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BEYOND COVERAGE AS A METRIC FOR SDG 6 SUCCESS IN THE DECADE OF ACTION (2020-2030): THE SUSTAINABILITY BURDEN OF RURAL COMMUNITY HANDPUMPS IN MALAWI

By

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DOCTOR OF PHILOSPOHY

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DECLARATION

‘This thesis is the result of the author’s original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.’

Signed:

Date:

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PREFACE

The main content of this thesis was developed as a series of papers to be published in peer-reviewed journals. Each chapter consists of an abstract, introduction, materials and methods, results, discussion, and a conclusion. A bridge of text was provided at the beginning and end of each chapter to highlight the connections between the chapters and provide context to the overall thesis aim. The papers, included in each chapter, are published, and drafted in the following:

CHAPTER 4

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STATEMENT OF NOVELTY

This thesis has novelty within the global and local contexts. These consist of:

GLOBAL NOVELTY

- Investigation into the impact a focus on increasing water supply access in the global goals has on local communities, that have implications for other low-income countries.
- Life-Cycle Cost Approach (LCCA) to investigate potential capacity of communities under the community based management approach to sustain rural handpumps.
- Logistic regression approach to determine the likelihood of 'affordability' and 'operations and maintenance costs' reflected at the local level, key aspects of localising SDG 6.
- Logistic regression approach applied to an infrastructure related issue, an underlying factor of 'Functionality'.

LOCAL NOVELTY

- Comprehensive and recent national monitoring dataset of Malawi's water supply sector.
- Comparison of Total Dissolved Solids (TDS) and Electrical Conductivity (EC) limits and the implications for Malawi water quality guidelines.
- Detailed investigation on the variations within a Community Based Management (CBM) approach and financial mechanisms in rural Malawian communities.
- Increased understanding of community behaviours towards Capital Maintenance Expenditure (CapManEx) at the community level in Malawi.

ABSTRACT

Access to reliable and safe water has been recognised as a fundamental human right across the last 20 years of global goals. Handpumps have played a fundamental role in increasing the number of people with access to safe water for rural populations in low-income countries. However, monitoring indicators and investments based solely on increasing coverage alongside the challenge of maintaining handpumps across their intended life-cycle, may risk hiding low and inherently unsustainable services for rural communities in low-income regions.

This thesis addresses the need to move beyond coverage as a metric for success in the global goals. By investigating the sustainability burden on decentralised rural water supply in Malawi, through a comprehensive national monitoring dataset.

First, the impact a focus on drinking water coverage in global goals and Malawian rural water supply policy is addressed. The acceleration to meet targets, coupled with challenges of community based management, risks unsustainable infrastructure and a loss of the intended benefits. Second, the variation of tariffs to maintain water supply infrastructure are investigated. Significant explanatory variables associated with considering affordability and operations and maintenance costs are identified through regression analysis. Finally, the principles of life-cycle costing are adopted to determine the capacity of rural service providers sustaining infrastructure across their intended life-cycle. Findings show low costing repairs are prioritised while high costing repairs are left until the complete failure of the asset. Regression analysis further identifies significant variables that increase the likelihood of handpump breakdown.

As the global goals move into the decade of action (2020-2030), increased efforts towards capacity building, localising the goals, significant explanatory factors and identifying risks relating to sustaining services are required. True representation of rural service provision may be misrepresented if the lessons of the global goals to date are not fed back into monitoring strategies and investment appraisal.

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LIST OF ABBREVIATIONS

Abbreviation	Description
BUA	Borehole Users Association
CapEx	Capital Expenditure
CapManEx	Capital Maintenance Expenditure
CBM	Community Based Management
CI	Confidence Interval
CJF	Climate Justice Fund
CoC	Cost of Capital
EC	Electrical Conductivity
ExpDS	Expenditure on Direct Support
EXpINDS	Expenditure on Indirect Support
F	Functionality
GPS	Global Positioning System
IWRM	Integrated Water Resource Management
JMP	Joint Monitoring Programme
LCC	Life-Cycle Cost
LCCA	Life-Cycle Cost Approach
MDG	Millennium Development Goal
MIS	Monitoring Information System
MWK	Malawian Kwacha
NF	Non-Functionality
NGO	Non-Government Organisation
OpEx	Operating and Minor Maintenance Expenditure

O&M	Operations and Maintenance
OR	Odds Ratio
PF	Partial Functionality
R.R	Recommended Repairs
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TA	Traditional Authority
TDS	Total Dissolved Solids
T.OpEx	Total Operations Expenditure
UN	United Nations
USD	United States Dollars
UNICEF	United Nations Children's Fund
VLOM	Village Level Operations and Maintenance
WASH	Water, Sanitation and Hygiene
WHO	World Health Organisation
WPB	Water Point Bank
WPC	Water Point Committee
WUA	Water Users Association

CHAPTER 1. INTRODUCTION

1.1 Overview

Access to safe and clean drinking water is crucial for human livelihoods and is a fundamental human right. Investment to increase the coverage of water supply infrastructure has been a key component of global goals, government targets, and projects throughout the aid sector. Between 2000 and 2015 the Millennium Development Goal (MDG) target for water and sanitation (7c) aimed “to halve the proportion of people without sustainable access to safe drinking water and basic sanitation”. A global focus for coverage continued into the Sustainable Development Goal (SDG) era in 2015 through goal 6, which aims to “ensure availability and sustainable management of water and sanitation for all” and displays an increased focus on global water and sanitation challenges.

Over two decades, investments into increasing the coverage of improved water supplies resulted in an alleged 91% of the global population with access to an improved source by the end of the MDGs in 2015 (WHO/UNICEF, 2015). Progress towards the global goals is measured by the Joint Monitoring Programme (JMP) of the World Health Organisation (WHO) and United Nations Children’s Fund (UNICEF) that use terms such as ‘improved drinking water source’ for proxy indicators. However, the indicators to measure the success of the MDGs and SDGs do not measure sustainability. Concerns have been raised that these indicators are hiding low levels of services at the local level (Adank *et al.*, 2016; Martínez-Santos, 2017). Affected water users may depend on unimproved supplies or surface-water sources, temporarily or definitively. This will ultimately have a considerable effect on the health and overall poverty reduction of the region, that has compromised Sub-Saharan Africa (SSA) in its efforts in relation to the MDGs, and will continue to hinder progress towards the SDGs.

Handpumps have played a fundamental role in increasing access to safe water for rural populations across Sub-Saharan Africa (SSA) (Macarthur, 2015). However, if there is a focus on the capital expenditure (CapEx) of water supply coverage, the investment decisions can favour cheaper infrastructure, which can lead to premature major repairs and breakdowns (Franceys and Pezon, 2010). Furthermore, poor siting, poor construction and improper design for the local context leaves a poor delivery of supply in terms of availability and quality (Bonsor *et al.*, 2015; Kalin *et al.*, 2019). The original investments and benefits of increasing the coverage of improved supplies are therefore lost for the communities they are intended to serve (Hunter, MacDonald and Carter, 2010). They may also place a burden on communities to sustain services that are inherently unsustainable, as conceptualised in Figure 1.1.

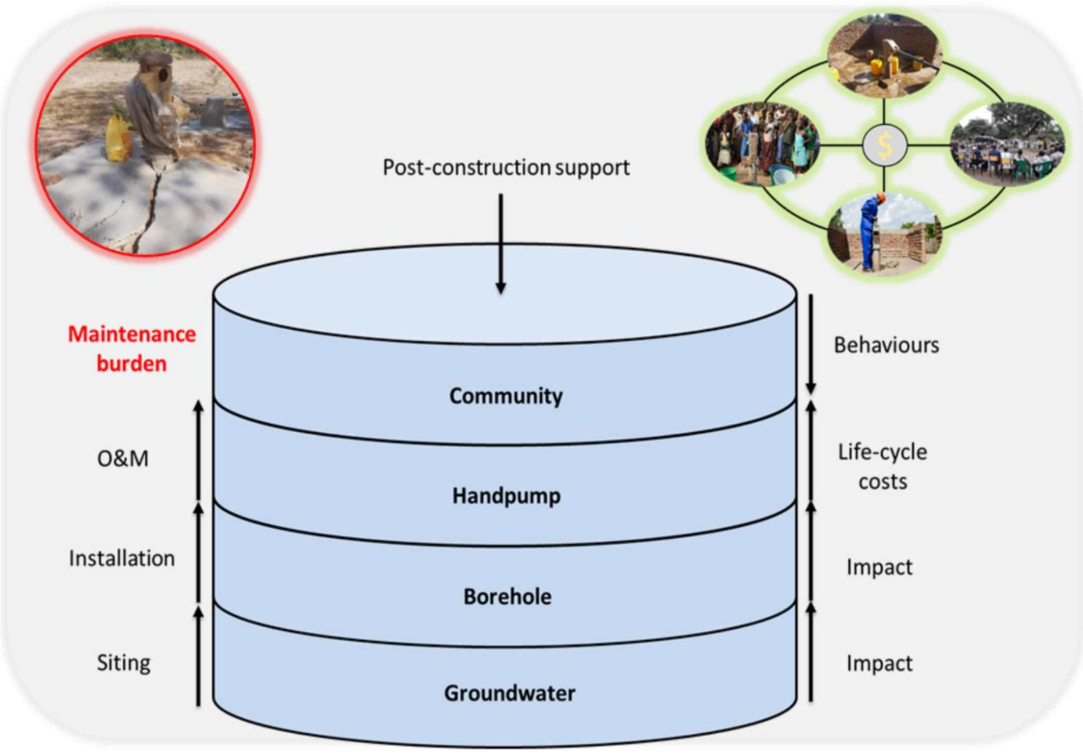

Figure 1.1 Maintenance burden on rural communities conceptual model.

This study focuses on the rural context of water supply. Encompassing the majority of Malawi's population and where groundwater exploitation through boreholes equipped with handpumps is most common. The decentralisation of rural water supply management is accomplished through community based management (CBM), which is dominant in low-income countries. However the application of this model is limited in what can be achieved through informality and voluntarism (Moriarty *et al.*, 2013; Chowns, 2015a; van den Broek and Brown, 2015). Furthermore, capacity building and life-cycle thinking to sustain such services has been lacking (Moriarty *et al.*, 2010, 2013; RWSN Executive Steering Committee, 2010; Fonseca *et al.*, 2011). Limited capacity to accommodate the life-cycle responsibilities and challenges under decentralised management hinders long term sustainability and benefits for rural communities. Addressing the sustainability burden on decentralised rural water supply in Malawi, requires moving beyond solely coverage as a metric for success. The SDGs decade of action (2020-2030) requires attention towards the current capacity, localising the goals, causal linking factors and risks relating to sustaining services.

1.2 Research Motivation

This doctoral research is motivated by the need for sustainable and continued water supply services to deliver the intended benefits to rural communities. While the focus over the last two decades of investment has been increasing water supply coverage, the emphasis on community managed handpumps has not delivered the results for the rural communities they are intended to serve.

The intention to pursue doctoral research was motivated by previous experience and passion for international relief and sustainable development, particularly for improving the livelihoods of rural communities. During 2010, 2012 and 2014 I had the opportunity to visit Rwanda through partnerships with churches. During this time I engaged with local construction and teaching projects, which inspired me to learn more about international development.

During my third year of MEng Civil Engineering, I had the opportunity to engage with the Engineers without Borders UK design challenge. The challenge was to improve the water supply from a spring while addressing the needs and social aspects of the community. This experience highlighted how I could use my engineering expertise to tackle inequalities and improve livelihoods of communities, and motivated me to pursue engineering for global development as a field of study.

Through connections from my visits to Rwanda, I designed a rainwater harvesting system for a community goat farm project in Burundi for my fourth year dissertation. Between my fourth year and fifth year, I received a research internship at the University of Strathclyde to design a methodology for assessing rural water supply in developing countries. In my final year I applied this methodology in the field, to assess current and design new community and school water supply projects in Rwanda, in partnership with Christian Engineers in Development (CED). My experience in the field and during my masters research highlighted the challenges of long term sustainability for local community water supply in low-income countries, that I sought to explore through doctoral research.

1.3 Research Aim and Questions

1.3.1 Research Aim

The aim of the research was to investigate the influence the global goals in the MDG period and subsequent SDG period have on maintaining rural community water supply across their life-cycle in low-income countries. A comprehensive live dataset in a management information system (MIS), regression analysis and life-cycle cost approach principles were utilised to interrogate the domains associated with providing decentralised rural water supply (e.g. service delivery, operational, cost-recovery, condition of infrastructure). The impact from this research is to support data driven decisions and policy. Particularly to promote long term delivery of sustainable services, contrary to the short term achievement of increasing coverage, as the global goals move into the 'decade of action'.

1.3.2 Research Questions and Specific Objectives

To achieve the overall goal of the thesis, research questions (RQ) and specific objectives (SO) are developed. These are outlined as follows:

RQ 1: Has the drive to meet the success and coverage targets of the Millennium Development Goals (MDG) resulted in low-levels of service and a burden on decentralised service providers?

- **SO 1:** Investigate the installation, functionality and rehabilitation of Afridev handpump boreholes during the MDG period under decentralised service provision.
- **SO 2:** With the aid of a case study, investigate how water quality thresholds contribute to coverage investments that are unfit for use.

RQ 2: How are global goals reflected and highlight challenges in the cost-recovery mechanism for decentralised rural water supply?

- **SO 3:** Investigate the variations in decentralised service providers and cost-recovery characteristics for the Operation and Maintenance (O&M) of rural water supply assets.
- **SO 4:** Identify service provider consideration when setting tariffs, SDG specific considerations and the significant explanatory predictor variables behind them.

RQ 3: Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi?

- **SO 5:** Develop scenarios based on tariffs for O&M set by service providers under community based management.
- **SO 6:** Identify the current approaches to maintenance and repairs.
- **SO 7:** Develop a Life-Cycle Cost (LCC) model of Afridev handpump O&M requirements and potential financial resources, to be used as proxy indicators, for real world monitoring data.

RQ 4: How can a proactive approach to monitoring identify and target increased risk to handpump breakdown?

- **SO 8:** Identify the LCC element (i.e. issue of infrastructure) within the temporal snapshot monitoring indicator, functionality.
- **SO 9:** Identify significant explanatory predictor variables (e.g. domains relevant to service delivery and LCC model proxy indicators) behind the LCC element occurring.
- **SO 10:** Discuss how techniques (Life-Cycle Cost Approach (LCCA)) and monitoring (Management Information System (MIS)) can assist in data driven investment/intervention decisions to move from a coverage approach to fulfil the SDGs, to a service delivery approach for sustainable systems.

