Water supply is reliable	1	.627	.2104	
	2	.432	.3186	
	3	.572	.2531	
	4	.219	.2038	
	5	.657	.2080	
	6	.098	.1772	
	7	0		0.009

Table 3.13 Best fit model negative chlorine perception

Variable/factors		B	Standard Error	Significance
Family or friend has been ill due to drinking water	1	0.751	.3137	
	2	0.076	.4267	
	3	1.326	.5470	
	4	0.716	.5606	
	5	0.284	.6065	
	6	0.084	.4091	
	7	0		0.008
It is safe to drink from tap with water filter	1	-.728	.2216	
	2	-.856	.4199	
	3	-.483	.3559	
	4	-.148	.3077	
	5	-.134	.2631	
	6	-.089	.2026	
	7	0		0.023

3.5.4 Factors influencing behaviour and practice related to drinking water

Finally, this chapter will look at the relationship between sociodemographic, water quality perception and risk perception with the behaviour or practice of the respondents relating to drinking water with two dependant variables, the first whether he or she treat the water before drinking, and the second question was whether they consume water direct from tap.

3.5.4.1 Overview of respondent's behaviour or practice relating to drinking water

Figure 3.19 and 3.20 below describes in general the respondent's drinking water behaviour. 91% of respondents treat water before drinking, however, 30% still drinks water direct from tap.

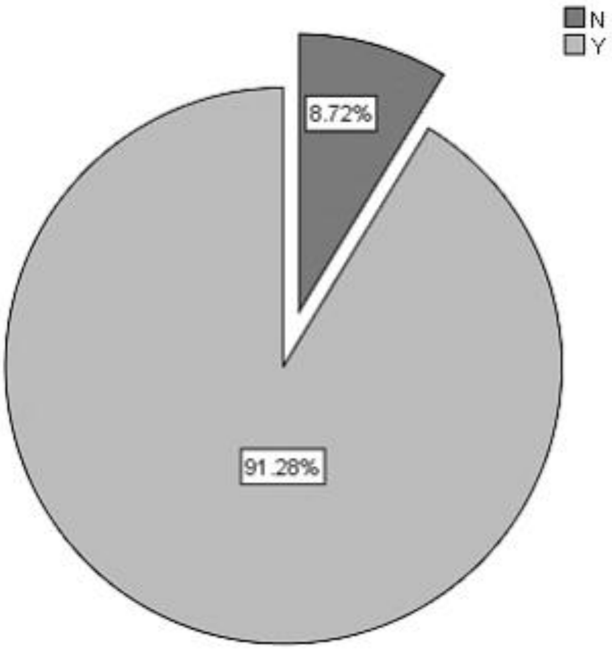

Figure 3-19 Do you treat water in any way before drinking?

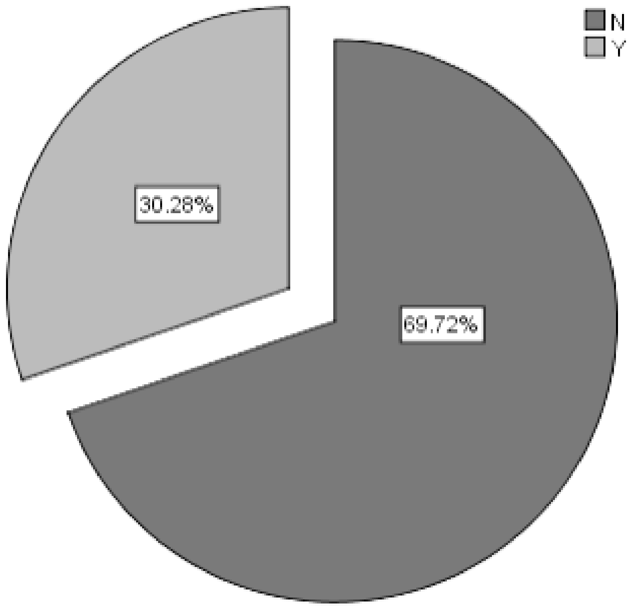

Figure 3-20 Do you ever drink water direct from the tap?

3.5.4.2 Regression analysis of behaviour and practice relating to drinking water

Univariate analysis of the factors that may play a role in behaviour and practice relating to drinking water among the respondents (Table 3.14 and 3.15) were conducted. From the result, significant factors are tested in a multiple regression model. Table 3.16 and 3.17 shows the best explanatory model for the two dependent variables.

Table 3.14 Univariate regression; do you treat the water in any way before drinking?

	Do you treat the water in any way before drinking?			
	B	P	OR	X^2
Age group respondent (Years):				
13-30	-0.047	0.959	0.955	3.770
31-40	0.916	0.374	2.500	
41-50	-0.526	0.540	0.591	
51-60	-0.294	0.738	0.745	
> 60	0			
Gender of respondent				
Female	0.196	0.684	1.216	0.166
Male	0			
Education level respondent				
Didn't finish or start	-2.485	0.053	0.083	6.735
Primary level	-1.991	0.063	0.137	
Secondary level	-1.386	0.201	0.250	
Tertiary level	0			
Highest education level in household				
Primary level	-1.984	**.005**	.138	9.301
Secondary level	-.142	.819	.868	
Tertiary level	0			
Respondent Income level (RM):				
<1000	-.016	.984	.984	3.717
1000-1999	-.529	.468	.589	
2000-2999	.318	.708	1.375	
3000-3999	1.159	.326	3.187	
4000 or >	0			
Highest household income level (RM):				
<1000	-1.386	.117	.250	8.498
1000-1999	-1.230	.092	.292	
2000-2999	.298	.705	1.347	
3000-3999	.118	.900	1.125	
4000 or >	0			

Table 3.14 Univariate regression; do you treat the water in any way before drinking? (Cont.)

Employment status				
Not working	0.063	0.915	1.065	0.011
Working/employed	0			
Respondent's village				
Air Batang	-2.087	**.006**	.124	16.847
Juara	-2.212	**.001**	.109	
Salang	-1.924	**.018**	.146	
Tekek	0			
House ownership				
Own	.854	.274	.426	6.857
Rented	.428	.731	1.535	
Family or friend	-2.663	**.022**	.070	
Staff quarters	0			
Happy with colour:				
1 (1-3)	0.902	.394	2.464	0.968
2 (4)	0.223	.735	1.250	
3 (5-7)	0			
Happy with odour:				
: 1 (1-2)	.223	.836	1.250	5.467
2 (3-5)	1.872	.072	6.500	
3 (6-7)	0			
Water supply is safe:				
: 1 (1-2)	2.265	**.030**	9.633	14.410
2 (3-5)	2.285	**.029**	9.822	
3 (6-7)	0			
There is health risk from tap water:				
1 (1-3)	.894	.102	2.446	2.811
2 (4)	1.052	.341	2.864	
3 (5-7)	0			
Safe to drink from tap with filter:				
: 1 (1-2)	.686	.382	1.986	2.169
2 (3-5)	.927	.235	2.528	
3 (6-7)	0			

Table 3.14 Univariate regression; do you treat the water in any way before drinking? (Cont.)

Easy to buy and install water filter:				
1 (1-3)	.857	.171	2.355	2.356
2 (4)	.929	.393	2.531	
3 (5-7)	0			
Friends or family have been ill:				
: 1 (1-2)	.698	.316	2.010	0.920
2 (3-5)	.719	.552	2.053	
3 (6-7)	0			
Satisfied with pressure:				
1 (1-3)	1.513	**.049**	4.541	5.374
2 (4)	.459	.560	1.583	
3 (5-7)	0			
Water supply reliable:				
1 (1-3)	1.063	.171	2.895	2.548
2 (4)	-.094	.890	.910	
3 (5-7)	0			
	B	P	OR	x^2
Material score of household	0.691	**0.003**	1.996	8.976
Years respondent lived in the house	0.004	0.760	1.004	0.094
No of people in the household	-0.057	0.665	1.058	0.192

Table 3.15 Univariate regression; do you ever drink water direct from the tap?

	Do you ever drink water direct from the tap?			
	B	p	OR	x^2
Age group respondent (Years):				
13-30	.182	.758	.833	7.552
31-40	.158	.777	1.171	
41-50	.965	.084	2.625	
51-60	.16794	.771	1.182	
> 60	0			
Gender				
Female	-0.905	**0.003**	0.404	9.148
Male	0			
Education level respondent				
Didn't finish or start	-.958	.388	.384	6.627
Primary level	.822	.052	2.275	
Secondary level	.377	.361	1.457	
Tertiary level	0			
Highest education level in household				
Primary level	.792	.159	2.208	4.261
Secondary level	.672	.056	1.958	
Tertiary level	0			
Respondent Income level (RM):				
<1000	.644	.246	1.904	6.096
1000-1999	1.219	**.022**	3.383	
2000-2999	.818	.135	2.266	
3000-3999	.659	.259	1.933	
4000 or >	0			
Highest household income level (RM):				
<1000	.524	.453	1.689	5.849
1000-1999	1.168	**.019**	3.217	
2000-2999	.655	.136	1.926	
3000-3999	.660	.204	1.935	
4000 or >	0			

Table 3.15 Univariate regression; do you ever drink water direct from the tap? (cont.)

Employment status				
Not working	-0.334	0.369	0.716	0.833
Working/employed	0			
Respondent's village				
Air Batang	1.001	**.045**	2.722	28.182
Juara	1.805	**<.001**	6.082	
Salang	1.710	**.001**	5.529	
Tekek	0			
House ownership				
Own	.794	.056	2.212	5.196
Rented	.208	.706	1.231	
Family or friend	.000	1.000	1.000	
Staff quarters	0			
Happy with colour:				
1	-1.415	.199	.243	10.310
2	-1.010	.375	.364	
3	-2.021	.058	.132	
4	-.653	.128	.520	
5	-.896	.062	.408	
6	-.484	.251	.616	
7	0			
Happy with odour:				
1 (1-3)	-1.361	0.076	0.256	4.430
2 (4)	-0.311	0.568	0.732	
3 (5-7)	0			
Happy with taste:				
1 (1-3)	-0.565	0.400	0.569	1.499
2 (4)	-0.518	0.379	0.596	
3 (5-7)	0			
Water supply is safe:				
1 (1-3)	-1.880	**p<.001**	0.153	28.694
2 (4)	-1.828	**.018**	0.161	
3 (5-7)				

Table 3.15 Univariate regression; do you ever drink water direct from the tap? (cont.)

There is health risk from tap water:				
1 (1-3)	0.776	**0.044**	2.173	9.210
2 (4)	-0.849	0.301	0.428	
3 (5-7)	0			
Safe to drink from tap with filter:				
1 (1-2)	-1.948	**.002**	0.143	14.639
2 (3-5)	-.562	.146	0.570	
3 (6-7)	0			
Easy to buy and install water filter				
1	1.319	**.022**	3.738	8.020
2	1.435	**.041**	4.200	
3	.182	.843	1.200	
4	.913	.188	2.492	
5	.913	.188	2.492	
6	.924	.167	2.520	
7	0			
Friends or family have been ill:				
1	-1.142	.088	.319	6.039
2	-.742	.395	.476	
3	-1.792	.165	.167	
4	-1.504	.256	.222	
5	-1.792	.165	.167	
6	-2.015	**.046**	.133	
7	0			
Satisfied with pressure:				
1	-1.168	**.016**	.311	14.239
2	-1.322	.101	.267	
3	-1.833	.090	.160	
4	-.474	.355	.622	
5	.087	.836	1.091	
6	.102	.839	1.108	
7	0			

Table 3.15 Univariate regression; do you ever drink water direct from the tap? (cont.)

Water supply reliable:				
1	-.758	.124	.469	5.817
2	-.912	.270	.402	
3	-1.317	.100	.268	
4	-.273	.562	.761	
5	-.567	.287	.567	
6	-.347	.425	.707	
7	0			
	B	p	OR	x^2
Material score of household	0.174	0.222	1.190	1.509
Years respondent lived in the house	0.012	0.093	1.012	2.824
No of people in the household	0.050	0.510	1.052	0.433

Table 3.16 Final model for do you treat water in any way before drnking

Variable/factors		B	Standard error	OR	Significance
Highest education in household	Primary	-1.882	.8301	0.152	
	Secondary	.241	.6811	1.273	
	Tertiary	0			0.010
Respondent's village	Air Batang	-1.993	.8024	0.136	
	Juara	-2.223	.7101	0.108	
	Salang	-1.774	.8748	0.170	
	Tekek	0			0.011
Material score		0.586	.2585	1.798	0.023

Table 3.17 Final model for do you drink water direct from tap?

Variable/factors		B	Standard error	OR	Significance
Respondent's village	Air Batang	0.386	0.5415	1.471	
	Juara	1.177	0.4325	3.244	
	Salang	1.135	0.5811	3.113	
	Tekek	0			0.028
Gender	Female	-0.877	0.3392	0.416	
	Male	0			0.010
Water supply is safe to drink without treatment	1 (1-3)	-1.526	0.4768	0.217	
	2 (4)	-1.301	0.7976	0.272	
	3 (5-7)	0			0.003

For the question do you treat the water in any way before drinking, the model that best fit included highest education level of the household, material score and respondent's village. This model however, only gives a -2 log-likelihood chi square of 31.935 away from intercept ($p<0.001$). The higher the material score, the likelier the respondent would say yes to applying treatment to the water before drinking. There is a pattern that people with lower highest education level in the household are less likely to treat water before drinking, though it is only significant for the lowest level group against highest level group. There is a different in likelihood of treating water between the villages, where people from Tekek are more likely to apply some kind of treatment compared to people from other villages.

For the question do you ever drink water direct from the tap, the model that best fit included respondents' gender, water supply is safe to drink without treatment and respondent's village. This model gives a -2 log-likelihood chi square of 45.960 away from intercept ($p<0.001$). Female are less likely to say yes to ever drink water direct from tap. Respondent which scores lower (disagrees) on the statement that water supply is safe to drink without treatment is less likely to drink directly from tap. While people from Tekek are less likely to drink directly from tap compared to the other villages.

3.6 Discussion

There were several limitations to this survey. This study had to limit the number of villages selected as most requires travel by boat, which can be unreliable, especially during the rainy season. Houses were not always within easy reach and actual house status could only be confirmed during the day of the survey. The interviewers only had time for a second attempt to reach non-respondents. There was skewness to some of the data which could be improved by a larger sample size or by reducing respondent bias. Yes or no questions also limits the ability of the respondents to express themselves. The study could benefit from a focus group interview to explore some of the issues or themes that appeared. Based on these limitations the following observations were made.

3.6.1 Factors influencing risk perception of drinking water supply

Based on the single variable defined as low risk perception produced from factorial analysis of three different variables on risk perception, the independent factors of age group, happy with colour of water supply perception and the village that the respondent lives in are the main factors influencing the perception of risk from the drinking water supply in the community. The higher the age group, the safer they feel the drinking water supply is without any treatment. The happier the respondent with the colour of the water supply, the safer they feel the water supply is. Also, Air Batang and Juara significantly has lower risk perception compared to the main village of Tekek.

The relationship between age and risk perception has been mixed in previous studies. de Franca Doria (2010) found that age is usually weakly associated with risk perception. The finding of this study seems to be similar with the study of Parkin (Park, Scherer & Glynn, 2001; Parkin et al., 2001) which shows that younger people perceive tap water as riskier or less safe. However other studies have shown an opposite finding where older people are more sensitive to risk in drinking water (Syme & Williams, 1993).

In this community, there is a sense (from the fieldwork and experience during interviews) that the older generation are more protective of the untreated drinking water, claiming that people have been drinking the water for generations without getting sick, and more opposed to ideas that challenges that notion.

The finding of perception of colour of drinking water source is in agreement with previous studies showing the importance of organoleptics in influencing the perception of whether the water supply is safe or not (de Franca Doria, 2004; Nauges & Van Den Berg, 2009)

The third independent variable is village of the respondent. As stated at the start of the chapter, there are certain differences between the villages in aspects that may be relevant to drinking water. The analysis has shown that these differences are important and have an impact on their perception of risk from the untreated drinking water source. Air Batang and Juara are villages which have good drinking water supply, with little interruptions compared to Salang and Tekek. The difference in opinion on risk between these two villages and Tekek can be suggested as a result of Tekek being a town with more people migrating from the mainland and staffs of government and private offices that are present in Tekek. Though this factor can only be suggested here, other findings, though not expressed in the final model, but seen in univariate regression, do support this. This include factors of where the person was born, whether they come from outside of Tioman, factors of house ownership, where people who own houses has certain tendencies with regard to risk perception compared to those who are living in staff housing, who mostly come for Tioman as a result of work requirement.

3.6.2 Factors influencing perception towards water treated with chlorine

The analysis of perception towards water treated with chlorine is relatively less straightforward than the result of the factors influencing risk perception. Many of the variables examining the perception of the community on water treated with chlorine has shown poor relationship with most of the studied independent factors.

