Water quality management for domestic rainwater harvesting systems in Fiji

WATER QUALITY MANAGEMENT FOR DOMESTIC RAINWATER HARVESTING SYSTEMS IN FIJI

by

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Executive Summary

Abstract

Health risks from drinking rainwater are relatively small in the developing world context, but action is needed to ensure water safety. This research seeks to develop guidance for sustainable water quality management by considering the Water Safety Plan and Self Supply approaches using households in Fiji as a case study. A literature review, cross-sectional case studies of selected households using semi-structured interviews and sanitary inspections, and key informant interviews were carried out. An absence of contamination barriers before storage, poor gutters, and openings on storage tanks were the most prominent risks observed. Rainwater harvesters require on-going support, but government resource limitations are an obstacle to this in Fiji. A lack of perceived susceptibility to infection and ignorance of causes of faecal-oral diseases are possible barriers to sustainable management while prevention of physical contamination is the main driver. Key areas recommended for improving the sustainability of domestic rainwater harvesting quality management are:

- Provision of prioritised risk management instructions
- Tackling identified barriers and utilising identified drivers of management practices
- Methodical plans for on-going support
- Strengthened engagement of the private sector
- Strengthened links between major stakeholders
- Knowledge management

Introduction

Unsafe drinking water is one of the main contributors to millions of preventable deaths of children every year (Pruss-Ustun, et al., 2008, p. 7). To combat this, in 1990 countries around the world committed themselves to achieving Millennium Development Goal 7c: “Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation” (UN, no date). Rainwater harvesting is a type of “improved” water source that about 89 million people across the world primarily rely on for drinking (UNICEF/WHO, 2012, p. 10) and it is likely that hundreds of millions more utilise rainwater as a supplementary source for both potable and non-potable uses (Elliott, et al., 2011, p. 58). Rainwater harvesting is widely practiced in Fiji and other Pacific island countries (Duncan, 2011, p.19) and there are calls to use it to an even greater extent (SOPAC, 2007, p. 16; Overmars & Gottlieb, 2009, p. 10; Kumar, 2010).

Domestic rainwater harvesting (DRWH) systems have often been found to have microbiological contamination levels exceeding international water quality guidelines (Lye, 2002; EnHealth Council, 2004, p. 10; Ahmed, et al., 2011; Kwaadsteniet, et al., 2013) and drinking untreated rainwater has been found to be a source of illness in the past (Kwaadsteniet, et al., 2013). However, reports of illness associated with rainwater harvesting are relatively infrequent (EnHealth Council, 2004, p. 11; Thomas & Martinson, 2007, p. 39). In the context of the developing world, DRWH systems are likely to be just as good as other "improved" water supplies and better than "unimproved" supplies in terms of water quality (Thomas & Martinson, 2007, p. 25; Dean & Hunter, 2012).

Nevertheless, action is required to ensure the safety of collected rainwater. While there is a great amount of literature available on technical measures for ensuring the safety of collected rainwater, strategies for sustainable management of self supply systems (SSS) such as DRWH systems have received little attention compared to public and communal supplies (Oluwasanya, 2009, p. 45; Kumamaru, 2011, p.8). The problem being addressed, then, may be stated as follows: Guidance for water quality management at the household level is currently underdeveloped, which poses health risks for users of SSS.

Water Safety Plans (WSPs) and Self Supply are two approaches for improving water quality that have shown signs of success in other similar contexts (Mahmud, et al., 2007; Hasan, et al., 2011; Sutton, 2011). The sustainability of these approaches when applied to DRWH systems in Fiji will largely depend on the demand for them from households, the presence of measures for protecting water quality, and the capacity of stakeholders to implement or support implementation of those measures. With these factors in mind, the **aim** of this research is **to develop guidance for sustainable water quality management of DRWH systems by considering the WSP and Self Supply approaches using households in Fiji as a case study.**

The **objectives** of this research are:

1. To determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context.
2. To assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably.

3. To gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems.
4. To assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality.
5. To make recommendations for implementation and support of sustainable water quality management activities for DRWH systems.

Methods

An extensive literature review was performed to learn from previous research about the quality of water and health risks associated with DRWH, application of the WSP approach, and application of the Self Supply approach. Searches were made in selected databases, online, and in the WEDC Knowledge Base. Literature was also retrieved by browsing the library at Loughborough University and making use of personal contacts. Relevant pieces of literature were catalogued in an Excel spreadsheet for later reference.

A qualitative research design with cross-sectional and case study elements was used in this study. This approach was chosen because qualitative research is typically more holistic, exploratory, and provides more in-depth understanding of the human participants than quantitative research does (Rudestam & Newton, 2007, p. 37). This is important in this study since the attitudes and perceptions of DRWH users may be complex and difficult to predict.

A total of 34 households across 12 communities in Fiji were visited unannounced using a convenience sampling method from 17 to 21 June 2013. Households within communities were selected using a mixed approach of snowballing and transect walks. A household was considered eligible if it regularly collected rainwater and an adult resident was available. Semi-structured interviews focusing on knowledge, attitudes, and practices relating to rainwater harvesting were conducted with any adult resident. Interviews were recorded using a voice recorder. Along with each interview, a sanitary inspection was performed on the household DRWH system using a prepared sanitary survey form. Semi-structured interviews were also performed in Fiji with six key informants. These informants had expertise or specialist knowledge in WSPs, DRWH or government support for rural water schemes in the Pacific island country context. These interviews were also recorded.

The data were processed by transcribing the interviews and sorting sanitary survey scores using Excel. The data were first analysed by a series of thematic and numeric coding where fragments of the transcriptions were placed into groups with common themes or were assigned numbers if they were distinct enough (e.g. yes or no answers). The grouped themes were then repeatedly read and judged to make sense of their contextual meaning, link them with other groups of data, and relate them to the research objectives.

Results and discussion

Overall, DRWH systems observed in the field were usually in good condition. Sanitary inspections in the field concur with the literature that contamination via the catchment usually poses the greatest risk (EnHealth Council, 2004, p. 9; Fewtrell & Kay, 2007; Thomas & Martinson, 2007, p. 39; Abbasi & Abbasi, 2011). An absence of barriers (e.g. screens or first-flush diverters) against pollutants prior to storage, poorly designed gutters, and uncovered openings on the storage tank were the most prominent concerns. These risks should receive priority during interventions to improve DRWH management.

Respondents are generally capable of performing routine maintenance except for those who have physical limitations. These households require special support. Resource limitations and lack of specialised knowledge at the household level, and mobility and man-power limitations of the government, inhibit the practicality of traditional WSPs at the household level. Rainwater harvesters are often scattered outside traditional villages, and self-invested systems may go unrecorded, which makes them difficult to target for training or interventions. Generic risk management instructions are a tool that is feasible to implement and can provide a level of protection for water quality. On-going support for this is paramount, needs to be well planned, and should include input from major stakeholders.

The role of the private sector needs to be considered. Locally made materials are available for making some incremental improvements to DRWH systems. Technologies, such as first-flush diverters, have the potential to significantly improve water quality, but respondents were mostly unaware of them and the technologies are not currently accessible or affordable. There appears to be capacity to locally produce and stock them, and this should be investigated further. Private vendors of plastic storage tanks are also often the first external stakeholder that self-investing rainwater harvesters come into contact with. This puts them in a position to pass on knowledge and advice at a critical time. NGOs and government would be wise to take note of this and seek opportunities to encourage and establish good management practices from the beginning.

A lack of perceived susceptibility to infection and lack of awareness on disease transmission routes and potential control measures were identified as potential barriers to sustainable management practices. The majority of respondents did not believe that drinking from their DRWH systems could cause illness to anyone in their family. None of the respondents mentioned faecal-matter or bacteria during discussions about their concerns with water quality. The principal driver for quality management practices was prevention of physical contamination; usually mosquito larvae and dirt/dust. Water quantity featured as a much greater concern than water quality for respondents. Identified barriers give insight to what issues should be tackled by supporting institutions. Identified drivers can be tied to water safety to motivate sustainable action.

Conclusions and recommendations

Resource limitations inhibit the practicality of traditional WSPs at the household level, but provision of prioritised risk assessment and management instructions is feasible and potentially impactful. Self Supply has potential in this context but elements of demand stimulation and availability of technologies first need to be addressed. The following are recommendations for developing sustainable water quality management practices for DRWH systems in Fiji:

• Develop risk assessment and management instructions that prioritise the most prominent risks	• Link water safety with physical contamination and water quantity for motivation
• Implement a public awareness programme to focus awareness-raising on sources and transmission routes of faecal-oral diseases	• Develop national WSP policy that is sensitive to the constraints and opportunities of SSS
• Partner NGOs with the private sector to promote safely designed plastic storage tanks	• Seek to engage the private sector in making and stocking DRWH technologies locally
• Develop methodical, goal-oriented plans for providing on-going support to rainwater harvesters	• Form a national or regional rainwater harvesting association that links NGOs, government, the private sector, and community-based organisations
• Disperse instructions and register new rainwater tanks whenever they are sold	• Encourage rainwater harvesters to be proactive around certain weather events
• Give special attention to rainwater harvesters with physical limitations or disabilities	• Design activities to share lessons learned from successes and failures of relevant projects

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Abbreviations

DRWH:	Domestic rainwater harvesting
FSM:	Federated States of Micronesia
HWTS:	Household water treatment and safe storage
LCP:	Library Catalogue Plus
MDG:	Millennium Development Goal
NGO:	Non-government organisation
PIC:	Pacific island country
RWSN:	Rural Water Supply Network
RWSP:	Rural Water and Sanitation Policy
SPC:	Secretariat of the Pacific Community
SSS:	Self-supply system(s)
WEDC:	Water, Engineering and Development Centre
WSMP:	Water supply management plan
WSP:	Water Safety Plan

1 INTRODUCTION

This chapter sets the scene for the research undertaken for this dissertation. It describes what problem is being addressed, the aims, objectives and scope of the research, and how the research might be of use. Additionally, it describes the geographical context in which the research is undertaken and the author's preferred use of terms throughout the paper.

1.1 Research background

Unsafe drinking water is one of the main contributors to millions of preventable deaths of children every year (Pruss-Ustun, et al., 2008, p. 7). Around 10% of the world's total burden of disease could be alleviated by improvements in drinking-water, sanitation, hygiene, and water resource management (ibid). To combat this, in 1990 countries around the world committed themselves to achieving Millennium Development Goal (MDG) 7c: "Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (UN, no date). Studies show that interventions to improve water supplies across the world are capable of reducing the incidence of disease and have a favourable cost-benefit ratio in a range of contexts (Hutton & Haller, 2004; Hunter, et al., 2009). Even low-cost water improvements for small community water supplies in developing countries are expected to produce a surplus of benefits to costs (Edwards, 2011, p. 225).

1.1.1 Rainwater harvesting

Rainwater collection, or rainwater harvesting, is recognised as one type of improved drinking-water source (WHO/UNICEF, 2013). Domestic rainwater harvesting (DRWH) using the roof as a catchment is a common way of collecting rainwater which can then be used for a variety of domestic or productive purposes including consumption. It has been estimated that in 2010 about 89 million people relied on rainwater harvesting for drinking (UNICEF/WHO, 2012, p. 10) and hundreds of millions more across the world utilise it as a supplementary source for both potable and non-potable uses (Elliott, et al., 2011, p. 58). Pacific island countries (PICs) in particular have a long history with rainwater harvesting (SOPAC, 2004, p. 9). Self-supply rainwater harvesting systems, where the household is responsible for building, operating, and maintaining the system, are common in some countries (Thomas & Martinson, 2007, p. 19). The author often observed the presence of these self-maintained DRWH systems while living in Fiji.

1.1.2 Water Safety Plans

Water Safety Plans (WSPs) are an approach for improving water quality. WSPs were first introduced by WHO in the third edition of the Guidelines for Drinking-water Quality (2004, p. 48). The WSP approach is summarised by WHO (2011, p. 45) as follows:

"The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer"

WHO (2011, p. 45) goes on to say that this approach can be applied to large piped drinking-water supplies, small community supplies, and household systems. The principles of WSPs are based on the Hazard Analysis Critical Control Point and 'multi-barrier' models and aim to (Davison, et al., 2005, p. 11):

- Prevent the contamination of source waters
- Treat water to reduce or remove contaminants
- Prevent re-contamination during storage, distribution and handling of treated water

1.1.3 Self Supply

Self Supply may be defined as "the improvement to household or community water supply through user investment in water treatment, supply construction and upgrading, and rainwater harvesting" (Sutton, 2009). It has also been described as "local-level or private initiatives by individuals, households or community groups to improve their own water supplies, without waiting for help from Government or non-government organisations (NGOs)" (Carter, 2006) and "the provision of improved rural water supply and sanitation services, based upon historic practices, simple technologies and low-cost interventions, that brings local knowledge and resources to bear towards achieving progressive improvements in service levels" (Waterkeyn, 2006).

While definitions vary in wording, the core principle remains consistent: intervention and management of water supplies is concentrated to the lowest appropriate level (often a household or small-group level) as a complement to conventional communal supply to improve the quantity of and accessibility to safer water (Waterkeyn, 2006). In general, improvements to water quality are made by incremental technological improvements to the water supply system and water treatment by the users themselves (Sutton, 2009).

1.2 The study area

PICs belong to what is sometimes referred to as the Pacific region, the South Pacific region or Oceania. In this paper, PICs refers to the following countries: Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. A map of these countries is show in Appendix 1. Fiji is located in the lower centre of this map.

In 2006, the total population of PICs was 8.4 million with 81% of people living in rural areas (WHO/SOPAC, 2008, p. 2). The total landmass of the PICs is just over half a million square kilometres, with the islands being spread out over 180 million square kilometres of ocean (Duncan, 2011, p. 12). This remoteness, along with characteristics of small size, fragility, natural vulnerability and limited human and financial resources, restricts PICs' ability to manage water sources effectively (SOPAC, 2006, p. 1). In spite of this, most PICs have a high coverage of "improved" water sources, as shown in Figure 1.1 (WHO/UNICEF, 2011). However, the accuracy of some of these figures can be called into question due to conflicting reported figures, being out-of-date or lacking corroborating data from separate surveying activities (University of Technology Sydney, 2011). Further, "improved" water sources do not necessarily provide water safe for drinking.

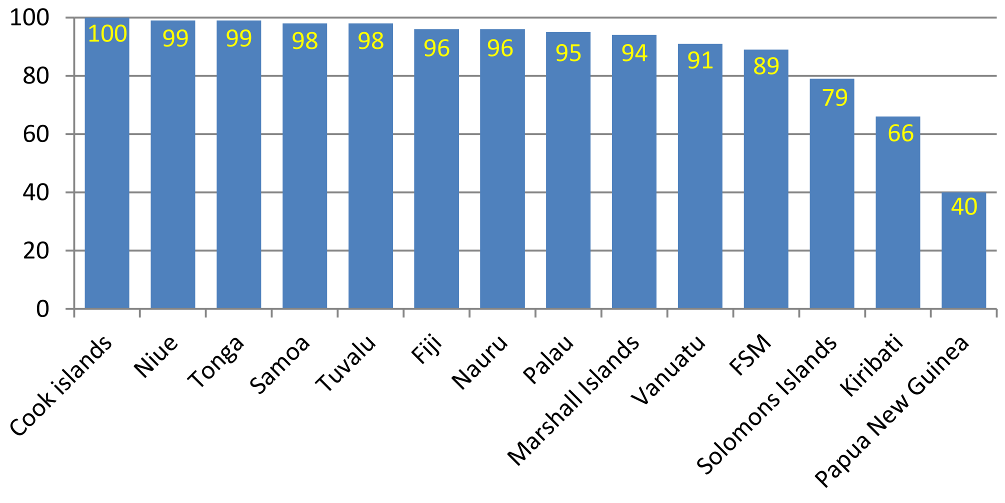


Figure 1.1: Percentage of PIC populations with access to an improved water source

The availability of data for which types of systems are used for water supply in Oceania is very limited (Charles, et al., 2010, p. 72) but it is known that collection of rainwater is a common source of water in PICs (Falkland, 2002, p. 12; Duncan, 2011, p.19).

The Republic of Fiji (population: 837,271) is located in the Pacific Ocean at 17° S and 177° E, approximately 2,000km northeast of New Zealand and 3,300km east of Townsville, Australia (Figure 1.2 and Appendix 1). The country comprises of over 300 islands, a third of which are inhabited (GWP/SOPAC, 2007, p. 12).

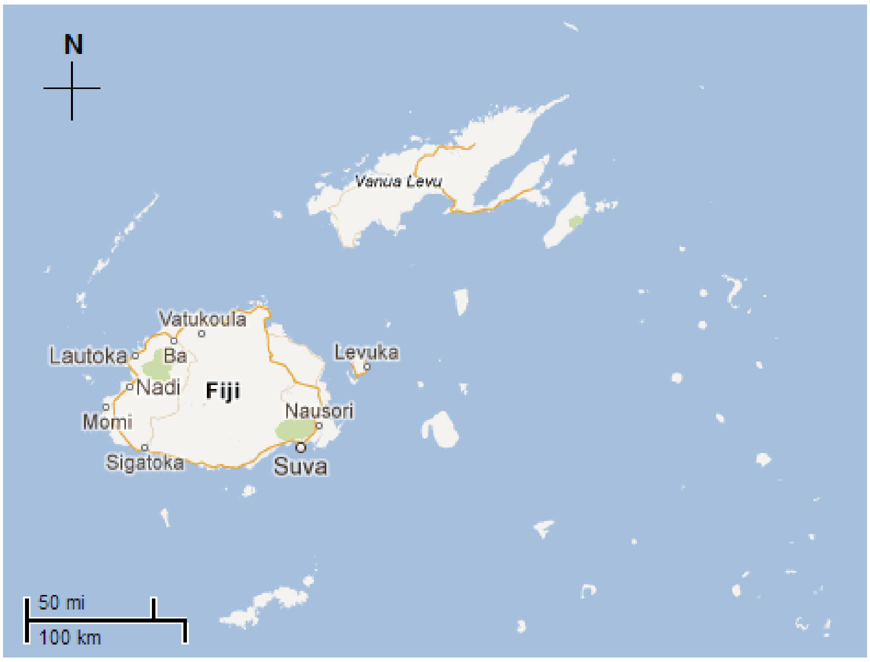


Figure 1.2: Map of Fiji
Source: Google maps, 2013

Rainfall in Fiji is highly variable, ranging from an annual average of 1500mm on some smaller islands to 2000mm in ‘dry zones’ (north-western sides of the main islands) to 3000mm around coastal areas to 6000mm on mountainous sites (Fiji Meteorological Service, no date). A distinct wet season spans from November to April while the dry season is controlled by the South Pacific Convergence Zone (ibid).

In 2008-09, the average household size was reported as being 4.7 and the percentage of population living below the basic needs poverty line was 31 (Fiji Islands Bureau of Statistics, 2010, pp. vi, 6). About half (48%) of Fiji’s population lives in rural areas (WHO/UNICEF, 2011). UNICEF (2011, p. 38) reports that 65% of all children in Fiji have access to a metered water supply, although this figure sits at 37% for children living in rural areas. A combination of surface water and groundwater is often used to supply rural settlements not serviced by a utility, but DRWH using roof catchments remains widespread (SOPAC, 2007, p. 9).

1.3 Research aims, objectives and questions

As mentioned in the above sections, domestic rainwater harvesting is widely practiced throughout the world. In addition to rainwater harvesting, it is also common for households around the world to supply water for themselves and their neighbours via water holes, wells, and even boreholes (Carter, 2006; Sutton, 2009). Oluwasanya *et al*. (2011) argues that these household self-supply systems (SSS) should be viewed as a third angle to the water supply triangle formed with public and communal water systems. Given the prevalence of SSS around the world, it is fitting that appropriate water quality management of these sources should be promoted and practiced in much the same way as for public and communal sources. However, water quality management of SSS receives little attention in literature compared to public and communal sources (Oluwasanya, 2009, p. 45; Kumamaru, 2011, p.8). The problem being addressed, then, may be stated as follows: Guidance for water quality management at the household level is currently underdeveloped, which poses health risks for users of SSS.

The **aim** of this research is **to develop guidance for sustainable water quality management of DRWH systems by considering the WSP and Self Supply approaches using households in Fiji as a case study.**

The **objectives** of this research are:

1. To determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context.
2. To assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably.
3. To gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems.
4. To assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality.
5. To make recommendations for implementation and support of sustainable water quality management activities for DRWH systems.

To achieve the first four objectives, the author developed research questions to be answered (Figure 1.3). Objective 5 is achieved from the findings of the first four.

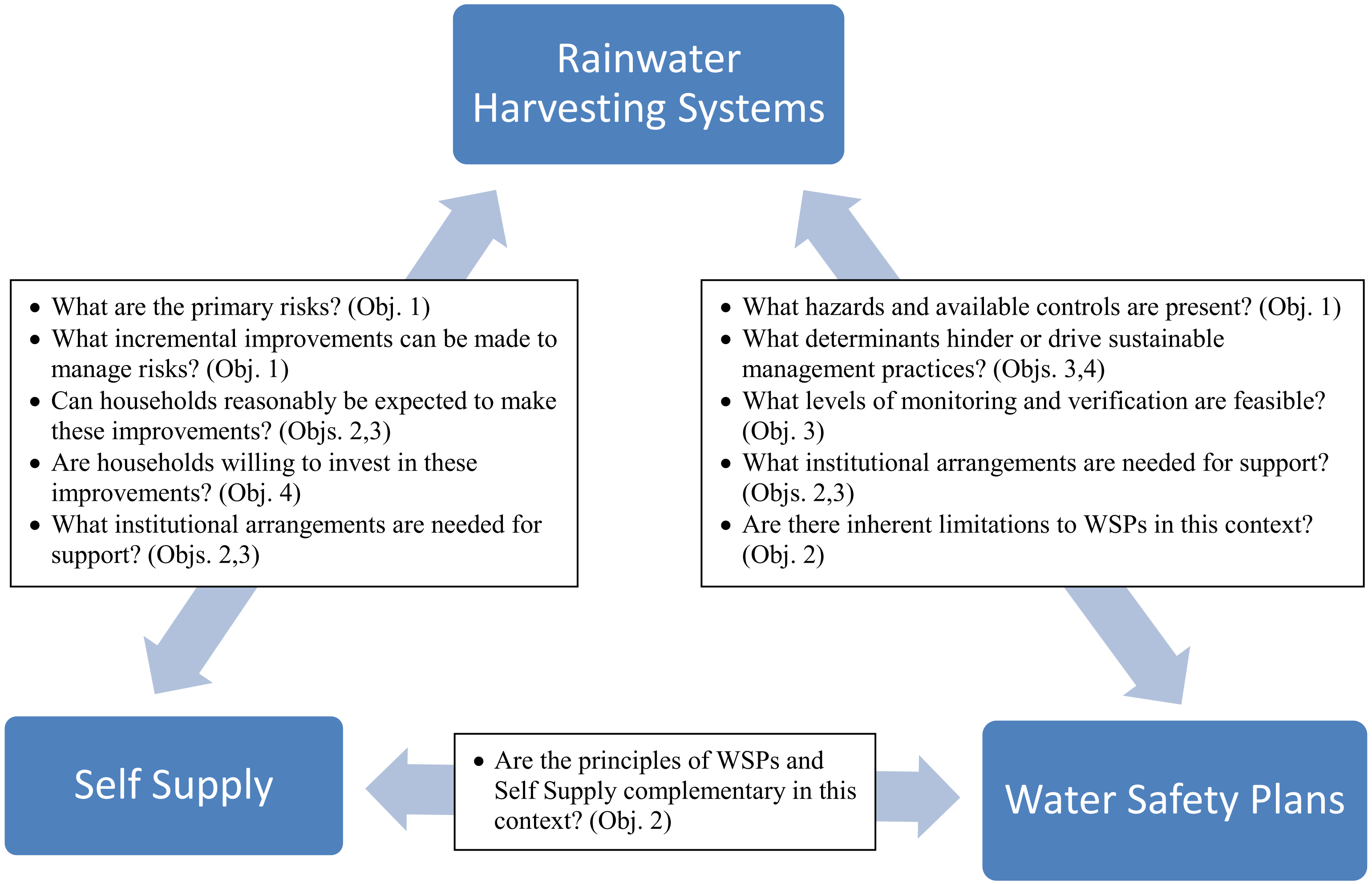


Figure 1.3: Research questions

1.4 Research justification and intended use

SSS play a substantial role in supplying water for potable and non-potable uses in many parts of the world, but have received little attention from literature. What literature does exist tends to focus on coverage, cost, and technical sustainability rather than management practices for controlling water quality. Water and health are indisputably directly linked so this research, and more like it, is needed to contribute to improving the quality of life of those that are most vulnerable to water-borne diseases.