1.4 Thesis Structure

A brief outline of each thesis chapter is provided below and an overview of the thesis structure is presented in Figure 1.2.

Chapter 2 presents background on the global goals for water and the decentralisation of management for rural water supply in Malawi. Indicators for monitoring rural water supply status are presented alongside the use of life-cycle costing methodology for sustainable service delivery.

Chapter 3 demonstrates the research philosophy, and the main research materials used throughout the research in fulfilling the aims and knowledge gaps of the thesis. This includes the use of 'big data' in a national rural water supply dataset and software. The main research methodologies are then presented, highlighting the use of the monitoring dataset, and life-cycle costing and regression methodology.

Chapter 4 (RQ 1) builds on the review undertaken in Chapter 2 to investigate the effect and influence of the global goals and Malawian national policy's focus on coverage targets. In particular, it highlights the depreciation of assets since the beginning of the Millennium Development Goals that require costly rehabilitation exercises to remediate. Exercises which rely on external support to fund. A case study conducted in Kakoma, Chikwawa further investigates the influence national policies can have in implementing assets that are unsustainable for use. Highly saline groundwater influences water users behaviours towards usage and financial contributions towards maintaining supplies. These supplies are deemed suitable for use under Malawian salinity standards but are unsuitable under WHO thresholds.

Localising the global goals is key to their success. Coverage is a key component of global targets, however challenges may arise for local service providers alongside unsustainable infrastructure (Chapter 4). Chapter 5 (RQ 2) investigates the challenge of affordable tariffs and sustainable management of water supply at the local level. Annualised financial resources for maintenance, through the collection of household tariffs, significantly vary based on the frequency of collection. Setting the tariffs to meet the operations and maintenance costs over the life-cycle of the Afridev, while setting a tariff that is affordable is a notable challenge. There are potential drivers and trade-offs when setting tariffs that hinder the achievement of the SDGs at the local level and meeting the life-cycle requirements for sustainable infrastructure.

Capital Maintenance Expenditure is an often neglected life-cycle cost in pre and post construction. This is addressed in Chapter 6 (RQ 3). Behaviours towards required maintenance and major repairs over the life-cycle potentially varies due to the variations in tariff amount and frequency. Low costing repairs are prioritised while high costing repairs are left until the complete failure of the asset. A lack of capacity building and reliance on external support questions if current cost-recovery and maintenance approaches are capable of meeting the life-cycle requirements of assets.

Chapter 7 (RQ 3 and 4) builds on the life-cycle challenges identified in the previous chapters. A life-cycle cost model is developed to identify if local variations in cost-recovery are capable of meeting the maintenance costs across the 15 year design life of the Afridev handpump. The operational status of water supply encompasses multiple factors that contribute to continued functionality. This study focuses on the life-cycle element of functionality and the significant explanatory variables that contribute towards broken components. This is accomplished through the life-cycle cost model and logistic regression.

Throughout the previous chapters (Chapter 4-7) the primary data source has been a 'big dataset' collected through a water point functionality survey data in a management information system. Chapter 8 (RQ 4) considers the main lessons presented in the thesis to consider service delivery investment and improvements can be better targeted through a life-cycle cost approach and management information systems. In particular how these methods contribute to data driven asset management and inform policy changes for sustainable service delivery.

Chapter 9 presents the general conclusions of the research and future recommendations for policy and practice.

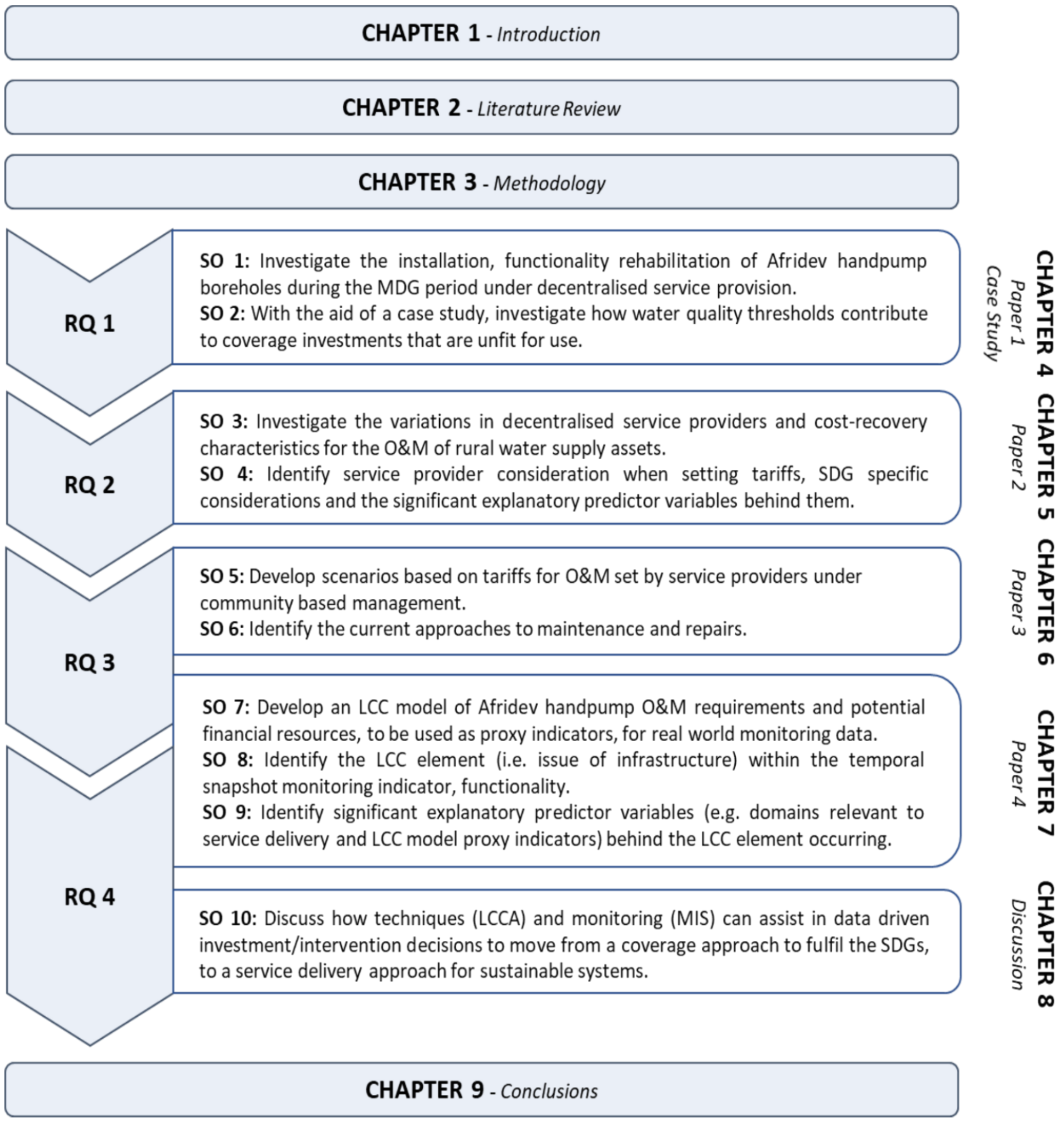

Figure 1.2 Roadmap of thesis outlining research questions, objectives and content of chapters.

CHAPTER 2. GENERAL LITERATURE REVIEW

2.1 Introduction

The previous chapter outlines the problem this thesis aims to address, and the research questions and specific objectives to fulfil the aim. This chapter presents a general literature review relevant to the thesis aim. The global goals relating to water are explored and their focus relating to increasing coverage of drinking water access. After highlighting the importance localising the global goals are for their success, the structure and challenges of decentralised rural water supply management in Malawi are demonstrated. Finally, the challenges of establishing, maintaining and monitoring sustainable service delivery at the local level are demonstrated.

2.2 Global Goals

Access to safe and clean drinking water is crucial for human health, well-being and development (Bartram and Cairncross, 2010), and is recognised as a fundamental human right (United Nations, 2002, 2010). Monitoring of drinking water informs national and international development policies, while highlighting the gaps in knowledge and progress. Global monitoring of drinking water has been ongoing since the 1930s. This has primarily been conducted under the global targets established by the United Nations (UN). The timeline of international monitoring targets driven by UN goals since the 1960s is presented in Table 2.1.

Table 2.1 International monitoring timeline by UN, adapted from Bartram *et al.*, 2014.

Year	Monitoring
1960-1970	Beginning of the UN-led monitoring.
1970-1980	Second UN Development Decade.
1980-1990	Third UN Development Decade and International Drinking Water Supply and Sanitation Decade.
1990-2000	Fourth UN Development Decade and beginning of Millennium Development monitoring.
2000-2015	Millennium Development Goals (MDG) and International Decade for Action: Water for Life (2000-2015).
2015-2030	Sustainable Development Goals (SDG) and Decade for Action (2020-2030).

In 1990, the World Health Organisation (WHO) and United Nations Children's Fund (UNICEF) combined monitoring efforts through the Joint Monitoring Programme (JMP) for Water Supply and Sanitation (WHO/UNICEF, 2015). The JMP has since provided regular estimations towards international monitoring targets for the Millennium Development Agenda and the Sustainable Development Agenda.

2.2.1 Millennium Development Goal for water

In September 2000, the Millennium Declaration was adopted by the UN General Assembly member states (United Nations General Assembly, 2000). The subsequent MDGs set out eight time-bound objectives associated with development policy (United Nations General Assembly, 2001). The seventh goal "Ensure environmental sustainability", sets out the target for drinking water (MDG 7c), "By 2015, halve the proportion of people without sustainable access to safe drinking water and basic sanitation". To monitor the progress towards this target, the JMP set out 'service ladders' for water and sanitation, as outlined in Table 2.2.

Table 2.2 Drinking water service ladder, adapted from WHO/UNICEF (JMP), 2008.

Service		Description
Improved	*Piped*	Piped household water connected to user dwelling, plot or yard.
	Other	Public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs or rainwater connection.
Unimproved	*Unimproved*	Unprotected dug well, unprotected spring, cart with small tank/drum, bottled water.
	Surface Water	River, dam, lake, pond, stream, canal, irrigation channels.

In 1990, it was estimated that 76% of the world's population had access to 'improved' water. MDG 7c was declared met in 2010 with an estimated 89% of the global population with access to 'improved' water (WHO/UNICEF, 2010), which further increased to 91% with 'improved' access (WHO/UNICEF, 2015). The JMP further observed over the MDG period that the inequalities between rural and urban drinking water coverage have reduced. While there has been little change in water supply coverage in the urban setting (95% improved coverage in 1990 to 96% improved coverage in 2015), the rural setting has expressed rapid increase of coverage (62% improved coverage in 1990 to 84% improved coverage in 2015).

While the MDGs have shown an impressive increase in water supply coverage, the target met in 2010 was largely influenced by populous countries such as China and India, with Sub-Saharan Africa (SSA) lagging behind (WHO/UNICEF, 2010). The end of the MDGs also saw 663 million people without access to an improved supply, with half of these people living in SSA (WHO/UNICEF, 2015). Furthermore, the actual number of people with 'sustainable access to safe drinking water' may be much lower. The indicator to measure MDG 7c's progress primarily encompasses the number of people with access to an 'improved' source, by which MDG 7c's success is measured. This fails to account for important parameters such as water quality, reliability of the source, sufficient yield, the distance and the time to collect water (Martínez-Santos, 2017). The indicator further fails to include the human right to water, which states “the right of everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses” (United Nations, 2002, 2010). Targets in the post-2015 agenda required addressing the unfinished business of the MDGs and service indicators that build on the existing MDG indicators that address inequalities (WHO/UNICEF (JMP), 2016).

2.2.2 Sustainable Development Goal for water

At the end of the MDG era, all members of the UN General Assembly agreed to 17 goals set out in the 2030 Agenda (United Nations, 2015). The Sustainable Development Goals (SDG) ambitiously set out to “end poverty in all forms”, “shift the world onto a sustainable and resilient path” and to ensure “no one is left behind”.

The sixth goal, “ensure availability and sustainable management of water and sanitation for all”, sets out the target for drinking water (SDG 6.1), “By 2030, achieve universal and equitable access to safe and affordable drinking water for all”. The normative interpretation of SDG 6.1 can be used for designing monitoring indicator, while recognising routine monitoring of some elements is not possible. WHO/UNICEF (JMP), 2016, describes this as follows:

- **‘Universal’:** *All exposures and settings such as households, schools, health facilities, public spaces and workplaces.*
- **‘Equitable’:** *Reduction and elimination between inequalities.*
- **‘Access’:** *Sufficient and available water to meet domestic needs.*
- **‘Safe’:** *Drinking water free from pathogens and high toxic chemicals levels at all times.*

- **'Affordable':** *Payment for service does not prevent access or meeting basic human needs.*
- **'Drinking water':** *Used for drinking, cooking, food preparation and personal hygiene.*
- **'For all':** *Does not exclude gender, age or disabilities.*

The transition between the global goals also required an improvement to the monitoring indicators set out under the JMP. The indicators built on the MDGs by going beyond measuring the infrastructure to provide access to take into account the quality of service (Ortigara *et al.*, 2018). The indicator 'improved' under the MDG service ladder was split into 'safely managed', 'basic' and 'limited' under the new SDG service ladder. This is described in Table 2.3.

Table 2.3 Drinking water service ladder, adapted from WHO/UNICEF (JMP), 2016.

Service		**Description**
Improved*	*Safely Managed*	Drinking water from an improved source that is available when needed, accessible on premises and free from contamination.
	Basic	Drinking water from an improved source that does not meet any of the safely managed criteria but takes less than 30 minutes round trip.
	Limited	Drinking water from an improved source that does not meet any of the safely managed criteria and takes more than 30 minutes round trip, including queuing time.
Unimproved	*Unimproved*	Unprotected dug well or unprotected spring.
	Surface Water	River, dam, lake, pond, stream, canal, irrigation channels.

* Improved sources include: piped water, public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs, rainwater connection or delivered water.