Factorial analysis was used to try and simplify, and at the same time clarify the relationship, but the result is again a mix. Factorial analysis produced two new variables, one that represent positive perception on water treated with chlorine (Water treated with chlorine is safe and good for health, should be supplied to all, and willingness to pay for water treated with chlorine), and another one that represent negative perception on water treated with chlorine (water treated with chlorine has bad taste or smell, has chemicals hazardous to health and is too expensive).

For the variable representing positive perception on water treated with chlorine, the best fit model included factors of happy with colour score, water supply reliable score, and status of house ownership, which is whether the person owns his or her house, renting, living with family or living in housing quarters.

It makes sense that those who are happy with the colour of the untreated water supply, and those who feels that the water supply is reliable, has lower score in positive perception on water treated with chlorine. As have been discussed from the findings of the earlier analysis, and in previous studies, organoleptics can be an indicator of perception of water quality and perception of health risk. The happier people are with their water supply the less likely they would feel that they need the water to be treated with chlorine, moreover to pay for that treated water. This finding is in line with finding from previous studies looking at impact of perception and water treatment (Nauges & Van De Berg, 2009; Anadu, 2000).

The third factor is regarding status of house ownership, where house owners are more likely to score lower on positive chlorine score compared to those living in staff quarters. House owners are most likely locals or those who has been on the island much longer, compared to those living in staff quarters, which may be a mix between locals and those coming from outside. This can indicate a few things, such as the fact that those from outside of the island may already be used to water treated with chlorine, or that non-locals are less likely to be protective or trusty of the age-old drinking water source that is the source of life for the people on the island. Familiarity with water supply has been shown to be an important determinant for positive perception of water quality in other studies (Dupont et al., 2014; de Franca Doria, 2004), which is in agreement with these results.

Negative chlorine perception variable has been less well defined in this study compared to positive chlorine perception variable. The final model was contributed by two Likert scale based variables, family or friend has been ill due to drinking water, and it is safe to drink from tap with water filter. The first variable is based on studies which had shown that past experiences and information from others contribute to perception of water quality (Dupont et al., 2014). For this study the people with higher agreement score on family and friend has been ill due to drinking water have lower negative chlorine perception score. If someone has negative experience with the water, they are less critical of water treated with chlorine. Understandably for the second variable that is in the final model, when people agree strongly that it is safe to drink from tap with water filter, they score higher in negative chlorine perception.

An interesting observation to note is on the factor of which village the respondent is from. Though there are some indication in some of the analysis that it has a role here in chlorine perception and attitude, such as when Juara village is significantly less likely to be willing to pay for water treated with chlorine compared to Tekek, the village factor is not so prominent and not present in the overall final model, meaning that the village factor is not as strong here compared to previous analysis of perception of health risk from drinking water. It suggests that even those with village specific issues such as low water supply in Salang are not necessarily happy with accepting water treated with chlorine or pay for them.

Considering income level, though in one-way ANOVA there is a significant difference, it does not show in the final model, suggesting that it is not as important as perception of water quality and familiarity with drinking water source or water treated with chlorine (reflected from the place of birth variable).

One other observation that is interesting from this study, based on findings from regression analysis and factor analysis, is that positive perception on water treated with chlorine is not inversely correlated with negative perception on water treated with chlorine. For example, a person who thinks chlorinated water has dangerous chemicals is not always against the authorities supplying chlorinated water or paying for it. Two reasons could explain this, one is that the respondent’s perceived danger could be conditional, in the sense that poor management could lead to chlorine becoming a problem, but with proper management it could be controlled. The other reason is that looking at the perception of water treated with chlorine having a bad taste or smell, this is a factor that can be tolerated to an extent, considering other more important issues, for example, if chlorinated water could provide reliable and adequate water supply. This brings up another important point, which is if people are not really happy with chlorinated water, but can tolerate when required, there is a possibility that they would actually choose an alternative source if or when the alternative source of water is readily available.

3.6.3 Factors influencing drinking water behaviour

There were two variables that reflected drinking water behaviour that was analysed against the various independent variables. The first was whether they treat the water before drinking and the second was whether the respondent ever drink water direct from tap. Even though 90% of respondents treat water before drinking, 30% still drink water direct from tap.

With regard to treating drinking water, even though 90% reported boiling water before consumption, this does not necessarily provide an accurate picture. A study in Cambodia showed that even though more than 90% of household reported boiling water, only 31% could provide them when requested (Brown & Sobsey, 2012). It was not possible to compare this to a national average as no recent study or data could be found. However, a study on Giardia infection in indigenous community in rural Malaysia in 2014 found that 85% of the study population boiled water before consumption (Choy et al., 2014). This gives 90% as a good estimate considering the community has better exposure to health services.

From the analysis, this pattern is related to education level of the household, material score and respondent's village. Respondents are more likely to treat water when any member of household has a higher level of education, and when material score is higher. This in general supports findings from other studies which shows that higher socio-economic status is associated with better health behaviour (Contoyannis & Jones, 2004).

The second variable was drinking water direct from tap, since this a good method to measure exposure to untreated water. The finding that women are less likely than men to drink water direct from tap agrees with many previous studies that discusses how women and mothers perceive higher risk and less likely to engage in risky behaviour, especially in areas of health risk (Dupont et al., 2014; Wang et al., 2009). The other contributing factor is related to perception of risk from the drinking water supply. The water is safe to drink without treatment variable signifies whether a respondent perceive the water as high risk or not, and the higher the agreement to this statement in the questionnaire, the lower the risk perception and the higher the likelihood to drink water direct from tap.

The respondent’s village appears in both final models for the two drinking water practice variables. Other villages are significantly less likely to treat water and more likely to drink water direct from tap compared to the main village of Tekek. This finding reinforces that there are important differences between these villages that contribute to the issue of drinking water management in the community.

3.7 Conclusion

The survey focused on three areas of interest that is important for the study community, drinking water supply risk perception, perception and attitude towards water treated with chlorine and behaviour and practice related to drinking water. The theory was based on the model by de Franca Doria (2004) and the result showed the strength in relationship in some areas of the model pertaining to the study community. It would be useful to refer to the model to conclude and summarize the results.

The figure and table below have been edited to show the summary of relationships that have been found in this study (Table 3.18). The highlighted arrows show the relationship between factors that were prominent in each domain related to the study area (Figure 3.21). The thickness of the arrow lines reflects the strength of the relationship based on the best fit model. Arrows with dashed line shows relationships found in the original model (Figure 3.12) that were not tested in this study.

This framework and the new information that were discovered from this study, will be useful for future intervention to the study community, and can form a basis to management approach to other areas which are relevant. Again, strength of association between the factors will be different in different communities, but this study has shown a method to investigate these relationships in different communities.

There are certainly many areas that can be further expanded, depending on the capacity of research that can be conducted. For example, the reason for the differences between the villages can only be postulated due to only small number of samples in each village, except for the main village of Tekek, where 65% of the total respondents are from. A more targeted study could identify an approach which is more specific to that village if deemed necessary. Kampung Air Batang and Kampung Juara are in general quite happy with the status quo, it would be interesting to find out whether socioeconomic background have an impact, or whether community pressure is stronger, and would intervention like health education bring any change.

The findings and the framework from this chapter will form part of an overall conclusion from this study (in chapter 5) that will combine the results from the systematic review in the previous chapter and the microbial risk assessment from the next chapter. As the study has shown the perception of risk of the villagers by conducting this survey, it is important to try and assess the actual microbial risk, next.

Table 3.18 Summary of findings (Table)

Model component	Variable name	Contributing Factors
Risk perception	Low risk perception score	Respondent’s age group Respondent’s income Respondent’s village I am happy with odour Water supply reliable
Chlorine perception	Positive chlorine perception	Status of house ownership I am happy with colour Water supply is reliable
	Negative chlorine perception	Family or friend has been ill due to drinking water It is safe to drink from tap with water filter
Attitude& practice of drinking water supply	Do you treat water before drinking	Highest education in household Respondent’s village Material score
	Do you drink direct from tap	Gender Respondent’s village Water supply is safe to drink without treatment

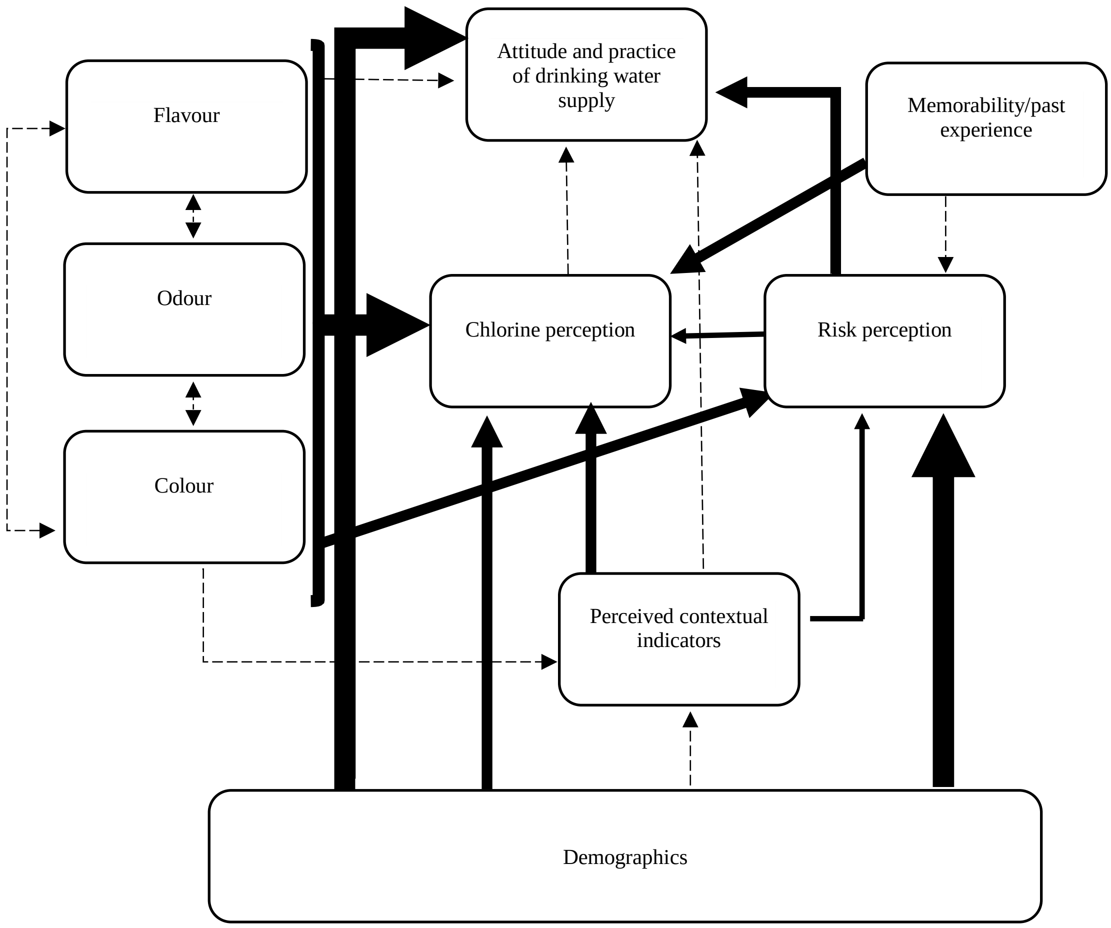

Figure 3-21 Summary of findings (Model)

Chapter 4: Risk assessment of drinking water supply

Following from the previous chapter which looked at issues of perception of the community, including the community's risk perception of their drinking water source, chapter 4 will discuss another segment of the study, which is the assessment of the actual health risk to the study population from their exposure to the untreated drinking water source.

4.1 Background

From the outset, the situation of drinking water supply in Tioman has raised a lot of questions. For example, the drinking water supply on the island, though quite remote, is still under the observation of the health authorities, where the water source is sampled twice yearly (due to difficulty of access and seasonal limitations) for the presence of total coliform and other baseline data on water quality. The result of these monitoring, as far as I can tell from verbal report and recent records, has always been above acceptable limit, especially with the detection of faecal coliform (Appendix A). However, despite this, the water treatment plant (in the main village) that was built in 2008 has ceased from doing any treatment of the water supply and now, according to the local health inspector, only functions as a reservoir for distributing untreated gravity fed water from the main dam.

Once the matter has been investigated, some of these issues have become clearer, however an important question which remains unanswered is, what is the actual health risk from these untreated water sources. The population, at least those who are vocal, were certainly unconvinced of any risk, confidently consuming a bottle of the untreated water while offering another to the interviewers, declaring how fresh it tasted. The findings from the previous chapter has shown some distribution of the level of risk perception, but support the impression that most of the locals are happy with the untreated drinking water source.

4.1.1 The site and the water, again

Though the status of water supply in Tioman have been discussed before in the preceding chapters, there is a need to provide some further details as it is mainly relevant to this chapter.

There are three main type of water source in Tioman;

- Piped water to dwelling from untreated large hill stream dam
- Piped water to dwelling from untreated low-lying river with small collection well
- Piped water to dwelling from tube well

However, other than the long connecting pipes from the source to dwelling they may or may not be a storage point in the middle, in the form of a water treatment reservoir, elevated storage tanks, or deep well.

In term of the location, most of the source water is difficult to reach, though some of the source, like tube wells are located quite near. To begin with, one has to travel by boat to get to most of the other villages from the main village. The sea can be rough during the wet season or just during stormy weather. Once there, it depends on which village or water source that you need to sample. The river sources are located inland, and can only be reached by either a motorcycle or walking for up to half an hour through forested pathways. The hill stream water sources for the villages are high up in the central areas of the island, where it could take up to an hour to climb up a small track or path between dense vegetation, and then of course, you need to get back down. Some of these sources are accessed so infrequently, like twice a year for monitoring, you would need an experienced staff to lead the way, clearing the pathway of tree branches which has grown since the last visit.

It has also been mentioned in the preceding chapters about the weather on the island, with the presence of wet and dry season, and it would be useful to clarify that during the dry season, situation can change, where for example, if the river source collection point runs dry, the local may have to choose an alternative, such as changing from getting water direct from the main river, to getting a pipe connected to a tank which collects water from a tube well.

4.1.2 The risk assessment

To evaluate the risk properly, the best approach that would be able to provide the answer would be by using a quantitative microbial risk assessment method (QMRA). QMRA has been used in urban and rural settings, and in situations of limited data availability (Machdar et al., 2013; Hunter et.al., 2009; Howard et al., 2006).

The basis of the QMRA is the measurement of exposure to a pathogen and calculating the risk based on the infective rate. Based on the QMRA methodology, there is a need to identify;

- Consumption of untreated drinking water or ineffective treatment, or possible exposure from other route such as food preparation
- Pathogen concentration in the water.
- Dose response of specific pathogen to be used in risk modelling.

The first step to conducting a QMRA would be to identify the reference organism. This would depend on the knowledge of the study location, and on the result of the detection and quantification analysis of the pathogens in the water samples.

The second step is to calculate the dose response. This refers back to the reference organism that will be used for the analysis. Dose response data already published in literature and in the main reference, which is from QMRA network database (QMRA wiki) can be utilized for this purpose.

The third step is exposure assessment, which again depends on the reference organism, but in the case of this study, as the pathogen is in drinking water, exposure assessment would depend on drinking water consumption data.

The fourth step is putting the information together to characterize the risk. There can be various approaches to do this based on the data of microbial concentration, dose response and water consumption or exposure data.

Training for qPCR was undertaken in Genoa, Italy for two weeks. After the training it was decided to run the qPCR analysis in UEA lab as it was easier to obtain resources such as primers and assays and with the availability of those trained in PCR and qPCR.

Lab analysis for qPCR was done between March to December 2016. Positive samples were obtained from previous stock samples that had shown positive results for the relevant positive strains. These were used to run standard curves, and produced good results establishing the quality of primers, essays and the qPCR methodology.

I however had trouble getting conclusive results from the samples that had been collected. The samples yielded amplification at high CT, sometimes similar CT with control wells. Even after several troubleshooting attempts the results were still inconclusive at best. In the end I was running out of time and samples.

I decided to proceed with an alternative approach to QMRA, based on studies by Machdar (2013) and Howard (2006) in areas with limited data and resources, where the reference pathogen concentration is calculated based on the ratio between indicator organisms and pathogen concentration in previously published studies. This is due to the fact that data on indicator organisms are more readily available or easily measured compared to the specific pathogens. Careful considerations however, have to be taken to adapt the ratios from previous studies before implementing it to do QMRA in another setting.

4.2 Objectives

Based on the requirements for quantitative risk assessment, the objectives were;

- To detect and quantify the presence of specific pathogens in the drinking water, either at the source, distribution or at the tap.
- To measure the consumption of treated and untreated drinking water of the population.
- To assess the health risk from exposure to untreated drinking water among adult and children in the population.