The author chose DRWH systems in Fiji to study for several reasons. First, as previously mentioned, DRWH systems are commonly used in Fiji, the Pacific region, and throughout many other parts of the world. Second, two previous studies related to this topic focused solely on hand-dug wells in Sub-Saharan Africa (Oluwasanya, 2009; Sakariya, 2011). Oluwasanya (2009, p. 331) recommends that other forms of SSS should be investigated. Third, while rainwater harvesting is already widespread in PICs, there are calls to utilise it in the region to an even greater extent (SOPAC, 2007, p. 16; Overmars & Gottlieb, 2009, p. 10; Kumar, 2010). Fourth, the author is familiar with the Fijian context having lived and worked in Fiji previously. Finally, while the Self Supply approach is designed for any household or small-group level water supply in the developing world, most case studies to date have focused on private hand-dug wells in Africa (Sutton, 2011).

The author chose to investigate the WSP and Self Supply approaches as methods of managing the quality of household water supplies because they have shown promise in some contexts and were designed, at least in part in the case of WSPs, for utilisation at a household level. The author is personally interested in this topic because of its integration of technical, social, and human resource aspects, and because of his fondness for Fiji and the Fijian people.

This research targets NGOs and governments who are interested in promoting water quality management in areas where a significant number of households partially or wholly rely on individually owned DRWH systems. As a result of the research, the author expects that NGOs or governments attempting to promote or implement water quality management practices, such as WSPs, at a household level will be able to deliver a more effective plan with more sustainable uptake resulting in improved health of the community.

1.5 Research scope

This research focused primarily on DRWH systems in Fiji. The author only examined artificial catchments in-depth; primarily domestic roof catchments. Natural land or improved land catchments are not reviewed. Fieldwork took place entirely in Fiji, however the author kept an eye toward all PICs in general when considering various aspects. While the focus is centred on PICs, the author expects the findings of this research to be applicable to a degree to developing countries in other parts of the world that are also known to widely practice rainwater harvesting, such as Vietnam (Ozdemir, et al., 2011), Uganda (Baguma, et al., 2010), and Trinidad (Dean, et al., 2012). To a more limited degree, findings may also be applicable to other SSS around the developing world.

This research on DRWH systems is concerned only with the quality of the water they yield in terms of health and social acceptability. Issues of quantity of water yielded, accessibility of water, promotion and financing for construction of core components of the system, and environmental impacts are not examined in-depth. Technical operation and maintenance and affordability of system accessories that affect the quality of the water are considered. Various sustainability aspects (social, technical, economic, financial and institutional) of the WSP and Self Supply approaches are considered.

A major characteristic of the Self Supply approach is construction of new water supplies. However, this study focuses mainly on incremental improvements to, and management of, existing DRWH systems rather than provision of new ones.

1.6 Terminology

In this paper, DRWH refers to any raised artificial catchment for use by a single or small group of households, but not natural or improved land surfaces. The categories considered include both roof catchments and other customised raised catchments. They do not include collection systems installed on communal or institutional buildings.

In literature, the term “self-supply” sometimes refers to a discrete household or community water supply and sometimes refers to an approach for developing water supplies as described in section 1.1. In this report, the author distinguishes these definitions by referring to discrete household water supplies as self-supply systems (SSS) and the development approach as “Self Supply”.

Fiji's two largest ethnic groups are the islands' indigenous population and ethnically Indian people that are predominantly the descendants of Indian contract labourers brought to Fiji by British colonial powers in the 19th century. The demonyms for these two groups of people has been a sensitive source of social and political controversy. The indigenous population have been referred to as *iTaukei*, indigenous Fijians or simply Fijians, while the ethnically Indian population have been referred to as Indo-Fijians, Indians or also Fijians. In this paper, the author chooses the demonyms "indigenous Fijian" and "Indo-Fijian" when referring to the particular ethnic groups, because these terms seem to be the most sensitive and easiest to understand for those not familiar with the country's social makeup.

1.7 Report structure

Chapter 1 has set the scene for this research by describing the context under which it is taken and what it aims to achieve. Chapter 2 is the report's literature review which gives a broad review of existing knowledge and research relevant to the topic. Lessons learned from this chapter provide guidance for this particular research. Chapter 3 describes the steps the author took to design and carry out various aspects of the report. Chapter 4 is the results chapter and describes what the author saw, heard, and experienced in the field. Chapter 5 then discusses what those results mean in the context of the research objectives and existing knowledge in the literature. Finally, Chapter 6 summarises key points from the report and makes recommendations for NGOs and relevant government departments.

2 LITERATURE REVIEW

This chapter explores previous literature to learn what has already been found about topics relating to Self Supply, WSPs and the quality of water yielded from DRWH systems. It describes the approach taken to locating literature, categorises and synthesises findings, and identifies gaps in knowledge and how this research may address some of them. Discussion of the literature in the context of this research's findings is located in Chapter 5. A chapter summary is provided at the end.

2.1 Search strategy

To investigate the research topic, the research questions listed in Figure 1.3 were used as guidance. The WSP and Self Supply approaches as introduced in section 1.1 are relatively recent developments that have come on to the scene in the last decade so the amount of published literature, especially in the case of Self Supply, is limited. Rainwater harvesting, on the other hand, has been widely covered for many years and the amount of relevant material published and available online is enormous. To make this range of material more manageable, the author focused on articles and book sections that centred on water quality. While the focus of this paper is on Fiji and the rest of the PICs, the author searched for relevant material that took place in any part of the world.

Before the literature review began, an Excel workbook was created to record and categorise what had been found. Separate spreadsheets were made for literature relevant to WSPs, Self Supply, rainwater harvesting, background on Fiji and PICs and cross-sectional information. In each spreadsheet, columns were made to record the title of the material, the primary author and date of publication, a link to or description of where to find it, the key relevant points of the material, and which objective(s) the material pertained to. Each time relevant material was found, it was logged in one of these spreadsheets in a row adjacent to the most similar material, so that it could easily be referred to later.

Another spreadsheet was made to record studies that had similar research methods to this study. In this spreadsheet, the literature's title, primary author, date of publication, and a link to the source was recorded as well. Additionally, the number of study participants, why that number was chosen and the sampling method was recorded if they were provided by the author(s). Finally, another spreadsheet was made to contain which search terms were used for which database, how many results were returned, and how relevant they were. A table of these search terms, their results, and relevance is show in Appendix 2.

The first tool used for searching for literature was Loughborough University's Library Catalogue Plus (LCP). LCP was chosen because of the substantial and wide range of high-quality material that it is able to locate. Nearly all the journal articles that it searches are peer-reviewed. Additionally, the majority of articles that LCP searches are available online. This makes the material much easier to access and the CTRL+F function on Windows operating systems can be used to find key words within the articles. The reference pages of relevant articles were another valuable method of locating useful information.

Within LCP, searches were performed on selected databases. The databases searched were Proquest (all subscribed content), Geobase, Compendex and Referex. These databases were chosen based on the advice of Water, Engineering and Development Centre (WEDC) librarian Tricia Jackson. Searching selected databases was useful when regular LCP searches were turning up too many irrelevant articles.

Google Scholar was also used to search for relevant material. Google Scholar searches a wide range of reputable peer-reviewed journals that are made freely available to the public. Using Google's regular search engine was helpful in finding useful content on websites that was not necessarily published in a journal article or book. Google's search results could be easily screened to see which ones came from websites of reputable institutions.

The WEDC Knowledge Base was used to find relevant books, magazines, former WEDC MSc and PhD theses, and WEDC conference papers. Further material was found by browsing the WEDC library; specifically within publications having the Dewey-Decimal classification 628.

Finally, material was also obtained by making use of personal contacts. By querying the author's supervisor, other WEDC staff members, and former work contacts and by networking, a collection of other relevant documents was obtained.

To search for material related to WSPs, the terms “water safety plan*”, “water safety planning” and “water safety management” were initially used. These terms generally turned up a manageable number of results with good relevance. The term “water quality management” was also used but resulted in far too many irrelevant results. Combining it with the word “household” reduced the number of results and provided better relevance.

The search term “self supply” typically returned hundreds of results that had little relevance. Combining “water” and “self supply” reduced the number of results but also had limited relevance. “Household led water supply” and ‘water supply AND “self financing’” were also searched in various databases which turned up a couple of relevant sources. In general, it was difficult finding literature on Self Supply using online search databases. The author had more success by using the Rural Water Supply Network (RWSN) website (http://www.rural-water-supply.net/en/), recent PhD theses related to Self Supply (Oluwasanya, 2009; Kumamaru, 2011), and their reference pages.

To locate literature on quality of rainwater yielded by DRWH systems, the term “rainwater quality” was initially used in LCP. This returned 161 results with good relevance. This same term was used in Geobase/Compendex/Referex and 1353 results were returned; many with good relevance. It was realised at this point that there have been a great number of studies carried out on the water quality of DRWH systems and there was insufficient time to collect, review, and compare them all. Given this, it was decided to search instead for systematic reviews and meta-analyses of these studies.

The search terms “rainwater AND review” and “rainwater meta-analysis” and variations of these were used. These typically produced a few dozen results with good relevance. The term “roofwater” was also used in place of rainwater but this did not turn up any additional useful results.

The varying combinations of search terms and the number of results they yielded in different databases are listed in Appendix 2.

Searches using the above terms in Google Scholar usually resulted in sources that were already located in the searches above. Using these terms in normal Google searches and in the WEDC Knowledge Base returned many relevant sources.

2.1.1 *Ensuring quality and relevance*

A number of methods were used to determine the relevance of a piece of literature to the objectives. Because of the abundance of material available, even after refining search terms, it was necessary to find a way to scan articles for their content efficiently. The first, and most obvious method, was reading the title of articles and making a snap judgement about its potential relevance. Reading the abstract and the conclusions of a paper was a very effective way of determining if it had findings relevant to the objectives. It was rarely necessary to read further into a paper beyond the abstract and conclusions to determine relevance.

In addition to this, more recent publications were targeted; preferably research since 2000. In the case of DRWH, this is because it is possible that in recent years the methods for testing the quality of water from DRWH systems have changed and become more accurate. In regards to WSPs, the literature review focused mainly on WSPs for small community or household water supplies which are more relevant to this study than WSPs for public utilities.

To ensure quality of the literature being reviewed, mainly books, articles from peer-reviewed journals, and reports from well-established organisations were relied on. The majority of this literature had authors who worked at reputable institutions, included extensive references to support their work or had been cited by many other articles. A qualitative judgement of the writing in the abstract and conclusions for clarity and coherency would also be made. Some of the results turned up theses by Master's students. These sources were cautiously considered reliable sources of material if they seemed well-written and backed up their claims with good evidence.

When reviewing content on websites, only information from established, reputable institutions (WHO, UNICEF, SOPAC, RWSN, etc.) was relied on. Information from smaller, unknown NGOs was not considered.

2.2 *Past research methods*

To assess how researchers approached this area of study in the past, journal articles and reports that investigated similar topics were examined. To the author's knowledge, no studies have been published incorporating all of the three major areas of interest in this paper (DRWH, WSPs, and Self Supply). Therefore, studies that looked at one or more of the aspects of this research were searched for. In particular, recent studies on attitudes toward DRWH, evaluations of Self Supply interventions, and investigations into applying WSPs at a small rural community or household level were sought. Five studies on DRWH, three on Self Supply and four on WSPs were found to have approaches similar to this study (Table 2.1).

Table 2.1: Data gathering tools of similar studies

Author	No. of sites	Study area of focus	Structured interview	Semi-structured interview	Water quality tests	KI interview	SI	DO	FGD
Howard (2003)	69	WSP			✓		✓		
Roche (2006)	40	SS	✓		✓			✓	
Mahmud, et al. (2007)	82	WSP	✓		✓		✓		
Oluwasanya (2009)	41	WSP		✓	✓	✓	✓	✓	
Baguma, et al. (2010)	90	DRWH	✓		✓				
Harvey (2011)	440	SS	✓		✓				
Kumamaru (2011)	269*	SS	✓	✓	✓	✓	✓		✓
Sakariya (2011)	36	WSP		✓		✓	✓	✓	
Ozdemir, et al. (2011)	619	DRWH	✓						
Dean, et al. (2012)	292	DRWH	✓					✓	
Domenech, et al. (2012)	120	DRWH	✓		✓	✓		✓	✓
Lange, et al. (2012)	541	DRWH	✓						

SS: Self Supply; KI: Key informant; SI: Sanitary inspection; DO: Direct observation; FGD: Focus group discussions; *Number of water points surveyed. The author investigated several other parameters as well.

Past research methods were reviewed primarily by examining the methods section of the similar studies. Aspects of the methods that were recorded were how the target sample was selected, the number of individuals, households or systems that were surveyed, and what tools and sampling methods were used to survey them.

In all of the studies reviewed, a sample was selected to study in place of a population for practical reasons. Authors used a variety of social and geo-political boundaries to describe their study areas including districts, provinces, cities, towns, townships, land use areas, physical geographical areas, villages and communities. Some articles did not give a reason for why or how they chose to study their particular areas. Those that did give a reason stated they were chosen because they were known to have poor service (Howard, 2003; Oluwasanya, 2009, p. 64; Harvey, 2011; Kumamaru, 2011, p. 76), because they were known to have received a particular intervention in the past (Roche, 2006; Baguma, et al., 2010), to represent a variety of geographical areas (Mahmud, et al., 2007; Dean, et al., 2012) or because certain practices were known to be done there (Domenech, et al., 2012).

Once sample areas were defined, various methods for selecting individual households or water supplies to be studied within the area were used. Sampling methods included stratified random sampling (Kumamaru, 2011, p. 90), quota sampling (Roche, 2006, p. 38), simple random sampling (Ozdemir, et al., 2011; Sakariya, 2011, p. 47), systematic random sampling (Dean, et al., 2012), purposive sampling (Mahmud, et al., 2007; Baguma, et al., 2010; Domenech, et al., 2012) and transect walk / snowball sampling (Oluwasanya, 2009, pp. 65,70).

The authors utilised a range of tools for gathering data. Nearly all of the studies included face-to-face interviews with householders in one form or another as at least one of their tools. The most common form used was a structured interview using a questionnaire read off by an interviewer. The other form of interview used was semi-structured.

In addition to interviews with householders, other tools for data gathering employed by the researchers included interviews with key informants,water quality tests, sanitary inspections, direct observation, and focus group discussions. Domenech, *et al*. (2012) also used a technique called 'free listing' where participants were asked an open-ended question and prompted to answer spontanesouly with a list of elements. Nearly all of the authors utilised two or more of these tools to collect both quantitative and qualitative data and reinforce their findings through triangulation.

The number of households or water sources surveyed varied greatly as shown in Table 2.1. Authors infrequently explained why they chose the number of sites they did. Kumamaru (2011, p. 87) used a statistical equation to determine the number of sites while Oluwasanya (2009, p. 64) and Dean, et al. (2012) surveyed what they felt was a sufficient number of sites but had no statistical justification. Baguma, et al. (2010) surveyed all of the households that had received a particular intervention.

Data collected from the studies were processed and analysed using a range of different methods. Microsoft Excel, SPSS, and STATA were identified as computer software used in some of the studies for analysing quantitative data. Methods identified for processing and analysing qualitative data were analytic induction, coding and interpreting, and a software package called Anthropac, which can be used to "collect and analyse structured qualitative and quantitative date" (Analytic Technologies, 2010).

2.3 Household level water quality management

There have been several systematic reviews that have evaluated the health impact of water, sanitation and hygiene interventions, including those that improve water quality (Esrey, et al., 1985; Esrey, et al., 1991; Fewtrell, et al., 2005; Waddington, et al., 2009; Cairncross, et al., 2010). Each of these studies reported that water quality interventions significantly reduced the risk of diarrhoeal disease, although DFID (2013, p. 49) concluded the evidence from these studies is only suggestive and susceptible to bias and confounding. DFID also states the literature on the effects of these interventions on mortality is lacking. Another systematic review of water quality interventions that was not evaluated in DFID's report (2013) agrees with previous studies that interventions to improve water quality at the household level reduce the incidence of some diseases (Gundry, et al., 2004).

It appears that when the studies mentioned above refer to water quality interventions, they are predominantly, if not wholly, referring to exercises to treat water either at the source or in the household. Fewtrell *et al.* (2005) describe water quality interventions as relating to the provision of water treatment and water supply interventions as relating to the provision of a new or improved water supply. DFID (2013, pp. 70-71) categorises water interventions as being either water quantity or water quality; the latter of which also refers to the provision of water treatment. The other studies appear to follow a similar procedure.

Several recent studies that focused on household water quality management were located (Sobsey, 2002; Clasen & Carincross, 2004; Trevett, et al., 2004; Tambekar, et al., 2008; Davis, et al., 2011). Similar to the systematic reviews above, the only examples of household water quality management practices given are household water treatment and safe storage (HWTS). The Safe Water System developed by the Centers for Disease Control and Prevention and the Pan American Health Organization (CDC, 2012) is designed to be a household level water quality intervention but also focuses on HWTS.

One exception to this is a study by Baguma *et al.* (2010) who focused on how DRWH system users in Uganda managed the quality of their systems. They found users took better care of their systems if they had them for longer, received usage instructions in the local language on how to keep their water safe, and lived near local water associations that supported rainwater harvesters.

Overall, outside of HWTS, any other approaches for ensuring good household water quality appear to receive scant attention. This is likely because researchers in the past have focused on communal and public water supplies and have neglected SSS. One of the advantages of a SSS over a shared source is that it gives the householders personal control of their drinking water from catchment to consumption. This offers more opportunities for water quality interventions aside from HWTS that should be taken advantage of. Current literature has insufficiently explored this and this research will contribute to expanding knowledge in this area.

2.4 Domestic rainwater harvesting

This section explores literature pertaining to the quality of water yielded by DRWH systems around the world. It includes literature on the history of DRWH, known sources of contamination, controls for contamination, policy and legislation regarding the quality of water from DRWH systems, and gaps in knowledge.

2.4.1 History

Rainwater harvesting is believed to have been practiced in many parts of the world since pre-historic times (Gould & Nissen-Peterson, 1999, pp. 7-11). Sophisticated roof catchments and storage systems for rainwater collection dating back to 1700 BC have been discovered in ruins in the Mediterranean region (UNEP, 1983, p. 5). Evidence of other roof catchments and storage vessels used thousands of years ago have been found in Europe, East Asia, South Asia, and sub-Saharan Africa (Gould & Nissen-Peterson, 1999, pp. 8-10). It is believed the first Polynesian settlers of the Pacific islands practiced rainwater collection (ibid, p. 11). Rainwater continued to be utilised in these areas and others over the centuries, until there was a decline in utilisation in the 20th century that coincided with increased development of other sources and piped water (ibid, p.11). However, in recent decades there has been resurgence in interest in rainwater harvesting around the world (ibid, p.11; Thomas & Martinson, 2007, p. 9).

2.4.2 System components and sources of contamination

The components of the most basic roof catchment DRWH system are the roof of the domicile, a storage vessel, and guttering to convey the water from the roof to storage (Thomas & Martinson, 2007, p. 16). More complex systems may also include components that filter and remove contaminants, distribute water from storage to a tap, purify or disinfect the water, heat the water, handle overflow or gauge the water level in storage (Kinkade-Levario, 2007, p. 14; Thomas & Martinson, 2007, p. 17). A diagram of a simple roof catchment DRWH system is show in Figure 2.1.

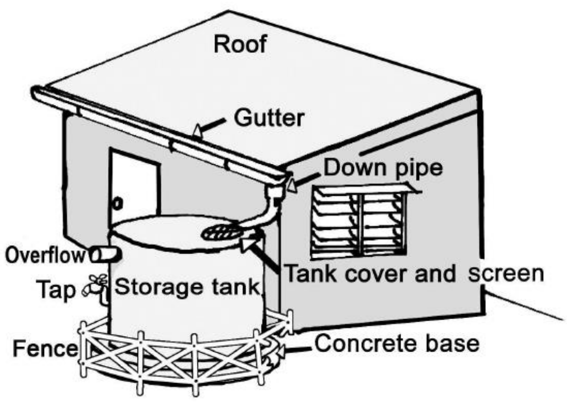


Figure 2.1: Simple DRWH system
Source: (SOPAC, 2004)

Other low-cost artificial raised catchments may consist of only two components: a catchment surface and a storage vessel that receives water directly from the catchment.

Each component of the DRWH system introduces an opportunity for contaminants to enter the water. Martinson and Thomas (2003) developed the diagram shown in Figure 2.2 below that shows the most common routes of contamination.

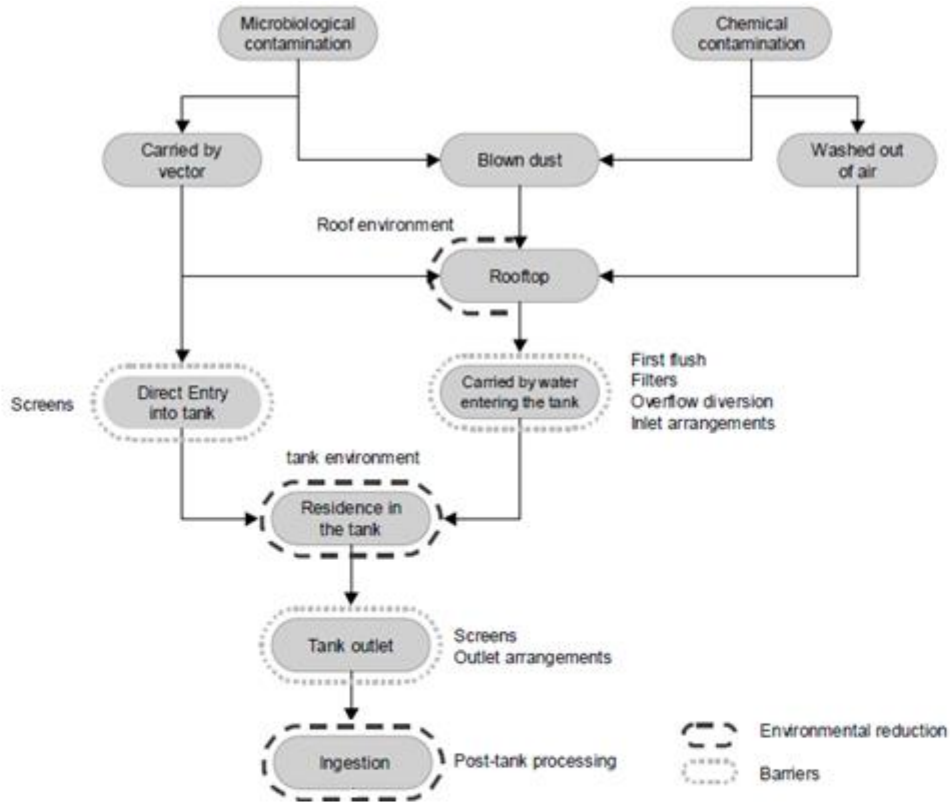


Figure 2.2: Possible routes of contamination for rainwater collection
Source: (Martinson & Thomas, 2003)

As raindrops fall through the sky, they may pick up physical and chemical contaminants from the air as they approach the catchment (Abbasi & Abbasi, 2011). However Thomas (1998) writes that in all but the most industrially polluted areas this contamination can be neglected. SOPAC (2004, p. 66) concurs that this is unlikely to be a problem in PICs.

The catchment, usually the roof, is perhaps the largest single source of contamination in a DRWH system (Lye, 2002; Thomas & Martinson, 2007, p. 118). Chemical contamination can occur from roofing materials such as lead flashings and lead-based paint (Pacey & Cullis, 1986, p. 17), brass fittings, tanalised timber shingles (Ashworth, 2002, p. 21), acrylic paints, and bitumen-based (tar) materials (Abbasi & Abbasi, 2011). Chemical contaminants may also be deposited on the roof from air pollution from urban sites and from aerial sprayed pesticides (Abbasi & Abbasi, 2011).

Microbiological contamination of water through the catchment may be caused by soil and leaf litter, faecal material deposited by animals (birds, rats, lizards, etc.), dead animals and insects, and airborne microorganisms blown by the wind (Abbasi & Abbasi, 2011). These sources plus particulate from the catchment itself can also cause physical contamination that affects the aesthetics of the water (SOPAC, 2004, p. 66; Thomas & Martinson, 2007, p.43; Abbasi & Abbasi, 2011).

Microbiological and physical contamination can also occur directly in the storage vessel via animals drowning, children swimming, accidental spillage of sewage (Thomas & Martinson, 2007, p. 42), maintenance activities, mosquito breeding (SOPAC, 2004, p. 67), agitation of the sludge layer (Manson, 2000; Spinks, et al., 2005), wind-blown particles, and animal faeces. Uncovered openings, inlets, and outlets on the storage vessel are potential entry points for contaminants. Certain tank materials have been found to have an effect on the pH and aesthetics of the stored water (Gould & Nissen-Peterson, 1999, p. 145; EnHealth Council, 2004, p. 16).

If water is collected and transported from the main storage vessel with a container, more opportunities for contamination arise. A systematic review of literature by Wright *et al.* (2004) determined faecal contamination often occurs, and to a significant degree, after water has been collected from the source.