The transition to the 2030 Agenda required assessment of the global populations access to drinking water respective of the JMPs redeveloped service ladder. In 2015 it was estimated that 89% of the global population utilised at least basic level of drinking water, with 844 million people utilising limited, unimproved or surface water (WHO/UNICEF, 2017a). Users that utilise unimproved or surface water sources that take longer than 30 minutes to collect, are subjected to a double burden (WHO/UNICEF, 2017b).

In 2018, the UN produced a synthesis report on the progress towards SDG 6. While it acknowledged progress had been made, the world was not on track to meet the target without significant acceleration. Furthermore, the success of the SDGs commitment to ‘leave no one behind’ requires increased attention, monitoring and elimination of the inequalities in drinking water services (United Nations, 2018a). This includes the elimination of inequalities between urban and rural populations, high and low incomes, vulnerable subnational areas and disadvantaged groups (WHO/UNICEF (JMP), 2016; Roche, Bain and Cumming, 2017). The report also acknowledged the significant attention needed towards increasing the capacity to plan and manage water resources across the sector.

The UN General Assembly in 2019 further acknowledged the slow progress towards the 2030 deadline. The UN General Assembly pledged to accelerate progress by addressing themes in the trends impacting achievement the SDGs, accelerating and influencing progress towards the SDGs, localising the SDGs and the partnerships required (Editorial, 2019). The 2020-2030 vision, declared as the ‘decade of action’, calls for accelerating sustainable solutions to deliver the SDGs by 2030.

Box 2.1 Knowledge Gap 1 – Monitoring reliability and operational status of systems.

The monitoring indicators used in the MDGs and SDGs shows an increase for improved sources usage. However, this focuses on coverage to dictate progress and fails to denote the reliability and operational status of the systems. It is unknown if these systems provide a sustainable source of drinking water, a requirement of the global goals. This knowledge gap is addressed through RQ 1. SO 1

2.3 Drinking water in Malawi

SSA largely fell behind in achieving MDG 7c, however, Malawi was one of the few countries within the region that was on track in 2010 (WHO/UNICEF, 2010) and met the target in 2015 (WHO/UNICEF, 2015). Table 2.4 outlines the increase in drinking water coverage between 2000 and 2015 under the MDG and reassessed SDG service ladders. Safely managed assets cannot be estimated in Malawi due to the lack of monitoring data collected on water quality during the MDGs.

Table 2.4 Progress of coverage in Malawi, adapted from WHO/UNICEF, 2015.

Service Ladder		**Year**	**National (%)**	**Rural (%)**	**Urban (%)**
MDG Service Ladder					
Improved	Piped	2000	22	12	79
		2015	22	10	81
	Other	2000	44	49	14
		2015	65	75	15
Unimproved	Unimproved	2000	25	29	6
		2015	10	12	4
	Surface Water	2000	8	10	1
		2015	3	3	0
SDG Service Ladder					
Improved	Safely Managed	2000	-	-	-
		2015	-	-	-
	At least basic	2000	52	46	84
		2015	67	63	87
	Limited	2000	15	16	9
		2015	20	22	9
Unimproved	Unimproved	2000	25	29	6
		2015	10	12	4
	Surface Water	2000	8	10	1
		2015	3	3	0

The monitoring of water supply during the MDG period shows a reduction in unimproved sources use, but also the distinct difference in the type of improved source coverage between the urban and rural setting. The urban setting presents a significant coverage of piped networks while the rural setting presents other types of improved sources, typically in the form of boreholes equipped with handpumps.

Of the country's 18.6 million people approximately 84% reside in the rural setting, with more than 50% below the poverty line (Government of Malawi, 2018). There is an overall reliance on groundwater access for the main source of daily water needs and for social and economic development of Malawi's population. However, the benefits of groundwater access can be hindered by poor or objectionable water quality, resulting from poor siting and construction of water points. In the Southern region of Malawi, saline water is a known issue for rural groundwater access (Monjerezi and Ngongondo, 2012; Rivett, Miller, *et al.*, 2018; Rivett, Budimir, *et al.*, 2019). A borehole encountering saline water is defined as a 'defective borehole' and should be sealed off and confined to the strata it is found (Government of Malawi, 2013). Proper reporting of saline groundwater is required to avoid tampering and further implementation of saline assets.

Salinity can be indicated by the levels of Total Dissolved Solids (TDS) which incorporates inorganic salts, and the Electrical Conductivity (EC) of water. While there are no health concerns associated with TDS, high levels may impact the acceptability and may become objectionable to communities in saline groundwater regions of Malawi (WHO, 2017a). Multiple source use is a common behaviour among water user (Vedachalam *et al.*, 2017; Foster and Willetts, 2018), and may lead to increasing unimproved source use as communities find saline source objectionable. Thereby posing risks to community health from unimproved source usage (Hunter, MacDonald and Carter, 2010).

Box 2.2 Knowledge Gap 2 – International vs. national standards for salinity thresholds.

Monitoring water quality is required for 'safely managed' services in the SDG 6 monitoring ladder. However, national water quality guidelines may be at odds with international standards. However, salinity thresholds in Malawi (TDS of 2000mg/L and EC of 3500 µS/cm (Malawi Bureau of Standards, 2005)) are significantly higher than the WHO guidelines (good quality water with TDS of 600 mg/L and increasingly unpalatable greater than 1000 mg/L (WHO, 2017a)). Significantly higher limits in Malawi may influence improved source coverage in saline areas, that are unfit for use and impact community behaviours towards source usage. This knowledge gap is addressed through RQ 1. SO 2.

Access to safe and clean drinking water impacts the fulfilment of multiple SDGs, not just SDG 6 (Mainali *et al.*, 2018; Kroll, Warchold and Pradhan, 2019). Under the SDG monitoring ladder problems arise for the rural population as limited access has increased during the MDG era (Table 2.4), which must be addressed in the 2030 agenda. Further issues of access arise as Malawi is one of the most water-scarce countries in the world, with less than 1400 m^3/year/person of available total water resources (Rijsberman, 2006). Seasonal variations impact water resources as rainfall and surface water is reduced, further highlighting the importance of groundwater resource management during this period (Kelly *et al.*, 2018; Kelly, Bertram, *et al.*, 2019; Thomson *et al.*, 2019).

2.3.1 Groundwater exploitation for rural populations

In rural SSA, an estimated 184 million people rely on handpumps for domestic supply (Macarthur, 2015). Boreholes equipped with handpumps have played a fundamental role in increasing access to improved drinking water sources during the MDGs. This is particularly evident in Malawi where the JMP monitored an increase in improved drinking water sources such as boreholes equipped with handpumps, while piped access declined during the MDGs (WHO/UNICEF, 2015).

Community deep-well handpumps typically serve 200 to 500 people. The most popular of these in the public domain are the India Mark II/Mark III, the Zimbabwe Bush Pump and the Afridev (Baumann and Furey, 2013). Handpump standardisation, led by UNICEF in the 1990s, determines the choice around specific handpumps installed in a country (Macarthur, 2015).

In Malawi, the Afridev is the main handpump design choice due to its initial development in Malawi as the Maldev in early 1981 in collaboration with the Malawi Government, UNICEF, UNDP and the World Bank (ERPF, 2007). The aim of the Maldev was to develop a handpump that was easy to maintain at village level and manufactured in industrial resource limited countries such as Malawi. The concept of village level operations and maintenance (VLOM) was conceived in the 1980s through the idea that if handpumps were easier to maintain, communities could be responsible for them (Arlosoroff *et al.*, 1987). The Afridev has been described as the most widely recognised VLOM handpump since its development, that can be produced locally while being affordable and reliable (Hankin, 2001; ERPF, 2007; Baumann and Furey, 2013; Macarthur, 2015).

2.4 Decentralisation of rural water supply management

Malawi's vision for rural water services reflect the MDGs, subsequent SDGs and the idea of decentralising service provision to community level.

> "*To achieve sustainable provision of community owned and managed water supply and sanitation services that are equitably accessible to and used by individuals and entrepreneurs in rural communities for socio-economic development at affordable cost.*"
>
> (MoAIWD, 2005).

Box 2.3 Knowledge Gap 3 – Monitoring affordability at the local level.

There is no commonly agreed way to monitor affordability (United Nations, 2018a). The specification of affordability in Malawi's national policy and the SDGs, does not provide detail about how this is to be accomplished, particularly at the local level. Considerations by local service providers, when establishing necessary financial contributions for O&M, and the drivers behind them may highlight how affordability is reflected in the local context. This knowledge gap is addressed through RQ 2. SO 3 and 4.

Decentralisation of the management and ownership of community supplies is complex in Malawi. Oates and Mwathunga (2018), discuss in detail how many challenges of Malawi's water sector are systemic. Improving sustainable services are challenged by complex governance structures, weak regulation and monitoring, insufficient human and financial capacity, incoherent governance structures and policies.

2.4.1 Central Government

Rural water supply services are the responsibility of the Ministry of Agriculture, Irrigation and Water Development (MoAIWD) (MoAIWD, 2005). The Water Resources Department (focus on the development and monitoring of groundwater sources, and water quality) and the Water Supply Department (focus on the O&M of water points including the training of Area Mechanics and water point committees) are the main departments involved with rural groundwater supplies (Oates and Mwathunga, 2018). The agency guides programme implementation through policies, legislation and regulation. However, competition for funding with other development sectors in Malawi adds additional challenges for the MoAIWD. As a result there is no dedicated budget line for O&M for water points (Baumann and Danert, 2008).

2.4.2 District Government

The planning at district level is primarily a bottom-up process, as water is high priority for communities. There are a range of district level stakeholders that hold responsibilities for different areas of the planning and implementation process (MoAIWD, 2010), however the local government structure is often informal or fragmented due to incoherent legal frameworks and policy (Oates and Mwathunga, 2018). Generally, the overall development of district sector activities is the District Council. Executive decisions are made by the District Executive Committee (DEC) who are supported by the District Coordination Teams (DCT), the technical arm for the water sector. Building capacity at the community level requires training and assistance to plan, manage, repair, maintain and monitor water services. This is the responsibility of the DCT (MoAIWD, 2010). However, the overall lack of human and financial capacity at the district level undermines sustainable rural water supply and fulfilling crucial district functions (Oates and Mwathunga, 2018). It is heavily supported by other sector stakeholders to fulfil capacity shortfalls.

2.4.3 NGOs and Private Sector

Private sector and NGOs are actively encouraged to play a fundamental role in delivering water supply services (MoAIWD, 2005). Malawian policy recommends borehole construction and rehabilitation to international aid and the private sector (MoAIWD, 2010). While long term maintenance costs rely on NGOs to finance (Scanlon *et al.*, 2016; Kativhu *et al.*, 2018). Malawi's water sector encompass a range of international and local NGOs, and civil society organisations that support the delivery of water supply to rural communities (Oates and Mwathunga, 2018). However, this also makes coordinating, monitoring and accountability within the sector challenging (RWSN Executive Steering Committee, 2010). Efforts are often duplicated (Songola, 2011), with NGOs rarely reporting new constructions (Baumann and Danert, 2008). Furthermore, financing, monitoring, and post-construction training communities and local Area Mechanics is limited. Service delivery is often a one-time investment as NGOs typically have their own agenda (Whittington *et al.*, 2009; RWSN Executive Steering Committee, 2010; Baumann and Furey, 2013). In most cases NGOs allocate rehabilitation budgets at the time of failure rather than as a part of sustainability planning (Geremew and Tsehay, 2019).

2.4.4 Area Mechanics/Technical service providers

Technical service providers provide specific technical services on a contractual or a compensatory basis in a designated area (MoAIWD, 2010). Area Mechanics in particular operate in the local area undertaking water point repairs that are out with routine maintenance conducted at community level. They are part of the government structure at sub-district level, trained in water point maintenance to serve their local communities. However, Area Mechanics are not paid a government salary but are paid with their agreements with communities for work conducted on local water points. This results in confusion over the role of the Area Mechanic in this regard. Baumann and Danert (2008), highlight that communities are reluctant to compensate Area Mechanics as they believe they are government workers or volunteers. Oates and Mwathunga (2018), further discuss this challenge as Area Mechanics balance social obligations, resulting in voluntary work, and economic relationships with the community in their area. Despite these challenges, both authors acknowledge that Area Mechanics are a positive influence on the sector. They are trained to undertake repairs without assistance from other layers of government, that fills a gap in support to local communities.

2.4.5 Community Level

The community management of VLOM water supply technologies has become a popular paradigm since its emergence during the International Decade of Drinking Water Supply and

Sanitation in the 1980s (Arlosoroff *et al.*, 1987; Briscoe and de Ferranti, 1988). The concept of Community Based Management (CBM) aims to benefit and empower communities by voluntarily having a major role in development, have ownership of the water supply system and have 100% of the operations and maintenance (O&M) responsibilities (Briscoe and de Ferranti, 1988; Evans and Appleton, 1993; Harvey and Reed, 2006a; Lockwood and Smits, 2011). The model has gained widespread acceptance by governments and organisations across SSA since its conception. This model is a core aspect of Malawi's decentralised rural water sector policy.

Government of Malawi guidance advises communities to form Water Point Committees (WPC), carrying out repairs and collect maintenance funds in the form of household contributions to fulfil the costs of water point O&M (MoAIWD, 2010). However, the sustainability of the CBM model requires appropriate institutional support and structure which is lacking in most cases (Schouten and Moriarty, 2003; Blaikie, 2006; Harvey and Reed, 2006a; RWSN Executive Steering Committee, 2010; Baumann and Furey, 2013; Moriarty *et al.*, 2013; Mcintyre *et al.*, 2014; Chowns, 2015b).

The CBM model has been seen as way of removing responsibilities of Government and implementing organisations for sustainable service delivery, by referring to assets as 'community managed' (Harvey, 2008; Chowns, 2015a). Community participation, whereby communities are established as effective decision makers, and training are important for the continued O&M of the water point (Matamula, 2008; Whittington *et al.*, 2009). While this is acknowledged as a crucial aspect of sustainable rural water provision in SSA, the community management, i.e. ownership and control, is not (Harvey and Reed, 2006a). This is problematic in rural Malawi when policy dictates 'sustainable provision of community owned and managed water supply services'.

Decentralisation through the CBM model must be adequately supported and should not leave communities isolated by themselves. The understanding that a sense of ownership improves sustainability is a major assumption in CBM. However, the model is 'often a one size fits all' paradigm that rarely reflects the ideal context of the community or translate into sustainability (Moriarty *et al.*, 2013; van den Broek and Brown, 2015; Kativhu *et al.*, 2018). This has led to more professionalised approaches as greater levels of service delivery are expected (Lockwood and Smits, 2011; Hutchings *et al.*, 2015). Particularly due to the limitations of CBM through its informality and voluntarism (Moriarty *et al.*, 2013; Chowns, 2015b; van den Broek and Brown, 2015).