4.3 Methodology

To achieve the above objectives, the main methodology for risk assessment for this study can be described three parts, the first part was to collect consumption data from the questionnaire (the same questionnaire for risk perception component), the second part was to collect water samples and conduct laboratory analysis for the detection of reference and pathogenic microbes, and the last part is to conduct a quantitative risk assessment.

4.3.1 Questionnaire

A questionnaire survey was already conducted at the beginning of the study for risk perception where data on water consumption for adult and children below 5 years were also collected, as well as data on drinking water practices such as water treatment and the practice of drinking water direct from tap.

The adult respondent was asked for drinking water consumption during dry and wet season and for any consumption of water direct from tap, which bypasses any possible treatment, and the amount of such consumption.

Interviewers then proceeded to ask whether there is a child aged 5 years old or below in the household, and if there is, would then interview the respondent concerning one child’s consumption pattern, again during dry and wet season, and direct from tap.

4.3.2 Water sampling and lab analysis

4.3.2.1 Sampling points

As have been described earlier, the study was conducted in 4 of the 7 main villages on the island. Water sampling was conducted in these 4 villages from the source, storage and at their distribution tap (eg: homes, offices or shops). The study aimed for 26 water sampling points:

a. Tekek (main village): 1 x dam, 3 x distributions

b. Juara: 1 x dam, 3 x distributions

c. Air Batang: 1 x dam, 3 x distributions

d. Salang: 2 x river, 3 x storage tank, 3 x ground water, 6 x distributions

The sample collection part of the study was conducted in 2014. Collection was done twice; once during the dry season between March to September and once during the wet season between October to February. This sampling was then repeated in 2015 as a backup to the 2014 samples.

4.3.2.2 Target organisms

Samples were collected to identify microbial density of indicator organisms and pathogens in the source water. The list of organisms that were targeted is given below;

- Indicator organisms:

    1. *Escherichia coli* - *E. coli* is the standard indicator for faecal contamination in water, though it is not specific to human. It is present in warm blooded animals and does not easily grow in the environment.

    2. Enterococci - Enterococci are a subgroup within the faecal streptococcus group and is also a useful indicator for faecal contamination, especially in salt water but also useful for fresh water.

3. *Clostridium perfringens* – Gram-positive, rod-shaped, anaerobic, spore-forming bacteria which produces toxin that are harmful to humans. It is resistant to disinfection and is commonly used as indicator to faecal pollution or indicator to resistant organisms such as protozoan and viruses.

- Pathogens. These pathogens have been chosen because of their frequent association with drinking water consumption and for the severity of its impact on children.

1. *Cryptosporidium sp*. - a coccidian protozoa that lives in the intestines of vertebrates, causes cryptosporidiosis in humans with many documented cases of outbreak that spread through contaminated drinking water.

2. *Giardia sp*.- a flagellate protozoan that lives in the intestine of various mammals and has been associated with diarrhoeal illness in human.

3. Pathogenic *E. coli* strains;

- Enterotoxigenic *E. coli* (ETEC)
- Enteropathogenic *E. coli* (EPEC)
- Enteroinvasive *E. coli* (EIEC)
- Enterohemorrhagic *E. coli* (EHEC)
- Enteroaggregative *E. coli* (EAEC)

4.3.2.3 Sampling method

For each sampling point 50L of water sample were collected using a portable ultrafiltration machine which allows sampling of large volume of water in the field to produce a concentrated volume (200-250ml) that is easier to store and transport to the lab (Figure 4.1). The main advantage is allowing the sampling of relatively larger volume of samples from remote sampling points (Figure 4.2 and 4.3).

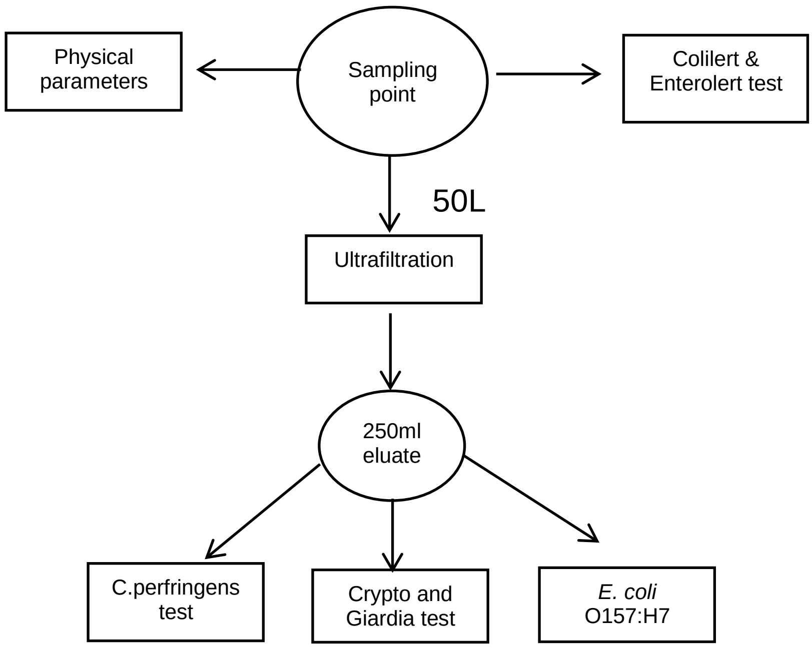

Figure 4-1 Water sampling flow chart

Figure 4-2 Portable but not invulnerable. Carefully loading the ultrafiltration machine onto a boat.

Figure 4-3 Setting up the machine to filter 50 litres of water from a distribution point

4.3.2.4 Field and laboratory tests

The water samples are tested for microbial concentration of indicator organisms and pathogens in the source water and tap water. Below are the Indicator organisms and methods used for detection. The methods selected are standard detection methods which also allow the quantification of the microbial concentration in the water samples.

- *Escherichia coli* - Recognised standard method for detection is the colilert test which is simple and can easily be done in the field. The colilert substrate is added to the water sample and after 24 hours of incubation the water would fluoresce under ultraviolet lights if positive. For quantification, this method will utilize the most probable number (MPN) method using a Quantitray well system (Appendix F).

- Enterococci - The standard test is the enterolert test which uses the same principle as the colilert test, using a substrate which would react with the water and then read under ultraviolet after 24 hours (Appendix F).

- *Clostridium perfringens* - Detection of *C.perfringens* is by culture with selective media and confirmation tests (Appendix G).

Below are the pathogens that have been selected, and the methods of analysis.

- Cryptosporidium - Recovery and detection from environmental water sample by ultrafiltration and immunomagnetic separation (Dynal IMS), and immunofluorescence detection under fluorescence microscope (Appendix H).

- Giardia - Detection of giardia uses similar method with Cryptosporidium, and combination dynal IMS kits are available to detect the presence of both *Giardia sp*. and *Cryptosporidium sp* (Appendix H).

- Pathogenic *E. coli* were calculated based on standard *E. coli* measurement and using ratios published in literature.

4.3.3 Quantitative microbial risk assessment

Step 1: Quantification of reference pathogen

At the outset, the method was to detect the presence of pathogenic *E. coli* using qPCR, where 5 *E. coli* pathotypes were selected and their primers identified for detection. However, as had been mentioned in the background section of this chapter, the approach had to change when the results from qPCR tests were inconclusive.

Alternatively, to fulfil the requirement for the first step of QMRA the study referred to the methodology used by studies of QMRA in area of limited data, which used published ratios of standard *E. coli* against pathogenic organisms (Machdar et al., 2013; Howard et al. 2006). The study decided on this approach and using the standard *E. coli* data that have been collected from the study location against the published ratios (Table 4.2).

Table 4.2 Standard *E. coli* to pathogen ratio from literature

Reference pathogen	Ratio used	Reference
E. coli:*E. coli* O157	1:0.08	Haas et al., 1999
E. coli:Rotavirus	$5:10^{-6}$	Machdar et al., 2013; Mara et al., 2010
E. coli:Cryptosporidium	$1:10^{-7}$	Smeets et al., 2008

Step 2: Exposure parameters

Exposure parameters depend on untreated drinking water consumption and dose response. Data on consumption is available from the questionnaire survey data.

For dose response the study refers to the QMRAwiki for the dose response of the reference pathogens. The dose response equations are shown in Table 4.3.

Table 4.3 Pathogen dose response parameters from QMRAwiki

Organism	Parameters	Type of model
EHEC	$K=2.18E^{-04}$	Exponential
Rotavirus	α = 2.53E-01 , N50 = 6.17E+00	Beta-Poisson
Cryptosporidium	$k = 5.72E^{-02}$	Exponential

Step 3: Conducting the risk assessment

Data from Step 1 and 2 will be entered into the risk model to calculate risk. This is done using @risk risk analysis software version 7.5.

4.4 Results

Here I will present the result of water consumption from the survey, microbial analysis from water sampling, and finally the QMRA analysis.

4.4.1 Water consumption

Table 4.4 and 4.5 summarize the findings of water consumption of adults and children under 5 years old from the questionnaire survey.

Table 4.4 Adult water consumption in study area

	N	Minimum	Maximum	Mean	Std. Deviation
Amount of cup drink per day during dry season	218	2	30	10.45	5.492
Amount of cup drink per day during wet season	218	1	24	8.06	4.564
Amount of cup drink per week direct from tap	62	.25	140.00	23.1452	25.18154
(1 cup equals 250ml)					

Table 4.5 Child below 5 years water consumption in study area

	N	Minimum	Maximum	Mean	Std. Deviation
Amount of cup drink per day during dry season	71	1	12	4.52	2.396
Amount of cup drink per day during wet season	71	1	10	3.99	1.987
Amount of cup drink per week direct from tap	5	.50	21.00	8.9000	8.57613
(1 cup equals 250ml)					

4.4.2 Microbial analysis from water sampling

At the end of sampling, the sampling team managed to collect 46 samples from 23 sampling points (1st sampling in dry season, 2nd sampling in rainy season).

Analysis for the detection of *Clostridium perfringens, Cryptosporidium sp.* and *Giardia sp.* did not reveal any positive findings from any of the samples. I describe below the results from Colilert and Enterolert tests for *E. coli* and Enterococci.

Dry season:

91.67% samples positive for *E. coli*

91.67% samples positive for Enterococci

Rainy season:

83.33% samples positive for *E. coli*

79.17% samples positive for Enterococci

Figure 4.4 to 4.7 below shows the level of *E. coli* and Enterococci according to the sampling locations.