2.4.3 Harvested rainwater quality and health

The quality of harvested rainwater and its level of safety for domestic use has received increased attention in recent years. Several literature reviews have determined that harvested rainwater is frequently found to be microbiologically contaminated (Lye, 2002; EnHealth Council, 2004, p. 10; Meera & Ahammed, 2006; Fewtrell & Kay, 2007; Lye, 2009; Ahmed, et al., 2011; Kwaadsteniet, et al., 2013). Pathogens identified to be present from these studies include *Cryptosporidium*, *Campylobacter, E. Coli, Legionella, Salmonella, Giardia,* and *Aeromonas.* Fewtrell and Kay (2007), Lye (2009) and Ahmed *et al.* (2011) note in their studies that levels of contamination varied greatly from source to source. Contamination in these studies is usually determined by measuring against international quality guidelines set by WHO.

It is worth noting that the adequacy of tests commonly used to measure the microbological quality of water has been questioned when applied to DRWH systems. Some studies (Lye, 2002; Evans, et al., 2007; Ahmed, et al., 2009) report that traditional faecal indicator organisms may be inadequate for detecting novel combinations of opportunistic pathogens while another (Coombes, et al., 2006) says non-pathogenic organisms can grow on approved media and potentially result in a misleading view that a particular rainwater supply is unsafe. It has also been suggested in order to get an accurate portrayal of microbial quality, rainwater needs to be sampled several times over a period and the geometric mean of the samples calculated (Thomas & Martinson, 2007, p. 42).

To a less concerning degree, DRWH systems have been found to also be contaminated with chemicals (EnHealth Council, 2004, p. 14; Meera & Ahammed, 2006; Lye, 2009; Kwaadsteniet, et al., 2013). Gould and Nissen-Peterson (1999, p. 145) say serious chemical contamination is rare while Meera and Ahammed (2006) say heavy metals and trace organics could cause problems in some cases. DRWH systems have also been associated with breeding of vectors that carry malaria and the dengue virus (Vasudevan, et al., 1999; EnHealth Council, 2004, p. 13; Mariappan, et al., 2008).

While contamination of stored rainwater is well documented, the public health risk associated with drinking untreated rainwater is not (Kwaadsteniet, et al., 2013). Illnesses associated with drinking untreated rainwater have been reported a number of times (Kwaadsteniet, et al., 2013), but reports are relatively infrequent (EnHealth Council, 2004, p. 11; Thomas & Martinson, 2007, p. 39). This may be because outbreaks tend to be small because DRWH systems typically serve a small group of people (Lye, 2002; Thomas & Martinson, 2007, p. 39) or simply because DRWH systems usually deliver safe water (Thomas & Martinson, 2007, p. 39). A study by Heyworth *et al.* (2006) found that children in an area of south Australia that drank solely from DRWH systems were no more likely to get gastroenteritis than children that drank from treated public water mains.

Two recent studies reviewed the evidence of health risks associated with rainwater consumption. Dean and Hunter (2012) concluded that rainwater harvesting systems are just as safe as other improved water supplies, an improvement over unimproved water supplies, and that rainwater harvesting should be encouraged in achieving MDGs. Meanwhile, Ahmed *et al.* (2011) concluded the quality of harvested rainwater should in general be assumed to be less than potable until further rigorous testing can be done. Both authors commented that data are lacking. It should be noted that Ahmed *et al*. focused on developed countries and Dean and Hunter focused more on developing countries, so the latter study is likely to be more relevant to this research.

At the beginning of this literature review, the author sought to learn what were the most common causes of contamination and subsequent illness associated with DRWH systems. However, it appears that illnesses from drinking rainwater have seldom been documented let alone what polluted the water and caused the illness. Overall, authors seem to agree that the principal quality hazard to roof catchment DRWH systems are pathogenic microorganisms that come from the faeces of animals with access to the roof (EnHealth Council, 2004, p. 9; Fewtrell & Kay, 2007; Thomas & Martinson, 2007, p. 39; Abbasi & Abbasi, 2011).

In light of all the information available on the quality of harvested rainwater, various authors give different opinions on how it should be regarded. Gould and Nissen-Peterson (1999, p. 141) state that just because the water quality does not meet some national or international standard does not mean it is not safe to drink, and that rainwater collected from a well-maintained roof is normally safe to drink untreated. The Development Technology Unit of the University of Warwick (no date) and Thomas and Martinson (2007, p. 39) concur that rainwater may be drunk untreated if collected from a well-designed system. These opinions are backed by an epidemiological study (Rodrigo, et al., 2011) that suggests drinking untreated rainwater does not contribute appreciably to community gastroenteritis (although the authors note this may not be generalisable to immunocomprised people, young children, and the elderly). Thomas and Martinson (2007, p. 25) agree with Dean and Hunter (2012) that DRWH systems are just as good as some other improved water supplies such as protected wells, boreholes, and protected springs in terms of water quality.

On the other hand, several other studies conclude that in general rainwater needs to be treated before it can be considered fit for drinking (Lye, 2002; Meera & Ahammed, 2006;

Ahmed, et al., 2009; Abbasi & Abbasi, 2011; Kwaadsteniet, et al., 2013). These authors often cite the prevalance of microbiological contamination in DRWH systems and records of illness associated with drinking rainwater as reasons. Dean and Hunter (2012) state the need for treating rainwater before consumption cannot be inferred from their health risk study. In their latest edition of drinking-water quality guidelines, WHO (2011) states post-collection treatment of rainwater can reduce health risk but stops short of saying it should or needs to be done.

This divergence in opinion could be due to a couple of reasons. First, as previously stated, some systematic reviews have found that levels of contamination vary greatly from system to system. The need for treatment could very well depend on local factors. Secondly, some studies focused on developed countries while others focused on developing countries. The level of quality is expected to be higher for developed countries so, depending on the targeted population, treatment may or may not be recommended.

Overall, none of the studies condemned DRWH systems in general as unsafe sources. However, all of the studies recognised that some action is needed on the part of owners to ensure the water is fit for consumption. Gould (1999) perhaps summarises it best: “While health risks may be small … there is little room for complacency and every effort needs to be taken to minimise rainwater contamination”. This sentiment supports the need for this research’s aim of developing sustainable houshold water quality management.

2.4.4 Controls for contamination

DRWH systems by their nature provide some treatment without intervention from the users. This includes bacteria being destroyed on the catchment from exposure to UV rays, heat, and desiccation, biofilms inside the storage vessel destroying pathogens and removing heavy metals and organics, and settlement of suspended solids and other contaminants during storage (Spinks, et al., 2003; Thomas & Martinson, 2007, pp. 41,119; Abbasi & Abbasi, 2011). Water quality tends to increase with storage time (Ashworth, 2002, p. 26; Skinner, 2003, p. 18) although pathogens can multiply in storage as well if nutrients from organic matter are present (Abbasi & Abbasi, 2011).

A number of technologies exist that can be added to DRWH systems by users to improve water quality. They include first-flush diverters, screens, filters, and customised inlets, outlets, and overflow arrangements (Gould, 1999; Way & Thomas, 2005; Thomas & Martinson, 2007, p. 110; Abbasi & Abbasi, 2011). Diagrams and brief descriptions of some of these technologies are located in Appendix 3.

There are a great number of design, operation, and maintenance measures recommended for controlling water quality throughout the literature. Readers seeking more information should refer to documents by Gould and Nissen-Peterson (1999, pp. 148-158), the enHealth Council of the Australian Government (2004), SOPAC (2004, pp. 68-73), the Texas Water Development Board (2005), Thomas and Martinson (2007, pp. 110-119) and the Master Plumbers and Mechanical Services Association of Australia (2008). In their review of literature on the pathways in which pollutants can enter a rainwater harvest, Abbasi and Abbasi (2011) identified the following five control measures as being most critical:

1. Ensure that the rooftop surface is made up of water resistant material that does not contribute any chemicals to the runoff;
2. Keep the rooftop well dusted and broomed when rain is expected, and keep it well maintained in all other respects;
3. Install screens at the inlet points of all pipes and drains leading to the storage tank, which could prevent insects and dead animals from being carried into the tank and also control other debris;
4. Organise the first flush properly; and
5. Ensure proper design of the storage tank, especially from the viewpoint of managing overflow.

There is generally good consensus among the DRWH research community that the above five measures are useful for improving water quality. One control measure that is often brought up that does not have good consensus regards storage cleaning and disinfection. Recommendations for how frequently the storage vessel should be cleaned out include twice per year (Dillaha & Zolan, 1985), annually (Pacey & Cullis, 1986, p. 64; SOPAC, 2004, p. 68), every 1 – 5 years (UN-HABITAT, 2005, p. 40), every 2 – 3 years (EnHealth Council, 2004, p. 33) and every 3 years (MPMSAA, 2008, p. 52; Macomber, 2010, p. 25). Thomas and Martinson (2007, p. 119) argue that desludging is one of the least important maintenance activities and should only be done when the sludge layer is nearing the tap.

This argument is supported by studies that concluded that removing sediment is not essential to maintenance of high quality water (Krampitz & Hollander, 1998/99; Spinks, et al., 2005). On the other hand, a study in Bermuda (Levesque, et al., 2008) found cleaning of rainwater tanks in the year prior to sampling appeared to protect against water contamination.

Some sources recommend disinfecting the tank when cleaning it, usually with chlorine-based products (Pacey & Cullis, 1986, p. 64; Ashworth, 2002, p. 31; SOPAC, 2004, p. 68; Macomber, 2010, p. 34). However, this could kill a beneficial biofilm that forms inside of the storage vessel and helps destroy pathogens and absorb heavy metals (Thomas & Martinson, 2007, p. 119; Evans, et al., 2009; Kim & Han, 2011). The Texas Water Development Board (2005, p. 2) warns that chlorinating water tanks can produce carcinogenic trihalomethanes, although it has been suggested that it is not likely they will be produced in sufficient quantities to make a real health impact (Macomber, 2010, p. 35).

2.4.5 Policy and legislation

There is no global agreement regarding water quality from DRWH systems (Birks, et al., 2004). A variety of guidelines, regulations, and policies for rainwater systems exist at the country, state, and regional levels (Ward, 2010, pp. 86-90; Schuetze, 2013). Much of this legislation is directed at facilitating and promoting the uptake of rainwater harvesting systems to address water scarcity issues. For example, certain buildings and houses in parts of India (UN-HABITAT, 2006), the USA, Australia (Centre for Science and Environment, no date), Bermuda (Rowe, 2011), the US Virgin Islands, and other Caribbean islands (Texas Water Development Board, 2005, p. 3) are required to have some form of rainwater collection system attached to them.

Policy relating to rainwater quality is not as prominent, and exists mainly only in developed countries. Guidelines that require harvested rainwater to meet a certain quality standard or mandate that collection systems be constructed in a certain way to prevent contamination are present in North America and Europe (Ward, 2010, pp. 86-90). It is likely that this type of legislation is not found in developing countries because it would be difficult to enforce and could discourage people from upgrading from an unimproved water supply.

2.5 Water Safety Plans

This section explores the available literature on what WSPs are and how they have been applied. It covers expert opinions on implementation, outcomes of implementation, research on WSP application, discourse, and gaps in knowledge.

2.5.1 Background and definition

WSPs were first introduced by WHO in their third edition on Guidelines for Drinking-water Quality (2004, p. 48) and endorsed by The Bonn Charter for Safe Drinking Water in 2004 (IWA, 2004). The drive for developing WSPs came from increasing recognition that safe drinking water could only be consistently secured through a risk based approach (Breach, 2012, p. 1). The traditional approach of managing water quality, by monitoring it through testing before distribution, has several concerning limitations (Smith & Reed, 2012):

- Little input or communication from the consumer;
- Inadequate protection of public health as an operational tool;
- By the time contamination is identified, water will have been consumed;
- Samples can be difficult and expensive to collect and analyse;
- Sampling only considers quality at a particular time and place;
- Focus is on measuring water quality and not on the means by which it is assured;
- Focus is reactive rather than proactive and does not cover the whole system from catchment to consumer.

WSPs do not eliminate the need for water quality monitoring, but rather provide guidance for preventative action to ensure good water quality which can then be confirmed by testing (Godfrey, 2005).

WHO places WSPs into a larger framework for safe drinking water that also includes setting health based targets and independent surveillance (WHO, 2011). Many principles of the WSP draw from the Hazard Analysis and Critical Control Point approach commonly used in the food manufacturing industry (Davison, et al., 2005, p. 6). The main components of the WSP as designed by WHO are shown in Figure 2.3.

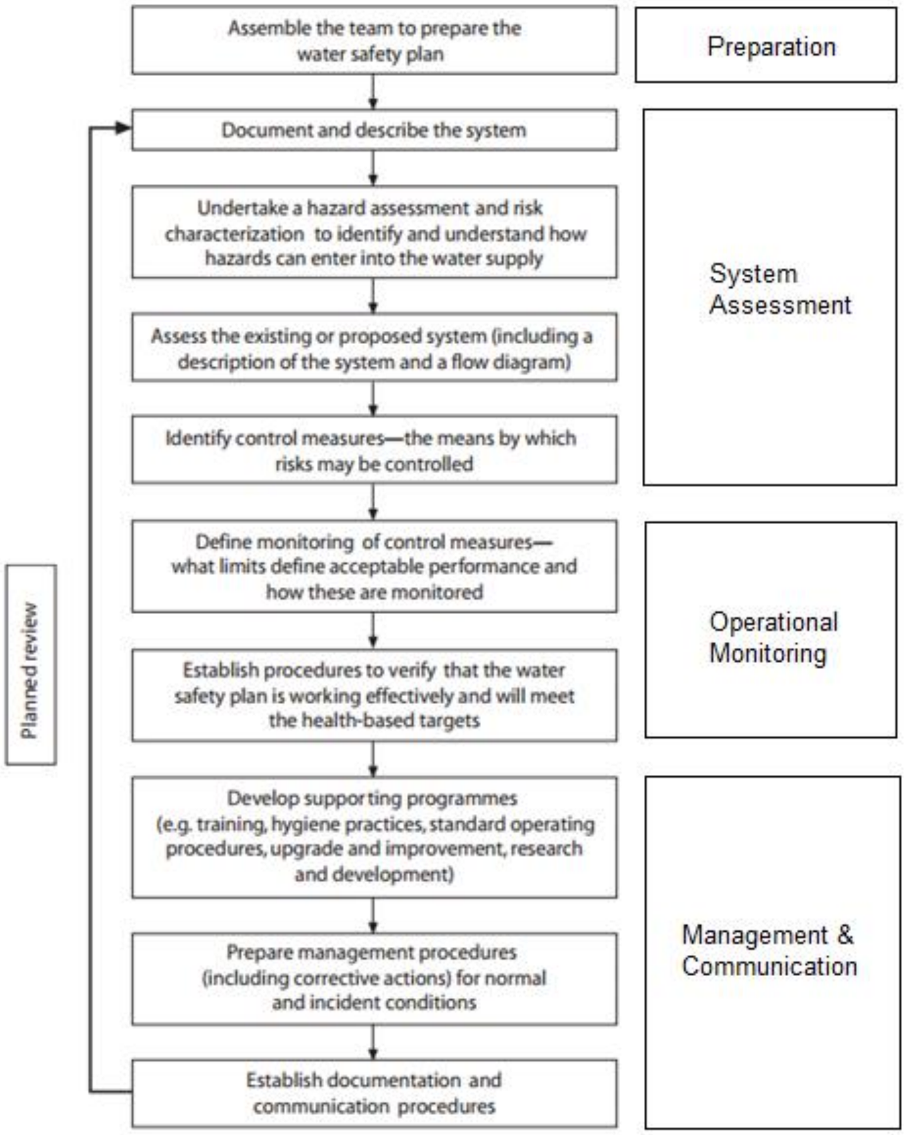


Figure 2.3: Steps to developing a WSP
Source: Adapted from (WHO, 2011)

The steps to developing a WSP have been presented in various ways, sometimes with fewer steps than above, but always retain the core principles of proactive risk assessment, risk management, monitoring, verification, and communication (Davison, et al., 2005, p. 20; Mudaliar, et al., 2008, p. 10; Bartram, et al., 2009).

Ultimately, the goal of the WSP is to ensure the safety of drinking water through preventing contamination of source waters, treating water to reduce or remove contaminants, preventing re-contamination during storage, distribution, and handling (Davison, et al., 2005, p. 11), and giving consumers greater involvement and control over maintaining water quality (Smith & Reed, 2012).

In addition to improving water quality and better protecting public health, WSPs help provide a better understanding of the water supply they are applied to, operational efficiency gains, performance improvements, improved stakeholder relationships, and targeted use of financial resources (WHO/IWA, 2010). However, even though WSPs are said to be suitable for small community and household water supplies (WHO, 2004, p. 49), the claimed benefits of WSPs in literature are derived mostly from focusing on public piped water supplies (Oluwasanya, 2009, p. 19).

2.5.2 Application

Since 2004, uptake and implementation of WSPs in varying contexts across the world has been rapid. Documentation of the implementation of WSPs has mostly covered public piped water supplies. Examples of this can be found in Asia (Gherardi, 2008; Yamada, et al., 2010), Europe (Malzer, et al., 2010; Gunnarsdottir, et al., 2012), Africa (Howard, et al., 2005; Viljoen, 2010), Latin America (Garzon, 2006; Rinehold, et al., 2011) and PICs (Gregor, 2007; Khatri, et al., 2011). WSPs have also been implemented for community managed water supplies in Laos, Bhutan (WHO/IWA, no date), Nepal (Khatri & Heijnen, 2011; McMillan, 2011), South Sudan, the Democratic Republic of Congo (Greaves, 2011), Afghanistan (Greaves & Simmons, 2011), Bangladesh (Mahmud, et al., 2007; Shamsuddin, 2008) and elsewhere. An NGO-initiated programme to implement WSPs for community managed supplies in Fiji is expected to begin sometime in 2013 (R Singleton 2013, pers. comm. 10 May).

To support and further encourage the application of WSPs, many manuals and guidebooks have been developed. Some of these target public utilities (Godfrey & Howard, 2005; Davison & Deere, 2007; Bartram, et al., 2009; Breach, 2012), some target community-managed supplies (Live & Learn Environmental Education, no date; AusAID, 2007; Ministry of Health Bhutan, 2010; State Institute of Rural Development Sikkim, 2010; Greaves & Simmons, 2011; WHO, 2012) and others attempt to cover both types (Davison, et al., 2005; Mudaliar, et al., 2008). The author is not aware of any published manuals that focus on household water supplies although one is currently (2013) being developed for PICs (K Khatri 2013, pers. comm. 27 March).

Manuals that focus on community-managed water supplies often recognise these schemes do not require an approach as detailed as for urban utilities (Rouse, et al., 2010, p. 19) and have accordingly simplified the approach shown in Figure 2.3. An example of the modified steps is shown in Figure 2.4.

Figure 2.4: Developing a WSP for a community-managed water supply
Source: (WHO, 2012, p. 6)

The core principles of this modified approach remain the same as shown in Figure 2.3. With these approaches routine management practices are delegated to a trained 'water committee' that carries out assessment, maintenance, monitoring, and feedback activities. Training, verification, and general support are usually provided by an external agency such as the local government or an NGO. Unlike with public utilities, managers of these water supplies are usually not expected to ensure the water meets lofty national quality standards but rather make incremental improvements wherever they can (WHO, 2012, p. 5). WHO (2012, p. 3) states their manual is also applicable to household water supplies but the focus is largely on communal supplies. WHO states elsewhere that WSPs may not always be practical at the household level (WHO, 2011, p. 94). None of the manuals discuss in-depth the particular challenges and opportunities associated with managing the quality of household water supplies versus communal or public ones.

2.5.3 Outcomes and impacts

While WSPs have rapidly gained popularity in the last decade and there is little doubt they can improve supply performance and provide greater confidence in drinking water, little evidence has been documented on their associated benefits (Mudaliar, 2012). This lack of systematic evidence could be due to an inadequate established framework for monitoring and evaluating implemented WSPs (Gelting, et al., 2012; Mudaliar, 2012). Reviewing the literature reveals some outcomes and impacts that have been observed. One study found that implementing WSPs in utilities in Iceland resulted in improved regulatory compliance with water standards, improved water quality, and a significant reduction in incidences of diarrhoea in areas where a WSP was implemented (Gunnarsdottir, et al., 2012). Another study of a health clinic in Germany also found water quality improved, and incidences of certain diseases reduced after implementation of a WSP (Dyck, et al., 2007).

The depth of evidence regarding benefits associated with WSPs applied at a community or household level is also sparse. Using pilot projects across 82 communities in Bangladesh, Mahmud *et al.* (2007) found that uptake of WSPs at the community level was good and resulted in a reduction in sanitary risks and an improvement in microbiological quality for most community-managed water supplies. The associated health impact was not studied. Greaves (2011) says communities in South Sudan addressed sanitary issues around water supplies more readily and demonstrated better knowledge of hygiene issues after WSPs were promoted by an NGO, but notes these changes cannot be solely attributed to the WSP.

The Mahmud *et al*. (2007) study mentioned above focused on communal water supplies but also introduced WSPs to households with DRWH systems. In contrast to the successful results of the communal systems, a reduction in sanitary risks and improvements in water quality were not observed in DRWH systems after WSPs were introduced to householders. The authors remarked that this is perhaps because more training and support is needed for household water supplies. Hasan *et al.* (2011) on the other hand, found that householders in the Marshall Islands managed sanitary risks to their

DRWH systems better in the short-term after sanitary surveys were introduced to them by trained local facilitators during a pilot study.

2.5.4 Policy

WSPs are beginning to gain attention in the form of government policy, especially in the developed world. WSPs in some form have become or are becoming part of guidelines or regulations in Australia, China, Iceland, New Zealand, Sweden, and the United Kingdom (Byleveld, et al., 2008). In developing countries uptake has been slower at the national level. To encourage policy changes and institutional support for implementing WSPs, some guidelines have been published (Rouse, et al., 2010; WHO/IWA, 2010). Rouse *et al.* (2010, p. 8) recommend five key policy issues be addressed:

1. **Adopt drinking water safety plans**: Establish WSPs as a necessary precursor to end-product sampling and testing and provide associated support.
2. **Establish roles and responsibilities**: Coordinate planning to interpret state policy in terms of deliverables, and train facilitators and village-representatives.
3. **WSPs as a basis for investment**: Identify investment priorities for both quality and quantity of water and build them into decision-making processes for each scheme.
4. **Set performance targets to reflect health objectives**: Establish targets for operational, water quality, and health improvements to support evidence-based decision-making.
5. **Policies on interventions**: Improvements at various stages of the supply chain including source protection, purification, distribution system protection, and household management may require supporting policies.

These guidelines however were written for the Indian context and may be more applicable to utilities and community managed supplies. WHO/IWA (2010) describes eight steps for scaling up WSPs that reflects the above points and also includes knowledge sharing and demonstration projects.

In 2012, the Fijian Government approved and put into effect the Rural Water and Sanitation Policy (RWSP) that declared a water supply management plan (WSMP) must be completed and approved before funding and installation of new rural water schemes can proceed (Ministry of Information, 2012; Ministry of Works, Transport & Public Utilities, 2012). The WSMP includes:

a) A review of water sources
b) An estimate of future water demand
c) Measures for controlling changes in wastewater and sanitation
d) Operational and maintenance requirements
e) Rules for water extraction
f) Health guidelines
g) Training and education measures
h) Management arrangements
i) Agreement between the Government and direct beneficiaries

The WSMP includes elements of the WSP that it integrates with water resources management and sanitation. Rainwater harvesting is included in the list of potential rural water supply schemes, although the focus is on new water supplies and not existing ones. Referring to the five key policy issues listed by Rouse *et al.* (2010) on pg. 31, the policy document satisfies points 1 and 2 and partially point 4 (targets are set for performance but not associated health benefits). A national drinking water safety plan that focuses on existing rural water supplies is in a draft phase.

2.5.5 Lessons learned

Although research into WSPs implemented at a community or household level is limited, a number of authors have listed their lessons learned and provided recommendations as a result of studies in this area. Rural water supply schemes often need to be managed by community members that lack technical expertise, have limited time they can commit, receive little or no financial remuneration, and have poor access to maintenance and water quality testing equipment (Davison, et al., 2005, p. 95). It is therefore recognised that external support is usually needed to train and support communities in managing their water supplies (Howard, 2003; Greaves, 2011, p. 5; Khatri, et al., 2011;WaterAid, 2012, p. 16).

Hasan *et al.* (2011) suggest training of local facilitators to empower communities with the WSP concept may be effective, and highlights the importance of providing sanitary inspection forms in the local language. The authors also suggest using hydrogen sulphide paper-strip tests for water quality verification. These tests have been determined to be reasonably good at indicating faecal contamination and have been touted before as a verification tool for community WSPs (Mosley & Sharp, 2005; Shingles & Saltori, 2008).

Alternatively, sanitary surveys may be able to sufficiently indicate the safety of a household water supply (Skinner, 2003, p. 14). Nussbaumer (2008, p. 43) and Oluwasanya (2009, p. 167) found there was a poor correlation between sanitary survey scores and microbiological contamination of a water supply, but Oluwasanya suggests survey scores still may be able to predict the maximum expected level of contamination. People undertaking sanitary surveys should have basic knowledge and understanding of water supply technology, public health principles, and water supply operations and management (Smith & Shaw, no date).