2.5 Sustainable Service Delivery

Both the MDGs and SDGs have emphasised 'sustainable access' as part of their water goals and targets. VLOM handpumps have increased access to drinking water however an estimated two out of three are operational at a given time (RWSN Executive Steering Committee, 2010). The challenges associated with CBM further hinder the continued sustainability of handpumps which last approximately 5 years without appropriate O&M (Baumann, 2006). As a result, the intended benefits of functional water services are lost for the communities (Hunter, MacDonald and Carter, 2010).

2.5.1 Functionality

Mapping and monitoring has commonly used the term 'functionality', to define water point performance and sustainability (Carter and Ross, 2016). This term has been used to represent the water point at a point in time and its overall service performance (Carter and Ross, 2016; Bonsor *et al.*, 2018). The default indication dictates whether a water point is working or not working, however there is difficulty in comparing statistics due to the lack of a sector wide definition amongst studies. Wilson *et al.* (2016), reviews 111 studies to categorise six main functionality categories:

1. No explicit definition that defaults to working or not working.
2. Binary category defined as working or not working at the time of visit.
3. Multiple categories to compare levels of functionality.
4. Tiered category to examine greater functionality detail.
5. Sustainability assessment examining different factors to indicate the reliability of a system.
6. Assessment if the system is providing the design yield at the time of visit.

Functionality as an indicator is acknowledged as being limited in measuring performance particularly due to it being a snapshot in time of the service (Adank *et al.*, 2014; Carter and Ross, 2016). Functionality alone fails to accommodate influential factors affecting handpump services. This has been the focus of recent studies to uncover drivers of functionality such as the influence of seasonality, groundwater quality and availability, socio-cultural factors, technical aspects, and institutional and financial characteristics (Foster, 2013; Adank *et al.*, 2014; Bonsor *et al.*, 2015; Walters and Javernick-Will, 2015; Fisher *et al.*, 2015; Carter and Ross, 2016; Cronk and Bartram, 2017; Kativhu *et al.*, 2017; Kelly *et al.*, 2018; Foster, Willetts, *et al.*, 2018; Foster *et al.*, 2019; Whaley *et al.*, 2019; Kalin *et al.*, 2019; MacAllister *et al.*, 2020).

Box 2.4 Knowledge Gap 4 - Component breakdown as a driver for functionality.

Functionality has been the focus of studies and the drivers behind it when concerning handpump sustainability. This is often generalised and encompasses the functionality of multiple types of handpumps that consist of different components. Life-cycle planning involves understanding when components need replacing before their failure, to avoid breakdown and eventual, or premature, abandonment. It is important to better understand how component breakdowns influence functionality, and the drivers behind this issue. This knowledge gap is addressed through RQ 4. SO 8 and 9.

Common approaches include the use of multivariable logistic regression (Whittington *et al.*, 2009; Foster, 2013; Fisher *et al.*, 2015; Cronk and Bartram, 2017) and systems thinking methodology (Fisher *et al.*, 2015; Cronk and Bartram, 2017; Liddle and Fenner, 2017). Understanding the drivers behind functional services is crucial to target appropriate ways to ensure continued serviceability. Particualrly as low functional or abandoned services leads to unsafe, unimproved source use (Hunter, MacDonald and Carter, 2010).

2.5.2 Life-Cycle Costing and Management

Life-cycle costing (LCC), refers to the costs of ensuring service delivery from the construction of new systems to the costs of maintaining them in the short and long term, at the lower and higher institutional levels (Moriarty *et al.*, 2010). Investments can then take a building-block approach to improve capacity building, governance and guidance over the *ad hoc* investment approach into increasing access at present (Reddy and Batchelor, 2012). The life-cycle cost approach (LCCA) can be adopted into decision support systems and management information systems (MIS) to improve the monitoring and service delivery of water supply infrastructure across their life-cycle at the national, district and local levels (Fonseca *et al.*, 2011; Reddy and Batchelor, 2012) This service delivery approach requires investment to continue following the installation of new water services. Such costs are outlined in Table 2.5.

Table 2.5 Aspects of life-cycle costing adapted from (Fonseca et al., 2010).

Component	Description
Capital Expenditure (CapEx)	Consists of one-time costs that cover the construction of the fixed asset (hardware) and the pre-construction capacity building for stakeholders to continue service (software).
Cost of Capital (CoC)	The costs associated with funding a programme.
Capital Maintenance Expenditure (CapManEx)	Consists of work that goes beyond routine maintenance to cover renewal, repairs, replacement, and rehabilitation of services in order to keep systems running.
Operating and Minor Maintenance Expenditure (OpEx)	Includes minor maintenance to keep systems running, typically between 5 and 20% of capital costs. Does not include major repairs.
Expenditure on Direct Support (ExpDS)	The costs of providing post-construction support to local stakeholders. Local government has the capacity to monitor systems and support communities when systems break are often overlooked.
Expenditure on Indirect Support (ExpIDS)	Includes macro-level government planning, policy making, establishing frameworks and institutional arrangements, and capacity building for professionals.

Accounting for the costs highlighted in Table 2.5 is required by governments, donors and implementing stakeholders to understand how much they are required to invest, and budget for, across the life-cycle of water supply assets. Fonseca *et al.* (2011), discuss in detail three potential accounting methodologies that consider the life-cycle cost of services to assist with service providers financial planning. These are as follows:

- Cash accounting.
- Regulatory approach.
- Economic or Engineering approach.

‘Cash accounting’ adopts a cash flow management approach, which looks at the historical costs recorded to help governments and agencies budget for future requirements. This method is particularly used by accountants. Cash flow management is concerned with the efficient use of a stakeholders cash and short-term investments (Gregory, 1976). This records the investment costs, however, does not account for fixed assets after investment has been distributed. As a result there is typically no record of what fixed assets have been constructed, the condition and the costs required to maintain or renew, and are unlikely to deliver sustainable services (Fonseca *et al.*, 2011). This is a particularly problematic approach for investments across Malawi as investments intended to increase access, fall into disrepair and are abandoned (Kalin *et al.*, 2019).

The ‘regulatory’ approach adopts fixed asset accounting and asset management to deliver a service, and provides the most useful answer to the question ‘what is the cost per year per person of delivering clean water services’ (Fonseca *et al.*, 2011). This allows monitoring and control of service provider performance to set appropriate tariffs for water users (Akhmouch, 2012), to ensure infrastructure continues to provide an agreed upon level of service that is cost effective across its life-cycle. Assessments utilise current costs to accommodate CapManEx costs and depreciation of assets which cannot be accomplished using historic costs. This is predominantly used in urban utility services as issues arise in the rural water sector due to a lack of monitoring information and lack of understanding of the costs incurred (Fonseca *et al.*, 2011). Overall highlighting the importance of adopting an asset management approach to ensure the appropriate funding, planning and management of rural water services.

The ‘economic’ or ‘engineering’ approach considers a life-cycle assessment using the present value technique, particularly used by planners and economists. Woodward (1997), describes the “LCC seeks to optimise the cost of acquiring, owning and operating physical assets over their useful lives by attempting to identify and quantify all the significant”. This is particularly appropriate when comparing alternative future services. For example, a large CapEx project, such as a dam, may require low OpEx, while a low CapEx project, such as boreholes equipped with handpumps, will require higher future OpEx. The approach is the most useful when considering single asset system. In the rural community context, this single asset system accounts for the VLOM handpumps managed under CBM.

2.5.2.1 CapEx - Hardware and software costs of increasing access

The 'hardware' of CapEx consists of the construction costs of fixed water supply assets. In the case of point source access in rural Malawi, this consists of the borehole or well and the handpump lifting mechanism, typically the Afridev handpump. Boreholes typically have long design lives (Driscoll, 1986), while handpumps have a significantly shorter life (i.e. approximately 10 years). The Afridev handpump in particular has an estimated design life of 15-20 years, that can last years with little to no maintenance (Wood, 1993). Since each component can be replaced, handpumps theoretically can continue to provide a service indefinitely (Arlosoroff *et al.*, 1987). The 'software' of CapEx accounts for the pre-construction capacity building into service provision to ensure a continued service. In rural Malawi and across SSA, the previously discussed CBM model is the promoted decentralisation mechanism to accomplish this. Investments from implementing stakeholders tend to focus on the installation of new water supplies (hardware) while training service providers for the O&M is lacking (software) (Baumann, 2006; Reddy and Batchelor, 2012; Kativhu *et al.*, 2018; Olaerts *et al.*, 2019). The heavy bias in favour of 'hardware' investment can lead to cheaper infrastructure being installed that incurs more frequent costs and maintenance to keep services running (Morgan, 1993; Franceys and Pezon, 2010; Reddy and Batchelor, 2012; Fonseca *et al.*, 2013).

Box 2.5 Knowledge Gap 5 – Monitoring CapEx 'software' costs.

> Malawian national policy recommends WPCs are established to be responsible for continued serviceability. The training and capacity building of decentralised service providers and establishing a financial mechanism for O&M are known drivers for successful services (Hutchings *et al.*, 2015; Etongo *et al.*, 2018; Whaley *et al.*, 2019). However, while monitoring the CapEx 'hardware' investment is accounted for in the global goals, the monitoring of CapEx 'software' is lacking. This knowledge gap is addressed through RQ 2. SO 3 and RQ 3. SO 5 and 7.

2.5.2.2 OpEx – Costs of maintaining service delivery

OpEx consists of the recurring expenditure to keep services running, estimated between 5% and 20% of the CapEx costs. This includes minor, routine maintenance but does not consist of major repairs or renewals (Moriarty *et al.*, 2010). The cost-recovery mechanism to fund such OpEx activities by local communities are primarily tariffs in the form of household contributions (United Nations, 2018a). Routine or preventative maintenance is the act of replacing components before they fail as opposed to corrective action which replaces components when they fail (Percy and Kobbacy, 1996). Owners or committees for Afridev handpumps are responsible for preventative maintenance and are therefore entitled to regular and necessary training (ERPF, 2007). However, preventative maintenance is rarely conducted and is not seen as a priority by communities (Chowns, 2015b; Etongo *et al.*, 2018). The majority of water users make financial contributions towards the O&M of systems after a breakdown has occurred which increases the time to mobilise spare parts and extends the downtime of systems (Kativhu *et al.*, 2018). Users value reliable assets alongside fast and timely maintenance, that can influence a community's willingness to pay towards these services (Olaerts *et al.*, 2019). However, where new investments have been made into providing services, there is a common belief that the maintenance is not the users responsibility (Morgan, 1993; Whittington *et al.*, 2009). Establishing systems or the capacity to maintain services over the duration of their life-cycle is essential to avoid abandoned handpumps and lost investment (Morgan, 1993; Franceys and Pezon, 2010). However, short term rewards remain popular over establishing long term sustainable services for communities (Morgan, 1993).

Box 2.6 Knowledge Gap 6 – Maintenance requirements of service delivery.

> Preventative, or routine, maintenance is seldom conducted by decentralised service providers in Malawi and is often seen as the responsibilities of others. Understanding the drivers behind why preventative maintenance is unconducted may aid in establishing maintenance models alongside infrastructure. CapManEx is also unconsidered in the life-cycle planning of water supply. Malawian policy recommends it be left to external stakeholders. However, the point where routine maintenance becomes CapManEx is poorly understood and results in services falling into disrepair. This knowledge gap is addressed through RQ 3. SO 6 and 7.

2.5.2.3 CapManEx – Beyond the costs of routine maintenance

The point where routine maintenance becomes CapManEx is a matter of frequency (if the cost occur more than once a year) and cost (greater than OpEx) (Franceys and Pezon, 2010). These describe the costs associated with major repairs, renewal, and rehabilitation costs to ensure continued service at the level it was first implemented. In the rural setting a borehole with a handpump consists of multiple components with their own life-cycles. This may require replacements of borehole casings, pump rods, handles and foot valves. The failure of components may result in the complete failure of a system. Figure 2.1 presents how regular CapManEx is necessary to continually provide serviceability and avoid breakdown. A lack of, shows early service decline that requires costly rehabilitation to re-establish service delivery.

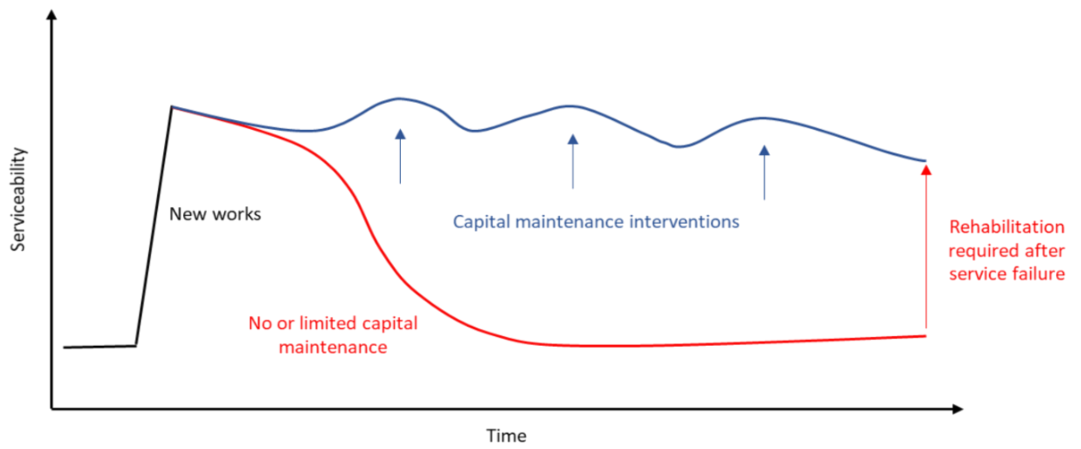

Figure 2.1 Serviceability and CapManEx of water supply assets, source Franceys and Pezon (2010, p.3).