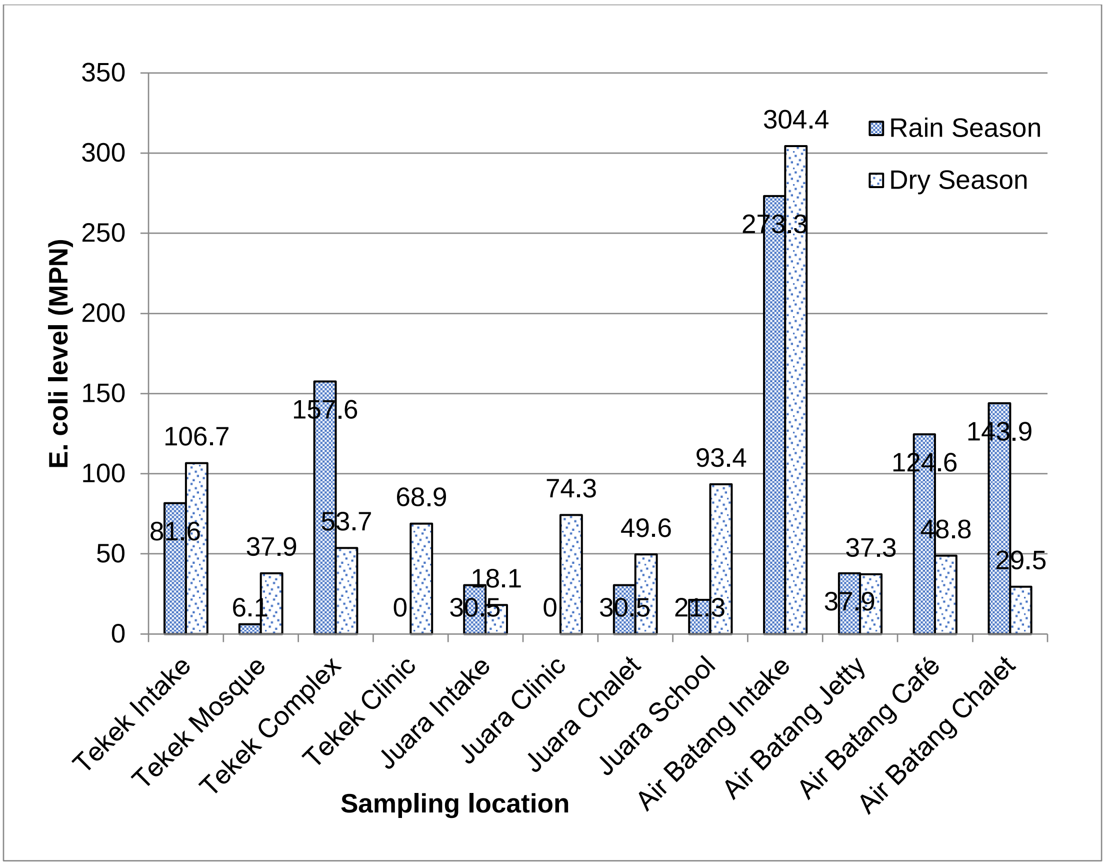

Figure 4-4 Air Batang, Juara and Tekek *E. coli* levels

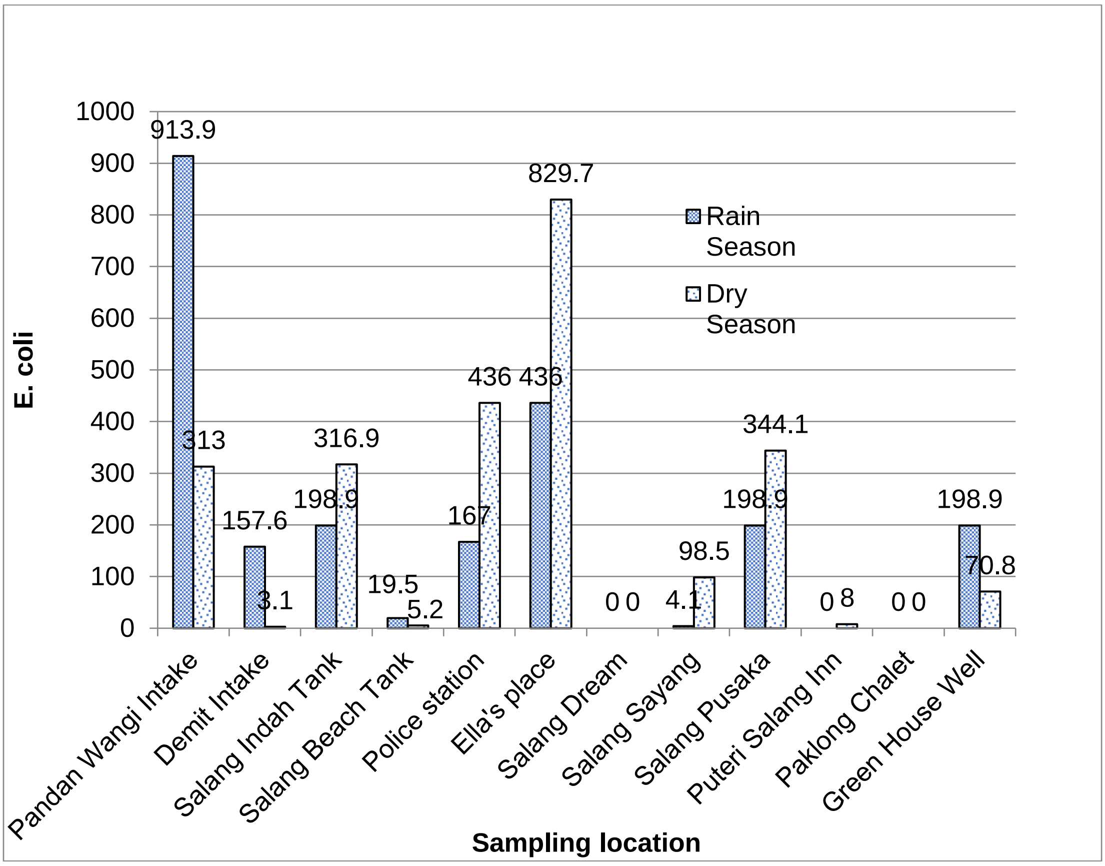

Figure 4-5 Salang *E. coli* levels

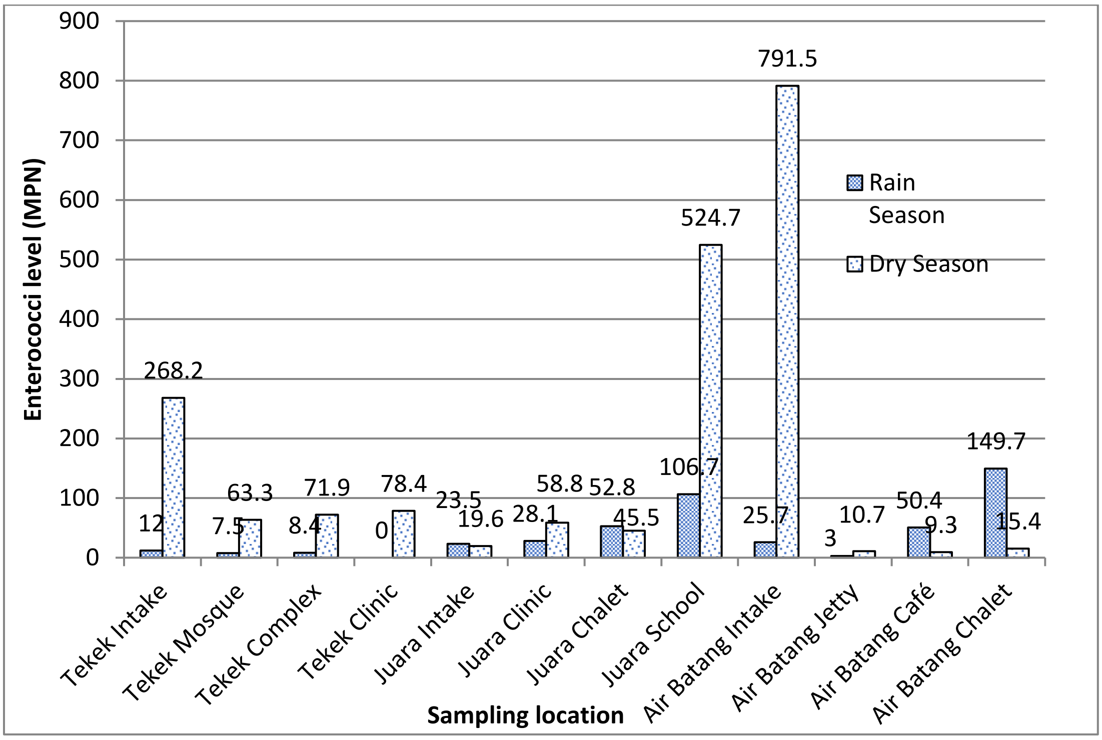

Figure 4-6 Air Batang, Juara and Tekek Enterococci levels

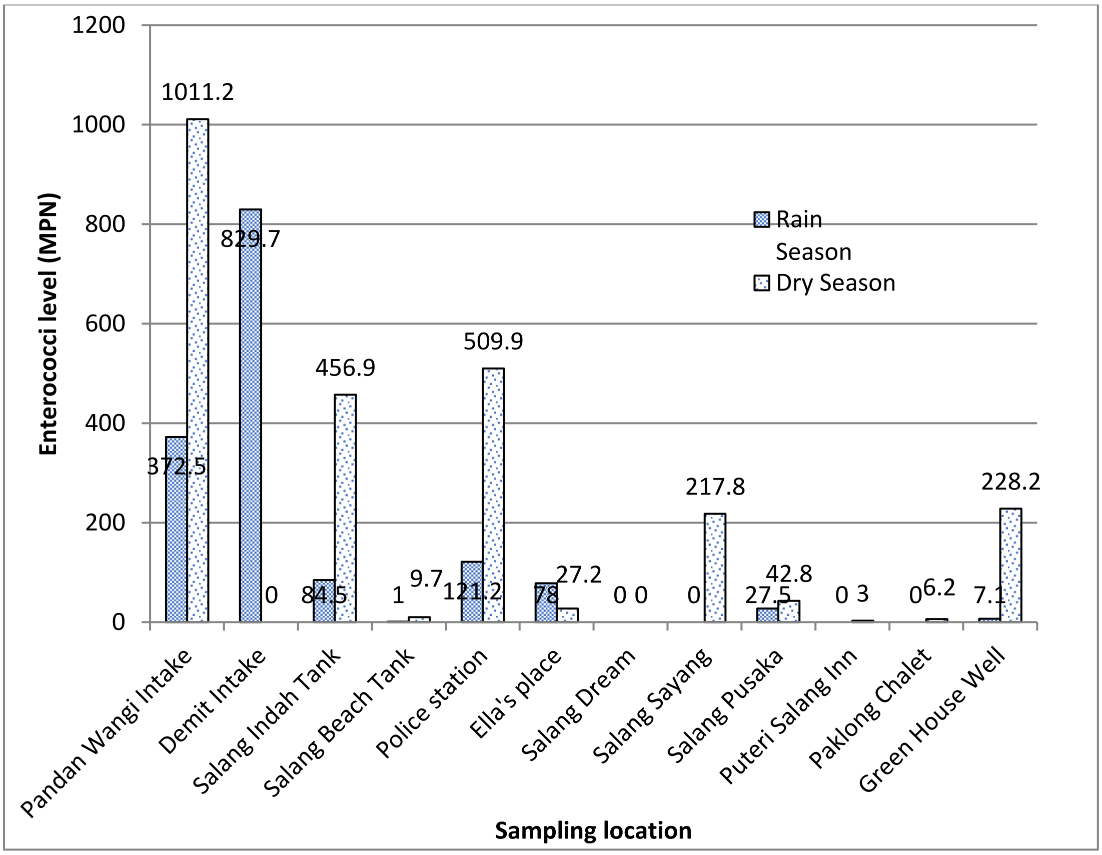

Figure 4-7 Salang Enterococci levels

4.4.3 QMRA

Simulation was done separately to show the annual infection risk for adult and for children 5 years or below. The simulation was done for the risk of *E. coli* O157, rotavirus and cryptosporidium since the ratio to *E. coli* for these pathogens are available in literature (Machdar et al., 2013; Mara et al., 2010; Smeets et al., 2008; Haas et al., 1999).

From the parameters entered, the simulation shows that for adult exposed to untreated water, the mean annual risk of infection from *E. coli* O157 is 99.96%, from rotavirus is 91.27% and from Cryptosporidium is 6.59%. While for children under 5 years old, the mean annual risk of infection from *E. coli* O157 is 93.57%, from rotavirus is 69.21% and from Cryptosporidium is 2.87% (Figure 4.8 - 4.13).