Mahmud *et al*. (2007) noted from their study that it was difficult to get water supply managers to document monitoring activities, and suggest occasional surveillance visits from external authorities may work better. These authors and others (Mudaliar, et al., 2008, p. 35; McMillan, 2011) agree that while a model WSP is useful, implementation and monitoring tools may need to be tailored for each water supply. A structured approach to water quality monitoring of rural water supplies is important for identifying priority actions to be taken (Cronin, et al., 2006). Khatri and Heijnen (2011) suggest from their pilot study that the community should be motivated to take the lead in WSP implementation, examples of successful WSPs are useful motivating tools, external surveillance is important for sustainability, and water quality testing in front of people is an effective educational tool.

Oluwasanya (2009, p. 311), who studied SSS in Nigeria, concluded in order for WSPs to be successful at a household level, WSPs must be facilitated and coordinated by an external institution, incentives need to be provided to source owners, stipulated safety measures must be acceptable to users, awareness and enlightenment campaigns are necessary, and involvement from a wide stakeholder group is needed. Well defined sanitary surveys are a necessary tool for water safety interventions at the household level (Oluwasanya, 2013).

2.6 Self Supply

In this section literature on the Self Supply approach is explored. This includes an investigation into the recent development and application of Self Supply, outcomes of implementation, opinions from researchers, and gaps in knowledge.

2.6.1 Background and definition

SSS have existed since long before the advent of public water utilities and piped supplies. However, the approach of supporting households to construct and improve their own private water sources is recent. Most of the ground-breaking work of this approach was in the early 1990s in Zimbabwe (Carter, et al., 2005, p. 3). Since then, projects to promote Self Supply have also been carried out in Ethiopia, Zambia, Mozambique, South Africa, Uganda, Mali, Tanzania, Bolivia, Haiti, Moldova, and Ukraine (Kumamaru, 2011, p. 30; RWSN, 2013) and could potentially be carried out in several other countries (Sutton, 2005). Many of these projects have been backed by the RWSN. Even without projects to support them, millions of people around the world in both developed and developing countries manage their own SSS (Sutton, 2009).

It has been claimed that Self Supply offers improved water quality, quantity or accessibility where communal sources are less sustainable (Waterkeyn, 2006). However, SSS are generally seen as a complement to communal water supplies rather than a replacement (Sutton, 2004; Carter, 2006; Waterkeyn, 2006). Owners of SSS are encouraged to aspire to make incremental improvements to their system, building on what they have already done and copying from neighbours (Sutton, 2009). SSS may be taken up where people feel regular shared water supplies provide inadequate service (Sutton, 2009) or where they wish to use it for productive purposes as well as domestic (Noel, et al., 2006). The key characteristics of Self Supply are (RWSN, 2008):

- A ladder of incremental improvements in steps which are easily replicable and affordable to users, linked, when necessary, to micro-finance systems and/or productive use;
- Official recognition of lower steps of the ladder as necessary stages towards a level (to be defined) which is recognised as contributing to MDGs;
- Availability of low-cost technical options and information on source construction and upgrading, rainwater harvesting and household water treatment;

- Management and maintenance based on strong ownership by individual (or community) and local skills; and
- Demand built through government promotion and private sector marketing.

2.6.2 Application

To date, documentation of studies on the application of Self Supply has predominantly focused on wells in communities in Africa (Workneh, et al., 2009; Harvey, 2011; Kumamaru, 2011; Sutton, 2011; Sutton, et al., 2012). However, DRWH systems have been given some attention as well (Danert & Sutton, 2010; Blanchard, 2012). In a recent online forum between RWSN members, Self Supply together with rainwater harvesting was identified as an area deserving of more development (Olschewski, 2013). This research is expected to contribute to this.

Sutton *et al* (2012, p. xi) identify six building blocks for enabling the successful application of Self Supply:

1. Creating demand through promotion;
2. Providing technology options and advice;
3. Strengthening the private sector;
4. Establishing supportive financial systems;
5. Building facilitative government policies; and
6. Monitoring progress and learning from research into new options and more effective impact.

One of the most frequently raised concerns regarding Self Supply is a perception among government health officials, water sector professionals, and development workers that SSS are likely to be unsafe and unreliable. Other barriers to application of Self Supply include a perception of moving backwards, views that SSS is competing with other supplies rather than complementing them, preference for larger schemes that have more straightforward management, belief that end-users are not capable water managers, SSS not meeting lofty government construction standards, reluctance from NGOs and government in supporting individual households rather than collective communities, and a lack of micro-financing schemes (Carter, et al., 2005, p. 13; Sutton, 2009).

To assuage concerns of water quality related to SSS, Sutton (2009) encourages HWTS be practiced jointly with other Self Supply practices. Sutton remarks "…it has become more widely acknowledged that point of use water treatment is more effective than source water treatment or dependence on source protection to provide water of potable standards". These remarks are backed by systematic reviews that found HWTS interventions to be highly effective (Fewtrell, et al., 2005; Clasen, et al., 2007; Waddington, et al., 2009). However, other studies have raised doubts about the effectiveness of HWTS interventions due to bias in reported figures and poor sustained use (Hunter, 2009; Schmidt & Cairncross, 2009a). These assertions have been a source of debate between specialists in the field (Clasen, et al., 2009; Schmidt & Cairncross, 2009b). Recent studies also suggest the effectiveness of HWTS is limited by imperfect compliance (Brown & Clasen, 2012; Enger, et al., 2013). Given the uncertainty surrounding the effectiveness of various household interventions, a multi-barrier approach to ensuring water quality as suggested by Deere *et al*. (2001, p. 262) may be most appropriate for SSS.

Unlike for WSPs, there is a lack of manuals that provide step-by-step guidance for how to promote and implement Self Supply practices. However, the RWSN has several documents on their website (http://www.rural-water-supply.net/en/self-supply) that make general recommendations for how donors, NGOs, and local government can nurture Self Supply.

2.6.3 Outcomes and impacts

Kumamaru (2011, p. 5) writes that while the Self Supply model could potentially provide benefits for a sustainable safe water supply, there has been little monitoring or systematic analysis of the impact made on water supplies and livelihoods. Pilot projects in Zambia (Sutton, 2004; Sutton, 2010a; Harvey, 2011), Mali (Sutton, 2010b), and Uganda (Kiwanuka, 2009; Danert & Sutton, 2010) found that when households were motivated and supported by NGOs and local government, they took initiative in making improvements to their privately-owned wells. Harvey (2011) found households could be compelled to make substantial improvements to their private wells without providing them with any material or financial subsidy whatsoever. Studies on Self Supply for DRWH systems (Carter, et al., 2005; Danert & Sutton, 2010; Blanchard, 2012) have focused on provision of DRWH systems to improve water quantity and accessibility and have not examined how they can be improved to provide better quality. This research will aim to fill this knowledge gap.

It was found that simple upgrades to private wells made by the owners led to marked improvements in water quality in Uganda, Zambia, and Mali although evidence is limited (Sutton, 2011). Similarly, Tillet (2007, p. ii) found upgrading shallow wells and excavated ponds by users in Uganda resulted in significant improvements to water quality. Kumamaru (2011, p. 225) also found upgrades made by users in Zambia to private wells could improve water quality, but usually only if the upgrades were made by a skilled artisan. Rogenhofer (2005, p. ii), on the other hand, found that upgrading wells by users in a town in Uganda provided only limited improvements to water quality. There does not appear to be any literature documenting the health impacts of the Self Supply approach.

2.6.4 Policy

Implementation of policies to support Self Supply appears to not have been taken up yet except for one instance: In Ethiopia, the government reformulated their Universal Access Plan strategy to advocate a greater move towards low-cost technologies and household investment and management of water supplies (Sutton, 2011). Other governments have shown support or interest. In the 2000s, the Ministry for Water Development in Zimbabwe subsidised the upgrading of 120,000 family-owned hand-dug wells (Sutton, 2009). The Government of Uganda is currently exploring options to encourage greater investments in water supplies from the users themselves (Kiwanuka, 2012).

Sutton (2009) identifies a set of processes that are needed for adoption of Self Supply in national policies and scaling up strategies:

- **Potential –** Establishing the scope for Self Supply in a given/region country
- **Piloting** – Testing out the package and demonstrating its relevance/limitations, monitoring impact/lessons learnt
- **Package** – Modifying the package building blocks to be relevant to the specific conditions (physical, cultural, public and private sector)
- **Promotion** – Analysing results and disseminating them among government, NGO and donor communities
- **Policy and Plans** – Adoption of enabling policies and plans for scaling up

2.6.5 *Lessons learned*

Most of the existing research related to Self Supply focuses on coverage, cost, and technical sustainability of SSS, but some attention has been given toward improving quality of existing SSS. Sutton (2011) advises the quality of SSS should not be held to the same standards as community supplies, and focus should be placed on making improvements where possible. Sutton also comments on the need for the presence of a supply chain for technologies that can be used for upgrading, means for buying these technologies (e.g. micro-credit or traditional savings schemes), and technical advice for people who are unaware of their options or how to implement them.

Kiwanuka (2009) comments that water quality can be significantly improved through upgrading, but users often wish to progress quickly up the "ladder" of improvements. Kumamaru (2011, p. iii) concluded from his PhD thesis in Zambia that the Self Supply model could significantly reduce the faecal contamination risk in water quality. Alford (2007, p. i) concurs the Self Supply approach is able to achieve significant improvements in water quality in certain contexts.

2.7 Chapter summary

The author's literature review strategy and a review of the methods of prior similar research were covered. Literature on DRWH indicates harvested rainwater is frequently found to have microbial contamination. Animal faeces entering through the roof is main culprit of contamination. Traditional quality tests using *E. Coli* and faecal indicator organisms may have limited adequacy for DRWH systems. Illnesses from drinking rainwater are not often reported. There are many simple design, operation, and maintenance options for protecting water quality. There is good consensus that DRWH systems deliver safe water if appropriate measures are taken. There is not good consensus on whether or not harvested rainwater should be treated before consumption.

WSPs have seen rapid uptake since their inception, mostly for utility-managed piped water supplies. WSPs have also been piloted for community-managed water supplies in several different countries. A range of manuals and guidebooks for implementing WSPs in a range of contexts have been developed. WSPs may have many benefits for water quality and other factors, but documentation of this has been limited. There is some evidence that implementing WSPs for community-managed supplies results in better management practices. Limited research indicates some principles of WSPs can be successfully implemented for SSS under the right conditions. Applications of WSP principles to DRWH systems have had differing outcomes.

Documentation of Self Supply projects to date is limited to countries in Africa. Studies have found households can be compelled to make incremental improvements to their SSS with or without material subsidy. Testing has found that incremental improvements made by the users themselves usually results in improvements in water quality although this evidence is limited. Thus far, studies on the ability of Self Supply to improve water quality have been limited to privately-owned wells. Studies on Self Supply and DRWH systems have concentrated on improving water quantity and accessibility.

From this review of literature, it has been shown that while DRWH systems are a viable and widely used source of water for potable and non-potable purposes, appropriate action is needed on the part of users to ensure good water quality. Aside from HWTS, few approaches to managing household water quality have been explored. WSPs and Self Supply are two such approaches that have shown indications of success in other contexts and could be extended to DRWH systems. To the author's knowledge, no studies have examined the joint application of Self Supply and the WSP to any water supply and very few studies have examined the application of either to DRWH systems. This research aims to contribute to filling both of these knowledge gaps.

3 METHODS

This chapter describes what steps were undertaken to answer the research questions. It explains how the author approached this project, the guiding methodology followed, how participants, tools, and procedures were selected and followed, and a summary of the chapter. The research design was a series of qualitative cross-sectional case studies utilising a mixed methods approach.

3.1 Research approach

The topic for this research was developed primarily by discussing it with personal contacts. This included soliciting ideas, identifying areas of need, and considering practicality with former work contacts and various WEDC staff members. Recent literature in the water and sanitation sector was also reviewed to search for topics that authors had commented as receiving inadequate attention. A journal was kept throughout the academic year to record ideas to follow up on and ask questions about. Once a general topic was selected, a mind map was created to identify relevant sub-topics that could be investigated. A preliminary literature review and eventually a research proposal were put together to further flesh out the topic.

3.2 Methodology

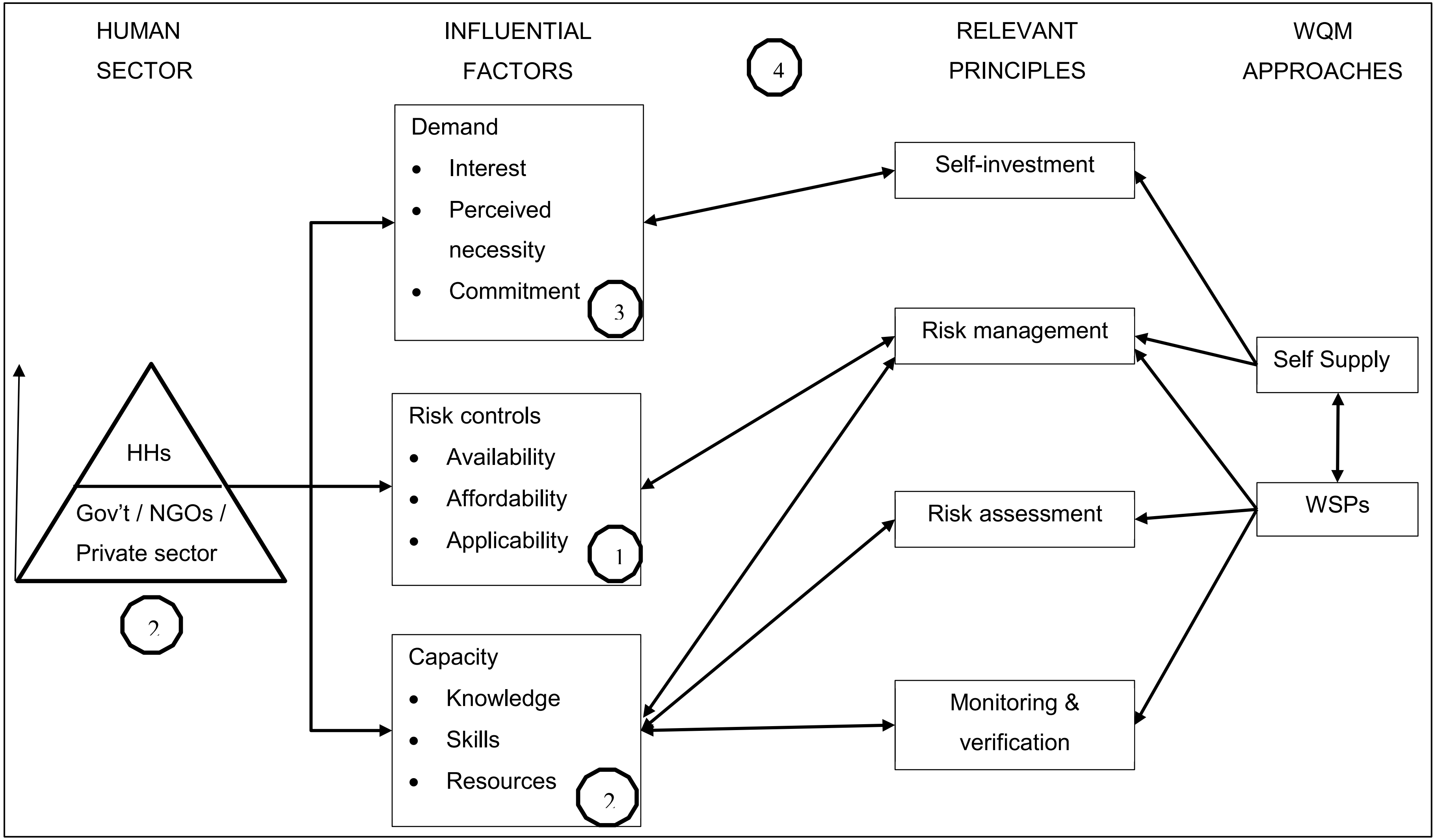
This section outlines the system of guidelines followed to achieve the research aim. It provides the logic behind how areas of investigation were chosen and the processes of selecting study and data collection designs.

3.2.1 Research strategy

The goal of this research is to contribute to improving the water quality of SSS in Fiji. To support this, a research aim, actions, indicators, and outputs were developed. These propositions are sorted and shown in a logical framework in Appendix 4.

This research takes a constructivist standpoint that recognises there are many factors in an individual's environment that shape how that individual behaves when using and interacting with a water supply. Both inductive and deductive reasoning are used at times. This is because the author attempted simultaneously to understand how individuals perceive and interact with their DRWH systems to form hypotheses about what issues need to be addressed to improve management (inductive reasoning) and to consider the WSP and Self Supply theories and investigate if they could be applied to DRWH systems to improve management (deductive reasoning). The research is largely qualitative although it also includes some quantitative aspects. A conceptual framework of the various elements studied and their interconnectedness is show in Figure 3.1. Circled numbers in the figure correspond to the objectives of this research as listed in section 1.3 and are placed near the relevant elements and links studied. The boxes labelled “influential factors” are elements that are hypothesised by the author as being most critical for sustainable uptake of water quality management practices. Boxes labelled “relevant principles” are taken from literature.

To address objective 1, “to determine what primary water quality risks to rainwater harvesting systems need to be controlled in the Fijian context”, sanitary inspections were carried out on DRWH systems. Objective 2, “to assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably”, was addressed by interviewing households and key informants. Objective 3, “to gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems”, was addressed by interviewing households. Objective 4, “to assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality” was addressed by studying the links between the findings of objectives 1, 2, and 3 and theory based in literature. The literature review was also used to substantiate findings of each objective. These activities are described further in sections 3.3 – 3.6.



HH = Household; WQM = Water quality management

Figure 3.1: Conceptual framework

3.2.2 Study design

This research design contains elements of both cross-sectional and exploratory case study designs. A sample (or cross-section) of participants was chosen that was known to have a certain characteristic (practiced rainwater harvesting) and was studied once without temporal variation to learn about a wider situation (water quality management of DRWH systems). However, a relatively small number of participants were studied in-depth and the Fijian context was constantly considered and analysed which gives it elements of a case study.

This approach was taken for a few reasons. First, a restriction on resources made only a smaller cross-section practical to study. Second, a case study allows for an in-depth investigation that can cope with the complexities and subtleties of real-life situations (Denscombe, 2007, p. 38). Since the author has no control over the settings being studied and the focus is on complex relationships and processes, the case study approach is suitable. Further, a more in-depth qualitative investigation of fewer participants allows for more "how" and "why" questions to be answered (Rudestam & Newton, 2007, p. 37) which is crucial to addressing this research's aim of developing guidance for improving management. Third, authors of previous similar studies that sought to understand the reasoning behind certain practices and relationships, such as Roche (2006), Oluwasanya (2009) and Sakaryia (2011), used similar approaches. Looking at section 2.2, many other authors used a much wider cross-sectional study, but these authors were usually seeking to identify problems or understand the impact of something that had already taken place rather than understanding how experiences and attitudes influence them.

3.2.3 Data collection and analysis

Given that a constructivist approach is used in this study, it conventionally follows that the research is predominantly qualitative (Bryman, 2012, p. 380). Strictly speaking, whether data are quantitative or qualitative depends on how the data are analysed (Denscombe, 2007, p. 247). However, some methods are associated as being commonly used with certain strategies (ibid, p. 133). The methods used in this research were chosen based on how useful they would be in producing valuable data in the given context, what resources were available for utilising them, what worked well in previous similar studies, and the author's skill set. Multiple data collection tools were used so findings could be strengthened through triangulation.

Data were processed and analysed using a thematic analysis approach as described by Bryman (2012, pp. 578-581). Underlying components or "themes" were identified from the data and their relationships were studied to develop hypotheses about how the objectives of this research may be addressed.

3.3 Participants

For qualitative research, a purposive sampling method is usually more appropriate than probability sampling (Rudestam & Newton, 2007, p. 106). This is because the researcher often wants to ensure (s)he gains access to a wide range of individuals that are relevant to the research questions (Bryman, 2012, p. 416). This was the sampling method initially intended to be used in this research.

3.3.1 Households

The first step taken for identifying participants to include in this study was to settle on the targeted number of participants. Previous studies by Oluwasanya (2009) and Sakariya (2011) that had a very similar methodological approach to this study, sampled 41 and 36 sites respectively. Oluwasanya commented her sample size was selected on personal judgement. Sakariya does not comment on this. It has been recommended that for Master's research, a qualitative study may include between 4 to 45 interviews within four to twelve case studies (Perry, 1998). Based on this past research, 40 households across eight communities were judged to be an adequate number to initially target for interviews. However, it was decided beforehand that these numbers were flexible and subject to change in the field, since theory evolves while data is being collected in qualitative research, which could change the sampling approach (Rudestam & Newton, 2007, p. 107).

Eight initial communities were purposively targeted to represent different socio-geographic areas: coastal, inland, rural, peri-urban, and informal. These areas were chosen so a variety of experiences and viewpoints could be covered. The chosen communities were identified using Google Earth. Due to a restriction on resources, all communities were purposively selected to be within a round day-trip of the capital city, Suva, where the author was based. However, in the field it was found that many of the pre-selected communities did not have households that practiced rainwater collection. Eligible communities were then instead identified using local knowledge and were selected using a convenience sampling method.

In order to be eligible, the households had to have a system for collecting rainwater using either the roof or another artificially raised catchment and an adult residing at the household had to be present. To select households within a community, two different sampling methods were considered: the snowballing method and the transect walk method. By snowballing, households with DRWH systems could be efficiently located by asking the previous participants if they knew someone else in the community that collected rainwater. However, this leaves the opportunity for exclusion of certain social groups. A transect walk, whereby participants are located by observing who appears to have a DRWH system, may be less likely to exclude participants on social grounds. However, the transect walk may cause smaller, more informal DRWH systems to be missed if they are not in plain view. In the field, communities with a traditional village hierarchy often insisted on having a community member escort the author to households which led to a snowball method being used. In communities without a traditional village hierarchy, the transect walk method was used. The snowballing / transect walk methods were used in a similar study (Oluwasanya, 2009, p. 70).

Households were visited between 17 June and 21 June 2013. The DRWH systems selected to inspect were always attached to a household that was interviewed. No households were interviewed without doing a sanitary inspection of the DRWH system and vice versa.

3.3.2 Key informants

Key informants were people who had specialist knowledge or expertise related to the research questions and were identified from the author's personal network of contacts. Specifically, people with experience (in the PIC context) in promoting or implementing WSPs at a community level, providing government support to community-managed water schemes or promoting rainwater harvesting were sought. The author is not aware of any experts on Self Supply with extensive experience in PICs.

3.4 Data collection tools

As seen in Table 2.1, a variety of different tools were used by researchers that investigated similar topics in the past. Interviews and water quality tests were the most popular measures. For this research, tools that were expected to yield rich qualitative data and quantitative measures to strengthen the data through triangulation were chosen.

Throughout the fieldwork, a research diary was kept to note circumstances and how the methods evolved.

3.4.1 Respondents

The semi-structured interview was chosen to directly study household participants. It was felt that a structured interview or questionnaire would restrict the respondents' freedom to speak openly too much, focus group discussions would be difficult to arrange and limit the variety of perspectives, and participant observations or ethnographies would take longer than what was possible for this research. The semi-structured interview allows participants to speak freely and provides talking points to keep the conversation going and relevant (Bryman, 2012, p. 471). Water quality testing was not used because it was expected it would be too costly and not contribute much to answering the research questions.

Questions for the interview were developed ahead of time by the author and were meant to address attitudes and perceptions toward the quality of rainwater for consumption, management practices around DRWH systems, and interest in upgrading the systems. Consumption here refers to drinking water and water used to prepare kava. Kava is a non-alcoholic traditional drink made by mixing water with the pounded root of the *Piper methysticum* plant and plays an important social and ceremonial role in Fijian culture (Lebot, et al., 1997, pp. 1,119). Kava is regularly consumed by adults, but not children in rural Fiji.

In a sense, the questions were designed like what is often found in a Knowledge, Attitudes and Practice (KAP) survey (WHO, 2008) but more open-ended. Respondents were also shown pictures and asked questions about the inlet screen, first-flush diverter, float tap, and inlet arrangement shown in Appendix 3. The questions were translated into Fijian and Fijian Hindi then back-translated into English to ensure the questions retained their original meaning. A list of the questions and their translations is located in Appendix 5. It should be noted that, as is with the nature of semi-structured interviews, these questions were not strictly adhered to. When translators were used for specific questions, they were encouraged to use the same wording as prepared beforehand. A voice recorder was used to record the conversations between the respondents and the author or translators.