CapManEx is crucial for the sustainability of water supply assets. However, these costs are seldom considered by stakeholders in the pre and post-construction of water supply assets (RWSN Executive Steering Committee, 2010; Mcintyre *et al.*, 2014; Geremew and Tsehay, 2019). Malawian national policy guidelines recommends these costs to non-community stakeholders (MoAIWD, 2010), due to inability of financing such costs at the local level (United Nations, 2018a). The rural water sector is further challenged by the implementation of shorter life technologies (i.e. handpumps) that require earlier CapManEx (Fonseca *et al.*, 2013). This is compounded by local behaviours of waiting until the failure of systems before action is taken (Moriarty *et al.*, 2013; Etongo *et al.*, 2018; Kativhu *et al.*, 2018; Whaley *et al.*, 2019). The investments by governments, donors and NGOs into the establishing services, are relied upon to finance CapManEx activities (Fonseca *et al.*, 2013; Scanlon *et al.*, 2016; Kativhu *et al.*, 2018).

2.6 Summary

This chapter demonstrated the context of water supply infrastructure investment and maintaining such infrastructure in the rural sector of Malawi, through a general literature review. Both the MDGs (set for 2000 and 2015) and SDGs (set for 2015 and 2030) have goals and targets relating to clean and sustainable access to drinking water. Malawi met the MDG target for water by 2015 which saw a significant increase of handpumps, primarily the Afridev handpump, installed across the rural areas. VLOM handpumps and CBM gained increased popularity by governments and implementing organisations as a form of empowerment to communities served by improved water sources. This is reflected by Malawian policy. However, it is widely accepted the decentralisation of water point management through CBM alone, is insufficient to ensure sustainable access emphasised under the global goals.

Both the MDGs and SDGs have emphasised a focus on increasing coverage of improved drinking water sources in their goals for water. The increased investments into improving coverage is encumbered by the enforcement of CBM to manage such investments post construction. Favouring the short term reward of providing new infrastructure over the long term investment of ensuring sustainable service delivery, hinders the achievement of the global goals and burdens communities. This is addressed in the following chapter.

CHAPTER 3. METHODOLOGY

3.1 Introduction

The previous chapter demonstrated the background to the global goals and decentralisation of rural water supply in developing countries. In general, continued sustainability across the lifecycle of rural water supply infrastructure under community management remains a challenge. Continuous monitoring is essential to further understand the quality of service provision, particular for sustaining aging infrastructure that has been subject to a major coverage goal initiative.

The main content of this thesis is developed as a series of papers to be published in peer-reviewed journals, each outlining methodology adopted in the publication. This chapter highlights the main materials and methodologies used throughout the research in fulfilling the aims of the thesis.

3.2 Research Philosophy

The research adopted a scientific (empirical) approach involving both inductive reasoning (starting with observations and moves towards theories) and deductive reasoning (to test if hypotheses are true). It is underpinned by a 'Pragmatist Research Philosophy' aligned with more practical research where methods are set around problem solving in the real world (Ormerod, 2006; Kaushik and Walsh, 2019). Typically encompassing multiple or mixed methods (Cresswell and Clark, 20011; Tashakkori and Teddlie, 2010; Tashakkori, Teddlie and Biesta, 2015). Ideas and quantitative methods are constructed and informed based in qualitative ideas drawn from literature review and a 'big dataset' of rural water supply in Malawi.

3.3 Climate Justice Fund Water Futures Programme

The Scottish Government Climate Justice Fund (CJF) Water Futures Programme has been working in partnership with the Government of Malawi evaluating the sustainability of rural water supplies since 2011. The programme aims to support the Government of Malawi to achieve SDG 6. The four work streams under the CJF programme include:

- ‘Asset Management and Data Collection’ to identify all water, waste, sanitation and irrigation/agricultural support infrastructure across Malawi, to be included in a live MIS for routine update, tracking of investment success and supporting data driven decision making by the Government of Malawi.
- ‘Capacity Building’ into groundwater development, hydrogeological studies, drilling practices and IWRM planning and monitoring. This includes workshops and training related to water management and water policy where Scotland and Malawi learn through joint and shared experience.
- ‘Policy Support’ vertical engagement for sub-district to ministerial levels of the water sector, through sharing policy best practice and development in the UK for consideration in Malawi.
- ‘Research and Knowledge Exchange’ to fill knowledge gaps for Government of Malawi decision making. The interdisciplinary research areas under this work stream are outlined in Table 3.1.

Table 3.1 CJF research areas in the public domain

Research Area	Study
Groundwater quality	• Contamination risk (Back *et al.*, 2018) • Monitoring frameworks (Rivett, Miller, *et al.*, 2018) • Salinity (Rivett, Budimir, *et al.*, 2019) • Arsenic (Rivett, Robinson, *et al.*, 2019) • Fluoride (Addison *et al.*, 2020)
Integrated Water Resource Management (IWRM)	• Transboundary assessments (Fraser *et al.*, 2018) • Local-scale water-food nexus: permaculture (Rivett, Halcrow, *et al.*, 2018) • Base-flow temporal variations using sporadic river data (Kelly, Kalin, *et al.*, 2019) • Discharge from groundwater to rivers (Kelly, Bertram, *et al.*, 2019) • Seasonal isotope variations (Banda *et al.*, 2020) • National assessment of base-flow temporal variations (Kelly *et al.*, 2020)
Asset Management	• Planning, construction and testing of water supply infrastructure (Mannix *et al.*, 2018) • Water point mapping for strategic decision making (Miller *et al.*, 2018) • Stranded water supply assets (Kalin *et al.*, 2019)
Sustainability of rural water supply	• Global goals and national policy influence on rural water supply functionality (Truslove *et al.*, 2019) • Localising global goals in rural water supply tariffs (Truslove, Coulson, Nhlema, *et al.*, 2020) • Life-cycle costing and barriers to handpump serviceability (Truslove, Coulson, Mbalame, *et al.*, 2020)

The research of this thesis falls under the Research and Knowledge Exchange work stream of the CJF programme. This research evaluates the sustainability of rural water supply assets across Malawi, as described in Table 3.1. This is accomplished by utilising and interrogating the data collected in the ‘Asset Management and Data Collection’ work stream, related to the community managed water supplies to evaluate long-term sustainability. Activities, field work and engagements throughout the research are described in Appendix B.

The technological focus of the thesis relates to boreholes equipped with Afridev handpumps. However, the research methods used throughout the thesis are transferable, to identify similar trends and issues for other rural water supply technologies under community management in Malawi.

3.4 Research Materials

3.4.1 mWater 'Big Dataset'

The 'big dataset' hosted on the MIS platform, mWater (www.mwater.co), provides the primary dataset for the research. Of the various MIS available, mWater was chosen as the preferred asset analysis platform due to a wide range of capacity and adaptability (BASEflow, 2017; Miller et al., 2018). The use of big data has significant potential in improving the understanding of the needs of low-income countries that can create more data driven and targeted policies (Taylor and Schroeder, 2015). There is a noticeable lack of local capacity to improve data collection in low-income countries (Jerven, 2013). The rising use of mobile technology has attempted to address this issue of data collection (Manyika *et al.*, 2011; Taylor and Schroeder, 2015; Dhoba, Nyawasha and Nyamuranga, 2017; Dickinson, Knipschild and Magara, 2017). However, it is imperative that policymakers are involved in identifying the development issues that need addressed, coupled with understanding the local context if targeted policies are to be adequately informed.

3.4.1.1 Data Collection and Live MIS

The data collection process in mWater by the CJF for a live MIS supports policy maker involvement coupled with local context understanding. Through a water point functionality survey, information regarding the viability and sustainability of each asset is collected based on SDG 6 indicators and the needs of the Government of Malawi in the rural water sector. This includes, but is not limited to, geographical information on water points and subsequent communities served, installation dates, donors and installers, service provider asset and water point O&M, accessibility, reliability, and functionality status of the water point. The water point functionality survey questions utilised throughout the thesis are described in Appendix A.

Rural water asset status data from 2011–2016 was collected under subcontract by the Non-Government Organisation (NGO) Water for People using AkvoFLOW (akvo.org/products) across 8 Southern Region districts of Malawi. A further mapping exercise was conducted across these Southern Region districts of Malawi in 2017–2018 using the mWater platform. All available historic data were subsequently imported into the mWater database. Since 2018, the programme has embarked on evaluating the asset status of every water point across Malawi, which was completed in December 2019. Since the completion of the mapping, the focus has been on capacity building for MoAIWD staff on the use of mWater for groundwater development and IWRM planning, through the 'Capacity building' work stream.

Data collection is conducted by Government of Malawi staff enumerators selected by each District Council in Malawi. The Government of Malawi staff go through classroom and field training to teach them how to respond to surveys which are provided in both English and Chichewa (local language). During this training they assess the functionality of the Afridev hand pump based on technical specifications. The additional data collected, such as the flow rate, assist with the functionality definition alongside design specifications. The data collection is conducted on mobile phones and uploaded to the live mWater dataset, 'Malawi CJF', for access to District, Regional and National Governments of Malawi staff to support data driven decision making.

Data that is uploaded to the server undergoes two rounds of approvals by the Governments mWater Task Force, before being accepted, viewable and shareable by the end user. These include extensive quality checks of the uploaded data, such as the accuracy of the mapped locations, and rejects any submissions that do not meet these quality checks. The rejection rate during approvals is less than 5% of the submitted data, and the monitoring of the accepted data is subject to thorough quality checks. Historic data that has been imported also goes through site deduplication, increasing the accuracy and reliability of long-term trends in the database.

3.4.2 Afridev Life-Cycle Dataset

The life-cycle of the Afridev handpump, being the licensed handpump in Malawi, was investigated in relation to the replacement intervals of components and associated costs for spare parts. The primary source for replacement intervals was the 'Installation and Maintenance Manual for the Afridev Handpump' in which Annex III describes the quantity of parts per pump, approximate lifetime and the recommended replacement interval of wearing parts (ERPF, 2007). Estimated costs of the Afridev components were gathered from 6 suppliers and estimators as part of a CJF workstream. The costs (in Malawian Kwacha, the currency in Malawi) and replacements are described in the Supplementary Information in Chapter 7.

3.4.3 Software

- mWater is free and open source MIS platform (www.mwater.co). Anyone can use the platform for free. Organisations have the option to invest into mWater to create new bespoke features, which are then offered to all users. The data portal allows for the design and deployment of surveys to be collected on mobile devices, monitor results in real time and custom visualisation of data for sharing and collaboration.

- Kobo Toolbox is a free and open source suite of tools for field data collection in challenging environments (http://www.kobotoolbox.org/) for survey creation and collection on mobile devices.
- QGIS 3.10.5 is free and open-source licensed under the GNU General Public License, produced by the Open Source Geospatial Foundation (OSGeo) (www.qgis.org), for viewing, editing and analysing geospatial data.
- MS Excel 2016 (v16.0) licence to the University of Strathclyde, produced by Microsoft, and used for data interrogation, data visualisation, life-cycle modelling, and scenario development in the thesis research.
- SPSS version 26.0 license to the University of Strathclyde, produced by IBM (https://www.ibm.com/uk-en/analytics/spss-statistics-software) for binary logistic regression analysis.

3.5 Research Methods

3.5.1 Data extraction from the mWater Dataset

The mWater platform allows for the data collected in the field to be visualised and collated into datasheets. The role of monitoring 'big data' allows trends and challenges for sustaining rural water supply infrastructure to be identified and further analysed. The live dataset collected by the CJF over the duration of the research is analysed and extracted for the purpose of papers published in the thesis chapters (Chapter 4-7). The total dataset encompasses 121,509 water points (by the end of the programme in December 2019). This research draws on the primary and policy recommended rural water supply technologies in Malawi. Boreholes (n=59,741 or 49.16% of all water points) equipped with Afridev handpumps (n=52,173 or 87.33% of lifting mechanisms). The dataset is further filtered using the aforementioned survey questions (in Appendix A) to identify data required for each chapter. Each chapter utilises 'big' data as more information is collected and added to the live MIS.

- Chapter 4 = 14,943 boreholes equipped with Afridev handpumps.
- Chapter 5 = 22,316 boreholes equipped with Afridev handpumps.
- Chapter 6 = 21,997 boreholes equipped with Afridev handpumps.
- Chapter 7 = 21,997 boreholes equipped with Afridev handpumps.

3.5.2 Life-Cycle Cost Approach Model for the Afridev Handpump

A life-cycle cost model of the Afridev handpump was developed for the analysis in Chapter 6. This incorporates a life-cycle cost approach (LCCA), described in detail in the previous chapter. Of the three approaches described, the Economic or Engineering approach was adopted. This was determined to be the most appropriate and reflective method to determine if local communities are capable of meeting future O&M requirements investigated in Chapter 7.

MS Excel was used to develop the model to address potential costs of the Afridev handpump over the 15 year design life. The components of the Afridev were assigned an expected life-cycle range (best and worst case) described in the Afridev maintenance manual (ERPF, 2007). The scenario builder function then allowed for the life-cycle and the number of replacements for each component across the design life, to be expressed in a best and worst case scenario. An average cost for each component was applied to be representative of each of the suppliers. These costs were then applied over the 15-years design life of the Afridev for two life-cycle models, upon the specified replacement intervals: life-cycle of replacing components under recommended repairs (R.R) and total operations expenditure (T.OpEx). T.OpEx included an assumed cost of transport costs and contracts for Area Mechanics to conduct repairs (MoAIWD, 2015). This is presented in the Supplementary Information in Chapter 7.

3.5.3 Regression Analysis

A binary logistic regression analysis was used to identify significant explanatory variables in Chapter 5 and 7, using the statistical package SPSS (version 26). This methodology allows for the determination of the relationship between a dichotomous dependant (Outcome = yes/no) and an independent predictor variable (categorical or continuous), while controlling for all other independent variables in the logistic regression model. This method has been widely adopted in the rural community setting, as outlined in Table 3.2.