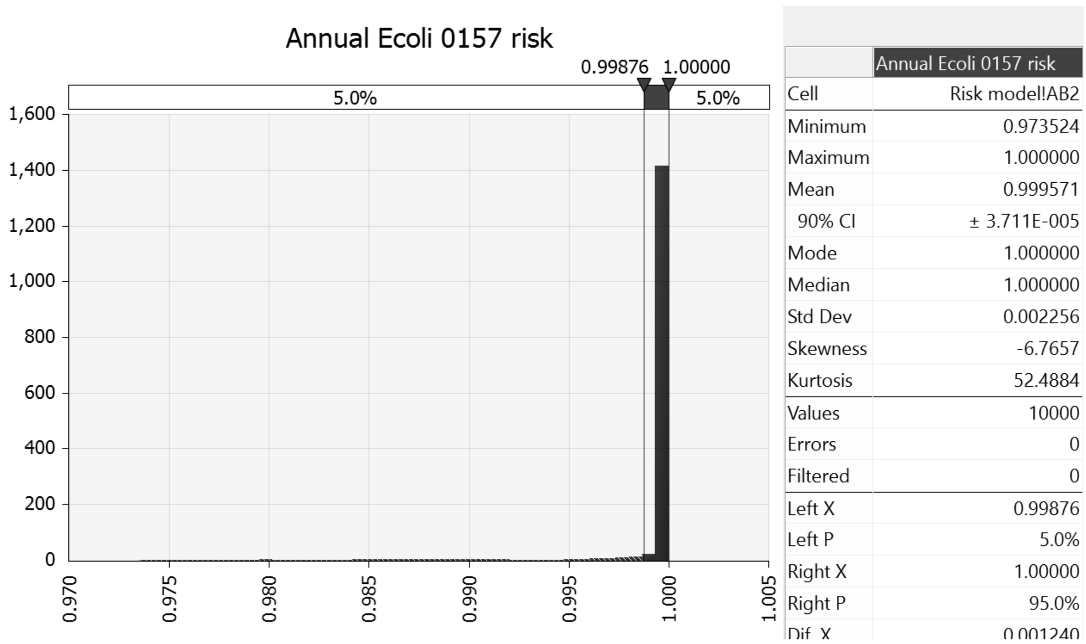

Figure 4-8 Adult annual *E. coli* O157 risk

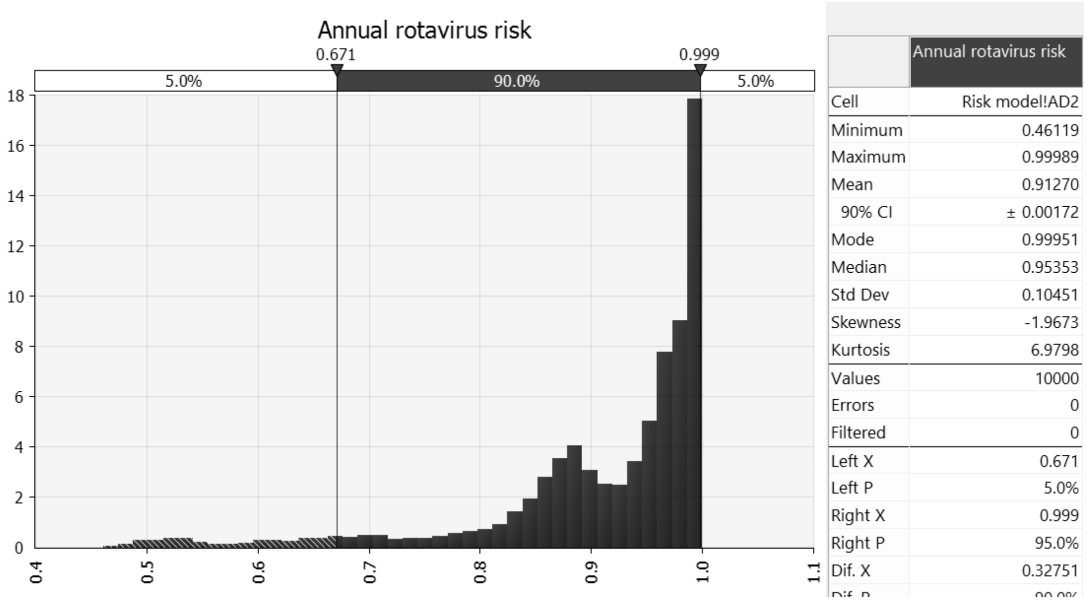

Figure 4-9 Adult annual rotavirus risk

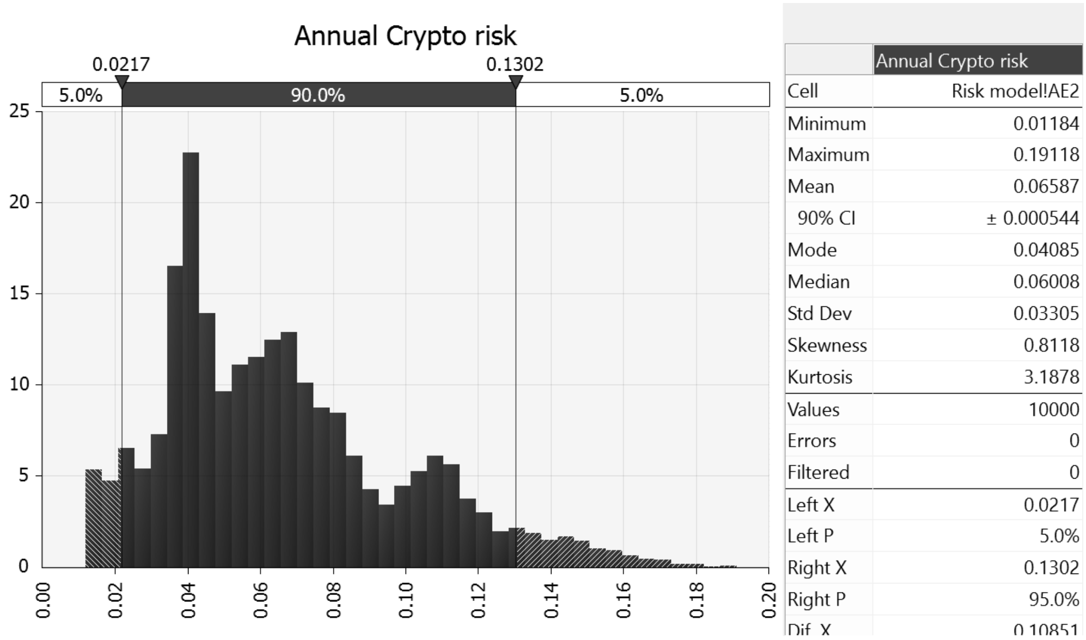

Figure 4-10 Adult annual cryptosporidium risk

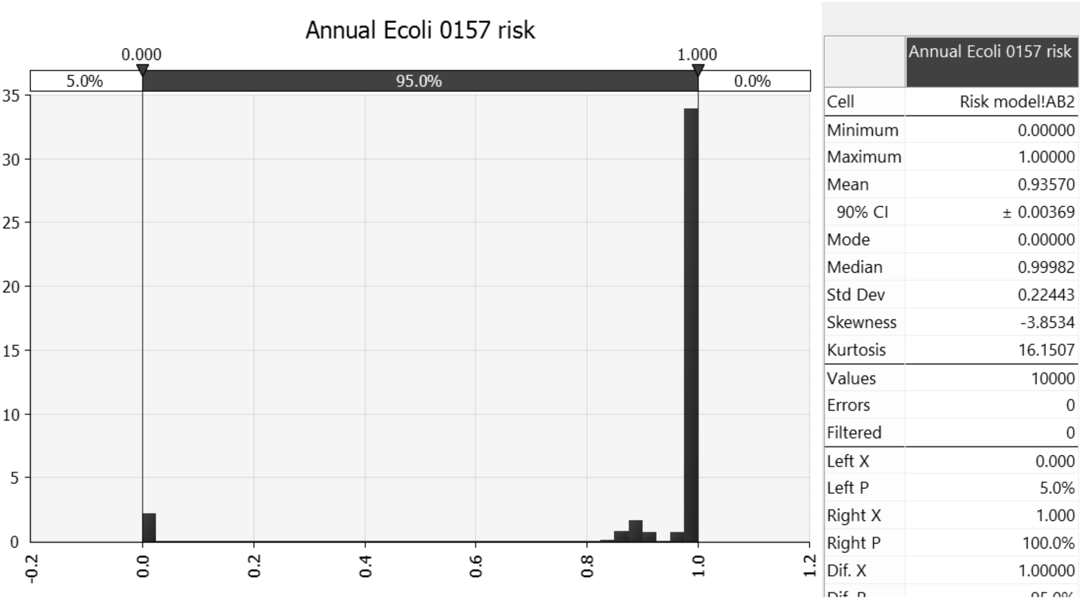

Figure 4-11 Child under 5 years annual *E. coli* O157 risk

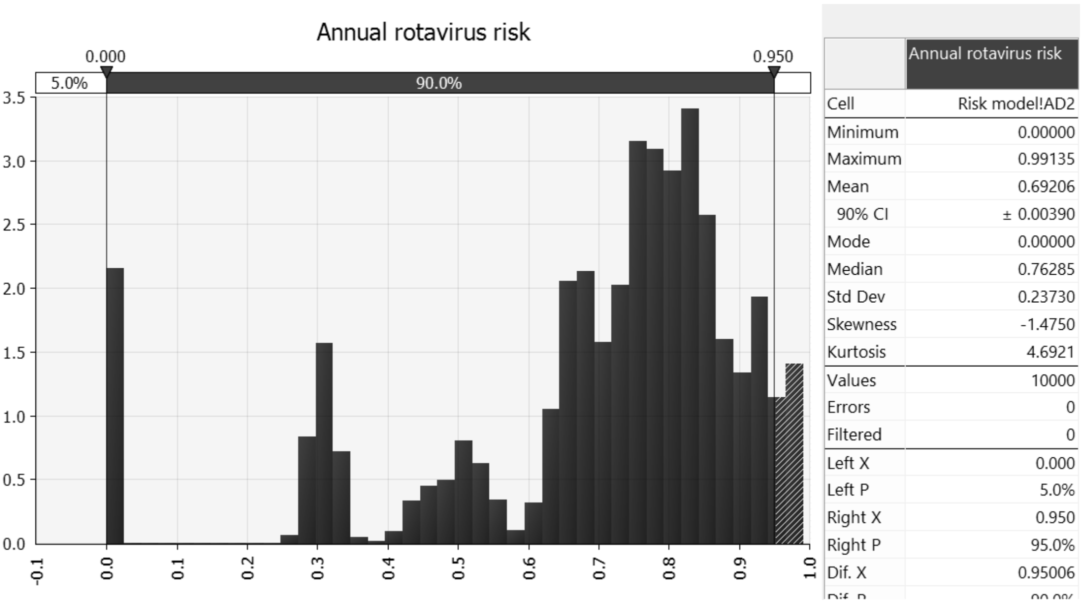

Figure 4-12 Child under 5 years annual rotavirus risk

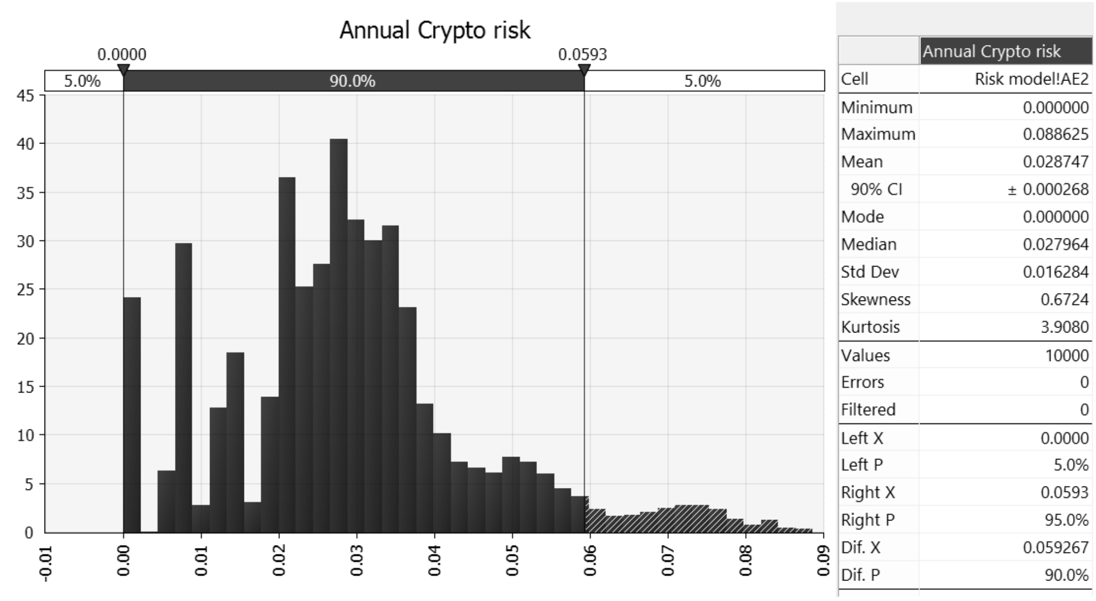

Figure 4-13 Child under 5 years annual cryptosporidium risk

4.5 Discussion

The simulation is based on the exposure of those who consume untreated water which can come from household with ineffective treatment, no treatment at all, or those who consume water direct from tap even when they have treatment for the main drinking water.

This shows very high risk due to the high concentration of *E. coli* in the drinking water from various sampling points. There is a limitation as the number of sampling is limited which can be improved with compiling a few years of sampling data, but routine monitoring does not measure *E. coli* levels.

The main household water treatment for the community is boiling and using a cartridge water filter. Using a household cartridge filter as seen in the study location was not considered to be effective in removal of pathogens from their drinking water due to the pore size of these filters (1-10 micron nominal pore size) and poor maintenance of water filters.

Assuming that boiling is 100% effective in removing the pathogens, the survey shows that 152 out of 218 respondents, about 68%, boil water and do not consume direct from tap. This suggests that 32% of the adult in the community is exposed to the risk.

Despite these results, there is no apparent increase in waterborne disease incidence in the community. There was no reliable data from the local clinic or nearest hospitals to the study location, which is due to several reasons such as lack of proper surveillance and identification system in place, and local treatment seeking and reporting behaviour. However, it would not be surprising even if the cases are actually low among the general population as this has been reported in previous studies comparing risk of infection from microbial density in drinking water and disease incidence in the community (Hunter et al., 2011). The low incidence can be explained by the presence of increased immunity among the local community as they have been repeatedly exposed.

It brings us to consider the impact on children in the community, which need to be investigated further. From the data, among respondents with children age 5 or below, 56 out of 75 household boil water and do not drink from tap (child), which is about 75%. This suggests that 25% of children under 5 in the community are exposed to the calculated risk.

These are very rough estimates as there are no large number of samples to calculate children exposure more precisely. However, this is a good starting point and can be used conservatively in planning health or drinking water intervention.

4.6 Conclusion

The analysis is based on estimation as it was not possible to successfully detect specific pathogens from qPCR. However, the methodology is suitable in similar settings where data is limited. A relatively more conservative estimate was chosen in selecting the data from available literature.

From the annual drinking water monitoring result itself, it was already clear that something needs to be done to improve the condition of the drinking water in the community, however with little change and high resistance from the community, an evaluation of risk that is quantifiable can prove to be indispensable to communicate the need to both the community and authorities.

In conclusion, as it is based on actual *E. coli* levels and water consumption data, one can cautiously use this risk simulation result as a starting reference point, in absence of actual pathogenic data. Information on pathogen concentration can be obtained in future studies, where the risk assessment can be updated using the model used in this study.

The importance of this analysis within the overall context of the study will be discussed in Chapter 5.

Chapter 5: Summary and conclusions

5.1 Overview

This final chapter serves to present the findings from the entire body of the thesis in a comprehensive and meaningful manner to try and answer the final objective of the study, which is to identify effective strategies of drinking water management on the island. This will be discussed with the backdrop that the thesis work was conducted to address the issues faced by the study population of about 3300 people using untreated and contaminated drinking water source and yet rejecting a water treatment system build by the authorities. At the same time the findings from this thesis is very relevant to the national interest as the authorities could face similar situations in developing an effective rural drinking water management system in other parts of the country.

5.2 Summary of main findings

From the systematic review detailed in Chapter 2, the study had discovered several factors that contributes to an effective and sustainable rural drinking water management system (Figure 5.1). One of the factors was reducing barriers that are preventing the community from acting on or adapting a drinking water management strategy, which means that to implement any intervention, it is necessary to discover what the barriers are. From an initial visit to the study site, it became apparent that issues of community perception were at the forefront of the problem faced by the target community. It so happens that in the systematic review, community perception and preferences was also one of the factors that determine system uptake by a community.

Based on the above, using a questionnaire survey method (Chapter 3), the study explored the issue of community perception in detail, using a developed perception model (de França Doria, 2004) as a basis to investigate factors in the community which played a role in; i) perception of risk, ii) perception of chlorine treatment of drinking water and iii) factors that influence attitude and practice of the survey respondents. The relationships between the community's perceptions and the contributing factors can be seen in full in

Figure 3.2 earlier. With the survey results, the study now has important information about the community that needs to be considered in the implementation of a drinking water management system on the island.

Following the survey, the study also utilized QMRA methodology to assess the actual risk to health from the untreated drinking water (Chapter 4). This study was able to show the stark differences between the high level of risk from QMRA calculation and the low perception of risk within the community from the questionnaire survey. The findings from the QMRA can also be an important tool in developing a strategy to improve drinking water management on the island.

The survey had shown that a large majority of the population are genuinely convinced that the water is safe to use without treatment. This is where the result of the QMRA can be useful, as the authorities can talk in term of actual health risks, instead of just quoting the level of contaminants, focusing perhaps on the impact on children. The QMRA result properly communicated can be part of community education and intervention. A study in the rural Appalachian region in the United States had successfully used fecal coliforms and *E. coli* levels in intervention programs that increased awareness and knowledge, together with improving access to clean water (Acripowski et al., 2017).

In implementing community education and intervention, the input from the systematic review finding can provide a guide. As had been discussed, the review found that community education cannot always be sustained or translated into action, and what is required is an education and intervention program that include community participation and provide a sense of ownership. A study done in Ghana showed that handpump sustainability is enhanced with community involvement in management related decisions, but when the community is involved in technical decisions, the system is compromised instead (Marks, Komives and Davis, 2014).

Even though the treatment system that was built (chlorinated water treatment plant) is controlled by the authorities, they can still find ways to get the community more involved with the process. For example, the authorities can set up a joint committee with village representatives that would be involved with the monitoring of the drinking water supply network safety and sustainability. This is one approach used in a rural drinking water supplies project in Kyrgyzstan for improved sustainability (Körner, 2010). Following training by the authorities, the committee would first determine the indicators for sustainability and then set up a plan of monitoring. This could include for example, monitoring of the water supply catchment.

With the involvement of the community in system management and governance, the findings from the systematic review about the governance and management practices that determines system sustainability (for example having training for the committee members and conducting regular committee meeting), should be used as a guide to ensure the effectiveness of the committee and the sustainability of the system. This is important because the review had also found that poor system reliability can be a problem for rural drinking water management.

System reliability is also related to the issues of acceptance to chlorine treatment and willingness to pay (under chlorine perception), as the survey had shown that these issues are not straightforward rejection of chlorine or unwillingness to pay but is related to other factors including perception of risk from the untreated water itself, and perception on system reliability. Because of this, it is possible to increase acceptance and willingness to pay among the community by using risk communication based on the QMRA findings and ensuring system reliability. A study in Nepal support this assessment as they showed that user's satisfaction with system reliability plays an important role in willingness to pay (Bhandari & Grant, 2017).

Another important finding from the survey is regarding the demographic factors which determine the different level of risk perception, chlorine perception and attitude towards drinking water practices. This include the village of the respondent, age group, income, education, gender and wealth. This finding should guide the authorities in focusing on the right target group, while at the same time engaging further to discover any other underlying cause, for example by doing a focus group interview, as the study itself is bound by the limitation of the questionnaire survey. While issues of wealth or level of education needs to be tackled in collaboration with other stakeholders.

In essence, the way forward towards improving drinking water management on the island begins with an understanding of the main barriers, which is the perception of risk and of chlorine treatment of the community and removing false prejudices which does not help with getting the support of the community. This is followed by adapting the effective strategies that had been proven to work such as community participation, sense of ownership and working towards removing the barriers. This is further summarized in Figure 5.1 to show how the findings from the different methods used in this study were applied to address the issues of drinking water management in the study population.

Outside the study population, there is a lot of flexibility in the application of the different methodologies used, which depends on the local situation, level of information available and limitation of resources. The framework (Figure 5.1) provided by this study can be adapted in other situations, by first determining what are the main barriers in that particular community, then following the relevant guidance from available literature on the factors important to the establishment of an effective and sustainable rural drinking water management. This is combined with the use of QMRA to provide a quantitative assessment of risk, which can also be flexible in approach, depending on the level of technical skills and resources that are available.

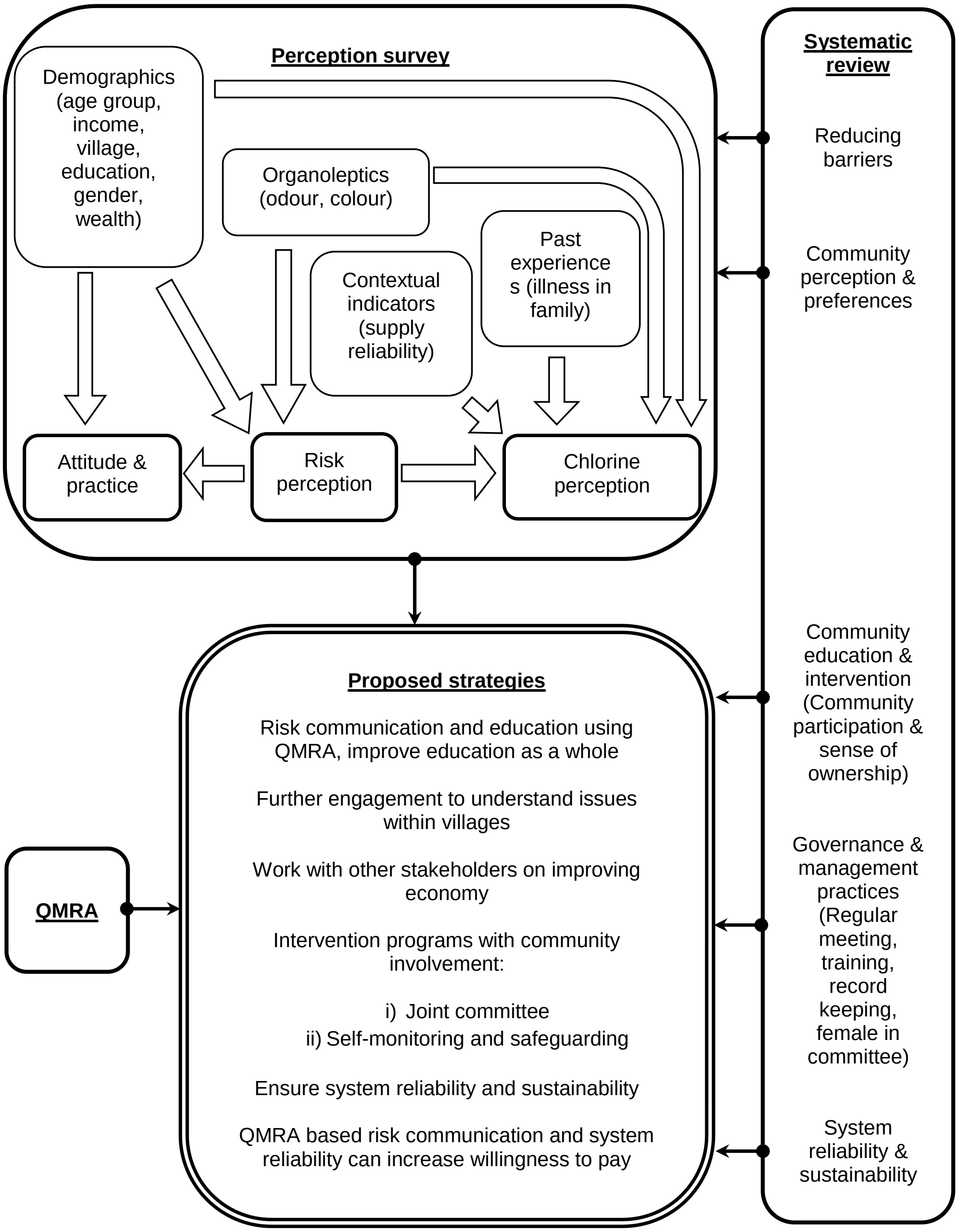

Figure 5-1 Strategies for rural drinking water management based on the thesis findings

5.3 Contribution of the thesis

The research that forms a large part of this thesis was done in collaboration with the local health authorities. The findings should help to assist in their future health program. There were a lot of assumptions that were around before the study, and a lot of it has been investigated in this study. The health authorities had felt that the reluctance to pay was the main hindrance to the implementation of drinking water treatment, but what have been found was that this was not entirely true. There are real issues of perception that can be addressed. This survey can also be repeated to show the level of progress in term of perception and drinking water practices that has been achieved after a period of campaign or intervention. The survey has also been able to collect important information about water consumption and drinking water practices which will be invaluable for many different health programs, locally or even to be applied in areas with similar background.

The risk assessment that was done using QMRA methodology can provide another important tool for risk communication. It should however, be used carefully since the calculation was based on published ratios. *E. coli* O157, though has been found in a few studies in Malaysia, is still not well known, however rotavirus has been the cause of several outbreaks in Malaysia, and can be more useful for the authorities to utilize.

Both community perception and risk assessment methodologies are relatively new in the country, and can be used in many settings either with similar characteristic as the study location or in different situations where they can be applicable. Near the end of the study period I was invited to present the findings at the 3rd National Environmental Health Action Plan Conference in Putrajaya, Malaysia, but unfortunately the timing did not work out. I hope to present the findings at future seminars and conferences in the country. The methodology is also relevant to the implementation of Water Safety Plans in Malaysia.

In more general terms I hope to bring forward the combined approach of conducting both community perception studies and risk assessment studies in managing issues of rural drinking water supply. There have not been many studies that have taken this approach and this thesis has not only shown how important and useful it is to investigate community's perception in managing rural or remote drinking water supply, but it has presented a doable method that is flexible and can be tailored to fit local needs.

The review that was conducted also shows that more studies are needed to evaluate sustainability of rural drinking water supply system or effectiveness of rural drinking water supply intervention, especially in a quantitative or measurable approach.

5.4 Limitations

- Systematic review: The systematic review was done to cover many areas of rural drinking water supply management, so was based on very broad definitions. There were not enough papers with similar methodologies to conduct any meta-analysis. At the same time, grey literature or articles in other languages from local journal databases were not covered by the review, which could be done in future collaborative effort. This could reveal other relevant effective strategies suitable for the study population.

- Community perception: There was a limit to what can be answered with regard to the factors that influence community perception based on the questions that are available in the questionnaire. A focus group study could elicit more relevant factors that could have been included in the questionnaire and tested. Also, though there are differences between villages, most villages had small sample size limiting the ability to test within village. This study had to limit the number of villages selected due to limited time and budget, considering the logistical issues of doing the survey in more villages. There is also the issue of bias in answering the questionnaire, as the villagers can view outsiders with caution. The survey team tried to dissociate as much as possible from the local authorities during the conduct of the interview, but water is a sensitive issue there. The study also tried to reduce respondent bias by conducting a second visit to houses with non-response, but there was no option for further attempts at getting responses.