Image 3.1: Author performing sanitary inspection

3.4.2 DRWH systems

DRWH systems were inspected through a risk assessment approach using sanitary surveys as recommended and developed by Howard (2003) and WHO (2011). The sanitary survey was created beforehand by the author using various templates found online. A copy of the survey is shown in Appendix 6. The sanitary survey is usually a quantitative form of data collection that records whether a particular risk to water quality is present or not. Traditionally, the questions are written to be answered with a yes (the risk is present) or no (the risk is not present). At the end of the survey, 'yes' answers are given one point and the total points are added up. The higher the total number of points, the riskier the system is. However, it has been argued that this binary approach to questioning may exaggerate or underplay particular risk factors and that a scale of 1 – 5 should be used to assess risks (Oluwasanya, 2009, pp. 29,73). This scoring strategy was adopted for this research and is explained in Appendix 6. Photographs of the systems were also taken for later reference.

Risks were ranked using a matrix approach described by WHO (2012, p. 24) where the risks are judged by their likelihood of happening and the severity of the consequences if they do happen. These aspects are based on the judgement of the author after reviewing the literature, making observations in the field, and previous experience.

3.4.3 Key informants

Interviews with key informants also followed a semi-structured approach. Questions were prepared ahead of time to explore the informants' knowledge and opinions on their field of expertise and how it pertained to this research. When the interviews were conducted face-to-face, a voice recorder was used to record the conversation. If the interview was over Skype, the conversation was recorded using the Amolto Call Recorder software programme.

3.5 Procedures

Prior to the fieldwork being carried out, full ethical clearance for this research was granted by the Loughborough University Research Office. Fieldwork was coordinated with the assistance of the Water Services Department of the Secretariat of the Pacific Community (SPC).

3.5.1 Households

The author was accompanied on visits to communities with three staff members from SPC. One staff member was fluent in English and Fijian and another was fluent in English and Fijian Hindi. The team showed up at the communities unannounced and went directly to the home of the village headman or other community leader which was located by asking any community member. The headman or leader was then asked in traditional fashion for permission to conduct interviews in the community. Once permission was granted, individual houses were visited using the sampling strategy explained in section 3.3.1. If the community did not have a traditional formal structure, this step was skipped and homes were visited directly.

Image 3.2: Author interviewing householder

Interviews were performed with any adult present that resided at the household. Before the interview began, it was explained to the respondent who the members of the team and what their intentions were. Respondents were also asked for permission to record the ensuing conversation and inspect their DRWH systems. Consent for the interviews was obtained verbally from the respondents. Interviews were offered to be carried out in English, Fijian or Fijian Hindi depending on the respondent’s preference. The SPC staff members, who were coached beforehand on interviewing techniques, acted as translators for the author when the respondents did not prefer to speak in English. All interviews were carried out face-to-face.

3.5.2 Key informants

Interviews with key informants were coordinated and set up through e-mail. It was explained through e-mail what the purpose of the interview was and an appointment was scheduled to carry it out. Some interviews were performed face-to-face while others were done over Skype. Consent to conduct and record the interview was obtained verbally from the key informants.

3.6 Literature review

The literature review should be seen as a valuable tool for collecting information that contributed to forming the conclusions of this paper. The methods used for reviewing the literature were explained in section 2.1.

3.7 Data analysis

The data from the interviews were processed by transcribing all of the interviews; a total of approximately 38,000 words (excluding one key informant interview where handwritten notes were taken instead). The interviews were not transcribed verbatim, but rather so each spoken sentence was clear. Translations were transcribed in English. Pleasantries and speech not in English were not transcribed.

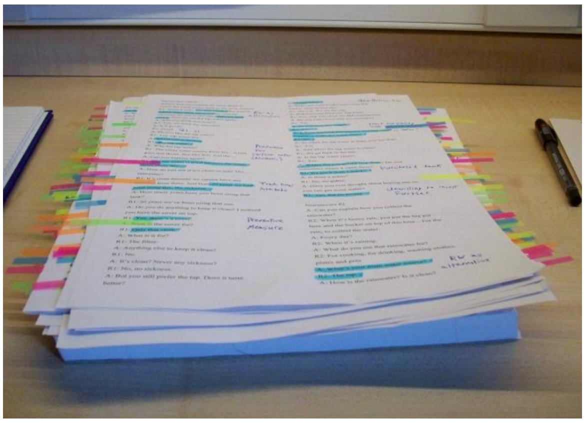


Image 3.3: Colour-coding data

Next, the transcriptions were read multiple times and notes were made in the margins to identify specific concepts and themes brought up. All the themes were then listed and categorised into broader themes and colour-coded. Relevant text was then tagged to correspond to its colour-coded theme. Finally, coded data were copied and pasted into groups with other data of the same code where they could be read, compared, and analysed easily. This process was done separately for the household and key informant interviews. Some of the data were numerically coded, for instance, questions where the respondents answered in the affirmative or negative.

The numerically coded data and grouped themes were then analysed in the context of the research questions and objectives. Various arrangements such as hierarchies and mind maps were used to visualise the relationships between the broader themes. Examples from the themes and codes were drawn on to link the processed data to the research questions and objectives.

Quantitative data from the sanitary surveys was sorted and processed in Microsoft Excel. These data were examined side-by-side with the qualitative data to establish connections between the datasets.

3.8 Verification

Verification of qualitative research is vital and credibility needs to be demonstrated somehow so it is known the findings were based on good practice (Denscombe, 2007, p. 296). There is debate among research experts about what evaluation concepts should be applied to qualitative research (Bryman, 2012, p. 48). This research verifies the quality of its practices through four commonly used bases as listed by Denscombe (2007, p. 296): validity, reliability, generalizability and objectivity.

The validity of research refers to its 'trustworthiness' or 'credibility' and how accurate the findings are (Denscombe, 2007, p. 297; Rudestam & Newton, 2007, p. 113). The validity of this research was obtained through triangulation, comparison with relevant literature, spending sufficient time gathering qualitative data, and documenting field notes. Deviant case analysis, where the author attempts to find cases that differ from the norm and explain why, was also performed.

Reliability refers to how consistently the same findings will be arrived at if the same research methods are replicated. This is difficult to know for certain in qualitative research since the researcher him/herself is an integral part of it (Denscombe, 2007, p. 298). Reliability in this research is strengthened by providing a detailed and transparent description of the steps taken to collect and analyse data.

Generalizability refers to how well the findings from the research can be applied to similar situations in other contexts (Denscombe, 2007, p. 299). It has been said that generalisation is the task of the reader rather than the author (Rudestam & Newton, 2007, p. 113), however this task can be made easier if the author provides a detailed description of the environment where the case studies took place (Denscombe, 2007, p. 300; Bryman, 2012, p. 392). In this research, the author attempts to discuss the culture and environment where the research took place and its influence on the data.

Finally, objectivity refers to the absence of bias in the research (Denscombe, 2007, p. 296). Again, this can be difficult to ensure in qualitative research since the researcher is an integral part of the process and bias is inherent in judgment. To remain objective throughout the thesis, the author consistently attempted to separate his preconceived beliefs from interpretation of the data and kept an open mind about information that did not neatly fit into his developing hypotheses and theory.

3.9 Methodological limitations

The approach taken for this research has a number of limitations. Due to the timeframe of the research project and limited resources, visits could only be made once to each household and selected communities had to be within a day-trip of the capital. Repeat visits could have been useful for follow up questions after initial conversations had been analysed and a broader sample including more distant communities could have drawn on a wider range of perspectives and experiences. Piloting was also not possible due to time constraints so adaptations had to be made while fieldwork was on-going. Translators were needed in some instances which could have caused some information to be lost or misrepresented in translation. This was mitigated by encouraging translators to translate as literally as possible. The number of households included in this study is not nearly enough to make the sample statistically representative, so findings from these methods must be generalised through other means. Sanitary inspections could only be done once at the time of the visit and it is possible that the weather that day or seasonal factors could influence the results of those. The sampling approach utilised for locating eligible households may have been biased toward larger, more formal DRWH systems that were easily noticeable. Smaller, more crudely built systems are more difficult to notice and therefore may be underrepresented in this study.

3.10 Summary

Semi-structured interviews with households and key informants were carried out to collect qualitative data. Sanitary inspections were performed on the household DRWH systems to collect quantitative data. The number of sites and the communities visited had to be changed in the field due to difficulty locating eligible households. Interviews were transcribed and analysed using thematic analysis. Sanitary survey scores were sorted in Excel. Verification of the data was ensured by strengthening its validity, reliability, generalizability, and objectivity. Limitations to the methods approach are discussed.

4 RESULTS

This chapter describes the outcomes and findings of the household interviews, sanitary inspections, and key informant interviews carried out in the field. It is organised by first introducing changes to the methods made in the field and profiling the study participants, then presenting the findings in the context of the research objectives.

4.1 Field adaptations

A few changes were made in the field from what was originally planned in Chapter 3. Semi-structured interviews were performed for all households, but in practice most interviews were more rigid than what was hoped for due to respondents frequently giving very brief answers or explanations. This could be due to nervousness of the respondents, limited facilitation skills of the author or respondents feeling indifferent towards the topic of water quality. In response to this, questions were asked in a more structured style. Also, more questions were asked on sub-topics that seemed to yield richer data.

As mentioned in section 3.3.1, a convenience sampling method based on local knowledge was used to select communities after it was found the pre-selected sites did not yield enough eligible households. However, it was still possible to sample a variety of different geographical areas. The initial target of visiting 40 households was reduced due to the initial difficulty finding eligible sites.

Question 9 of the sanitary survey shown in Appendix 6, which asks if the water in the tank appears turbid or contains organic matter, was dropped part of the way through because rainwater tanks were often sealed shut and it was decided it would be too much of a burden to ask the householders to open them. Total scores for all sanitary surveys were adjusted accordingly.

One of the key informant interviews was not recorded due to a failure in the Skype recording software programme. In this instance, handwritten notes were taken instead. One key informant responded (s)he wanted to remain anonymous when asked by the author before the interview began. It was felt the informant responded this way because (s)he was unsure what the nature of the questions would be, so in subsequent interviews the author decided to ask about anonymity after the interview was finished.

4.2 *Study participants*

A total of 34 households across 12 different communities were interviewed. Households were predominantly indigenous Fijian but some sites included Indo-Fijian families. 18 of the participating households belonged to three different communities that had a traditional indigenous Fijian social hierarchy consisting of a chief, a village headman, and extended family units. The remaining 16 households belonged to nine different communities that did not have this traditional social hierarchy. Locally, these types of communities are colloquially referred to as "villages" and "settlements" respectively. All inspected primary DRWH systems used the roof as the catchment although some households also had crudely built raised catchments that were used for secondary collection. All participating households reported drinking from their DRWH systems at least sometimes. Every household reported having access to another source of water separate from their own DRWH system; often an "unimproved" source. A map of the locations of the participating communities is shown below.

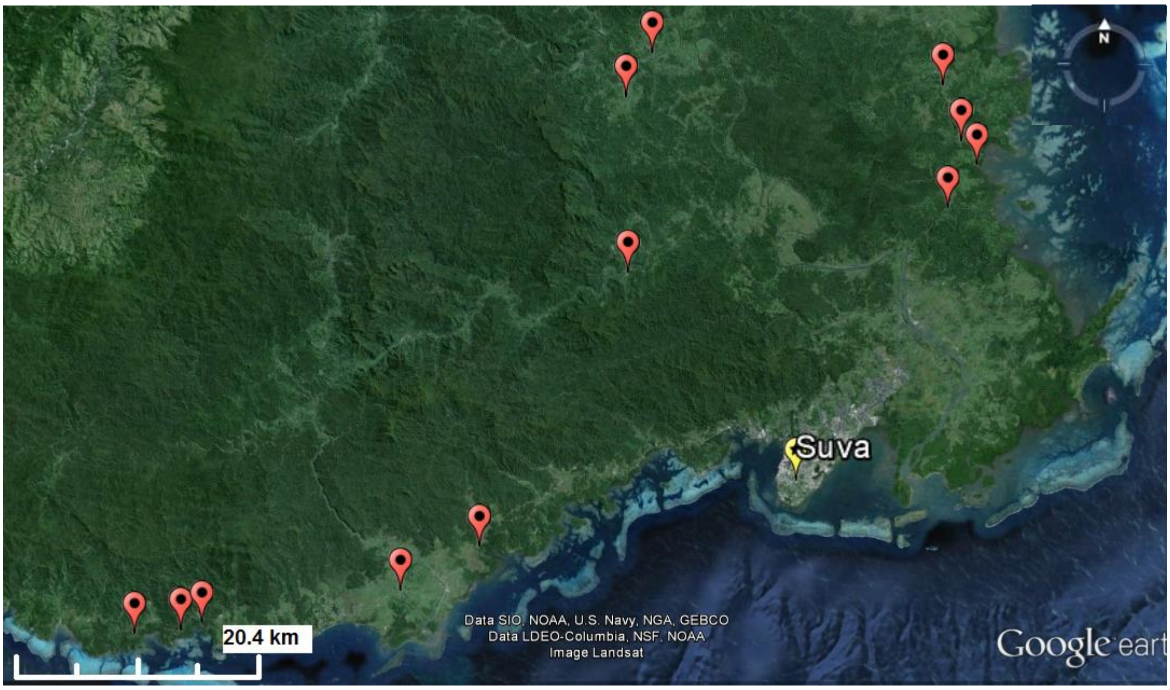


Figure 4.1: Locations of participating households relative to Suva
Source: Created by author with Google Earth

Six key informants participated in the study. Their names and credentials are listed in Table 4.1.

Table 4.1: Participating key informants

Name	Current job title	Current organisation	Relevant area of expertise
John Tagiilima	Project Engineer	SPC	DRWH
Requested to be anonymous	-	Department of Environmental Health – Ministry of Health	Government
Mohammed Nistar Khan	Acting Principal Engineer	Water and Sewerage Department	Government
Kamal Khatri	Water Services Coordinator	SPC	WSP
Tasleem Hasan	Senior Consultant	Viridis Consultants Pty Ltd	WSP
Rodney Lui	Climate Change Monitoring & Evaluation Officer	South Pacific Regional Environment Programme	WSP

4.3 Water quality risks

This section primarily pertains to objective 1 of this study: To determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context. The relevant research questions centre on identifying what risks are present, prioritising them, and identifying suitable controls. From the literature review it was seen that little research has been done that has connected illness with a specific hazard, but most professional opinions are that faecal matter from animals entering the water supply through the roof catchment poses the greatest threat.

4.3.1 Sanitary inspections

Sanitary inspections of DRWH systems in the field found most systems were in considerably good condition with mostly minor risks. Using a scoring system where each DRWH system was rated from 1 – 5 on 11 assessment questions, DRWH systems could receive an overall score ranging from 11 (best possible condition) to 55 (worst possible condition). The mean score of the systems was 21.5 while the median was 21. The highest score was 29 and the lowest was 16. There was almost no difference in the mean score between households in communities with traditional social structures and those without (21.3 and 21.6 respectively). Mean scores between households that bought their own storage tanks and households that had tanks donated to them were also similar (21.9 and

20.9 respectively). Aggregated sanitary survey scores for each question are listed in Table 4.2 below.

Table 4.2: Sanitary survey scores

	Mean	STD	Median
Q1. Does the roof have any visible contaminants?	1.1	0.3	1
Q2. Are the guttering channels that collect water dirty?	2.0	1.0	2
Q3. Is there any form of screening or filtering at the inlet?	2.6	1.9	1
Q4. Are there any other points of entry not covered?	1.6	1.1	1
Q5. Could dirty water ingress through faults in the base or walls?	1.5	1.0	1
Q6. Are there any faeces present around the collection area?	1.0	0.2	1
Q7. Is the collection container kept somewhere it can get contaminated?	1.6	1.2	1
Q8. Is a method of diverting the first flush present?	5.0	0.0	5
Q10. Are there overhanging branches above the catchment?	1.9	0.6	2
Q11. Is the rainwater collected by scooping it out?	1.1	0.7	1
Q12. Does water pool under the tap?	1.9	1.3	1

1 = Good; 5 = Bad

Every household visited had corrugated galvanised metal sheets for roofing and these were frequently free of visible contamination at the time of visit, although it should be noted the weather was mostly rainy around the time of the visits. Branches from trees or other foliage sometimes appeared to be encroaching on or above roof catchments, but this generally did not pose a significant risk. The largest risks to the catchments were associated with the gutters and inlets. 22 of 34 households had guttering or downpipes that contained organic litter and/or retained water. No first-flush devices were observed on any systems. 16 of 34 households had a screen between the inlet and the storage receptacle in the form of either intact fine wire mesh or cloth while 11 of 34 had nothing at all.

Image 4.1: Cloth screen on plastic tank

Image 4.2: Concrete tank

The majority of systems used manufactured polyethylene plastic tanks as storage receptacles. Other types identified were above ground concrete tanks, a below ground concrete tank, metal tanks, and smaller plastic drums. The plastic tanks often appeared to be in good condition. The likelihood of dirty water entering the tank through faults in the base or walls was normally low unless flooding brought water levels above the tap. 20 of 34 systems were properly sealed up (excluding whether or not the inlet was screened which was its own risk assessment question). Openings that exposed the stored water were usually from uncovered overflow outlets. While it was not listed as a question on the sanitary survey, it was observed that many tanks did not have overflow outlets. Few concrete and metal tanks were observed but these usually had more uncovered points of entry and more potential for water ingress to contaminate the supply.

In all cases but one, users retrieved water from storage through a tap installed on the tank. The one exception was a drum where water was retrieved by scooping. Some taps extended into the house via PVC piping whereas others required the users to go outside to collect water in containers. Animal faeces was found in the proximity of the collection area (>3m away) on only one occasion. The majority of householders (22 of 34) kept their collection containers shelved inside or had taps from the tank inside the house. Three households reported leaving their collection containers on the ground outside. Poor drainage at the collection point was a risk to varying degrees for 14 of 34 systems. No chemical hazards were observed.

Image 4.2: Plastic tank

Image 4.4: Metal tank

Image 4.3: Simple drum

Hazards observed in the field were grouped into six risk categories. The result of the risk assessment exercise is shown in Appendix 7. Risks from contamination via the catchment, gutters, and directly into storage were judged as being the most prominent.

4.3.2 Household interviews

Household respondents most frequently reported physical contaminants as their main water quality concern. Mosquitos or mosquito larvae and pupae appearing in the stored water were reported as being an issue by 16 of 34 households. Dirt, dust or leaves entering the tanks was mentioned by 14 households. Other quality concerns mentioned less frequently included salty taste, chipped paint washing off the roof and into storage, the smell of the water, the temperature of the water, and the stillness of the stored water (i.e. water that is in a perpetual state of motion such as in a flowing river is preferable to still water).

About a third of respondents associated the weather or seasons with times when their DRWH systems were most at risk. Rain and wind were frequently blamed for airborne physical contaminants entering the water supply through the catchment (Box 4.1). The dry season was also associated with being a time when quality was more likely to be compromised. Respondents often noted mosquito breeding in the stored water was also more common during these times, but were usually unsure of how the mosquitos were gaining access to the stored water. Other causes of compromised quality brought up included the roof catchment itself, the plastic material the storage tank is made from, the water pressure, and birds and chickens roosting on the roof.

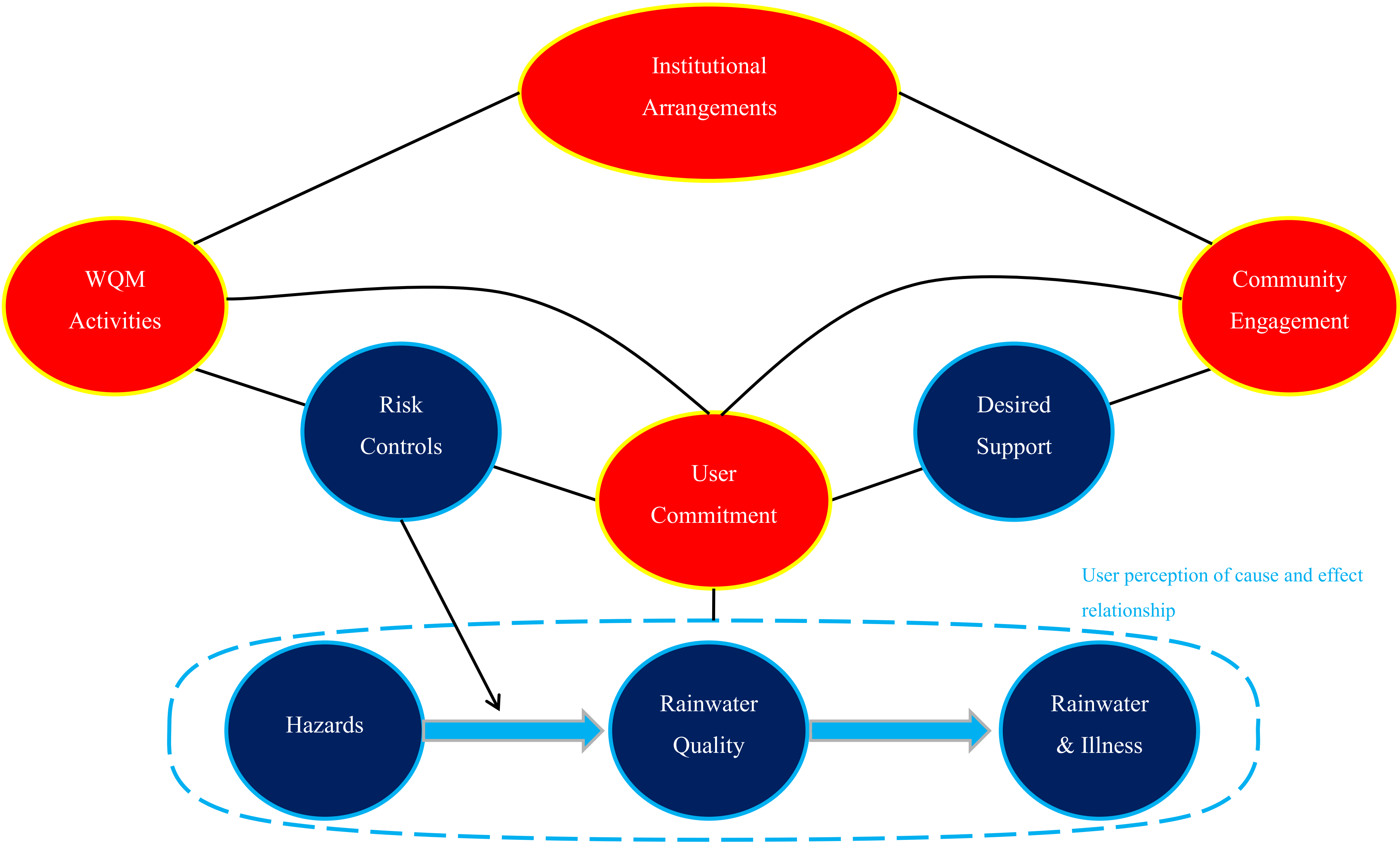
> *"Sometimes when it's raining in the dry season, the water will get mosquitos inside"*
>
> *"It's always clean except when it first rains because of the dirt on the roof"*
>
> *"Sometimes it gets dirty because of the leaves, especially when it's windy"*

Box 4.1: Households comment on causes of water quality compromise

4.4 *Water quality management capacity*

This section primarily pertains to objective 2 of this study: To assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably. Relevant research questions ask what determinants hinder or drive sustainable management practices, what level of monitoring and verification is feasible, what institutional arrangements are needed for support, and can households reasonably be expected manage risks through incremental improvements.

As a result of the coding and thematic analyses described in section 3.7, a list of hierarchically arranged themes and sub-themes was made and a mind map generated to consider the relationships between the themes. The thematic mind map is show in Figure 4.2. Red circles correspond to themes identified from the key informant interviews while blue circles correspond to themes from the household interviews. Lines linking the different themes denote relationships between them as perceived by the author. The hierarchical list of themes is shown in Table 4.3.



WQM = Water Quality Management

Figure 4.2: Thematic mind map

Table 4.3: Coded themes from interviews

Themes and sub-themes from key informant interviews			
Institutional arrangements • Stakeholders • Collaboration • Data/Knowledge management • Reactive • Resource limitations	**Community engagement** • Training/Capacity development • Advocacy/Awareness • On-going support • Outreach • Holistic approaches • Community management arrangements	**Water quality management activities** • Water quality monitoring • Evaluation • Risk assessment & management • Operation & maintenance	**User commitment** • Public reception • Buy-in/ Ownership • User mentality • Self-reliance • Self-investment • Knowledge
Themes and sub-themes from household interviews			
Hazards • Weather related • Mosquitos • Dirt/Dust/Leaves • Miscellaneous **Desired support** • Quantity • Treatment • Advice	**Rainwater quality** • Long-term experience • Inherent properties • Physical contamination	**Rainwater & illness** • Not a problem • Concerning • Children	**Risk controls** • Preventive • Treatment • Alternatives

4.4.1 Household interviews

Household interviews revealed that users were generally confident in their ability to manage the water quality of their DRWH systems. 29 of 34 respondents stated they felt their stored rainwater was usually clean and safe to drink. The five respondents that did not feel this way stated they would boil their drinking water and felt this provided adequate protection against disease.