Table 3.2 Summary of literature utilising multivariable logistic regression methods in the rural community setting in low income countries

Author	Country	Subject
Whittington et al., 2009	Bolivia; Peru; Ghana	Community managed model management and maintenance practices
Marks and Davis, 2012	Kenya	Relationship between user participation and ownership of systems
Foster, 2013	Liberia; Sierra Leonne; Uganda	Sustainability predictors for community managed handpumps
Marks, Onda and Davis, 2013	Kenya	Relationship between ownership and water system sustainability
Fisher et al., 2015	Ghana	Determinants for handpump functionality
Foster and Hope, 2017	Kenya	Water point sustainability; revenue collection approaches
Cronk and Bartram, 2017	Nigeria; Tanzania	Water system functionality
Cronk and Bartram, 2018	Honduras; Nicaragua; Panama	Improving piped water continuity; water system monitoring
Foster *et al.*, 2018	Kenya	Risks to failure of rural handpumps for water supply
Anthonj *et al.*, 2018	Ethiopia	Improving monitoring and water point functionality
Foster, Shantz, *et al.*, 2018	Cambodia	Operational sustainability of rural water supplies
Duchanois *et al.*, 2019	Bangladesh; Pakistan; Ethiopia; Mozambique	Factors associated with water service continuity for rural populations
Foster, McSorley and Willetts, 2019	Kenya; Gambia	Comparative performance of handpump technologies
Whaley *et al.*, 2019	Ethiopia; Malawi; Uganda	Functionality of community managed boreholes

Unadjusted odds ratio indicates the bivariate relationship between the dichotomous dependent variable and the independent predictor variable. Multivariable adjusted odds ratio allows for the calculation of odds ratios in which the effect of the other independent variables are accounted for. Explanatory variables were selected based on their relevance to sustainability and the rural water service provider context established through the water point functionality survey.

3.6 Summary

This chapter demonstrated the research materials and methods used to fulfil the thesis aim, research questions, specific objectives and knowledge gaps. The mWater and Afridev life-cycle datasets are presented as the primary sources of data for the thesis. The research methods are presented, highlighting the monitoring dataset, and the life-cycle and regression methods. The research methods used throughout the thesis are transferable to other low-income countries, to identify similar trends and issues where infrastructure is standardised (such as the Afridev in Malawi) under community management.

The large, live dataset collected in mWater allows for the analysis of trends and challenges of sustaining rural water supply infrastructure, identified by the knowledge gaps in Chapter 2. Both the MDGs and SDGs have emphasised a focus to increase coverage of improved drinking water sources in their goals for water. The increased investments into improving coverage is encumbered by the enforcement of CBM to manage such investments post construction. Favouring the short term reward of providing new infrastructure over the long term investment of ensuring sustainable service delivery hinders the achievement of the global goals and burdens communities. This is addressed in the following chapter.

CHAPTER 4. IMPACTS OF A COVERAGE TARGET APPROACH

The previous chapter demonstrated background to the global goals and decentralisation of rural water supply in developing countries. In general, continued sustainability across the life-cycle of rural water supply infrastructure under community management remains a challenge. Continuous monitoring is essential to further understand the quality of service provision, particular for sustaining aging infrastructure that has been subject to a major coverage goal initiative. This chapter addresses RQ 1: Has the drive to meet the success and coverage targets of the Millennium Development Goals (MDG) resulted in low-levels of service and a burden on decentralised service providers?

To investigate the burden of infrastructure resulting from the coverage targets of the MDGs, boreholes equipped with Afridev handpumps installed across Malawi were extracted from a comprehensive live dataset. The investigation was accomplished through a paper that addresses SO 1: Investigate the installation, functionality and rehabilitation of Afridev handpump boreholes during the MDG period under decentralised service provision. This is published in a peer reviewed journal, Water, as follows:

- Truslove, J.P., V. M. Miller, A., Mannix, N., Nhlema, M., Rivett, M., Coulson, A., Mleta, P. and Kalin, R. (2019) ‘Understanding the Functionality and Burden on Decentralised Rural Water Supply: Influence of Millennium Development Goal 7c Coverage Targets’, *Water*. Multidisciplinary Digital Publishing Institute, 11(3), p. 494. doi: 10.3390/w11030494.

Further discussion into the impact of sub-standard installations in the local context was established through the adaptation of a case study presented at an international peer reviewed conference. This addresses SO 2: With the aid of a case study, investigate how water quality thresholds contribute to coverage investments that are unfit for use, as follows:

- Truslove, J.P., Small, H., Nhlema, M., Harawa, K. A. Coulson, A. B. and Kalin, R. (2018) ‘An investigation of community pooled resources for sustainable handpump maintenance: The relationship between water user participation and saline water in Kakoma, Malawi.’ (Poster), Water and Health Conference: Where Science Meets Policy 2018, University of North Carolina.

4.1 Paper: Understanding the Functionality and Burden on Decentralised Rural Water Supply: Influence of Millennium Development Goal 7c Coverage Targets

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Keywords: borehole; decentralisation; functionality; hand pump; low-income regions; maintenance; Malawi; rehabilitation; sustainability

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[b] **Conceptualisation:** J.P.T.; **Methodology:** J.P.T. and A.V.M.M.; **Data Curation:** J.P.T., A.V.M.M., M.N., P.M. and R.M.K.; **Formal Analysis:** J.P.T.; **Writing (Original draft preparation):** J.P.T.; **Writing (Review and editing):** J.P.T., A.V.M.M., N.M., M.N., M.O.R., A.B.C. and R.M.K.; **Visualisation:** J.P.T. and A.V.M.M.; **Supervision:** A.B.C. and R.M.K.

4.2 Abstract

The sustainability of rural groundwater supply infrastructure, primarily boreholes fitted with hand pumps, remains a challenge. This study evaluates whether coverage targets set out within the Millennium Development Goals (MDG) inadvertently increased the challenge to sustainably manage water supply infrastructure. Furthermore, the drive towards decentralised service delivery contributes to the financial burden of water supply assets. A sample size of 14,943 Afridev hand pump boreholes was extracted from a comprehensive live data set of 68,984 water points across Malawi to investigate the sustainability burden as emphasis shifts to the 2030 agenda. The results demonstrate that the push for coverage within the MDG era has impacted the sustainability of assets. A lack of proactive approaches towards major repairs and sub-standard borehole construction alongside aging infrastructure contributes to reduced functionality of decentralised supplies. Furthermore, costly rehabilitation is required to bring assets to operational standards, in which external support is commonly relied upon. Acceleration towards the coverage targets has contributed towards unsustainable infrastructure that has further implications moving forward. These findings support the need for Sustainable Development Goals (SDG) investment planning to move from a focus on coverage targets to a focus on quality infrastructure and proactive monitoring approaches to reduce the future burden placed on communities.

4.3 Introduction

In 2015, the Millennium Development Goals (MDG) ended. Between 2000 and 2015, the MDG target for water and sanitation (7c) aimed “to halve the proportion of people without sustainable access to safe drinking water and basic sanitation”. According to the World Health Organisation (WHO)/United Nations Children’s Fund (UNICEF) Joint Monitoring Programme (JMP) for Water Supply and Sanitation, this target was globally delivered in 2010. Target achievement was highly influenced by large, populous countries such as China and India, with Sub-Saharan Africa (SSA) lagging behind (WHO/UNICEF, 2010). By 2015, 91% of the global population was reported to be using an improved drinking water supply, such as piped water, boreholes, protected wells and springs or rainwater. However, 663 million people did not have access to an improved supply, with half of these people living in SSA (WHO/UNICEF, 2015). In 2015, all member states of the UN General Assembly agreed to “the 2030 Agenda”, which aims to “end poverty in all forms”, to “shift the world on to a sustainable and resilient path” and to ensure “no one will be left behind”. Within the 17 Sustainable Development Goals (SDG) that were established, SDG 6 aims to “ensure availability and sustainable management of water and sanitation for all” and displays an increased focus on global water and sanitation challenges. The commitment to “leave no one behind” will require an increased focus on sustainable supplies for disadvantaged groups in low-income regions drawing on lessons learned from the coverage approach of the MDGs.

The JMP indicators have since been updated to reflect the SDGs, and to include additional criteria for water supply service levels. The 2017 progress report on the SDG highlights how the SDGs address the unfinished business from the MDGs and raise the bar with new monitoring categories (WHO/UNICEF, 2017a). At the high political forum in July 2018, the progress of SDG 6 was under review, highlighting the proportion of the population that meet these new monitoring criteria and the challenges of meeting a sustainable water future (United Nations, 2018b). This review further highlights the continued slow progress of SSA towards global targets as 38% of the population do not even have a basic level of service, compared to 12% of the overall global population in 2015.

While the JMP confirms positive progress in rural water supply usage during the MDGs, concerns have been raised that these indicators actually hide a low level of service, as further discussed by Adank *et al.* (2016). In rural SSA, an estimated 184 million people rely on hand pumps for domestic supply (Macarthur, 2015), with approximately two out of three hand pumps working at a given time (RWSN Executive Steering Committee, 2010). Across SSA, the Afridev hand pump is the most widely recognised village-level operations-and-maintenance (O&M) pump (Macarthur, 2015). While the installation of such improved supplies has improved the coverage of the region, the reliability of hand pump supplies remains a concern. The challenges of maintaining hand pumps at the rural level, including the Afridev, are well established and obstructed by more than just maintenance issues (Foster, 2013). When an improved source is unreliable, unaffordable or contaminated, and potentially leading to abandonment, the national monitoring statistics may not reflect this reality at the local level (Martínez-Santos, 2017; Mannix *et al.*, 2018; Miller *et al.*, 2018). Affected water users may depend on unimproved supplies or surface-water sources, temporarily or definitively. This will ultimately have a considerable effect on the health and overall poverty reduction of the region, that has compromised SSAs efforts in relation to the MDGs and will continue to hinder progress towards the SDGs.

This paper argues that the international push to meet the coverage targets of MDG target 7c resulted in the "sustainable access" aspect of this target falling short. It is contended that poor standards of water supply infrastructure installed to increase coverage during the MDG period have left rural populations in low-income regions with—or vulnerable to—the burden of maintaining the supply at the local level, contradicting national policies and hindering progress towards the SDGs. If SDG 6 is to be robustly met, appropriate targets must be set to ensure sustainable access. This includes essential monitoring of assets across the country (United Nations, 2018b), in which comprehensive management information systems (MIS) are useful tools (Gumbo, Juizo and van der Zaag, 2003; Nussbaumer *et al.*, 2016). This is essential for sustaining aging infrastructure that has been subject to a major coverage goal initiative. It is vital to look beyond simple indicators of coverage and consider the quality of the service provision (Adank *et al.*, 2016) to further understand and enable proactive approaches that will sustainably manage assets (Thomson and Koehler, 2016; Anthonj *et al.*, 2018; Kativhu *et al.*, 2018; Thomson *et al.*, 2019).

This paper investigates the Afridev hand pump boreholes that have been installed in 25 out of the 28 districts of Malawi during the MDGs, drawn from a large and recent national data set. Here we investigate the functionality of Afridev hand pump boreholes installed in Malawi that have been subject to the major coverage-driven initiative of the MDGs, and to review if the reliance on reactive approaches to maintenance are a sustainable solution for decentralised service providers. We found that the acceleration to meet the coverage targets of the MDGs contributed to unsustainable infrastructure, alongside the challenge of maintaining aging infrastructure that has contributed to the burden of sustaining water supply assets in the rural communities of Malawi. This provides evidence for water policy updates with associated guidance to practitioners on the impacts to long-term sustainability.

4.4 Methodology

4.4.1 Study Area

Malawi is a land locked country in SSA located between 9°S and 17°S (latitude) and 33°E and 36°E (longitude), bordered by Mozambique in the east, south and west, Tanzania in the northeast and Zambia in the northwest. Malawi has a population of 18.6 million (The World Bank, 2015), with approximately 84% located in a rural setting and with more than 50% of the population living below the poverty line. Malawi's population is set to double by 2030 (FAO, 2015), placing greater pressure on the country's water sector. Climate impacts further risk the provision of safe water as Malawi is prone to droughts and floods, with the main rainy season occurring between November to April and two dry seasons during the rest of the year. Furthermore, there is less than 1400 m^3/year/person of available total water resources, making Malawi one of the most water-scarce countries in the world (Rijsberman, 2006).

In rural settings there is a reliance on groundwater for the main source of daily water needs, and for social and economic development. Boreholes fitted with Afridev hand pumps are the main technology used for rural water supply. The Afridev hand pump emerged as the dominant hand pump in Malawi through standardisation in the 1990s (Macarthur, 2015), and is an approved and recognised technology by the Government of Malawi. Rural communities manage their water supplies under the community-based management (CBM) approach, as the Government of Malawi's National Water Policy promotes the decentralisation of rural water supplies to local governments, and further reflects the coverage targets set out in the MDGs. However, due to the limited capacity of local governments to develop the rural water sector, there is an over reliance on external funding and support (Scanlon *et al.*, 2016).

4.4.2 Data Collection

The Scottish Government Climate Justice Fund (CJF) Water Futures Programme has been working in partnership with the Government of Malawi evaluating the sustainability of rural water supplies since 2011. The programme aims to support the Government of Malawi to achieve SDG 6. A core workstream of the programme is to evaluate the sustainability of all rural water supply assets across Malawi. Information regarding the viability and sustainability of each asset is collected through a water point functionality survey based on SDG 6 indicators and the additional needs of the Government of Malawi. These include, but are not limited to, geographical information on water points and subsequent communities served, installation dates, donors and installers, service provider asset and water point O&M, accessibility, reliability and functionality status of the water point (www.cjfwaterfuturesprogramme.com).

This study draws on the data collected by the CJF and collated into the bespoke developed MIS, mWater (www.mwater.co). Of the various MIS available, mWater was chosen as the preferred asset analysis platform due to a wide range of capacity and adaptability (BASEflow, 2017; Miller *et al.*, 2018). Rural water asset status data from 2011–2016 was collected under subcontract by the Non-Government Organisation (NGO) Water for People using AkvoFLOW (akvo.org/products) across 8 Southern Region districts of Malawi. A further mapping exercise was conducted across these Southern Region districts of Malawi in 2017–2018 using mWater. Since 2018, the programme has embarked on evaluating the asset status of every water point across Malawi, expecting to complete in 2019. All available historic data were subsequently imported into the mWater database.

The Government of Malawi staff go through classroom and field training to teach them how to respond to surveys which are provided in both English and Chichewa (local language).

During this training they assess the functionality of the Afridev hand pump based on technical specifications. The additional data collected, such as the flow rate, assist with the functionality definition alongside design specifications.

Though the Government of Malawi staff are trained on data collection and the subsequent data undergoes rigorous quality assurance checks, non-sampling errors cannot be excluded. However, the field data that is uploaded to the server undergoes two rounds of approvals before being accepted. These include extensive quality checks of the uploaded data, such as the accuracy of the mapped locations, and rejects any submissions that do not meet these quality checks. The rejection rate during approvals is less than 5% of the submitted data, and the monitoring of the accepted data is subject to thorough quality checks. Historic data imported into the data set has undergone any site deduplication, increasing the accuracy and reliability of long-term trends in the database.