- Risk assessment: The study was not able to directly detect the presence of pathogenic *E. coli* from the water samples and depended on published pathogen to indicator ratios in literature. There was also limited number of water samples due to limited time and budget in view of the logistics of the study location. Routine monitoring by the health authorities only tested for faecal coliforms.

5.5 Further work

1. Development of sampling and sample processing procedures for remote sampling locations for future quantitative risk assessment based on qPCR. One of the difficulties of this research was the basic facilities available at the study site and the distance from the main lab in Kuala Lumpur. Limited travel options meant that it could take more than 8 hours for the samples to be transported to the main lab. This proved to be a problem for standard sampling for qPCR. The ability to directly measure pathogenic *E.coli* from the study site would help to improve the accuracy of the risk assessment. Therefore, it would be beneficial to develop ways that would allow reliable sampling from remote locations for testing with qPCR as well as improving the qPCR method for testing environmental water samples. For example, one aspect that could be assessed in a future study is the effectiveness of different sample DNA preservation methods.

2. QMRA can be further utilised to quantitatively evaluate the effectiveness of different approaches or strategies in management of rural drinking water supply, which could not be done in this PhD period. Since QMRA can be used to assess each component of drinking water management, including the treatment and there are issues of cost, acceptance of chlorine, and logistics to cover the entire island with chlorinated water treatment, it would be useful to investigate other strategies to improve the safety of the drinking water supply. These

strategies can be evaluated using QMRA, for example to find the most cost-effective methods.

3. Some unanswered questions in differences between villages can be further investigated using other research methodologies such as focus group study. As had been discussed in earlier paragraphs and chapters in this thesis the study methodology has its limitations as only factors that appear in the questionnaire can be studied. During the study and from the results there appear to be some findings that could not be fully explained, and methods such as focus group study can help to explore other issues that may play an important role in the villages and the community. A focus group study can also be useful to assess the opinion of the villagers about the study findings, such as the high level of health risk and the recommendations that has been put forward in this thesis.

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Appendix A: Drinking water monitoring result for Tioman by Rompin District Health Office, April 2011

	Code	Sample location	Physical parameters						Microb		Chemical						
			NTU <5.0	PH 6.5 - 9.0	RCL >0.2	DO >7.0	SUHU	CND 100	T.C <1	F.C NIL	TDS 1000	NH3 <0.5	NO3 <10	Fe 0.3	Al 0.2	Mn 0.1	Cl 250
11	RBJ1	Intake Berjaya 1	1.48	7.06	0	7.87	29.0	26.3	>200.5	25.4	0.03	0.93	0.6	0.02	0.08	NIL	
11	BBJ1	TPO Berjaya 1	0.79	7.23	0	7.65	29.2	22.2	>200.5	30.6	0.03	NIL	0.8	0	0.015	0	
11	ABJ1	Agihan Berjaya 1	0.68	7.52	0	7.89	29.3	23.4	165.1	50.4	0.03	NIL	0.7	0.01	0.008	NIL	
11	RBJ2	Intake Berjaya 2	3.22	7.59	0	7.81	25.2	20.1	>200.5	109.1	0.02	NIL	0.8	0.01	0.007	0.006	
11	BBJ2	TPO Berjaya 2	1.97	7.56	0	7.91	25.1	20.3	165.2	45.3	0.02	NIL	0.6	0.02	0.029	0	
11	ABJ2	Agihan Berjaya 2	1.14	7.58	0	8.09	26.2	20.7	>200.5	53.1	0.03	NIL	0.9	0.01	0.008	0.011	
11	ABJ3	Agihan Berjaya 3	0.82	7.52	0	6.64	28.8	20.0	>200.5	47.8	0.03	NIL	0.7	0.1	0.008	0.005	
			NTU <5.0	PH 6.5 - 9.0	RCL >0.2	DO >7.0	SUHU	CND 100	T.C <1	F.C NIL	TDS 1000	NH3 <0.5	NO3 <10	Fe 0.3	Al 0.2	Mn 0.1	Cl 250
11	RTK	Intake Tekek	3.27	7.61	0	7.78	25.3	10.46	>200.5	47.8	0.02	NIL	0.5	0.02	0.008	0	
11	BTK	Loji Air Tekek	4.01	7.04	0	8.02	26.4	12.51	>200.5	65.9	0.02	NIL	0.8	0.03	0.008	0.007	
11	ATK1	Agihan Tekek-Kedai	6.17	7.28	0	8,36	31.3	16.45	>200.5	83.1	0.02	NIL	0.6	0.03	0.008	0.005	
11	ATK2	Agihan Tekek-Klinik	5.18	7.01	0	8.47	31.1	17.41	>200.5	40.6	0.02	0.01	0.8	0.03	0.009	0	
11	RABC	Kolam ABC Zul	2.52	7.22	0	-	27.4	48.3	>200.5	>200.5	-	NIL	0.4	0.02	0.008	0.004	
11	AABC	Agihan ABC	5.01	7.18	0	-	28.2	49.7	165.2	165.2	-	NIL	0.7	0.04	0.008	0.012	
11	RAB	Intake Air Batang	2.49	7.14	0	-	27.1	45.8	>200.5	>200.5	-	NIL	0.8	0.02	0.008	NIL	
11	AAB	Agihan Air Batang	3.56	7.11	0	-	29.2	46.0	200.5	47.8	-	NIL	0.6	0.02	0.006	0.004	
11	RPY	Intake Paya	1.83	7.59	0	8.01	24.9	15.5	>200.5	62.4	0.02	NIL	0.6	0.02	0.008	0.01	
11	APY	Agihan Paya	1.42	7.06	0	7.66	27.3	15.7	>200.5	47.8	0.02	0.01	0.5	0.01	0.009	0.004	
			NTU <5.0	PH 6.5 - 9.0	RCL >0.2	DO >7.0	SUHU	CND 100	T.C <1	F.C NIL	TDS 1000	NH3 <0.5	NO3 <10	Fe 0.3	Al 0.2	Mn 0.1	Cl 250
11	RGT1	Intake Ulu Air Selarat Genting	0.89	6.72	0	7.31	25.8	17.2	>200.5	13.7	0.02	NIL	0.8	0.02	0.009	0.001	
11	AGT1	Agihan Ulu Air Selarat Genting	0.85	6.83	0	7.74	31.0	15.8	>200.5	17.8	0.02	NIL	0.7	0.01	0.009	NIL	
11	RGT2	Intake Bukit Sepanai Genting	2.08	7.00	0	9.53	26.5	11.9	129.8	3.1	0.01	0.03	0.7	0	0	NIL	
11	AGT2	Agihan Bukit Sepanai Genting	1.94	7.41	0	10.01	27.1	10.7	200.5	5.3	0.01	0.11	0.6	0.01	0.007	0.002	

Appendix B: Ethical approval letter from General Ethics Committee, UEA, 14 July 2014

UEA
University of East Anglia

Nik Muhammad Nizam bin Nik Hassan
School of Law
UEA

Research and Enterprise Services
East Office (Arts Building)

University of East Anglia
Norwich Research Park
Norwich NR4 7TJ
United Kingdom

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14th July 2014

Dear Nik,

I am writing to you on behalf of Professor Peter Kitson, Chair of the General Research Ethics Committee, in response to your submission of an application for ethical approval for your study 'Quantitative Microbial Risk Assessment as a Tool for Improving Drinking Water Quality to Safeguard the Health of the Population and Tourists of a Tropical Island'.

Having considered the information that you have provided in your correspondence Professor Kitson has asked me to tell you that your study has been approved on behalf of the Committee.

You should let us know if there are any significant changes to the proposal which raise any further ethical issues.

Please let us have a brief final report to confirm the research has been completed.

Yours sincerely

Tasha McGowan
Administrative Assistant
Research and Enterprise Services East Office
University of East Anglia
Norwich Research Park
Norwich NR4 7TJ
Email: GREC@uea.ac.uk

Appendix C: Ethical approval letter from Medical Research and Ethics Committee, Ministry of Health, Malaysia, 15 August 2015.

JAWATANKUASA ETIKA & PENYELIDIKAN PERUBATAN
(Medical Research & Ethics Committee)
KEMENTERIAN KESIHATAN MALAYSIA
d/a Institut Pengurusan Kesihatan
Jalan Rumah Sakit, Bangsar
59000 Kuala Lumpur

Tel : 03 2282 0491
Faks : 03 2282 8072 / 03 2282 0015

Ruj. Kami : ( ) KKM/NIHSEC/ P14-782
Tarikh : 15hb Ogos 2014

Nik Muhammad Nizam bin Nik Hassan
Institute for Medical Research (IMR),
Jalan Pahang,
50588 Kuala Lumpur.

Tuan/Puan,

NMRR-14-608-20003
Quantitative Microbial Risk Assessment As A Tool For Improving Drinking Water Quality To Safeguard The Health Of The Population And Tourists Of A Tropical Island.

Lokasi Kajian: Institute for Medical Research (IMR).

Dengan hormatnya perkara di atas adalah dirujuk.

2. Jawatankuasa Etika & Penyelidikan Perubatan (JEPP), Kementerian Kesihatan Malaysia (KKM) tiada halangan, dari segi etika ke atas pelaksanaan kajian tersebut. JEPP mengambil maklum bahawa kajian tersebut tidak mempunyai intervensi klinikal ke atas subjek dan hanya melibatkan pengumpulan data daripada borang soal selidik dan uji kaji sampel air sahaja.

3. Segala rekod dan data adalah **SULIT** dan hanya digunakan untuk tujuan kajian dan semua isu serta prosedur mengenai ***data confidentiality*** mesti dipatuhi. Kebenaran daripada Pengarah Hospital di mana kajian akan dijalankan mesti diperolehi terlebih dahulu sebelum kajian dijalankan. Tuan/Puan perlu akur dan mematuhi keputusan tersebut.

4. Adalah dimaklumkan bahawa kelulusan ini adalah sah sehingga **15hb Ogos 2015**. Tuan/Puan perlu menghantar *'Continuing Review Form'* selewat-lewatnya 2 bulan sebelum tamat tempoh kelulusan ini bagi memperbaharui kelulusan etika. Pihak tuan/puan juga perlu mengemukakan laporan tamat kajian pada penghujung kajian ini dan juga laporan mengenai "*All adverse events, both serious and unexpected*" kepada Jawatankuasa Etika & Penyelidikan Perubatan, KKM jika berkenaan. Borang-borang berkaitan boleh dimuat turun daripada laman web MREC (http://www.nih.gov.my/mrec)

Sekian terima kasih.

BERKHIDMAT UNTUK NEGARA

Saya yang menurut perintah,

DATO' DR CHANG KIAN MENG
Pengerusi
Jawatankuasa Etika & Penyelidikan Perubatan
Kementerian Kesihatan Malaysia

Appendix D: Questionnaire (English). Drinking water consumption, perception and practice questionnaire

1. Individual information

1.1. Gender： (1) Male (2) Female

1.2. Place of birth: ________________

1.3. Date of birth： __________________

1.4. Home address: ____

1.5. How many people live within the house? _________

2. **Water consumption practice** *[The focus of questions 2.1-2.9 is individual practices]*

2.1. What is the main source of water that you use for drinking?

Piped supply from the main dam/river 01
Piped supply from spring 02
Piped supply from tube well 03
Bottled water (eg: mineral water) 04
Other 05 (Clarify):___________________

2.2. During periods of low rain or dry spell, do you have to look for other source of drinking water? Yes No

2.2.1. If yes, please state this other source:______________________________

2.3. Do you treat the water in any way before drinking? Yes No

2.3.1. If yes, how?

Boil it 01
Chlorine tablets 02
Filtration 03
Alum 04
Other 05 (Clarify):____________________

2.4. Do you store water for drinking? Yes No

2.4.1. If yes, how? ______________________________

2.4.2. Is it covered? Yes No

2.5. What is the main source of water that you use for preparing food?

Piped supply from the main dam/river 01
Piped supply from spring 02
Piped supply from ground water 03
Bottled water (eg: mineral water) 04
Other 05 (Clarify):______________________

2.6. Do you treat the water used for preparing food? Yes No

2.6.1. If yes, how?

Boil it 01
Chlorine tablets 02
Filtration 03
Alum 04
Other 05 (Clarify):_________________________

2.7. How much water (including plain and sweet drinks) do you usually drink in a day during dry season? ____ Cup(s) *[If the respondent mentions in bottles note down bottle size and number]*

2.8. How much water do you usually drink in a day during rainy season? ____ Cup(s) *[If the respondent mentions in bottles note down bottle size and number]*

2.9. Do you ever drink water direct from the tap, for example to make cold drinks? Yes No

2.9.1. If yes how much? ____Cup(s) (per day/week/month)

3. Children water consumption

3.1. Is there any baby or child aged 5 and below in the household? Yes No
If yes we would like to ask about the consumption pattern of the child whose birthday is next
3.2. What is the age of the child on her next birthday? ____ years
3.3. How many glass of water does the child drink in a day during dry season (not including breast milk)?___ cup(s)
3.4. How many glass of water does the child drink in a day during rainy season (not including breast milk)?___cup(s)
3.5. Does the child ever drink water direct from the tap? Yes No
3.5.1. If yes how much? ___ cup(s) (per day/week/month)

4. Villagers perception on drinking water supply

Please read the statements below and circle how much you agree with them using a scale of 1 to 7, where **1="completely disagree"** and **7="completely agree",** circle **DK** if you don't know.

4.1. I am happy with the colour of my tap water

1 2 3 4 5 6 7 DK

4.2. I am happy with the odour of my tap water

1 2 3 4 5 6 7 DK

4.3. I am happy with the taste of my tap water.

1 2 3 4 5 6 7 DK

4.4. I often use bottled water at home

1 2 3 4 5 6 7 DK

4.5. The water supply to my house is safe to drink without any treatment

1 2 3 4 5 6 7 DK

4.6. Bottled water is too expensive

1 2 3 4 5 6 7 DK

4.7. It is easy to buy and install a water filter in your home

1 2 3 4 5 6 7 DK

4.8. One of my friends, family members, or myself was ill possibly due tap water.

1 2 3 4 5 6 7 DK

4.9. It is safe to drink from a tap fitted with a water filter

1 2 3 4 5 6 7 DK

4.10. I am satisfied with the water pressure in my house

1 2 3 4 5 6 7 DK

4.11. There are health risks associated with drinking tap water in my house

1 2 3 4 5 6 7 DK

4.12. The water supply system in my village is highly reliable

1 2 3 4 5 6 7 DK

4.13. Drinking water treated with chlorine… (tick all that applies)

4.13.1. Have a bad taste or smell
4.13.2. Have chemicals that are dangerous to health
4.13.3. Is safe and good for health
4.13.4. Is too expensive
4.13.5. Should be supplied to all household

4.14. Are you willing to pay for treated (chlorinated) water supplied by the authorities? Yes/No.

If Yes, how much are you willing to pay monthly? RM……………..