Respondents reported a variety of methods for managing or coping with the quality risks to their water including (n=): boiling (17), screening water before it enters storage (16), cleaning the inside of the storage tank (13), cleaning the guttering, downpipes or connections (10), sweeping the roof (6), draining the tank of dirty water (5), and filtering after collection from storage (2). Four respondents reported never taking any preventive or treatment action. When the quality of the water was found to be poor, some respondents also reported using alternative “unimproved” water sources such as surface water or distant, off-site sources. While boiling was often reported for drinking water, none of the respondents reported treating water used to make kava. The author was unable to get any of the respondents to explain clearly a reason for this divergence.

The actions respondents reported taking to manage risks were mixed between proactive and reactive. Some respondents reported cleaning parts of their systems routinely (e.g. wash the gutters every 4 months) or prior to expected weather events (e.g. cleaning the roof when it is expected to rain). Other respondents reported only taking action when the water was observed to be contaminated. Regardless of the type of action taken, most respondents saw maintaining their systems as their household's personal responsibility (Box 4.2). Three respondents commented they needed help from outside their household for maintaining their system.

> *"We can control the quality of our water….We used to rely on the village system of maintaining the water and we couldn't control the quality of our water"*
>
> *"We can take care of it ourselves. It is our own property"*

Box 4.2: Households comment on maintaining their DRWH systems

In regards to external support, respondents frequently expressed a need for assistance in terms of water quantity. Many respondents felt the storage capacity of their system was insufficient and wanted assistance in acquiring additional or larger storage tanks. In terms of quality, 5 of 34 respondents wanted to be provided with "cleaning chemicals" for treating the stored water and five respondents wanted advice on how to maintain their systems. One respondent wanted water quality testing done on his system to verify its safety.

4.4.2 Key informant interviews

The general consensus among the key informants was that households are responsible for and capable of maintaining their DRWH systems, but should be provided with a level of external support. From the interviews, four common themes emerged: institutional arrangements, community engagement, water quality management activities, and user commitment. When linked together (Figure 4.2), these themes form a sort of framework for supporting households that are responsible for managing their DRWH systems.

Sub-themes of institutional arrangements surrounded what stakeholders were present, how they interacted with each other, and to what extent their "reach" or limitations were. Aside from the households and communities themselves, key informants also identified government bodies and local and international NGOs as the major stakeholders. The RWSP, approved by the Fijian Government in 2012, identifies the roles and responsibilities of various stakeholders in supporting the management of newly implemented rural water schemes, including SSS. The outlined roles mainly pertain to different government bodies and include approving of WSMPs, setting technical guidelines and standards, monitoring and documenting operation and maintenance activities, and microbiological and chemical testing. The policy states water quality testing of all rural supplies should be carried out monthly for microbiological quality and annually for chemical quality by the Ministry of Health and supplies should meet the national drinking water quality standards listed in Appendix 8 (Fiji Ministry of Works, Transport and Public Utilities - Water and Sewerage Department, 2012). A national drinking water safety plan that focuses on existing rural water supplies is in a draft phase.

While key informants often stated support from the government was important, limited resources was highlighted as a significant obstacle (Box 4.3):

"There are about 2500 rural water schemes in Fiji and the level of engagement from the government to the household level is even more limited unless there is a specific project happening"

"There is a problem getting local government offices access to the very remote areas. In most cases we find that the most frequent tests are carried out to communities that are much closer to the stations. It's simply because of the mobility problem they have"

"At one time it was easy to access them because they were living in one place, but now because of economic development they are encouraged to leave their communities and move out. This is one thing that is making the issue very complicated. Because people are starting to move out, instead of going to a site and training them in one event, we have to move several times and visit each one of them. So from one community it has disintegrated into several others, they have become scattered"

Box 4.3: Key informants comment on problems accessing communities

Government intervention was often perceived as reactive; only occurring when outbreaks of disease were being reported. Local government offices were seen as important for reaching remote communities far from the central government bases. Data on rural water supplies are being collected by both the Ministry of Health and the Water and Sewerage Department, but are currently incomplete and still in the process of being collated.

NGOs were recognised as playing an important role in advocacy and awareness, implementation, and trialling concepts. One key informant suggested collaboration and knowledge sharing in this area needs to be improved and emphasised the importance of communication between different NGOs working in the water sector (Box 4.4).

> *"There needs to be consensus on what is said, how it's said, and why it's said"*

Box 4.4: Comment on NGOs promoting water quality

Engagement of communities and households by supporting institutions was frequently identified as a critical step in developing capacity to adequately manage rural water supplies. This included formal trainings, advocacy and awareness, on-going support, reaching out to communities in need and talking to them, and setting up sustainable community management arrangements. NGOs and government were both seen as being responsible for providing these measures.

Some key informants advocated the use of holistic approaches that addressed other water related issues, sanitation, and hygiene along with water quality management, although one informant warned this could cause rainwater harvesting to become peripheral compared to other topics. It was agreed that training was needed for water managers on these issues and that this was often done during the implementation period of a project or intervention. Local facilitators were suggested for trainings to overcome language and cultural barriers. On-going support was recognised as being needed to make management practices sustainable, but unlike initial trainings, this was not carried out diligently in several previous community-managed water supply projects. The local government has usually been tasked with providing on-going support.

Advocacy and awareness at the community level in the past has been done through in-person meetings and distributing literature that is understandable and relevant to rural dwellers. NGOs in Fiji have developed material related to water management that is suitable for the household level. Various potential tactics for motivating people were brought up including hydrogen sulphide paper-strip tests, sanitary surveys, focusing on child survival, women's groups, success stories and replication, and allying with local leadership. Setting up or making use of existing committees was the preferred way of managing communal water supplies and some of the informants felt these committees could also support individual household water supplies

Water quality management activities that were discussed included risk assessment and management, water quality monitoring, general operation and maintenance, and evaluation of approaches taken for promoting these. When it came to formulating a WSP, the informants felt an expert was needed to assist the household. Generic WSP templates were suggested where individual ones could not be designed but the potential for these to miss risks particular to a specific area were noted. The informants agreed most households were capable of routinely carrying out risk management/maintenance practices once those were identified for them.

Routine operation and maintenance and risk management of DRWH systems was seen as the household's responsibility. There were mixed perceptions about whether households would be able or willing to make incremental improvements to their systems. Some informants felt improvements would be too expensive while others thought households would be willing to pay for them if they were motivated enough. Variations of the technologies shown in Appendix 3 are available in Fiji but are imported from overseas. These technologies can be found in some hardware stores in the capital, but to the author's knowledge they are not widely sold in other towns.

Water quality monitoring was viewed as a practice that is difficult to carry out at a household level. Informants highlighted the costs of the tests and the impracticality of getting samples from a remote area to a laboratory in time as major obstacles. Hydrogen sulphide paper-strip tests were identified as a possible alternative to traditional coliform tests. The Ministry of Health and the Water and Sewerage Department both perform water quality testing but have limited resources.

There was no clear consensus on who should be responsible for evaluating whether a WSP is being followed or appropriate water quality management actions are being taken. The government, community leaders, the households themselves, and implementing agencies such as NGOs were each suggested as possibly taking up this role.

4.5 Demand for improved water quality

This section primarily pertains to objective 3: To gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems. Relevant research questions ask what determinants drive or hinder sustainable management practices and are households willing to invest in incremental improvements to their DRWH systems.

4.5.1 Household interviews

Overall, most respondents indicated they were satisfied with the general quality of their stored rainwater. 29 of 34 respondents stated the rainwater they collect is usually clean and safe to drink. Reasons given for trusting the safety of collected rainwater included long-term experience with no perceived illness from drinking it, belief that rainwater is inherently safe, rainwater having good aesthetics, and advice given by government health officials. Physical contaminants described in section 4.3.2 were the main concerns for illness (Box 4.5).

"We have been living on it forever. Since we were born. No sickness has affected us so far" *"Rainwater is clean because it comes from the heavens"* *"That's a good tank. When we drink from it, it has the best taste. It's really fresh"*	*"The kids can get diarrhoea if there are mosquitos in the tank"* *"Right now we are boiling the water because of the mosquitos in the tank. All over the village there are mosquitos in the tanks. So it's not safe to drink like that"* *"A lot of times my kids are sick, like with headaches. I don't know, I can't tell (if it is caused by our drinking water)"*

Box 4.5: Households comment on safety of collected rainwater

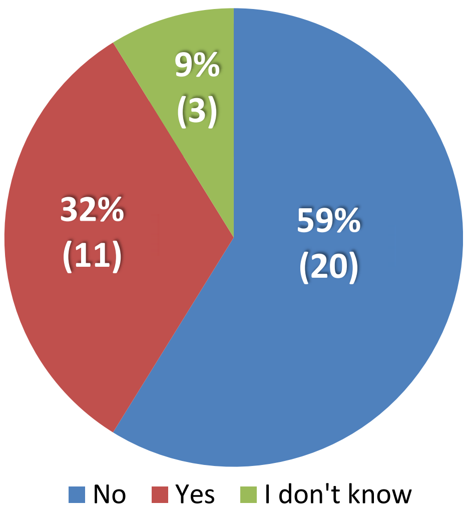


Figure 4.3: Responses to "Could drinking from your DRWH system ever cause illness for anyone in your family?" (n=)

The majority of respondents said they were not concerned about anyone in their family ever getting sick from drinking from their own DRWH system (Figure 4.3). Only one respondent reported drinking from her DRWH system caused an illness in the family in the past. Specifically, she believed mosquito breeding in the tank caused the drinking water to give her child diarrhoea. Two other respondents were unsure and the rest did not believe drinking their collected rainwater had ever caused illness.

To verify the safety of their collected rainwater, respondents most commonly reported doing a visual examination of the water itself. Three respondents said safety of the water is verified by the actions they take (e.g. boiling the water or cleaning the gutters). One respondent commented that the safety of the water cannot be entirely determined by simply looking at it. Other respondents did not have a method for verifying the quality of their collected rainwater.

When diagrams of DRWH technologies such as those shown in Appendix 3 were explained, 31 of 34 respondents said they would be willing to buy one if it was affordable and sold at a local store (Box 4.6). The self-cleaning inlet screen/filter was most popular (other technologies explained were the first-flush diverter, float tap, and a modified inlet arrangement). Respondents frequently stated they believed these technologies would reduce the amount of physical contamination in the water supply. Respondents were familiar with variations of the inlet screen, but none reported they had ever seen any of the other three technologies introduced. 20 of 34 respondents reported they bought their own rainwater storage receptacles while the others reported receiving them at no cost from an NGO or the government. A number of respondents also reported paying for rainwater tank screens which are sold separately from the tanks.

A: What do you think of these?

R: It's good, very good. I like that.

A: If they were selling one of these in town would you buy one?

R: Yes, I'd buy it. Maybe I'll go and search for it. Those plumbers can make one. If I showed them the drawing, maybe they could make it.

A: Author; R: Respondent

Box 4.6: A respondent interested in additional DRWH technologies

4.5.2 Key informant interviews

User commitment was one of the major themes identified from the key informant interviews (Figure 4.2). Sub-themes of this included public reception, buy-in/ownership, user mentality, self-reliance, self-investment, and knowledge. The sentiment surrounding this theme is that householders need to be motivated and a level of behaviour change is required in order for positive management practices to remain sustainable.

Informants that had experience promoting appropriate management of DRWH systems and WSPs for community-managed water supplies in similar contexts remarked that these interventions were well-received by communities. It was suggested that if households made a financial contribution to acquiring their DRWH system, as opposed to receiving it for free, they would be more likely to take better care of it. Empowering people to be self-reliant by providing them with good advice, tools, and awareness was often advocated. This was pointed out as being especially poignant for DRWH systems because the user nearly has complete control of the system from catchment to consumption.

"A lot of people do actually understand what the issues are in terms of the relationship between water quality and health"

"I think it's understood by a lot of communities and people that rainwater is quite pure in nature. However the collection part of it and if there are possible sources of contamination, how it would influence the quality is not well understood"

Box 4.7: Key informants comment on household knowledge of water quality

Behaviour change was highlighted as a significant obstacle in getting users to sustainably improve management practices. There may be adequate understanding of the link between water quality and health but not on how water becomes contaminated and how that can be stopped (Box 4.7). Informants also mentioned rainwater harvesters tend to have a much stronger focus on water quantity over quality, creating demand among households for managing water quality has been difficult to cultivate, and motivational factors other than health may need to be emphasised.

4.6 Applicability of WSP and Self Supply approaches

Research results associated with objective 4, to assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality, have largely been drawn out from the literature. Thus, relevant findings for this objective can be found in Chapter 2. Discussion of the application of these approaches in the studied context is in Chapter 5.

4.7 Summary

Scores from sanitary surveys revealed that the visited DRWH systems were in mostly good condition at the time of visit. Risks were mostly minor with absent screens and first-flush devices, poor gutters, and openings on storage tanks posing the biggest threats. Householders perceived physical contaminants such as dust and mosquitos as the biggest quality concerns. A thematic mind map and hierarchical list were generated from all the interviews to identify common themes to analyse. Householders felt capable of managing water quality while key informants described the importance of institutions engaging and supporting households. Resource limitations of major stakeholders were highlighted. Householders generally felt their collected rainwater was clean, had mixed views on whether drinking from their DRWH systems could cause illness, and were unaware of potential improvements to protect water quality. Key informants emphasised the importance of rainwater harvesters being committed to change for improved practice to be sustainable.

5 DISCUSSION

This chapter discusses the findings from the fieldwork and the literature review in the context of the research objectives and questions. The first four objectives are discussed separately in their own sections. Objective 5, which makes recommendations based on the findings of the other objectives, is addressed in Chapter 6. Chapter 6 also acts as a summary for this chapter.

5.1 Water quality risks

Objective 1 of this research is to determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context. The literature shows that DRWH systems around the world have frequently been found to be microbiologically or chemically contaminated according to international standards leading some authors to warn against using collected rainwater for potable uses. However, many of these studies are focused on developed countries where the quality of water is expected to be very high and illnesses associated with drinking rainwater are infrequently reported. Experts that have focused on developing countries have often concluded rainwater harvesting to be a relatively safe source of drinking water (Gould & Nissen-Peterson, 1999, p. 141; Thomas & Martinson, 2007, p. 25; Dean & Hunter, 2012). Many of the household respondents in this study stated they used surface water or distant sources as back-ups to their DRWH systems so DRWH is likely a favourable option over the alternatives. Further, regular consumers of stored rainwater may acquire immunity to low levels of contamination over time (Heyworth, et al., 2006), so drinking water with certain parameters exceeding international standards for ideal quality may not necessarily be dangerous for these people.

Nevertheless, users should always strive for well-designed and well-maintained systems to limit risks of contamination (Lye, 2009). DRWH systems observed in the field were in mostly good condition with minor hazards (e.g. receiving a score of 2 or less on individual assessment questions). Sanitary inspections from this research concur with the literature that the catchment appears to be the most likely contamination route (EnHealth Council, 2004, p. 9; Fewtrell & Kay, 2007; Thomas & Martinson, 2007, p. 39; Abbasi & Abbasi, 2011). Gutters that retain water could in part account for the frequent reports of mosquito breeding in well-sealed tanks. Risk of contamination from poorly designed and maintained gutters is exacerbated by the absence of inlet screens and first-flush diverters. All households visited had roofing made of metal sheets which are a very hostile environment to bacteria (Thomas & Martinson, 2007, p. 41) and organic litter on the roof was infrequently observed, although recent rains around the time of the visits could have improved roof conditions. Contamination during storage and collection from storage seems less likely to occur in comparison although uncovered openings on tanks and missing overflow outlets were observed to problems on numerous occasions. Direct contamination of stored water is likely to be more severe than contaminants coming from the roof.

Image 5.1: Water overflowing through inlet screen due to absent outlet

It has been argued that delivering too many messages during a single intervention can overwhelm communities and waste resources and that priority should be given to messages that are likely to deliver the most health impact (Curtis, et al., 2000). Given what the literature states about the most likely source (animal faeces) and route (catchment) of contamination and what risks were observed in the field, it is sensible to prioritise the following control measures for DRWH systems among the study group:

A. Installation and maintenance of screens or covers at inlets, outlets, and other openings of the storage vessel;
B. Proper design and maintenance of gutters and downpipes to prevent retention of water and build-up of debris; and
C. Installation and maintenance of first-flush diverters.

These general recommendations are similar to those presented by Abbasi and Abbasi (2011). This is not to say other control measures can be neglected. In individual systems, other controls may be more pertinent and this needs to be assessed case-by-case by an expert or trained person. However, from a broader perspective, promotion of these particular controls will likely make the most impact.

Locally manufactured plastic storage tanks are preferable to concrete and metal tanks and simple drums because they are usually designed to have fewer risks and have better longevity. These should be promoted, but should be fitted with an inlet screen and an overflow outlet. To the author's knowledge, first-flush diverters are not widely sold in Fiji and available ones are costly. Creation of a supply chain for these devices should be driven to make this option available and affordable to rural households. This is discussed further in the following sections. First-flush diverters have been shown to significantly improve the quality of water incoming from the catchment (Abbott, et al., 2007; Martinson & Thomas, 2009; Doyle & Shanahan, 2010; Kus, et al., 2010)

Ingesting water that contains mosquito larvae is not a direct health risk, but the presence of larvae indicates the DRWH system is being used as a breeding ground for mosquitos. Mosquitos in Fiji are capable of transmitting dengue fever and filariasis (SPC, 2010). The above recommended measures of maintaining gutters and screening or covering openings to the storage vessel are useful for controlling this risk. The discovery of mosquito larvae often led respondents to reportedly boil their drinking water which, while not always necessary, is a good practice. However, some respondents reported making use of less safe, alternative sources as a result, so the issue should be addressed. Practical, flow-permitting screens are too coarse to screen out the eggs of mosquitos from the *Aedes* genus (Vasudevan, et al., 2001) which is found in Fiji (Paine, 1943) and the buoyancy of mosquito eggs would allow them to bypass most first-flush diverters. Kerosene, certain insecticides, and certain breeds of fish and dragonfly can be introduced to tanks to control mosquito breeding (Vasudevan, et al., 2001), but these measures will likely meet strong cultural resistance and logistical issues. Screening out organic matter and preventing sunlight from entering the tank can mitigate mosquito breeding (Thomas & Martinson, 2007, p. 45). Proper design and maintenance of gutters and covering of all openings are the most practical options and therefore essential for controlling this problem.

Respondents' reports of water contamination coinciding with weather events are supported by the literature. The quality of roof-harvested rainwater has been found to be influenced by wind speed, rainfall intensity, and the length of the dry period preceding rainfall (Yaziz, et al., 1989; Evans, et al., 2006; Abbasi & Abbasi, 2011). Rainwater harvesters should be encouraged to be especially proactive during these weather events or when they are expected.

The tendency for respondents to judge the quality of their water based on aesthetic factors is not unreasonable. In addition to being unpleasant to drink, aesthetic factors such as colour, turbidity or odour can indicate water is unsafe to drink. However, concerns arise if people incorrectly assume that clear, colourless water is always safe to drink, a link between dirty water and diarrhoea is not recognized, and the various ways drinking water can become contaminated are not identified. None of the respondents mentioned faecal matter or bacteria as a concerning contamination risk and several respondents reported judging the quality of water solely on its appearance. While respondents were not asked questions in-depth about their knowledge of the link between water quality and health, a previous study of rural households in Fiji found respondents frequently associated diarrhoea with unsafe drinking water and recognised diarrhoea could potentially cause death (Kohlitz, et al., 2013). These findings back the opinions of the key informants in this study that felt that many DRWH users understand unsafe drinking water can be a health risk, but perhaps have inadequate understanding of the mechanisms of disease transmission. This indicates a need for better awareness on sources of contamination and their transmission routes for this study group.

Many of the measures respondents reported taking for preventing or rectifying contamination issues in section 4.4.1 are supported by literature (Abbasi & Abbasi, 2011). Households that received storage tanks as a free donation had a similar mean sanitary score to those that self-invested and no overall difference was noted in the interviews on reported management practices. This indicates that worries of recipients of donated materials becoming complacent toward management may not be entirely substantiated in this context. Cleaning out the inside of the storage tank was one of the most frequently reported management practices but the necessity of this is contentious among experts. Until more conclusive research is carried out, routine cleaning of tanks should not be considered essential unless the sludge layer is nearing the tap or gross contamination is suspected. However, rainwater harvesters should not be discouraged from doing this either because it could send out confusing, mixed messages or discourage proactive behaviour. Similarly, chlorination of rainwater tanks is a contentious issue and should be considered less favourably to post-collection treatment until more conclusive evidence in this context is established.

While drinking untreated rainwater is not necessarily unsafe, boiling or other post-collection treatment methods should be encouraged, especially for drinking-water for children since they are more vulnerable to water-borne diseases (Pruss-Ustun, et al., 2008, p. 10). Many respondents indicated a willingness to do this and HWTS combined with management of the DRWH systems will form multi-barrier protection against microbiological contamination. Storage and handling was not investigated in depth in this study but most respondents reported collecting rainwater from storage using bottles or buckets. This is a critical link in the catchment-to-consumption chain and needs to be addressed alongside management of DRWH systems.

Wire mesh for screens and materials for properly designing gutters and installing overflow outlets are locally available and inexpensive. Simple PVC pipe could be used to install overflow outlets in tanks. Other openings on storage vessels can be covered by a variety of improvised means. Rainwater harvesters should be advised and assisted in taking advantage of these for making incremental improvements to their systems. Other DRWH technologies like those shown in Appendix 3 and others are not widely sold and are often imported from overseas. However, many of these could easily be made and sold locally. The potential for this is discussed further in the following sections.

Crudely built DRWH systems, such as the one show in Image 5.2, were occasionally observed in the field and respondents usually reported these as being secondary to a primary DRWH system. These systems are often open-top, placed on the ground, and require scooping to retrieve water which makes them much more vulnerable to contamination. Users of these should be advised to not drink from them unless it is absolutely necessary and preferably only if the water has been boiled first.

Image 5.2: Crudely built DRWH system

5.2 Water quality management capacity

Objective 2 of this research is to assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably. Most households reported being capable of carrying out routine maintenance tasks on their DRWH systems and saw this as their personal responsibility which is a good first step towards managing water quality. The three exceptions to this were households that had only elderly residents who did not feel physically capable. While two of these households were in a traditional village setting and could rely on neighbours for assistance, one lived remotely on her own. Users like this that have physical limitations require special attention from local government to ensure their drinking water is safe. For example, maintenance measures could be arranged for them or they could be advised to always boil drinking water.

The strategies households reported for controlling water quality were mostly based on common sense and intuition (e.g. dirt and leaves get into storage via the catchment, therefore a physical barrier can be used to stop them). However, some strategies were based on experience (users that took action when certain weather events were expected) or advice (boiling practices are likely a result of government/NGO health promotion activities). These results align with findings from Baguma *et al.* (2010). However, respondents were mostly unaware of novel technologies like the first-flush diverter and less intuitive contamination risks such as poor drainage at the collection point. Fortunately, respondents primarily identified the catchment as a contamination threat which the literature suggests is the most prominent risk. Building hygiene promotion activities on existing perceptions and good practices may offer a way for more sustainable behaviour change.

Key informants from this study overall agreed with authors from the literature review that sustainable, household-level WSPs require substantial external support. Attention on institutional arrangements for supporting WSPs has reached a national policy level in Fiji, but it is primarily focused on communal water supplies. The RWSP sets a good foundation for arranging responsibilities of government stakeholders, but resource limitations pose a major restriction on their capacity to carry them out at a household level. Data on where and to what extent rainwater harvesting is practiced are currently incomplete. Further, there is no method for registering new self-invested DRWH systems. This makes locating users to train and support difficult and inefficient. Mobility and man-power limitations of the local government make accessing scattered and remote households an enormous obstacle.

NGOs in the region have done well to produce training and promotional materials and to trial concepts. However, on the topic of DRWH and community-level WSPs, there could perhaps be better communication, as noted by one informant, and knowledge sharing. This is not limited to the Pacific region; throughout this study the author found many reports of WSPs being trialled at the community level around the world, but little information on the lessons learned and outcomes of these projects. Monitoring, evaluation, and knowledge dissemination activities should be designed into these types of projects so others may learn from successes and failures of similar projects. For WSPs, one such medium for sharing lessons is the WS portal (http://www.wsportal.org).

The role of the private sector receives inadequate attention. Many households are opting for locally manufactured plastic tanks and the initial design of a DRWH system is a critical step in ensuring good quality water. Engaging private vendors to market safer system designs offers potential to reduce contamination risks in the long-term. Also, private vendors are often the first external stakeholders that a household comes into contact with when self-investing in a new DRWH system, so they are in a good position to pass on advice and information at a critical time.

Figure 4.2 shows that supporting institutions are linked with performing, facilitating or assisting with water quality management activities. For WSPs this includes water quality surveillance, risk assessment and management, routine operation and maintenance, and evaluating whether or not the practices are being carried out. The resources available for the government to regularly test the water quality of all the DRWH systems in the country are severely limited, especially with the frequency stated in the RWSP (monthly for microbiological quality; annually for chemical quality). Further, the listed standards (e.g. 0 coliforms/100ml) are unnecessarily high and difficult to achieve for SSS. Cheaper hydrogen-sulphide paper-strip tests are locally available but transportation for regular testing is still an issue. Householders could be supplied directly with these testing kits but this would require extensive training, could promote a reactive mindset, and could possibly provide a false sense of security (Sobsey & Pfaender, 2002) or, conversely, discourage use of DRWH systems and consequently uptake of a less safe source.