4.4.3 Sampling and Methods

This study investigates the functionality status of water points installed in 25 out of the 28 districts in Malawi across the MDG period 2000–2016. It is recognised that when considering mapping and monitoring data, the term "functionality" is a snapshot temporal indicator for sustainability, which is a multi-variable service over time, discussed at length by Carter and Ross (2016). The term partial functionality has been introduced over recent years due to the need to further define functionality (Carter and Ross, 2016; Bonsor *et al.*, 2018). This concept incorporates many different situations that affect the overall performance of the water supply including maintenance issues, water quality and variations in yield. Additional supporting information is required to further support the classification of the status of water point assets, thus a wider range of information is included in the CJF Water Point Functionality Survey data set providing insights into the current burden of the MDG infrastructure in Malawi. Furthermore, it highlights the importance of continued and improved monitoring of water points and influencing factors to ensure the long-term sustainability of the Government of Malawi's assets.

Therefore, for avoidance of doubt, the term "functional" is used here to describe a water point that is in operational condition and providing water according to design specifications, "partial functionality" is a water point that is providing water, but in a reduced capacity (e.g., only certain times of the year, not according to flow rate specifications, changes in site conditions, repairs required, etc.), and "non-functional" is used to describe a water point that no longer provides water on a regular basis at the time of the asset audit. These definitions, alongside the additional information collected, allow for problem areas or areas of need to be highlighted for assistance with decision making. The definitions are adopted across the MIS mWater (see Section 4.3.2) that is used by NGOs and others.

From the 68,984 water points mapped by the CJF to date (January 2019), a subset of 23,073 drilled boreholes equipped with Afridev hand pumps were captured from the mWater live database. The data was filtered to those points installed during the MDG period between 2000 and 2015, and 2016 for the transition to the SDGs. This resulted in a data set of 14,943 Afridev hand pump boreholes. The distribution of this data set is shown in Figure 4.1 with further detailed information provided in section 4.8 Supplementary Information.

From this data set, further investigation was made into (a) whether or not the supply had a service provider present for O&M, and (b) if available, the service provider was decentralised (area or water mechanic, community members, an institution, local government, NGO, self-supplied, public operator, water point committee or water user association). Where a response was recorded as "don't know" for a present service provider, the data was omitted from that part of the analysis to ensure only supplies with decentralised service providers were considered.

Capital maintenance expenditure (CapManEx) is described as going beyond routine O&M from a service provider to repair and replace assets that keep them running (Fonseca *et al.*, 2011), which risks becoming an issue if not addressed through an asset's life cycle (Fonseca *et al.*, 2013). This accounts for major repairs which are crucial for the sustainability of a service and rehabilitation. Investments into rehabilitation treat the costs as the start of a new service, as they are required to bring the existing systems back to operational use if appropriate O&M is not conducted (Franceys and Pezon, 2010), but rehabilitation is seldom considered or practiced by communities or local government due to the costs involved. This further variable was evaluated across the data set to investigate (a) when rehabilitation was conducted by date (2000–2018), (b) the status of functionality from the result of the rehabilitation exercises and (c) who funded these rehabilitations. Within this data set, rehabilitation was defined as a single major repair consisting of 1,500,000 MK (Approximately 2062 USD, where 1 USD = 727 MK, as of January 2019). This monetary definition was defined by the Government of Malawi at the beginning of the 2017 mapping exercise. This variable was also constrained to the Afridev hand pump boreholes installed during the 2000–2016 timescale.

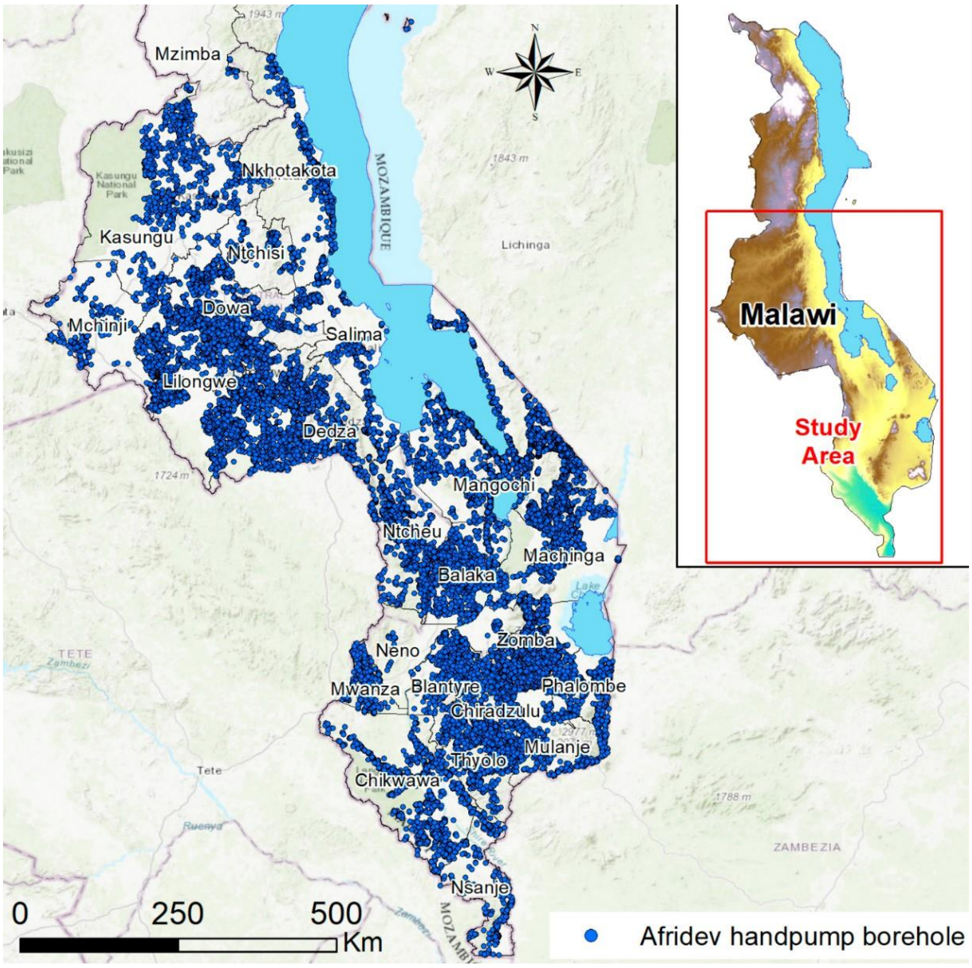

Figure 4.1 Afridev hand pump boreholes installed between 2000–2016 mapped to date by the CJF (n = 14,943 as of January 2019, with mapping generally proceeding from South to North).

4.5 Results and Discussion

4.5.1 Installation of Millennium Development Goal Afridev Hand Pump Boreholes

The MDG agenda saw an increase in improved access to drinking water, globally meeting the target by 2010, but with SSA falling behind (WHO/UNICEF, 2010). However, according to the JMP monitoring data, while SSA failed to meet the target, Malawi met the MDG coverage target by 2015 (WHO/UNICEF, 2015). Approximately 84% of the population of Malawi are located in a rural setting. According to the JMP, Malawi has shown a positive shift in rural water supply coverage with an initial 61% coverage in 2000 rising to an 85% coverage of improved supplies by the end of 2015 (63% at least basic and 20% limited). The reality in

Malawi is a substantial increase from 49 to 75% usage of non-piped improved supplies, which are predominantly hand-pumped groundwater supplies, with a decrease of 12 to 10% of piped improved supplies (WHO/UNICEF, 2015). Figure 4.2 presents the number of Afridev hand pump boreholes installed across Malawi through the 2000–2016 period. The data set supports that that the MDG targets led to an increase in new water supply installations across Malawi to increase coverage targets, with specific increases of coverage evident at various dates across the MDG period.

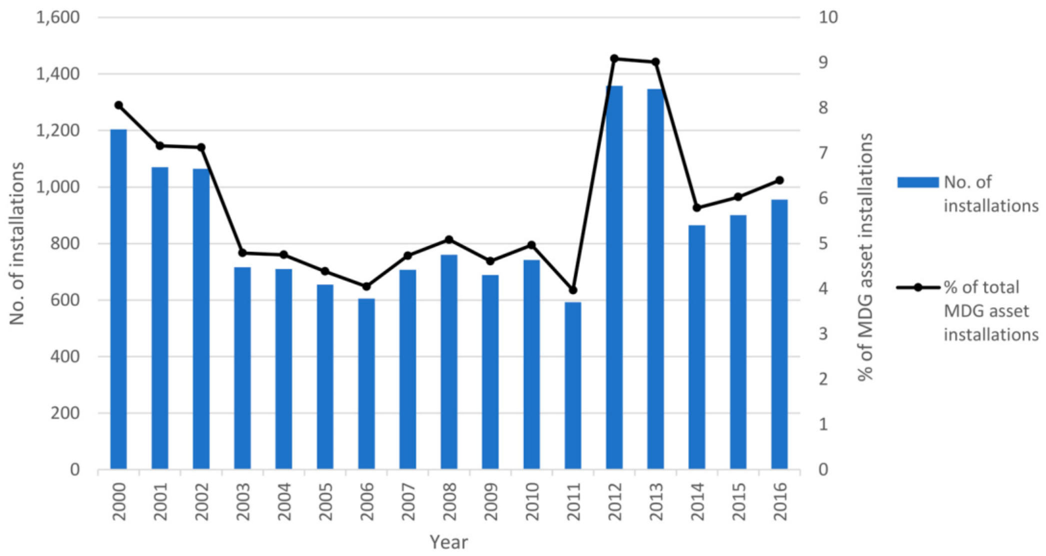

Figure 4.2 Trend of Afridev hand pump borehole installations across Millennium Development Goal (MDG) key dates in Malawi (n = 14,943).

The first key note of investment into MDG coverage expresses a large number of Afridev hand pump borehole installations at the beginning of this period (2000–2002), followed by a reduced rate up until 2011, before an increase in the years approaching to the end of the MDG period, with a marked jump in installations at 2012–2013 (see Figure 4.2). The MDG target for water, MDG 7c, was repeatedly edited until 2006 as further discussed by Bartram *et al.*, (2014). However, the target during this period and after its final adoption always had an emphasis on coverage for drinking water, with sanitation being added after 2002 (World

Summit on Sustainable Development, 2002). This increase of installations followed by a decline from 2002 onward suggests a response to a change in the coverage targets of MDG 7c, with a joint focus on drinking water and sanitation. However, JMP states that in 2010, as SSA was falling behind but the world was on track for MDG 7c, Malawi was one of the few countries within SSA that fell into the category of "on track" and progressing well towards MDG 7c by 2010 (WHO/UNICEF, 2010), with approximately 600–1200 installations per year up until that date evident in Figure 4.2.

The marked increase of 2012 and 2013 installations obvious in Figure 4.2 is attributed to the response to the introduction of Malawi's Water Resources Act 2013, the JMP progress reporting for Malawi in 2010 and the observed doubled effort compared to the 10 years prior to meet MDG 7c by 2015. As the MDGs gained momentum, there was a greater interest placed on policies and financing (Bartram *et al.*, 2014), including an increase of regional policies. In the case of Malawi, policy and guidelines were developed with an aim of reflecting the requirements of the MDGs (MoAIWD, 2005, 2010). However, the rapid response for coverage targets may have caused vulnerabilities and led to potential negative impacts, particularly to the long-term post-construction sustainability of the installed systems where policy primarily focused on improved access and CBM approaches.

The findings in Figure 4.2 are consistent with wider sector observations. RWSN Executive Steering Committee (2010) describes the tendency for actors in the development sector to commit significant amounts of funding to new water supply infrastructure with the focus of fulfilling numerical coverage targets. This subsequent push for coverage during the MDG era to meet MDG 7c, and increased investment from NGOs and social actors, lacked the investment into capacity development to maintain supplies for disadvantaged groups—an old and leading concern (Gumbo, Forster and Arntzen, 2005; Ortigara *et al.*, 2018). The post-construction period is often considered “somebody else’s problem” that has contributed to a burden of water supply assets across rural Malawi.

Rural water supply infrastructure can be complicated to maintain sustainably, and may often fall into disrepair before its anticipated design life expectancy, while infrastructure may be implemented regardless of considerations as to whether it can be kept operational (RWSN Executive Steering Committee, 2010). As such, problems in the rural water supply sector were gradually becoming more evident towards the end of the MDG period. This posed sustainability concerns moving forward from the year the MDG target for water was declared fulfilled in consideration of potentially many installed boreholes from the MDG era. The lack of long-term sustainability planning when implementing new assets risks having those assets fall into disrepair soon after installation before inevitably requiring the funding of large-scale rehabilitation to bring them back to operational use or risking complete failure and abandonment (Franceys and Pezon, 2010).

4.5.2 Trends in Post-Construction Service Provision and Functionality

In rural Malawi, the service delivery of water is focused on decentralisation, primarily through CBM (MoAIWD, 2010). This model is designed with the aim to benefit and empower communities (Briscoe and de Ferranti, 1988). Under CBM, the O&M management and financial responsibilities of water supply falls to the voluntary participation of the community. The most common approach for CBM is for capital costs to be primarily covered by external aid while 100% of O&M costs are community-owned. Research internationally has shown that the challenges service providers face to accommodate this, alongside the lack of willingness to pay for the financing of O&M within a community, have led to an array of additional problems and the approach being questioned (Harvey and Reed, 2006a; RWSN Executive Steering Committee, 2010; Foster, 2013; Moriarty *et al.*, 2013; Chowns, 2015a;

Hope, 2015; Hutchings *et al.*, 2015; van den Broek and Brown, 2015; Whaley and Cleaver, 2017; Foster, Willetts, *et al.*, 2018).

Table 4.1 presents the statistical overview of the extracted data set. Where service providers were present, the average functionality across the MDG years (71.44%) proved to be slightly higher than the trend expressed in literature, of two-thirds of installed hand pumps working at any given time. However, when rehabilitated supplies were excluded, the functionality became 66.58%, confirming the trend. The average functionality in Table 4.1 was influenced by the functionality of newer systems that steadily decreased as systems age (i.e., depreciation of the systems contributed to the lower functionality of older systems).