5. Background information

5.1. What is your highest level of education?

5.1.1. Didn't finish school/start school 01

5.1.2. Primary school 02

5.1.3. High school 03

5.1.4. College/University 04

5.2. What is your occupation? _________________

5.3. How much on average do you earn monthly?

<RM1000 RM1000-1999 RM2000-2999 RM3000-3999 RM4000 and above

5.4. Number of years living in locality: _____years_____months

5.5. Housing type (look rather than ask):

5.5.1. Solid/well-built house 01

5.5.2. Semi-solid house 02

5.5.3. Poorly-built house 03

5.5.4. Others 04 (Clarify):_______________________

5.6. Housing quality (look rather than ask):

5.6.1. Good 01

5.6.2. Lightly degraded 02

5.6.3. Heavy degrading 03

5.7. Housing status:

5.7.1. Having ownership 01

5.7.2. Rented 02

5.7.3. Stay with relatives/friends 03

5.7.4. Others 04 (Clarify): _________________________

5.8. Household property: Do you own the following

5.8.1. Motorboat/Speedboat 0 Yes 0 No

5.8.2. LCD/LED/Plasma TV 0 Yes 0 No

5.8.3. Motorbike 0 Yes 0 No

5.8.4. Car 0 Yes 0 No

5.8.5. 4WD 0 Yes 0 No

5.9. Details of all individuals staying in the house

No	Age	Gender	Relationship	Education level	Occupation	Income (Monthly)

Appendix E: Questionnaire (Malay): Drinking water consumption, perception and practice questionnaire

1. **Maklumat individu**
   5.10. Jantina : (1) Lelaki (2) Perempuan
   5.11. Tempat lahir: ________________________
   5.12. Tarikh lahir:___________________
   5.13. Alamat rumah: ____
   5.14. Berapa orangkah yang tinggal di rumah ini? _________ orang

2. **Tabiat pengambilan/penggunaan air** *[Fokus soalan 2.1-2.9 adalah amalan individu yang disoalselidik]*

2.1. Apakah punca air utama yang anda gunakan untuk minum?

Air paip dari sungai/empangan utama	01
Air paip dari mata air	02
Air paip dari telaga bawah tanah	03
Air botol (eg:mineral water)	04
Lain-lain	05 (Jelaskan):____________________

2.2. Ketika musim kemarau atau kurang hujan, adakah anda perlu mencari sumber air yang lain?
Ya Tidak

2.2.1. Jika Ya, sila nyatakan sumber lain tersebut:______________________________

2.3. Adakah anda merawat air melalui apa-apa cara sebelum diminum? Ya
Tidak

2.3.1. Jika Ya, bagaimana?

Masak	01
Tablet klorin	02
Alat penapis	03
Tawas/Kapur	04
Lain-lain	

05(Jelaskan):_____________________

2.4. Adakah anda menyimpan air yang akan digunakan untuk minum? Ya Tidak

2.4.1. Jika ya, bagaimana? ______________________________

2.4.2. Adakah ia tertutup? Ya Tidak

2.5. Apakah sumber utama air yang anda gunakan untuk penyediaan makanan?

Air paip dari sungai/empangan utama	01
Air paip dari mata air	02
Air paip dari telaga bawah tanah	03
Air botol (eg: mineral water)	04
Lain-lain	05 (Jelaskan):____________________

2.6. Adakah anda merawat air yang digunakan untuk penyediaan makanan? Ya Tidak

2.6.1. Jika ya, bagaimana?

Masak	01
Tablet klorin	02
Alat penapis	03
Tawas/Kapur	04
Lain-lain	05

(Jelaskan):__________________________

2.7. Berapa banyak air (termasuk air masak dan air minuman lain) yang anda biasa minum dalam sehari semasa musim kemarau? ____ cawan *[Sekiranya dinyatakan dalam bentuk botol catat saiz dan bilangan botol]*

2.8. Berapa banyak air (termasuk air masak dan air minuman lain) yang anda biasa minum dalam sehari semasa musim hujan? ____ cawan *[Sekiranya dinyatakan dalam bentuk botol catat saiz dan bilangan botol]*

2.9. Pernahkah anda minum air yang diambil terus dari paip, contohnya untuk buat air sejuk?
Pernah Tidak pernah

2.9.1. Jika pernah, boleh beri anggaran? ____ cawan (sehari/seminggu/sebulan)

3. **Pengambilan air kanak-kanak**

3.1. Adakah ada kanak-kanak atau bayi berumur 5 tahun ke bawah dalam rumah ini? Ya/Tidak

JIka Ya, kami ingin menyoal anda mengenai tabiat pengambilan air kanak-kanak yang **akan** menyambut ulangtahun kelahiran dalam masa terdekat.

3.2. Berapakah umur kanak-kanak ini pada hari lahirnya yang akan datang ini? ____ tahun

3.3. Berapa banyak air (tidak termasuk susu ibu) yang dia biasa minum sehari semasa musim kemarau? ____ cawan

3.4. Berapa banyak air (tidak termasuk susu ibu) yang dia biasa minum sehari semasa musim hujan? ____ cawan

3.5. Pernahkah dia minum air terus dari paip? Pernah Tidak pernah

3.5.1. Jika pernah, boleh beri anggaran? ____ cawan (sehari/seminggu/sebulan)

4. **Pendapat mengenai bekalan air minum ke rumah anda**

Sila baca kenyataan-kenyataan di bawah dan **bulatkan** sejauh mana anda bersetuju dengan kenyataan-kenyataan tersebut mengikut **skala 1 hingga 7**, di mana **1="Langsung tidak bersetuju"** dan **7="Bersetuju sepenuhnya"**, bulatkan **DK** jika tidak tahu)

4.1. Saya puas hati dengan warna air paip rumah saya

1 2 3 4 5 6 7 DK

4.2. Saya puas hati dengan bau air paip rumah saya

1 2 3 4 5 6 7 DK

4.3. Saya puas hati dengan rasa air paip rumah saya

1 2 3 4 5 6 7 DK

4.4. Saya selalu guna air botol/mineral di rumah

1 2 3 4 5 6 7 DK

4.5. Air yang dibekalkan ke rumah saya selamat untuk diminum tanpa rawatan

1 2 3 4 5 6 7 DK

4.6. Air botol/mineral terlalu mahal

1 2 3 4 5 6 7 DK

4.7. Senang untuk membeli dan memasang penapis air di rumah saya

1 2 3 4 5 6 7 DK

4.8. Salah seorang kawan, keluarga, atau saya sendiri pernah jatuh sakit, kemungkinan berpunca dari air paip

1 2 3 4 5 6 7 DK

4.9. Adalah selamat untuk minum air terus dari paip yang ada penapis air

1 2 3 4 5 6 7 DK

4.10. Saya berpuas hati dengan tekanan air di rumah saya

1 2 3 4 5 6 7 DK

4.11. Terdapat risiko kesihatan berkaitan dengan pengambilan air paip di rumah saya

1 2 3 4 5 6 7 DK

4.12. Sistem bekalan air di kampung saya amat boleh diharap

1 2 3 4 5 6 7 DK

4.13. Air minum yang dirawat dengan klorin… (tanda semua yang anda rasa benar)

4.13.1. Mempunyai bau dan rasa yang kurang menyenangkan
4.13.2. Mengandungi bahan kimia yang berbahaya untuk kesihatan
4.13.3. Selamat dan baik untuk kesihatan
4.13.4. Kosnya terlalu mahal
4.13.5. Patut dibekalkan ke semua rumah

4.14. Adakah anda bersedia untuk membayar untuk air terawatt yang dibekalkan oleh pihak berkuasa? Ya/Tidak. Jika Ya berapa RM………. Sebulan yang anda sanggup bayar?

5. **Maklumat latar belakang**

5.1. Apakah tahap pendidikan tertinggi anda?

Tidak tamat/tidak pernah sekolah	01
Sekolah rendah	02
Sekolah menengah	03
Kolej/Universiti	04

5.2. Apakah pekerjaan anda? ________________

5.3. Berapakah purata pendapatan bulanan anda?

<RM1000 RM1000-1999 RM2000-2999 RM3000-3999 RM4000 ke atas

5.4. Berapa lama anda telah menetap di kampung ini: _____tahun_____bulan

5.5. Jenis rumah [*melalui pemerhatian*]:

Kukuh	01
Separa kukuh	02
Binaan lemah	03
Lain-lain	04

(Jelaskan):______________________

5.6. Keadaan rumah *[melalui pemerhatian]:*

Baik	01
Sedikit lusuh	02
Amat lusuh	03

5.7. Status kediaman:

Hak milik	01
Sewa	02
Tinggal bersama saudara/kawan	03
Lain-lain	04 (Jelaskan):

____

5.8. Pemilikan harta: Adakah anda memiliki

5.8.1. Motorboat/Speedboat	Ya	Tidak
5.8.2. LCD/LED/Plasma TV	Ya	Tidak
5.8.3. Motosikal	Ya	Tidak
5.8.4. Kereta	Ya	Tidak
5.8.5. 4WD	Ya	Tidak

5.9. Maklumat semua individu yang tinggal di kediaman

Bil	Umur	Jantina	Hubungan	Tahap pendidikan	Pekerjaan	Anggaran Purata Pendapatan Bulanan (RM)

Appendix F: Colilert and Enterolert test procedure

A. Colilert test:

Introduction:

The Colilert test simultaneously detects total coliforms and *E. coli* in water. It is based on IDEXX's patented Defined Substrate Technology* (DST*). When total coliforms metabolize Colilert's nutrient-indicator, ONPG, the sample turns yellow. When *E. coli* metabolize Colilert's nutrient-indicator, MUG, the sample also fluoresces. Colilert can simultaneously detect these bacteria at 1 cfu/100 mL within 24 hours even with as many as 2 million heterotrophic bacteria per 100 mL present.

The test is available in the presence/absence (PA) or the most probable number (MPN) format. The PA format is suitable when we are only interested in the presence or absence result. The MPN format allows enumeration of the microbial volume in the water sample, but requires the use of a specially designed disposable incubation tray named the Quanti-Tray.

For the purpose of this study the Quanti-tray enumeration procedure is used.

Materials

• The Colilert substrate

• Special incubation trays (Quanti-Tray or Quanti-Tray/2000)

• The Quanti-Tray sealer machine

• Sterile sample collection bottles

Quanti-Tray* Enumeration/MPN Procedure

1. Add contents of one pack (substrate) to a 100 mL water sample in a sterile vessel.

2. Cap vessel and shake until dissolved.

3. Pour sample/reagent mixture into a Quanti-Tray or Quanti-Tray/2000 and seal in an IDEXX Quanti-Tray Sealer.

4. Place the sealed tray in a 35±0.5°C incubator for 24 hours.

5. Read results according to the Result Interpretation table below. Count the number of positive wells and refer to the MPN table provided with the trays to obtain a Most Probable Number.

Result Interpretation

• Look for fluorescence with a 6-watt, 365-nm UV light within 5 inches of the sample in a dark environment. Face light away from your eyes and towards the sample.

• Colilert results are definitive at 24–28 hours. In addition, positives for both total coliforms and *E. coli* observed before 24 hours and negatives observed after 28 hours are also valid.

• Count large and small positive wells that;

a. Fluoresce under a long-wave ultraviolet light as *E. coli*

b. Appear yellow under ambient light as total coliforms

c. Dim yellow colour and dim or off-colour fluorescence are not counted as positive results.

d. The large overflow well at the top of the tray is counted as a large well.

• Refer to the MPN table to obtain results based on your count above. The result is interpreted as MPN/100 ml.

References

1. Colilert test procedure. http://www.idexx.com/resource-library/water/colilert-procedure-en.pdf
2. USGS Ohio Water Science Center Colilert Method for Total Coliforms and *Escherichia Coli*. http://oh.water.usgs.gov/micro_methods_Colilert.htm

B. Enterolert test

Introduction

The Enterolert test detects enterococci, such as *E. faecium* and *E. faecalis*, in fresh and marine water. It is based on IDEXX's patented Defined Substrate Technology (DST). When enterococci utilize their ß-glucosidase enzyme to metabolize Enterolert's nutrient-indicator, 4-methyl-umbelliferyl ß-D-glucoside, the sample fluoresces. Enterolert detects enterococci at 1 cfu per 100 mL sample within 24 hours.

Like the Colilert test the Enterolert test is available in the presence/absence (PA) or the most probable number (MPN) format. The PA format is suitable when we are only interested in the presence or absence result. The MPN format allows enumeration of the microbial volume in the water sample, but requires the use of a specially designed disposable incubation tray named the Quanti-Tray.

Materials

• The Enterolert substrate

• Special incubation trays (Quanti-Tray or Quanti-Tray/2000)

• The Quanti-Tray sealer machine

• Sterile sample collection bottles

Quanti-Tray* Enumeration/MPN Procedure

1. Add contents of one pack to a 100 mL water sample in a sterile vessel.

2. Cap vessel and shake until dissolved.

3. Pour sample/reagent mixture into a Quanti-Tray* or Quanti-Tray*/2000 and seal in an IDEXX Quanti-Tray* Sealer.

4. Place the sealed tray in a 41±0.5°C incubator for 24 hours.

5. Read results according to the Result Interpretation table below. Count the number of positive wells and refer to the MPN table provided with the trays to obtain a Most Probable Number.

Result Interpretation

• Appearance Result:

Lack of fluorescence Negative for enterococci

Blue fluorescence Positive for enterococci

• Look for fluorescence with a 6–watt, 365 nm, UV light within 5 inches of the sample in a dark environment. Face light away from your eyes and towards the sample.

• Enterolert results are definitive at 24–28 hours. In addition, positives for enterococci observed before 24 hours and negatives observed after 28 hours are also valid.

• Count number of fluorescence wells and refer to the MPN table to obtain results based on the count. The result is interpreted as MPN/100 ml.

References

1. Enterolert test kit procedure. http://www.idexx.com/resource-library/water/enterolert-procedure-en.pdf

Appendix G: *Clostridium perfringens* test procedure

Enumeration of *Clostridium Perfringens* by Membrane Filtration.

<u>Principle</u>

This method involves filtering an appropriate volume of water sample through a membrane filter (pore size 0.45microns) to retain the bacteria present in the sample. The membrane filter is then placed on perfringens agar (P.A) O.P.S.P. and incubated anaerobically for 48 hours at 37°C. The concept is that one viable cell will equal one colony forming unit. *C. perfringens* appear as black colonies on PA agar and are confirmed by Lactose Gelatine Liquefaction and Nitrate Motility Test.

<u>Reagents/Materials</u>

1. Sterile, screw cap glass bottles (500ml or 1L capacity)
2. Micropipettes (various volumes)
3. Sterile various volumes pipette tips (0.01, 0.1, 1.0, & 10ml)
4. Forceps, with smooth tips to permit handling of filters without damage
5. Petri dish (55 x 14.2mm)
6. Bijou bottles
7. Test tubes, screw cap, 16 x 125mm
8. Inoculation loops
9. 95% alcohol (for flame-sterilization of forceps and inoculation loops)
10. Incubator at 35± 0.5°C
11. Anaerobic jar
12. Anaerobic gas pack kit
13. Membrane filtration materials
14. Sterile membrane filters (gridded 0.45 micron)
15. Perfringens agar (O.P.S.P.)
16. Lactose Gelatin Medium
17. Nitrate Motility Medium
18. Sterile ¼ strength Ringer's solution
19. Nitrate reduction reagents A & B, zinc dust

20. Control cultures:-

Positive: *C. perfringens* ATCC 13124

Negative: *E. faecalis* isolate

Procedure

1. Decide on the dilutions estimated to produce best results. Always start with the lowest concentration, i.e. the most dilute first, to minimize carry-over of bacterial cells from one filtration to the next.

2. Prepare the positive and negative control by putting three loops of each broth culture into 90ml dilution blanks. Set aside.

3. Grasp a sterile membrane filter by its edge using a sterile forceps and place on the sterile base, grid side up. Attach the sterile funnel to the base of the filter unit; the membrane filter is now held between the funnel and the base.

4. Pipette water sample into the funnel. For 100ml amounts pour directly into funnel. For lower volumes, pour approximately 50ml of sterile ¼ Ringers solution into funnel, and aseptically pipette required volume of sample. Top up to 100ml level mark with sterile ¼ strength Ringer's solution. This will disperse the cells across the membrane and reduce clumping.

5. Apply the vacuum to start filtration and draw the sample through.

Rinse the funnel walls with at least 50ml of sterile ¼ strength Ringer's solution. This washes cells down onto the filter, and provides sufficient cleaning between filtrations of the same site.

7. Remove the top section of the funnel and aseptically transfer the membrane filter to a Petri Dish containing P.A. agar. The membrane must be applied to the agar by placing the edge vertically on one side of the agar and then lowering it by a rolling action. This will avoid air being trapped under the membrane.

8. Filter the negative and positive controls (in that order).

9. Incubate anaerobically at 35± 0.5°C for 48 hrs.

10. After incubation, count the number of typical colonies. Ideal count will be plates with between 20 and 80 colonies on them. *C. perfringens* will appear as black colonies on PA agar. This will give you a presumptive count.

11. To confirm *C. perfringens* carry out Lactose Gelatine Liquefaction and Nitrate Motility Test.

Confirmatory Tests:

a) Lactose Gelatine Liquefaction:
Select a colony and inoculate part of it into a tube of Lactose Gelatine Medium.

Incubate at 35± 0.5°C for 24 hrs.

C. perfringens produces acid from lactose in the lactose gelatine medium causing phenol red indicator to change from red to yellow. It also hydrolyses gelatine preventing solidification. Incubate the tubes at 4°C for 1 hr. to check for liquefaction.

b) Nitrate Motility Test:

Using a straight wire loop, pick up the other half of the colony and stab it into a tube of Nitrate Motility Medium.

C. perfringens is non-motile. Non-motility is confirmed when growth is confined to the stab line. Motility is confirmed when there is diffuse growth throughout the medium.

C. perfringens reduces nitrate to nitrite. O.5ml and O.2ml of reagents A and B respectively are added to the tube. A colour change to magenta (reddish purple) indicates that nitrate has been reduced. If no colour change was observed after 5 minutes, zinc dust is added to the tube. Development of a violet colour indicates that nitrate is

c) Interpretation of results

	Characteristics of *C.perfringens*
PA agar	Black colonies
Lactose gelatine medium	Change colour from red to yellow
Nitrate Motility medium	Non-motile. Growth confined to stab line
Reagents A and B	Change colour to reddish purple

<u>References</u>:

1. Standard Methods for Examination of Water and Wastewater 19th Edition 1995

2. Oxoid Manual, 6th edition (1990). Oxoid Ltd., Basingstoke, England.

Appendix H: Dynal IMS procedure

Dynal IMS method for detection of Cryptosporidium and Giardia

This method designed for rapid, selective separation of Giardia cysts and Cryptosporidium oocysts from water sample concentrates using IMS. This method replaces flotation techniques currently used for separating cysts and oocysts from other debris in water sample concentrates.