Authors from the literature indicated that WSPs should be tailor-made for each individual system to be effective but this is not always practical, especially for SSS. Generic risk assessment and management instructions that emphasise the most prominent risks could give users the know-how to make the most positive improvements to their systems. However, generic forms may underplay, over-emphasise or completely miss risks particular to a local area. Still, where site-specific WSPs are not practical, this is an improvement over nothing and this study and other related literature can be used to make assessment and management forms as relevant and effective as possible. The author agrees with Oluwasanya (2009, p. 311) that these forms need to be simple to understand, practical to carry out, and acceptable to users. Sustainable use of these will largely depend on the attitudes of the users toward them which is discussed further in the following section.

As previously discussed, most households are capable of routine operation and maintenance. However, previous community-managed WSP projects indicated caretakers were reluctant to document management activities for evaluation (Mahmud, et al., 2007) and it seems unlikely households would be willing to do this in the studied context as well. Local government officials could make occasional visits but only frequent enough to evaluate if hardware has been installed or improvements have been made (e.g. if screens have been installed or gutters have an adequate gradient). Another option would be to hire a local community member to do regular evaluations and report to the government via mobile phone. Corruption could become an issue for this approach though and it might not be entirely practical for scattered households outside a traditional village setting.

The presence of locally manufactured plastic tanks was observed in very rural areas which indicates there is adequate infrastructure to get DRWH system components out to some remote areas. Local hardware stores often stock parts that can be used to make proper gutters, downpipes, and screens for rainwater tanks, so these are accessible for rainwater harvesters. Simple hardware improvements from these parts may make considerable improvements in water quality. Novel technologies like first-flush diverters, leaf eaters, and float taps are not widely sold and are imported from overseas but because of their simplicity, they could easily be made locally. The private sector's capacity and willingness to produce and stock these components locally was not investigated in-depth in this study, but it is worth looking further into. If viable, this would make technologies for improving water quality far more accessible and affordable for rainwater harvesters. This is in agreement with advice from Sutton (2011).

The other theme connected to 'institutional arrangements' shown in the thematic mind map in Figure 4.2 is 'community engagement'. A major sub-theme of this was trainings. Traditional in-person workshops and trainings on use of WSPs have been well-received in other similar contexts, but the scattered nature of rainwater harvesters inhibits the practicality of reaching many individual households. DRWH systems appear to be a popular option for households that live outside of a "village" setting, probably because it is an easier and more economical source at an individual household level than the alternatives. Training these households in comprehensive Water Safety Planning one-by-one or in small groups would be a slow process. The RWSP mandates that NGOs or the government should include assistance and training in the formulation of a WSMP along with implementation of a new DRWH system. However, households self-investing in DRWH systems are not likely to adhere to this policy. It is likely that every year many new DRWH systems are set up unrecorded, which increases the difficulty of targeting these households for training. Amending the RWSP in the future to be sensitive to the challenges of SSS and include provision of usage instructions and registration of newly bought rainwater tanks could be beneficial.

The importance of on-going contact was highlighted by key informants and this is a vital step that is often not methodically planned by agencies supporting water interventions (Barnes, et al., 2011). This can be for providing technical advice/assistance, evaluating progress, getting feedback, etc. While government resources may be limited for accessing very remote communities, a plan can still be put in place to work around this and establish when visits can possibly be made and what the objectives of each visit are. It is not enough to simply acknowledge on-going support must happen or to arrive at a site without any particular tasks to carry out. Support plans should be flexible, methodical, and goal-oriented. Some key informants indicated on-going support was not performed diligently in previous WSP related projects in the Pacific region, but the reasons for this were not revealed in this study.

NGOs in the region have produced useful materials pertaining to community-managed WSPs and managing DRWH systems (Live & Learn Environmental Education, no date; SOPAC, 2004) and some have good presence on the ground working with communities. There is a WASH Coalition that links relevant NGOs in the Pacific region (http://www.pacificwater.org/pages.cfm/water-services/123/) in covering a broad range of regional WASH initiatives, but it was suggested by a key informant that there needs to be better cohesion from stakeholders on the topic of community-based WSPs and DRWH. Rainwater harvesting associations are found around the developed (http://www.rainwaterharvesting.org.au/) and developing (http://www.gharainwater.org/about.html) world, but there does not appear to be any specific associations like this in the Pacific region despite calls for expanding rainwater harvesting and demonstrated interest in DRWH from the public. Formation of an association that links relevant NGOs, government departments, private vendors, and community-based organisations would be helpful for promotion of rainwater harvesting, promulgation of technologies, sharing of knowledge and best practices, and providing support. This association could work parallel to the Pacific WASH Coalition to ensure other water, sanitation, and hygiene messages are also delivered without making rainwater harvesting seem marginal. The viability of forming an association like this should be investigated further.

5.3 Demand for improved water quality

Objective 3 of this research is to gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems. Household respondents overall appeared to be satisfied with drinking collected rainwater and water quality management practices were largely driven by the presence or threat of physical contamination. While it is good that respondents reported taking various actions to address physical contamination, it is worrying that invisible pathogens did not feature more. Since physical contaminants usually have time to settle in storage, this often gives collected rainwater a clean, clear appearance which could account for most respondents reporting their water supply is usually safe to drink. While a visual examination is an easy and partially effective way to screen the quality of drinking water, it would be preferable if more respondents reported that quality is further substantiated by the proactive measures they take. This will likely require more education and awareness-raising for communities on faecal-oral diseases and their transmission routes in the context of DRWH.

Deviant cases from this include respondents that did not think drinking collected rainwater was generally safe. These respondents also identified physical contamination such as dirt and mosquito larvae as health risks. It is not clear why this led these respondents to state the source was generally unsafe while others felt it was safe other than they were perhaps just a little more wary of water quality in general.

Respondents that reported they are not worried about getting sick from drinking from their DRWH systems, which was the majority in this study, are probably less likely than those that are worried to sustainably change their management practices because perceived susceptibility to illness is a major determinant of behaviour change (Davis Jr., 2004, p. 25). Some households may have good reason to believe they will not get sick if they have well-designed systems, are diligent with maintenance and water treatment, and have acquired some immunity to low levels of contamination over the years. Comprehensive water testing and epidemiological studies were not performed as part of this research so water safety could not be accurately assessed, but sanitary surveys indicated all participating households had room for improving protection. Traditional attitudes that echo the sentiment "we have been drinking rainwater for many years and it has never caused us sickness" may be a difficult barrier to overcome. Education and awareness is needed to address this.

During interviews, the author never brought up the topic of water quantity but respondents frequently stated it as one of their main concerns. The perceived solution to this was usually increasing storage capacity. However, a few other more practical methods of addressing the quantity problem were noted in the field. Gutters were often poorly designed so that water could leak or overflow. Some storage receptacles were left partially uncovered allowing for evaporation. Some households reported throwing out the last amounts of water they had stored in their tanks because it appeared dirty. Incidentally, all of these problems are quality issues as well as quantity. Measures that address the quantity issues that people seem to feel more strongly about can be designed to also improve quality at the same time. This may offer a more effective strategy for encouraging people to change management practices than just approaching from a health angle.

Image 5.3: Fixable flaw in gutter

The majority of respondents reported that they paid for their own DRWH systems which indicates a willingness on their part to invest significantly in securing a water source. Hardware investments to improve the quality of collected water were limited to variations of screening and respondents were generally unaware of any other options. Nearly all the respondents stated they would be interested in buying one or more of the DRWH technologies introduced to them, but this needs to be investigated more in-depth. It is possible that a number of the respondents said they were interested in these options because they were hopeful it would result in them receiving an intervention or because they thought it was what the author wanted to hear. However, it is believed many of the respondents expressed genuine interest. Marketing of these technologies by the private sector and demonstrations of how they work, similar to the Sanitation Park in Fiji (Bower, et al., 2005), could raise awareness and demand for their use.

The three respondents that indicated an unwillingness to invest in hardware improvements did not give clear explanations why. One respondent emphatically answered with a simple “No” when asked if he would be interested in buying one of the technologies. The author felt the respondent misunderstood the question so it was asked again and met with the same response. Miscommunication may still have been the reason for this. The two other respondents repeatedly dodged the question and seemed to laugh nervously. The author interpreted this as the respondents being unwilling to buy the technologies but afraid or too polite to straightforwardly say so. If willingness-to-pay for these technologies is investigated more in the future, a method other than face-to-face questioning may be more effective at yielding candid results.

The sustainability of certain DRWH quality management activities like routinely cleaning the catchment and water treatment will largely depend on user commitment, one of the major themes from the key informant interviews (Figure 4.2), and behaviour change. Much of this has to do with how households and communities are engaged by supporting institutions. In particular, supporting institutions need to motivate households by making the management activities seems relevant to them (addressing the barrier of perceived susceptibility) and by stimulating demand by informing them of the options available. As discussed previously, raising awareness on transmission routes for faecal-oral diseases should be pursued, but overcoming preconceived beliefs about vulnerability in the short-term can be difficult. Physical contaminants were seen to be the greatest driver of water quality management practices so this could be used to promote good practices since physical contamination and water safety are not far removed. Giving advice on the risk controls available (and support for carrying them out such as providing simple instructions and linking households with providers of DRWH technologies) and demonstrating their efficacy for controlling quality could help to create demand. Also, while it was not brought up to be an issue in this study, simply remembering to regularly perform management practices can initially be difficult. Persistent attention from outside the household, perhaps from local government, local leadership or a designated community member, could provide a necessary push.

5.4 Applicability of WSP and Self Supply approaches

Objective 4 of this is research is to assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality. WSPs offer a systematic method of preventive actions to assess and manage contamination risks and ensure safe drinking water. This research did not find any reason to believe that complete and thoroughly carried out WSPs would not be effective for managing water quality in the studied context. On the contrary, limited action research indicates this approach provides improved protection for water quality at the community level when measures are taken (Mahmud, et al., 2007; Hasan, et al., 2011). The main concerns lie with the practicality and sustainability of certain steps of the traditional WSP process (Figure 2.4) at the household level.

To initially identify and assess hazards, risks, and control measures for a specific DRWH system, a trained person is needed. Providing comprehensive training to individual households may be overly-ambitious. Government and NGO workers can reasonably be trained to do this when they are the implementing agencies for a new DRWH project. This is one step incorporated into the RWSP of Fiji. However, for existing systems and self-investing rainwater harvesters, resource limitations may make it difficult to reach remote and scattered households in the short-term. In lieu of customised risk assessment for individual systems, assessment and management instructions that target the most prominent DRWH risks can be formulated. However, these are likely to be less effective than tailor-made forms. Occasional visits from supporting agencies, when possible, could strengthen the effectiveness of this step.

Developing a plan for improving the system based on the risk assessment will also likely require the assistance of a trained person. Again, resource limitations of supporting institutions are a constraint. Similar to the previous step, generic plans could be formulated and strengthened by visits from supporting agencies.

There does not appear to be a strong method for verifying water quality as prescribed by the WSP approach. The quality of collected rainwater can change rapidly so regular testing is needed. It is not envisioned that there is sufficient capacity and resources among stakeholders to do this with current water testing technology. Further, the literature indicates traditional testing may be inadequate for definitively determining the safety of stored rainwater. Operational monitoring can easily be done by householders since the system is on-site. External auditing could be carried out occasionally by local government or more frequently by designated community members. In the absence of regular water quality testing and health surveillance, outcome indicators could be measured in the form of improvements recorded on sanitary inspection forms.

It does not seem likely that most individual households will be willing to regularly document activities and results, even if trained to. This finding was arrived at after a series of pilot studies in Bangladesh (Mahmud, et al., 2007). Supporting institutions could help draft standard operating procedures and instructions for remedial action in emergencies in the local language to be held by the households. The literacy rate in Fiji has been estimated to be about 94% so this is not anticipated to be a major obstacle (CIA, 2003).

Overall, it does not seem practical to apply traditional, comprehensive WSPs to DRWH systems on a large-scale in this context. Substantial training and support would need to be given to many individual households on several different aspects of the model and the feasibility of doing this in the short-term is questionable. However, the principles of risk assessment and management guided by generic instructions and occasional visits by supporting institutions when possible offer a potentially effective method of protecting water quality. The sustainability of these steps have been discussed in the previous sections of this chapter and recommendations for achieving it are described in the following chapter. In the long-term, if the capacity of supporting institutions increases, full WSPs may become more feasible in this context. Generic risk assessment and management instructions could be a building block toward achieving this in the future.

The Self Supply approach shows some promise in this context if the elements for creating an enabling environment as listed in section 2.6.2 and suggested by Sutton *et al.* (2012, p. xi) are strengthened. Creating demand for incremental hardware improvements is an essential step. DRWH technologies that have evidence to show their effectiveness for improving water quality could be promulgated, advocated, and demonstrated to the public. NGOs and the private sector have this capacity and a shared interest in creating demand. Increased awareness and education on transmission routes of faecal-oral diseases could be driven by local health officials.

Supporting institutions need to provide advice to households about why and how they can make improvements to their systems. Local government and NGOs can provide this with visits when possible, solicitation in town centres, and through various mediums of communication (radio, newspaper, television, etc.). In order to make more options, such as first-flush diverters, available and affordable, NGOs will need to engage with the private sector to have them locally made and stocked around the country. The option of subsidising DRWH technologies could also be considered. Fiji has one of the most developed economies of the PICs and a robust private sector so it seems there is potential for this.

Sutton *et al*. (2012) also advise that supportive financial mechanisms should be present to enable Self Supply. This was not investigated in-depth in this study, but “rural banking” services (http://www.anz.com/fiji/en/personal/ways-bank/rural-banking/) are available.

In time, facilitative government policies that encourage the uptake of technological improvements could be made, but first a supply chain of technologies needs to be expanded and promotion and implementation for communities should be trialled. An example of facilitative government policy could be to update the guidelines on the RWSP to say that screening is required for newly installed DRWH systems.

Measuring outcome indicators for the Self Supply approach has the same restrictions as for the WSP approach. The impracticality of regular water quality testing and inadequate public health surveillance makes it difficult to measure a reduction in disease or improvement in water quality at a wide scale. Sanitary surveys that indicate the presence or absence of a component could be used as an alternative if there is enough evidence that the presence of a certain component reduces the likelihood of transmission of disease in most cases.

With either approach, the chance of success of a project to improve water quality management will increase if time is spent building rapport between the households and supporting institutions, on-going contact is planned ahead of time, the local government is involved, and households have a real voice in how they are expected to manage their system (Barnes, et al., 2011). With careful planning and an appropriate framework suited for SSS, supporting institutions in Fiji and many other PICs are capable of ensuring these steps.

In theory, it appears the relevant principles of Self Supply and WSPs are complementary and could be promoted side-by-side. The incremental improvements that Self Supply promotes are often the same as the risk controls that WSPs promote. However, it is possible that households will see making one-off hardware improvements to their DRWH system as giving them reason to neglect routine risk assessment and management or superseding the need for routine maintenance. A multi-barrier approach needs to be strongly advocated for. For instance, it would be worth reminding rainwater harvesters that screens can prevent leaves from entering storage, but will not stop mosquito eggs from getting washed in, while well-maintained gutters may help reduce mosquito breeding, but will not stop leaves from occasionally entering storage.

6 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the key points from the research and addresses them in the context of the research questions and objectives. A list of recommendations for supporting institutions is made. Finally, limitations to this research are described and recommendations for further relevant research are made.

6.1 Research aim, objectives and questions

Research Aim: To develop guidance on sustainable water quality management of DRWH systems by considering the WSP and Self Supply approaches using households in Fiji as a case study.

The aim of this research has been achieved and recommendations for encouraging sustainable water quality management of DRWH systems are listed in section 6. 2. The comments on the following research objectives and questions show how the recommendations were arrived at.

Objective 1: To determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context.

What hazards and available controls are present? What are the primary risks? What incremental improvements can be made to manage these risks?

Microbiological and physical hazards from animals and insects, the environment, and the users themselves that could affect water quality through the catchment, during storage, or during collection and handling were observed by the author during the field visits. No chemical hazards were observed. Respondents reported mosquito breeding in stored water, and the presence of other physical contaminants as primary quality concerns. Hygiene education could build on these existing concerns to raise awareness of other potential water quality issues. Respondents associated certain weather events with poor water quality, which is in agreement with the literature. Respondents reported both proactive and reactive measures to controlling water quality, including cleaning different system components, screening, throwing out water that appears dirty, and post-collection water treatment (primarily boiling).

Sanitary inspections from this study concur with the literature that contamination via the catchment poses the greatest risk in general. An absence of barriers to prevent contaminants from entering storage once they reached the roof or gutters was frequently observed during field visits. Poorly designed gutters that retain water were often observed and could explain in some cases the reason for frequent reports of mosquito breeding. Contamination directly into storage through uncovered openings also appeared to be a prominent risk. Interventions to improve the protection of collected water should focus on addressing these primary risks.

Locally made and stocked materials for properly designed gutters and improvised inlet screens are widely available. Well-designed and maintained gutters and screens have the potential to substantially improve the protection of water quality for many cases in the study group. First-flush diverters would also provide a good level of protection, but these are not widely available and are expensive. Openings on tanks can usually be covered with local materials by a variety of improvised means, and simple overflow outlets can be installed with PVC pipe.

Objective 2: To assess the capacity of households and supporting institutions in Fiji to carry out appropriate water quality management activities sustainably.

Can households reasonably be expected to make these improvements? What institutional arrangements are needed for support? What level of monitoring and verification is feasible?

Screening, designing gutters, covering openings, and installing overflow outlets are simple and do not require substantial technical knowledge to implement, although households require advice on how to design them properly. These parts are also locally available. First-flush diverters and other novel technologies are currently likely to be either inaccessible or unaffordable for many households. This situation is unlikely to change until a local supply chain is established.

Households, in most cases, seem capable of performing routine maintenance practices, but require advice on when and how to do so, and why maintenance is needed. Rainwater harvesters with physical limitations (for example the elderly, and those with physical disabilities) that have difficulty performing maintenance practices require special attention.

Government bodies, NGOs, and the private sector are major stakeholders along with rainwater harvesters themselves. Government bodies need to have a methodical plan for supporting rainwater harvesters that works around their resource limitations. This includes providing technical advice, assisting with risk assessment and management, and raising awareness on sources of faecal-oral diseases and disease transmission routes. More data need to be collected and collated on where and to what extent rainwater harvesting is practiced, so that interventions can be strategically targeted. Eventually, policy should be formulated that takes into account the challenges and opportunities particular to DRWH systems and other SSS.

The role of the private sector needs to be considered further. There appears to be potential to locally make, stock, and market DRWH technologies and vendors of storage tanks are in a good position to pass on information and ensure initial design safety at a critical time. This should be taken advantage of. Delivering messages on sustainable water quality management could perhaps be strengthened through improved communication and coordination between major stakeholders, including the private sector and the communities. This could be facilitated through forming a new national or regional rainwater harvesting association. Implementing agencies can improve each other's capacity by sharing lessons learned from successes and failures of relevant projects.

Verification through water quality monitoring is likely to be impractical in most cases for DRWH systems. Operational monitoring may be done by the households, but it does not seem likely they will be willing to document activities. External auditing could occasionally be done by local government but perhaps only enough to check if hardware improvements have been made. Community-based people possibly could be hired to do monitoring and report to local government offices on DRWH systems via mobile phone, but safeguards against corruption would be needed.

Objective 3: To gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems.

What determinants hinder or drive sustainable management practices? Are households willing to invest in these improvements?

A lack of perceived susceptibility and lack of knowledge on sources of faecal-oral diseases, disease transmission routes, and options for controlling them are likely the most prominent determinants hindering management practices. Physical and aesthetic quality issues are the main determinants driving water quality management. Interest in water quantity and accessibility drives uptake and use of DRWH systems in the first place. Targeting awareness-raising activities on the identified barriers and linking water safety with drivers of management practices may be an effective strategy. Action research is recommended for this. As noted above, hygiene education could build on existing concerns about water quality, to raise awareness of other potential water quality issues.

Some households have already taken measures to make incremental improvements in the form of installing screens on inlets. Respondents were mostly unaware of more novel technologies, but indicated they would be interested in paying for them if they were affordable, accessible, and perceived to be beneficial. However, bias in self-reporting may have an influence on this. Many respondents reported buying their own storage tanks, which suggests a willingness to invest significantly in water supply.

Objective 4: To assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality.

Are there inherent limitations to WSPs in this context? Are the principles of WSPs and Self Supply complementary in this context?

Traditional WSPs have limited practicality at the household level because certain steps of the model require substantial training and support that are difficult to deliver at the household level given resource limitations of supporting institutions. However, provision of generic risk assessment and management instructions that prioritise the most prominent risks are feasible and could be an effective tool.

The Self Supply approach has potential in this area, but issues of stimulating demand and availability of technologies first need to be addressed. Verification of water quality and evaluation of health impacts is also very challenging with this approach, because of the number of individual installations.

Self-investment in incremental improvements will often match with risk control measures identified by a WSP. However, rainwater harvesters may place undue trust in technical equipment, and consequently see implementation of hardware improvements as a reason to neglect routine risk assessment, or superseding the need for routine maintenance. A multi-barrier approach should be promoted, that recognises the need to implement numerous measures to control a variety of risks.

6.2 Recommendations for stakeholders

The aim of this research is to develop guidance on sustainable water quality management of DRWH systems by considering the WSP and Self Supply approaches using households in Fiji as a case study. As a result of the findings from this research, recommendations that contribute to achieving this research's aim have been formed and are presented in this section. Recommendations are listed starting from short-term measures to longer-term measures.

1. Focusing efforts on addressing primary risks will likely make a bigger impact when approaching the problem from a broad perspective. For the studied group, it is recommended that supporting institutions emphasise the importance of:

    a. Installation and maintenance of screens or covers at inlets, outlets, and other openings of the storage vessel;
    b. Proper design and maintenance of gutters and downpipes to prevent retention of water and build-up of debris; and
    c. Installation and maintenance of first-flush diverters.

    An improved supply chain for first-flush diverters will need to be established before the third control measure listed here can reasonably be expected for most households.

2. Awareness needs to continue to be raised on sources of faecal-oral diseases and their transmission routes; both in the context of DRWH systems and in the general living environment. Hygiene education could build on existing concerns about mosquito breeding and physical contamination, to raise awareness of other potential water quality issues.

3. Rainwater harvesters should be encouraged to be especially proactive in ensuring their facilities are clean and in a good state of repair during windy conditions, when heavy rains are expected, and when rain is expected after an extended dry period. Regular cleaning of tanks should not be considered essential unless the sludge layer is nearing the tap or gross contamination is suspected, but should not be discouraged either.

4. Rainwater harvesters that have physical limitations that inhibit them from maintaining their system require special support. Local health departments should make note of households that cannot, for physical reasons, carry out regular maintenance on their systems, and ensure they have secure access to a source of safe drinking water.

5. When promoting appropriate management and improvements for DRWH systems, water quality should be tied to water quantity for motivational reasons. Removal of physical contaminants should also be emphasised as a benefit of good management, but it is important to argue that clear, colourless water is not necessarily safe to drink. Action research is recommended for this.

6. NGOs should assist local government offices to develop methodical, goal-oriented plans for when to visit or communicate with rainwater harvesters, and what the objectives of each contact are. Part of these plans should be to ensure that the three measures listed in recommendation 1 (above) are being implemented to a reasonable degree.

7. Agencies that are implementing interventions on community-level WSPs, management of DRWH systems and other forms of SSS, and promoting Self Supply should design activities for documenting and sharing lessons learned.

8. The government and NGOs should partner with private vendors to promote use of manufactured plastic tanks. NGOs should advise vendors on how the safety of the water can be protected through better design and installation of DRWH systems.

9. It is also recommended that the government engage vendors of tanks to provide usage instructions, with the sale of tanks, on appropriate management that emphasise good practices and warn against the most prominent risks. Buyers of tanks should also fill out a form with purchase to have their tank registered with the local health department, so that future support can be efficiently targeted.

10. NGOs and the government should seek to engage the private sector to locally produce DRWH technologies such as first-flush diverters, stock them in rural areas, and market them to the public.

11. The viability of a national or regional rainwater harvesting association should be investigated to strengthen the links between the government, NGOs, the private sector, and community based organisations, on issues relevant to rainwater harvesting, and to promote good practices.

12. National policy promoting WSPs for existing water supplies should be approved and be sensitive toward the challenges of SSS. Policy should include provision of risk assessment and management instructions, promulgation of field-trialled technologies, and well-planned levels of support for rainwater harvesters.