<u>OBJECTIVES</u>

For rapid, selective separation of Giardia cysts and Cryptosporidium oocysts from water sample concentrates.

<u>PROCEDURES</u>

Regent/materials

1. Dynabeads anti-Cryptosporidium
2. Dynabeads anti-Giardia
3. 10X SL™-Buffer A (clear, colourless solution).
4. 10X SL™-Buffer B (magenta solution).
5. Filters, centrifuges and other equipment for preparation of the water sample concentrate from the original water sample
6. Vortex type mixer
7. Test-tubes, glassware, pasteur pipettes, microcentrifuge tubes
8. Micro-pipette (10-1000 µl)
9. Humid chamber
10. Incubator set at 37°C ± 1°C
11. Fluorescence microscope
12. Demineralised cyst/oocyst-free water
13. Hydrochloric acid (calibrated or standardized stocks must be used)
14. Sodium hydroxide solution (calibrated or standardised stocks must be used)
15. Methanol
16. Fluorescein isothiocyanate (FITC) conjugated anti-Cryptosporidium & anti-Giardia monoclonal antibody
17. Phosphate buffered saline (PBS)
18. 4’6 diamidino-2-phenyl indole (DAPI)

19. DABCO/glycerol mounting medium

20. Cover slips

PROCEDURE

A. Sample preparation

1. The sample should be prepared by standard filtration and centrifugation methods to give a final volume of 10 ml.

2. If the sample has been stored below room temperature, leave to stand at room temperature for sufficient time to allow sample temperature to equilibrate to room temperature.

3. If the sample is suspended in eluting, detergent or preserving solutions then it should be resuspended in water.

B. Preparation of reagents

1. For each 10 ml sample, sub-sample or control the following quantities of buffers will be required:

1 ml of 1X SL™-Buffer A

1 ml of 10X SL™-Buffer A

1 ml of 10X SL™-Buffer B

2. Prepare a 1X dilution of SL™-Buffer A from the 10X SL™-Buffer A (clear, colourless solution) supplied. Use cyst & oocyst-free demineralised water as the diluent. For every 1 ml of 1X SL™-Buffer A required, take 100 µl of 10X SL™-Buffer A and dilute to 1 ml with the diluents' water.

3. Retain the 1X dilution of SL™-Buffer A in a labelled vial for use later in the procedure (section C, step 12).

4. To a flat-sided Dynal L10 tube (125 x 16 mm with a 60 x 10mm flat sided magnetic capture area, Dynal Prod. No. 740.03) add 1 ml of the 10X SL™-Buffer A (supplied - not the diluted 1X SL™-Buffer A).

5. To the same tube containing the 10X SL™- Buffer A, add 1 ml of the 10X SL™-Buffer B (supplied - magenta solution).

C. Capture

1. Immediately transfer the water sample concentrate to the Dynal L10 tube containing the SL™-Buffer. Label the tube with a sample identifier code.

2. Shake (vortex) the Dynabeads anti-Cryptosporidium vial for 10 seconds on a vortex-type mixer.

3. Ensure that the beads are fully resuspended by inverting the vial and making sure that there is no residual pellet at the bottom. Add 100 µl of Dynabeads anti-

Cryptosporidium to the Dynal L10 tube containing the water sample concentrate and SL™-Buffer.

4. Shake (vortex) the Dynabeads anti-Giardia vial for 10 seconds on a vortex-type mixer.

5. Ensure that the beads are fully resuspended by inverting the vial and making sure that there is no residual pellet at the bottom. Add 100 µl of Dynabeads anti-Giardia to the Dynal L10 tube containing the water sample concentrate, Dynabeads anti-Cryptosporidium and SL™-Buffer.

6. Affix the Dynal L10 tube to a rotating mixer (e.g. Dynal-MX1 or Dynal Sample Mixer) and rotate at 15-20 RPM for 1 hour at room temperature.

7. After rotating for at least 1 hour, remove tube from mixer and place in the magnetic particle concentrator (Dynal MPC-1) with flat side of tube towards the magnet.

8. Without removing the tube from the Dynal MPC-1, place the magnet side of the Dynal MPC-1 downwards (tube is horizontal and above the magnet).

9. Gently rock the tube end to end through approximately 90°, tilting cap-end and base-end of the tube up and down in turn. Continue the tilting action for 2 minutes with approximately one tilt per second. To achieve this there is one tilt per second for the to and another for the fro.

10. Ensure that the tilting action is continued throughout this period to prevent binding of low mass material which is magnetic or magnetisable. If sample in the Dynal MPC-1 is allowed to stand motionless for more than 10 seconds, then the tube should be removed and the beads resuspended by gentle shaking. Repeat step 9 before continuing procedure.

11. Return the Dynal MPC-1 to the upright position, tube vertical, with cap at top. Immediately remove cap and decant (pour off) all the supernatant from the tube held in the Dynal MPC-1 into a suitable container. Carefully decant the tube such that the flat face and the magnet are uppermost to help retain the particles. Do not shake the tube and do not remove the tube from Dynal MPC-1 during this step.

12. Remove the tube from the Dynal MPC-1 and resuspend sample in 1 ml 1X SL™-Buffer A (prepared from 10X SL™-Buffer A stock supplied). Mix very gently to resuspend all material in the tube. Do NOT vortex!

13. Transfer all the liquid from the Dynal L10 tube to a labelled 1.5 ml microcentrifuge tube. Ensure that all the liquid and Dynabeads are transferred.

14. Place the microcentrifuge tube into the other magnetic particle concentrator (Dynal MPC-S), with magnetic strip in place in the vertical position.

15. Without removing the microcentrifuge tube from Dynal MPC-S, gently rock/roll the Dynal MPC-S through 90°. Continue for 1 minute with approximately one roll/rock per second. The magnet is rocked 90 degrees in one second in one direction and then

rolled back in another second. At the end of this step the Dynabeads-organism complex should form a clear ‘dot’ on the back of the tube.

16. Immediately aspirate the supernatant from the tube and cap held in the Dynal MPC-S. If more than one sample is being processed, conduct three 90° rock/roll actions before removing the supernatant from each tube. Take care not to disturb the material attached to the wall of the tube adjacent to the magnet. Do not shake the tube. Do not remove tube from Dynal MPC-S whilst conducting these steps.

D. Dissociation of Dynabeads-cysts/-oocysts complex.

1. Remove magnetic strip from the Dynal MPC-S.

2. Add 50 µl of 0.1 N hydrochloric acid (HCl) to the microcentrifuge tube and vortex thoroughly for 10 seconds.

3. Place the tube in Dynal MPC-S without magnetic strip in place and allow to stand in a vertical position for at least 10 minutes at room temperature.

4. Vortex thoroughly for a further 10 seconds.

5. Ensure that the entire sample is at the base of the tube. Place microcentrifuge tube in Dynal MPC-S.

6. Insert the magnetic strip in the Dynal MPC-S in the tilted position and allow the tube to stand undisturbed for about 10 seconds.

7. Prepare a Dynal Spot-On slide (Prod. No. 740.04) for sample screening. Label the slide appropriately and add 5 µl of 1 N sodium hydroxide (NaOH) solution to the sample well.

8. Transfer all fluid from microcentrifuge tube onto the same well of the slide which already contains 5 µl of 1N NaOH. Take care not to disturb beads at back-wall of tube. Ensure that all the fluid is transferred.

9. Air-dry the sample onto the slide.

E. Staining

1. Add one drop (50 µl) methanol to each well of the slide and allow to evaporate to dryness at room temperature.

2. Apply 50 µl of a combined fluorescein isothiocyanate (FITC) conjugated anti-Cryptosporidium and anti-Giardia monoclonal antibody at working dilution to each well of the slide. Ensure complete coverage of each well.

3. Put the slide in a humid chamber and place in an incubator at 37°C for 30 min.

4. Use a Pasteur pipette and gently aspirate the monoclonal antibody from the wells.

5. Apply one drop (50 µl) 4’6-diamidino-2- phenyl indole (DAPI) in PBS solution (0.4 µg DAPI/ml) to each well and allow to stand for 1 min.

6. Use a Pasteur pipette and gently aspirate the DAPI solution from each well.

7. Apply one drop (50 µl) of water to each well and leave for 1-3 seconds to remove residual PBS and DAPI solution.

8. Use a Pasteur pipette and gently aspirate the water from each well.

9. Immediately before screening each slide by fluorescence microscopy apply 10 µl DABCO/glycerol mounting medium to each well of the slide, allowing the drop to fall freely (i.e. avoid contact between slide and pipette tip) and apply cover-slip to slide. Do not press cover-slip.

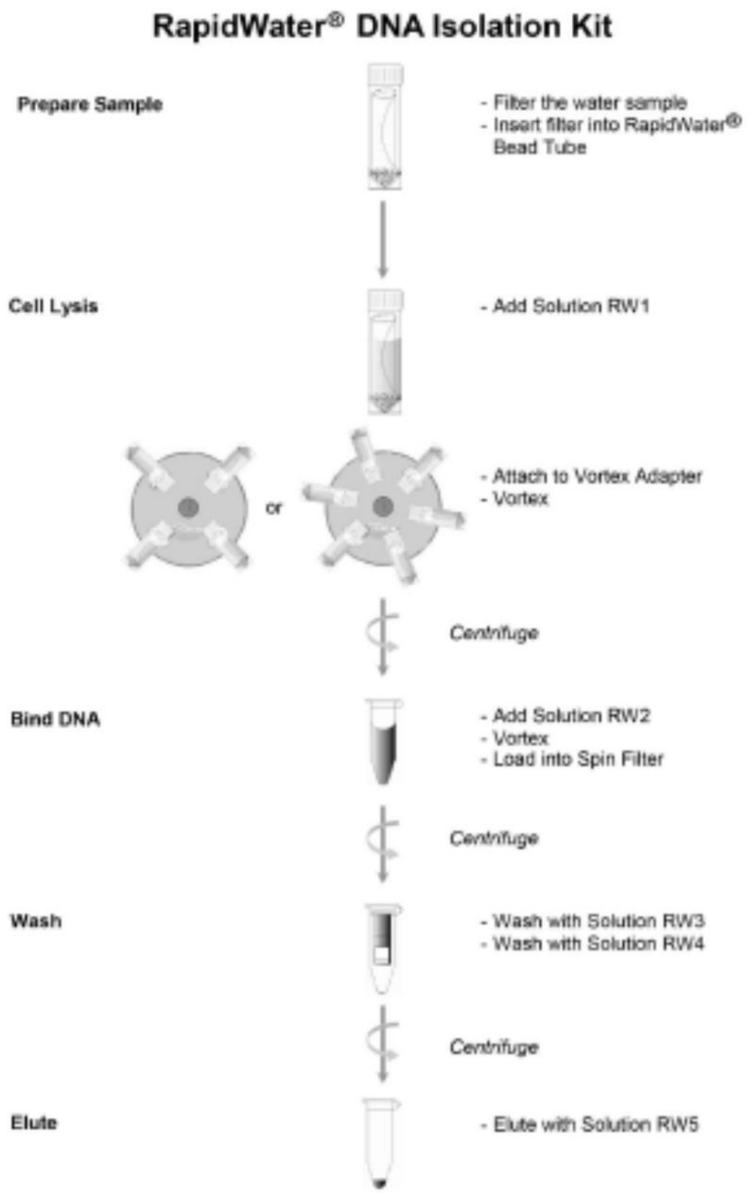
REFERENCE LIST

1. DNAL Biotech. Product No. 730.02, 730.12. Printed: 0803. Rev. no: 011

2. US EPA Method 1623: Cryptosporidium and Giardia in Water by Filtration/IMS/FA

Appendix I: MO Bio RapidWater DNA Isolation Kit Procedure

MO BIO Laboratories, Inc.



MO BIO Laboratories, Inc.

Detailed Protocol (Describes what is happening at each step)

Please wear gloves at all times

Warm Solution RW1 prior to use at 55°C for 5-10 minutes. Use Solution RW1 while still warm. Check Solution RW2 and warm at 55°C for 5-10 minutes if necessary. Solution RW2 can be used while still warm.

1. Filter water samples using a reusable or disposable filter funnel attached to a vacuum source. Disposable filter funnels, containing 0.22 µm or 0.45 µm filter membranes, can be ordered from MO BIO Laboratories (see page 3). The volume of water filtered will depend on the microbial load and turbidity of the water sample. **(Please see Types of Water Samples in the "Hints and Troubleshooting Guide" section of Instruction Manual).**

   What's happening: A reusable or disposable filter funnel is attached to a vacuum filtration system. Microorganisms are trapped on top of and within the filter membrane.

2. If using a reusable filter funnel, remove the upper portion of the apparatus. If using a MO BIO Laboratories filter funnel, remove the 100 ml upper portion of the filter cup from the catch reservoir by snapping it off.

3. Using two sets of sterile forceps, pick up the white filter membrane at opposite edges and roll the filter into a cylinder with the top side facing inward.

   Note: Do not tightly roll or fold the filter membrane. To see a video of this technique please visit the RapidWater® DNA Isolation Kit product page on www.mobio.com.

4. Insert the filter into the 5 ml RapidWater® Bead Tube.

5. Add **1 ml of Solution RW1** to the RapidWater® Bead Tube.

   Note: Solution RW1 must be warmed to dissolve precipitates prior to use. Solution RW1 should be used while still warm. For samples containing organisms that are difficult to lyse (fungi, algae) an additional heating step can be included. See **Alternate Lysis Method in the "Hints and Troubleshooting Guide".**

   What's happening: Solution RW1 is a strong lysing reagent that includes a detergent to help break cell walls and a protein precipitation agent that will remove non-DNA organic and inorganic material. When cold, this solution will form a white precipitate in the bottle. Heating to 55°C will dissolve the components without harm. Solution RW1 should be used while it is still warm.

6. Secure the RapidWater® Bead Tube horizontally to a MO BIO Vortex Adapter (Catalog# 13000-V1-15 or 13000-V1-5).

7. Vortex at maximum speed for 5 minutes.

   What's happening: The mechanical action of bead beating will break apart the surface of the filter membrane that contains trapped cells and aids in cell lysis. Use of the vortex adapter will maximize homogenization by holding the tubes equal distance and angle from the center of rotation. Avoid using tape, which can become loose and result in reduced homogenization efficiency.

8. Centrifuge the tubes ≤ 4000 x *g* for 1 minute at room temperature. The speed will depend on the capability of your centrifuge. **(This step is optional if a centrifuge with a 15 ml tube rotor is not available, but will result in minor loss of supernatant).**

9. Transfer the supernatant to a clean 2 ml Collection Tube (provided). Draw up the supernatant using a 1 ml pipette tip by placing it down into the beads.

    Note: Placing the pipette tip down into the beads is required. Pipette more than once to ensure removal of all the supernatant. Any carryover of beads will not affect subsequent steps. Expect to recover between 600-650 µl of supernatant depending on the type of filter membrane used.

    What's happening: The supernatant is separated and removed from the filter membrane and beads at this step.

10. Centrifuge at 13,000 x *g* for 1 minute.

    What's happening: Any remaining beads, proteins, and cell debris are removed at this step. This step is important for removal of any remaining contaminating non-DNA organic and inorganic matter that may reduce the DNA purity and inhibit downstream DNA applications.

11. Avoiding the pellet, transfer the supernatant to a clean 2 ml Collection Tube (provided).

12. Add **650 µl of Solution RW2** and vortex briefly to mix.

    Note: Check Solution RW2 for precipitation prior to use. Warm if necessary. Solution RW2 can be used while still warm.

    What's happening: Solution RW2 is a high concentration salt solution. Since DNA binds tightly to silica at high salt concentrations this will adjust the DNA solution salt concentration to allow binding of the DNA, but not non-DNA organic and inorganic material that may still be present at low levels, to the spin filter.

13. Load 650 µl of supernatant onto a Spin Filter and centrifuge at 13,000 x *g* for 1 minute. Discard the flow through and repeat until all the supernatant has been loaded onto the Spin Filter.

    Note: A total of two loads for each sample processed are required.

    What's happening: The DNA is selectively bound to the silica membrane in the Spin Filter basket and the flow through containing non-DNA components is discarded.

14. Place the Spin Filter basket into a clean 2 ml Collection Tube (provided).

    What's happening: Due to the high concentration of salt in solution RW2, it is important to place the Spin Filter basket into a clean 2 ml Collection Tube to aid in the subsequent wash steps and improve the DNA purity and yield.

15. Shake to mix Solution RW3. Add **650 µl of Solution RW3** and centrifuge at 13,000 x *g* for 1 minute.

    What's happening: Solution RW3 is an alcohol base wash solution used to further clean the DNA that is bound to the silica filter membrane in the Spin Filter. This wash solution removes residual salt and other contaminants while allowing the DNA to stay bound to the silica membrane.