6.3 Research limitations and recommendations for further research

The goal of this research is to contribute to improving the water quality of SSS in Fiji, but due to resource constraints, water quality testing was not possible. Therefore it cannot be definitively claimed that the studied systems are in need of an intervention. A carefully planned water quality testing study of DRWH systems in Fiji that accounts for geographic, seasonal, and meteorological variations could be helpful for understanding the necessity of water quality control measures in the studied context.

In this study, the approach of using semi-structured interviews for households often resulted in very brief responses. In future research in similar contexts, a different approach for yielding more analysable qualitative data is recommended. Spending more time with households to build rapport, and making repeat visits could be helpful for yielding richer data. Future research into this topic should also seek the perspectives of local NGOs working on the ground, local health officials, and private vendors of storage tanks, gutters, and other components of rainwater harvesting.

The fieldwork for this study was limited to DRWH systems in Fiji, but findings may be extended to other PICs or other forms of SSS. Transferability of the findings from this study to other cases needs to be demonstrated by identifying features for comparison and rationalising what aspects can be generalised. Making a collection of comparisons between the studied group and other cases and analysing them would be helpful for drawing the maximum value out of this study.

The cost of locally producing, stocking, and selling technologies to improve the water quality of DRWH systems was not investigated in this study. Further research should look into the cheapest ways of making these technologies accessible to rural households while maintaining their effectiveness. Research should also be done to evaluate people's willingness-to-pay for these technologies.

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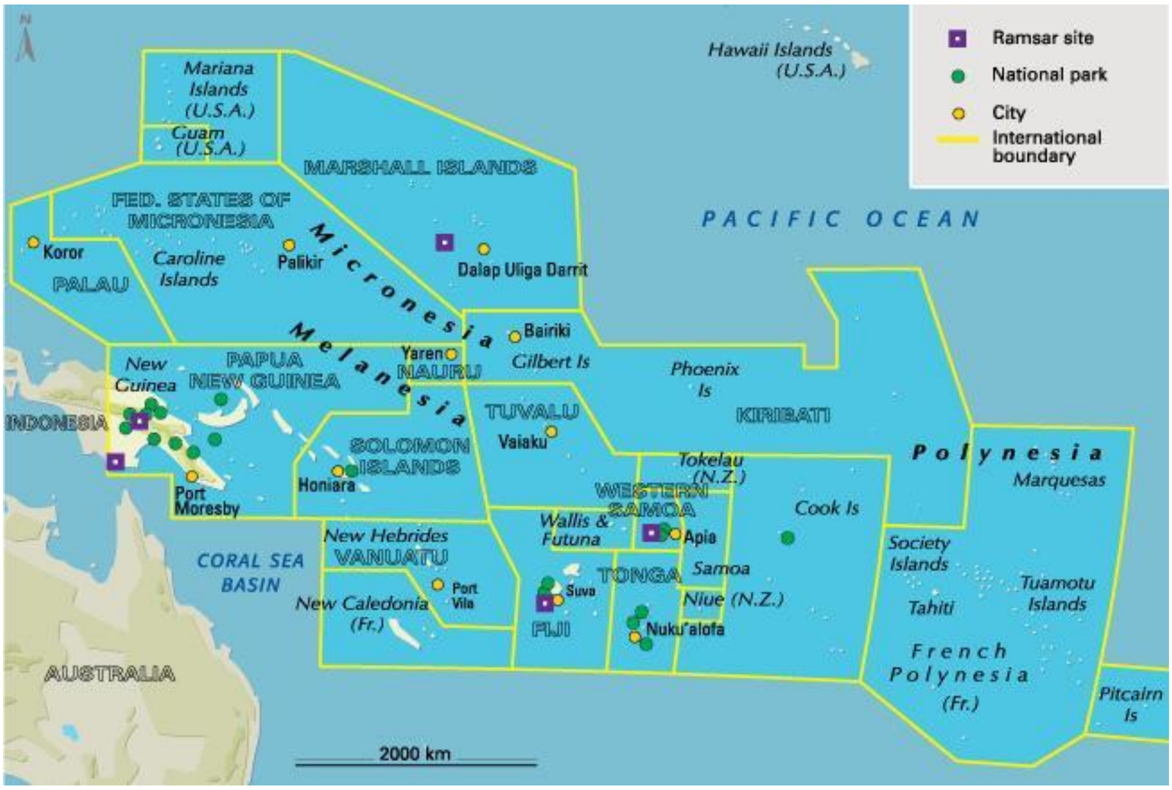
Appendix 1: Map of Pacific island countries



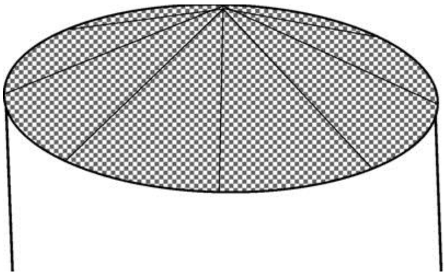
Source: AFDEC prepared for UNESCO, 2009

Appendix 2: Table of search terms

Search terms	Database(s)	# of results	Relevance
"water safety plan"	LCP	82	Some
water safety plan in title field	LCP	31	Good
water safety management in title field	LCP	54	Some
"water safety management"	LCP	27	Some
water quality management	LCP	5000+	Low
"water safety plan"	Proquest	104	Good
"water safety plans"	Proquest	131	Good
"water safety plan" in title field	Proquest	28	Good
"water safety plans" in title field	Proquest	41	Good
"water safety planning" in the title field	Proquest	5	Good
"Water safety management" in abstract field	Proquest	6	Low
"Water quality management"	Proquest	5000+	Low
"water quality management" household	Geobase/Compendex/Referex	12	Some
"water quality management" household	Proquest	742	Low
"water quality management" "household" in abstract	Proquest	1	Low
"water quality management" "domestic"	Geobase/Compendex/Referex	80	Low
"water management" AND household	Proquest	1777	Low
"water management" AND household in title field	Proquest	10	Some
"water management" AND domestic	Proquest	2507	Low
"water management" AND domestic in title field	Proquest	6	Low
"water management" AND household	Geobase/Compendex/Referex	522	Low
"household water management" OR "domestic water management"	Geobase/Compendex/Referex	24	Some
"household water management" OR "domestic water management"	Proquest	30	Low
"self supply"	LCP	720	Low
"self supply"	Proquest	398	Low

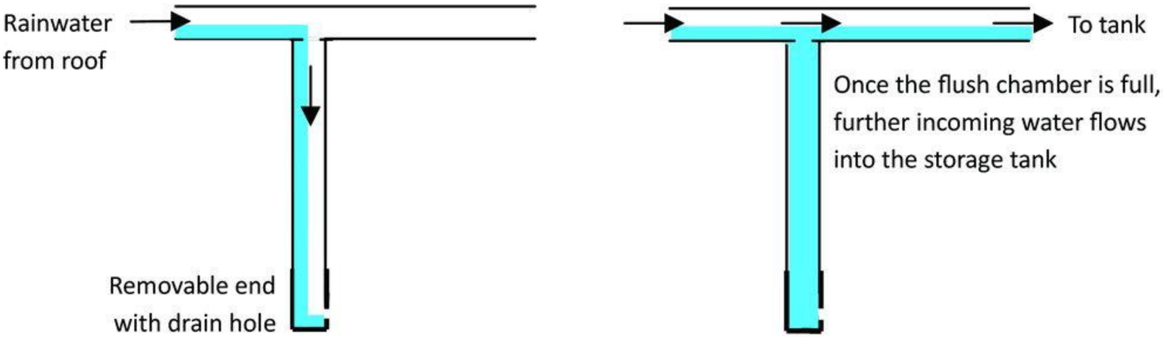
"self supply"	Geobase/Compendex/Referex	98	Some
"self supply" AND water	LCP	320	Low
"self supply" in title field	LCP	10	Low
"self supply" AND water	Geobase/Compendex/Referex	22	Some
"self supply" AND water	Proquest	173	Some
"self supply" AND "drinking water"	Proquest	31	Some
"household led water supply"	Proquest	1	Some
"self financing" AND water supply	Proquest	333	Some
"self financing" AND water supply	Geobase/Compendex/Referex	5	Some
"rainwater quality"	LCP	161	Good
"rainwater quality"	Geobase/Compendex/Referex	1353	Good
rainwater review	Geobase/Compendex/Referex	137	Good
rainwater meta-analysis	Geobase/Compendex/Referex	5	Some
rainwater review	Proquest	5000+	Low
rainwater review in title field	Proquest	21	Good
"rainwater harvesting" in title field AND perception	Proquest	15	Low
"rainwater harvesting" in title field AND perceive	Proquest	1	Good
"rainwater harvesting" in title field AND perception	Geobase/Compendex/Referex	16	Low
"rainwater harvesting" in title field AND perceive	Geobase/Compendex/Referex	3	Good

Appendix 3: DRWH technologies



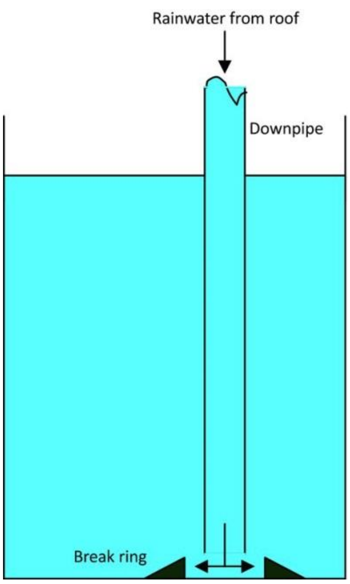
Self-cleaning inlet filter

A cloth is stretched over a conical frame that is placed on an inlet pipe. The cloth filters out particulates which are washed off by runoff created by the sloped sides. Image source: Abbasi & Abbasi, 2011.



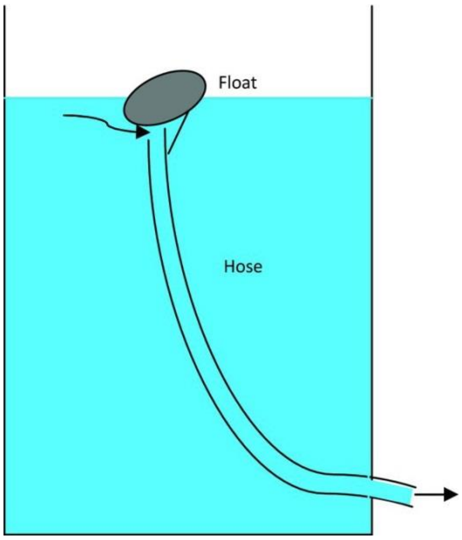
First-flush device

The first runoff from the roof, which normally contains a higher concentration of contaminants, is diverted from storage to a flush chamber. The chamber is slowly emptied through a drain hole or drip valve. Image source: Abbasi & Abbasi, 2011.



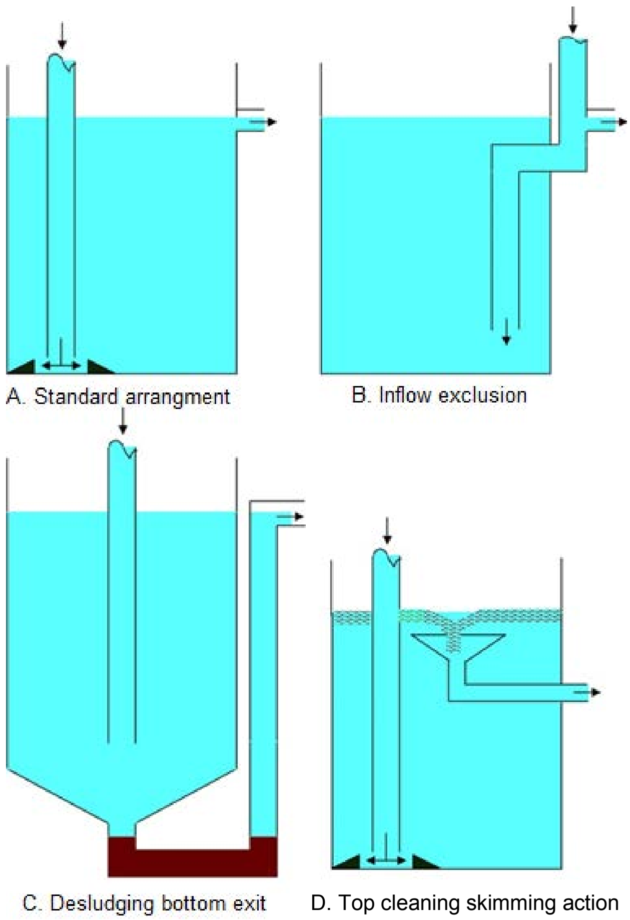
Inlet arrangement

The inlet to the storage vessel is arranged so that incoming water is directed to the bottom of the vessel. This allows sedimentation to happen quickly. A break ring at the bottom prevents the momentum of the incoming water from agitating the sludge layer. Image source: Abbasi & Abbasi, 2011 adapted from Martinson & Thomas, 2003.



The outlet of the storage vessel is attached to a flexible hose which is suspended near the water surface by a float. This allows water to be drawn from the top of the column where it is normally cleaner. Image source: Abassi & Abassi, 2011 adapted from Martinson & Thomas, 2003.

Outlet arrangement



Overflow arrangements

Diagram A shows a typical overflow arrangement. In diagram B the inlet/overflow pipes block contaminants from mixing with the stored water. In diagram C, overflow is taken from the bottom of the vessel where the water is dirtiest. In diagram D, floating contaminants are drained from the water surface with the overflow. Image source: Abbasi & Abbasi, 2011 adapted from Martinson & Thomas, 2003.

Appendix 4: Logical framework

Research summary	Actions	Indicators	Outputs
Problem statement Guidance for water quality management at the household level is currently underdeveloped which poses health risks for users of household SSS	Disseminate findings to stakeholders and encourage implementation of recommendations	Project reports, list of recommendations and oral presentations	Improved knowledge of how to implement and support sustainable household WQM
Research aim Develop guidance on sustainable water quality management of DRWH systems by considering the WSP and Self Supply approaches using households in Fiji as a case study	Use critical thinking, experience and judgement of research to form guidance and recommendations	Written discussion, conclusions and recommendations sections	Clear, coherent advice and guidance for implementing and supporting household water quality management
Research objectives Determine what primary water quality risks to DRWH systems need to be controlled in the Fijian context	Process sanitary survey scores, describe user practices and compare with literature	Written results and discussion sections	Description of risks and controls that need priority
Assess the applicability of the WSP and Self Supply approaches to DRWH systems for improving and maintaining water quality	Review literature and compare with findings from key informant and household interviews		Benefits and challenges of the WSP and Self Supply approaches in this context
Assess the capacity of households and supporting institutions in Fiji to sustainably carry out appropriate water quality management activities	Code and interpret household and key informant interviews, compare with literature and use judgment		Opportunities and limitations of households and institutions to support WQM activities
Gauge the interest and perceived necessity of households in Fiji to managing water quality of their DRWH systems	Code and interpret household interviews, compare with literature and use judgment		Description of current household demand for improved water quality
Make recommendations for implementation and support of sustainable water quality management activities for DRWH systems	Develop potential solutions based on evidence from objective findings		Discussion of what needs to be done to sustainably improve WQM activities
Research questions What hazards and potential controls are present?	**Research activities** • Literature review • Semi-structured household interviews • Semi-structured key informant interviews • Sanitary inspections of DRWH systems	Written literature review, methods and results sections	• Snapshot of where current literature stands on relevant issues • Recordings and transcriptions of interviews • Sanitary survey scores
What determinants influence sustainable management practices?			
What level of monitoring and verification is feasible?			
What institutional arrangements are needed for support?			
Are there inherent limitations to WSPs in this context?			
Are principles of WSPs and Self Supply complementary in this context?			
What incremental improvements can be made to manage risks?			
Can households reasonably be expected to make these improvements?			
Are households willing to invest in these improvements?			

Appendix 5: Household interview guide

Fijian Hindi translation
Fijian translation

1. What is your primary drinking water source?
   Aap ka jo pine ka pani hai. woh kaha se ata hai?
   E dau taki mai vei nomudou wai ni gunu?

2. What do you use the collected rainwater for?
   Kya aap barsaat ka pani istamaaal karate
   Na cava e dau vakayagataki kina na wai ni uca?

3. Does anyone in your family drink it?
   Kyap Barsaat ka pani pine kilye bhi istamaal karte ho?
   E dua mai nomudou matavuvale e dau gunuva na wai ni uca?
   a. If not, why?
      Agar nahi, to kiyu?
      Ke sega, na cava na vuna?

4. Do you treat your water before drinking?
   Kya aap kisi tarha se barsaat ka pani jo hai use saaf kart ho?
   Ni dau vakasavasasavataka na wai se bera ni gunuvi?

5. Does anyone in your family make kava with it?
   Kya barssat ka pani se aaplong yagona banate ho?
   E dua nomudou matavuvale e dau vakayagataki na wai ni uca me losea kina na yaqona?

6. What do you use to collect water from the rainwater tank?
   Aap barsaat ka pani kis chiz se botorte ho?
   Na cava e dau vakayagataki me taki mai kina na wai mai na taqe?

7. Do you own the tank?
   Kya aapke ghar par ek tanki hai?
   E dua tiko nomudou taqe?

8. Who paid for it?
   Kisne yeh tanki banwana hai?
   O cei e volia mai?

9. How old is the tank?
   Kitne samaye se yeh tanki hai aapke paas?
   Sa yabaki vica na taqe e na nomudou matavuvale?

10. Have you ever cleaned the inside of it?
    Kya aapne kabhi iske bhitar saak kiya hai?
    Sa bau sava mada na loma ni taqe?

11. Who uses this tank (Just your family, neighbours, anyone)?
    Kaun kaun is tanki ko istamaal karte hai?
    O cei so e dau vakayagataka na taqe qo?

12. Do you ever have problems with collecting rainwater?
    Kya koi dikkato ka samna karte ho aap barsaat ke pani ko batorne mein?
    Ni dau sotakaya so na leqa ni tawa wai ni uca?
    a. What problems?
       Kya dikatte hai?
       Na leqa cava soti?
    b. How did you fix them?
       Kya kisi tarha aapne yeh dikkato ko sudhara hai?
       E rawa ni wali vakacava?
    c. What could you use to help you with the problems in the future?
       Kya koi tarkib aapne nikala hai ki agar bhabhishyeh mein koi dikkat ho to jald hi se chutakara pa sako?
       Na cava e rawa ni vakayagataki me na wali kina na leqa e so e na qai yaco mai liu?

13. Is the water from the tank clean and safe to drink?
    Kya Yeh tanki ka pani saaf hai pine ki liye?
    E vakacava na I tuvaki ni wai e taki main a taqe? E savasava me gunuvi?
    a. Why or why not?
       Kiyi aur kiyu nahi?
       Baleta?

14. How can you tell if the water is safe to drink or not?
    Kya kisi tarha aap bata sakte ho ki yeh pani saaf pine ke liye?
    Ni rawa ni tukuna vakacava ni savasava na wai ni uca me gunuvi?

15. Do you worry that the water from tank could get dirty and make you or your family sick?
    Kya kabhi yeh chinta hua ki shayed yeh pani mayela hoga aur aapke aur aapke pariwaar walo ko bimaar kar sakta hai?
    Ni bau leqataka ke vaka na wai mai na taqe e na duka ka rawa ni vakavuna na tauvimate e na loma ni matavuvale?
    a. If not, why?
       Agar nahi, to kiyu?
       Ke vaka e sega, na cava na vuna?

16. Do you do anything to make sure the water stays clean?
    Kya Koi tarkib aap istamaal karte ho jisse aap yeh jaan sake ki yeh pani har waqt saaf rehta hai?
    Ni dau cakava e dua na ka me savasava tiko ga kina na wai?

17. If these devices were sold in town would you be interested in buying one? (*Referring to first flush devices, float taps, inclined screens, etc.*)
    Agar Seher mein koi utpadam bikh raha hai jisse har waqt pani saaf reh sakta hai tab kya aap kharido ge who sab?
    Kevaka e volitaki tu na veika oqo e tauni, ko ni na via volia?

18. Do you think the government or anyone else should be responsible for helping to keep your drinking water safe or is it your own responsibility?
    Kya sarkaar zimidaar hai is pani ke dekh rekh ke liye ya phir aap?
    Cava nomu nanuma, e tavi ni matanitu se dua tale na tamata me vukei iko na kena maroroi vinaka na wai ni gunu se nomu I tavi sara ga o iko?

Appendix 6: DRWH system sanitary survey

Community name: ______________________________ Household #: _______ Date: ______________

Weather at time of visit: __________________________ Roof material: __________________ Tank Material: ___________________

	Risk Score				
1. Does the roof have any visible contaminants?	1	2	3	4	5
2. Are the guttering channels that collect water dirty?	1	2	3	4	5
3. Is there any form of screening or filtering at the inlet?	1	2	3	4	5
4. Are there any other points of entry not covered?	1	2	3	4	5
5. Could dirty water ingress through faults in the base or walls?	1	2	3	4	5
6. Are there any faeces present around the collection area?	1	2	3	4	5
7. Is the collection container kept somewhere it can get contaminated?	1	2	3	4	5
8. Is a method of diverting the first flush present?	1	2	3	4	5
9. Does the water in the tank appear turbid or contain organic litter?	1	2	3	4	5
10. Are there overhanging branches above the catchment?	1	2	3	4	5
11. Is rainwater collected by scooping it out?	1	2	3	4	5
12. Does water pool up under the tap?	1	2	3	4	5

Scale: 1 = Good; 5 = Poor

Total score:

Notes: ____

Guide to scoring questions

Q1. 1. No visible debris or litter
3. Moderate amount of debris and litter
5. Large amount of debris and litter

Q2. 1. No visible debris, litter or growing plants
3. Moderate amount of debris, litter or growing plants
5. Large amount of debris, litter or growing plants

Q3. 1. Inlet has a filter
2. Inlet has screen
5. No screen present

Q4. 1. All points of entry are covered
2. Small gaps or holes (1 – 3 inches) are present
3. Medium size gaps or holes (4 – 11 inches) are present
4. Large gaps or holes (12 inches or larger) are present
5. Vessel is completely uncovered

Q5. 1. No visible faults in base or walls
3. Visible faults in the tank high above ground level
5. Visible faults in the tank near ground level

Q6. 1. No faeces present
2. Faeces found within 5m of collection area
3. Faeces found within 3m of collection area
4. Faeces found within 2m of collection area
5. Faeces found within 1m of collection area

Q7. 1. Container kept inside
3. Container kept in a raised spot outside
5. Container on ground outside

Q8. 1. First flush diverter is present
5. No first flush diverter present

Q9. 1. Water appears clear
2. Small bits of organic matter floating
3. Some organic matter floating
4. Water appears slightly turbid and/or organic matter floating
5. Water appears turbid and/or large amounts of organic matter

Q10. 1. No branches overhanging
2. Branches slightly overhanging
3. Branches overhanging a quarter of the catchment
4. Branches overhanging half of the catchment
5. Branches significantly overhanging and coming into contact with the roof

Q11. 1. Water is collected from a tap
5. Water is collected by scooping

Q12. 1. Soakage pit or diverting channel/slab is present
2. Ground appears to drain water
3. Ground appears to hold some water
4. Ground is muddy
5. Stagnant water is pooling under the collection point

Appendix 7: Risk ranking matrix

		Severity/Consequences		
		No/minor impact	Moderate impact	Major impact
Likelihood	Likely		1, 2	
	Possible		5, 6	3
	Unlikely			4

1 = Contamination via catchment caused by pollutants transported by animals or airborne particles; 2 = Insect breeding or plant growth in gutters or catchment; 3 = Direct contamination of stored rainwater through uncovered openings; 4 = Dirty water ingress through faults in base or walls of storage; 5 = Contamination during collection from storage; 6 = Unhygienic area around collection point due to poor drainage and/or faeces

Descriptor	Description
Likelihood	
Likely	Will probably occur in most circumstances; has been observed regularly (e.g. daily to weekly).
Possible	Might occur at some time; has been observed occasionally (e.g. monthly to quarterly or seasonally).
Unlikely	Could occur at some time but has not been observed; may occur only in exceptional circumstances.
Severity/consequence	
Major impact	Major water quality impact; illness in community associated with the water supply; large number of complaints; significant level of customer concern; significant breach of regulatory requirement.
Moderate impact	Minor water quality impact (e.g. not health related, aesthetic impact) for a large percentage of customers; clear rise in complaints; community annoyance; minor breach of regulatory requirement.
No/minor impact	Minor or negligible water quality impact (e.g. not health related, aesthetic impact) for a small percentage of customers; some manageable disruptions to operation; rise in complaints not significant.

Source: WHO, 2012

Appendix 8: Fiji national drinking water quality standards

Parameter[a]	**Maximum value**
pH	6.5 – 8.5
Colour	5 TCU
Turbidity	5 NTU
Residual chlorine[b]	0.2 – 0.5 mg/L
Total dissolved solids	500 mg/L
Conductivity	1000 µS/cm
Thermotolerant coliforms	0 per 100 ml
E. Coli	0 per 100 ml
Total coliforms	0 per 100 ml

[a] Additional parameters can be monitored but these are the minimum requirements

[b] Only if chlorine is added to the water system