Table 4.1 Functionality at the time of audit of Afridev hand pump boreholes installed between 2000–2016, evaluating the influence of service providers present and rehabilitation conducted during the life cycle. Percentage values in parentheses are in relation to the total n

Service Provider Present	Variable	n	Mean over 2000–2016 %	Min. Annual Average Functionality between 2000–2016 %	Max. Annual Average Functionality between 2000–2016 %
Yes	No rehabilitation conducted during life cycle	12,476	70.77 (66.58)	62.78 (56.41)	84.14 (81.72)
	Rehabilitation conducted during life cycle	805	78.43 (4.86)	66.67 (1.34)	91.43 (11.09)
	Total	13,281	71.44	63.85	84.25
No	No rehabilitation conducted during life cycle	965	56.91 (55.03)	36.84 (34.43)	80.30 (80.30)
	Rehabilitation conducted during life cycle	35	77.16 (2.58)	0 (0)	100 (5.75)
	Total	1000	57.61	38.98	80.95

It is well established that post-construction management is essential to ensure its continuous service delivery of improved supplies. However, as the MDG era strived for drinking water coverage and Malawi's policy to promote service delivery at the CBM level (MoAIWD, 2005), the sustainability and performance of these systems is questionable, as shown by the functionality distribution where service providers are present in Table 4.1. Further research supports this observation, as financing and conducting preventative maintenance can appear a redundant exercise to service providers (Chowns, 2015a; Etongo *et al.*, 2018; Kativhu *et al.*, 2018) when they are an essential part of a water systems life cycle, and a more cost-effective strategy than an often-repeated rehabilitation exercise (WaterAid, 2011).

Table 4.1 shows that over the MDG era, Afridev hand pump boreholes could be functional for extended periods without a service provider to conduct O&M (55.03%). This average consists of systems dating to the beginning of the MDGs, suggesting that when water points are well constructed, they can operate for years without issue. While this improves sustainability, the presence of a service provider can significantly improve the functionality of a system as shown by the minimum percentages expressed in Table 4.1. However, service providers commonly struggle to undertake major repairs to maintain aging infrastructure that will ultimately require rehabilitation. This is supported by Figure 4.3, in which the functionality of Afridev hand pump boreholes with service providers is presented.

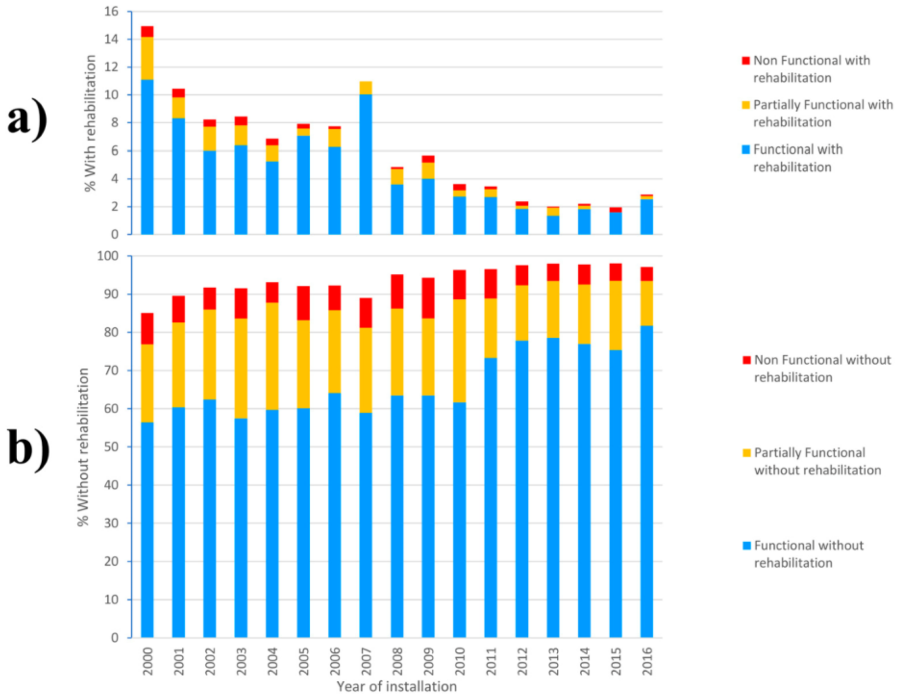

Figure 4.3 Afridev hand pump borehole functionality distribution across MDG period with service providers (n = 13,281). (a) % of data set with rehabilitation conducted during the life cycle; (b) % of data set without rehabilitation conducted during the life cycle.

The functional status confirms a higher percentage of fully functional Afridev hand pump boreholes between 2011 and 2016 (Figure 4.3), which is above the two-thirds trend found in the literature. This is preceded by a sharp reduction in 2010 that is less marked towards the start of the MDG period, further supporting the trend that hand pumps typically last 5 years without appropriate O&M (Baumann, 2006). This suggests that between 2000 and 2010, service providers were conducting the appropriate O&M required to maintain functionality, conforming to the trends expressed in literature.

The decline in functionality as the system age increased, alongside the subsequent increase in the rehabilitation of potentially partially functional or non-functional early MDG systems, highlights the lack of post-construction support for service providers who conducted routine O&M and were subjected to a depreciation of supplies requiring CapManEx. Furthermore, the focus on rapid provision of water without consideration of post-construction O&M

support had an impact on the sustainability of the supplies. “One-time investment” approaches adopted by NGOs and donors, and investments into new assets, risk leaving service providers who struggle to provide the maintenance and major repairs required for sustainability unsupported. The argument that “communities are always capable of managing their own facilities on their own” has been widely criticised (RWSN Executive Steering Committee, 2010), as has the debated CBM model since implementation. This can lead to a reduction of O&M or abandonment of service provision. A study by Hutchings *et al.* (2015) highlights that success is possible when the model takes a more professional approach to manage the complexities of rural water supply with an emphasis on external support.

Figure 4.4 presents the functionality of Afridev hand pump boreholes without service providers. These results further indicate that a rapid provision of water points (see Figure 4.2) has an impact on long-term sustainability, as no service providers were present, especially in the cases of those installed during the late MDG era. While the late MDG era boreholes suggest a rush for coverage without the necessary service provision capacity, it should also be considered that in installations from the early MDG period (Figure 4.4), water points may have once had a service provider that later departed.

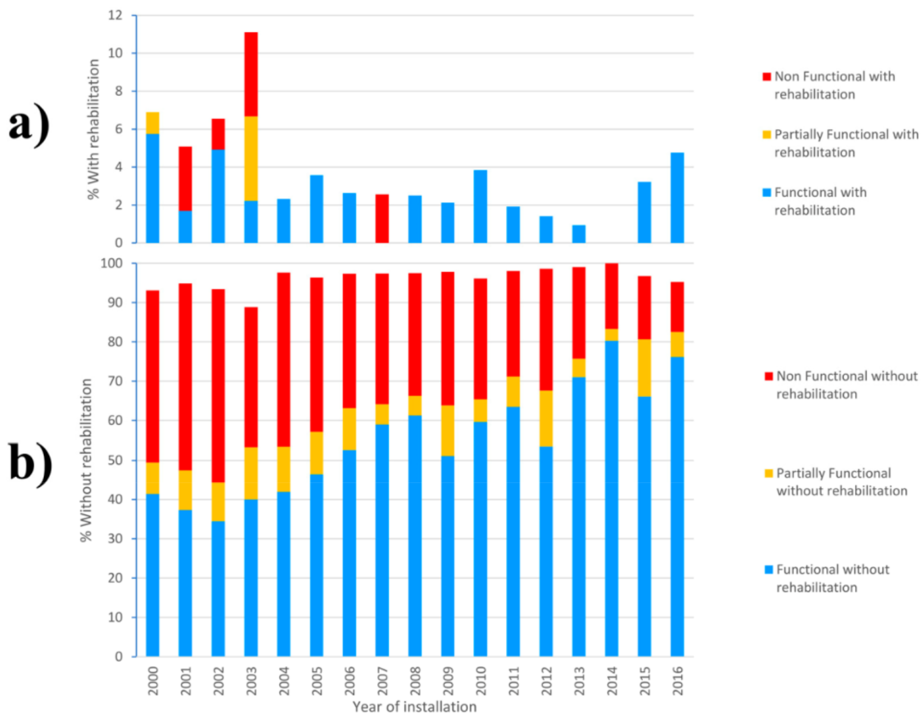

Figure 4.4 Afridev hand pump borehole functionality distribution across MDG period without service providers (n = 1000). (a) % of data set with rehabilitation conducted during the life cycle; (b) % of data set without rehabilitation conducted during the life cycle.

Generally, communities experience a reliable service after a new system is installed and a slightly reduced service after a few years as breakdowns begin to occur caused by a depreciation of infrastructure due to continued usage without appropriate O&M. Both the functionality and corresponding non-functionality expressed in Figure 4.4 highlight how unmaintained systems are affected by the depreciation of infrastructure. This trend supports previous interpretations by Foster (2013), who has described statistically significant predictors of non-functionality, and presented strong evidence of the negative relationship between system age and functionality. This further supports the importance of establishing O&M service provisions within post-construction support. However, when water points are well constructed, they have the potential to operate for years without issue. This is supported by Figure 4.4, which shows the presence of functional supplies installed during the MDG period, although the minimum expressed during this period was 34.43% in 1 year. However, this significant reduction of functionality due to depreciation during the MDG period risks the further reduction of functional supplies into the SDGs without adequate service provision.

Figure 4.3 suggests that while routine O&M was present beyond the 5-year mark, ultimately the limited CapManEx (or major repairs) conducted on aging supplies contributed to a reduced service that risked breakdown (i.e., partial functionality). When comparing this trend to Figure 4.4, the impact of depreciation is more noticeable. The lack of service provision to conduct O&M or CapManEx contributed to breakdown (non-functionality), rather than a reduced service (partial functionality). In reality, the costs of CapManEx often go unconsidered, even within service provision, which further contributes to the reduced service of the MDG assets. The non-functionality expressed in both Figures 4.3 and 4.4 risk costly rehabilitation to bring assets back to an operational standard, which is often beyond the capability of decentralised service providers to finance. These findings support the premise that sustaining functionality is heavily influenced by the institutional post-construction support and the depreciation of infrastructure.

4.5.3 Quality of MDG Infrastructure

The decline in functionality across the MDG era further supports the need for post-construction support to reduce the risk of premature failure of water supply assets. However, the partial functionality and non-functionality of boreholes installed towards the end of the MDG period point to a risk of poorly designed sub-standard installations that have contributed to a reduced service and abandonment of assets. Falkenmark (1982, p15), states at the beginning of the International Drinking Water Supply and Sanitation Decade (1981–1990), "If well-drilling and hand pump problems are focused during the first half of decade, it is probable that the operation and maintenance problems will be the ones dominating during the second half." However, issues with sub-standard borehole construction are still relevant across the assets installed during the MDGs. While there is a focus on hand pumps and institutional capacity building when planning the sustainability of rural water supplies, the effects of sub-standard borehole construction due to accelerating the MDG coverage likely contributes to excessive delivery costs for the rural service provision.

It is proposed here that borehole construction quality is an important contributing factor towards water point functionality and sustainability, alongside hand pump O&M. The logic for this proposition is evident in the assets constructed after 2011, where non-functionality without a service provider is considerably higher than those with service providers (see Figures 4.3 and 4.4, respectively). Baumann (2006) describes how hand pumps only last around 5 years without appropriate O&M within traditional CBM approaches, and therefore the premature non-functionality of these assets within this timeframe is potentially attributed to the quality of the initial borehole construction (e.g., the high rates of partial functionality and non-functionality in the Figure 4.4 data for 2011–2016). As there are no service providers present to conduct appropriate O&M or collect funds for appropriate O&M, attention falls on the quality of the infrastructure in place of these newly constructed assets. In particular, 2012 and 2013 saw a significant increase of installations (see Figure 4.2) and revealed a particularly high non-functionality rate within this 5-year timeframe.

Annual or seasonal variations in groundwater levels have also been found to contribute to a decreased level of service provision across Africa (Foster, 2013; Carter and Ross, 2016; Foster, Willetts, *et al.*, 2018; Kelly *et al.*, 2018). Boreholes constructed during the wet season, high groundwater level conditions, are often constructed shallower and can go dry during dry season, low groundwater level conditions. However, groundwater level variations contributing to water point downtime should not be considered an acceptable risk when implementing water supply infrastructure, but rather poor hydrogeological oversight during planning and construction (Mannix *et al.*, 2018). This further suggests that rapid provision of water supply has impacted the sustainability of water supply infrastructure, contradicting national policy requirements for sustainable coverage at the rural level (MoAIWD, 2005). Successes from other African countries found installations drilled to combat seasonal changes in the dry season were more reliable (Kelly *et al.*, 2018), as deeper water points increased sustainability and climate resilience (Anthonj *et al.*, 2018).

The Afridev hand pump boreholes constructed after 2011 (within the 5-year margin previously described by Baumann (2006)) without service providers to provide the appropriate O&M measures indicate potential sub-standard supplies. The data in Figure 3 of late MDG era supplies further endorse this. After 2011, the functionality distribution remained relatively consistent between 2012 and 2016, when it was assumed that well-constructed assets would express a higher rate of functionality than newer assets. This suggests that poor quality borehole installation and seasonal water levels are potentially causing functionality issues rather than hand pump O&M, a relationship expressed across other African countries (Foster, 2013). While issues such as poor O&M or willingness to pay factors cannot be ruled out at this stage, the partial functionality and non-functionally of these early assets are potentially problematic. This is notable in 2015, at the end of the MDG era, when very new assets expressed high rates of partial and non-functionality (14.52 and 16.13%, respectively) compared to adjacent years (see Figure 4.4).

This theme is supported by the findings of Mannix *et al.* (2018) in their related CJF forensics examination of boreholes, where water source and borehole issues in Malawi were seen to contribute strongly to a reduced service provision. Notably, the main findings highlighted that many functionality problems were a symptom of water resource issues (72% of all cases) and borehole and installation issues (72% of all cases). There were fewer cases where hand pump parts were the cause of impacted performance (24% of all cases), highlighting poor O&M through decentralised management. Foster *et al.* (2018) further describe this issue in regard to hydrogeological impacts on functionality. Both studies indicate that hydrogeology and borehole installation quality are a potentially permanent root cause of reduced functionality and to reduced service, even with routine O&M for water supply assets, which further highlights the need for improved standard of work prior to installation and during construction of the borehole.

Infrastructure sustainability suffers when technical oversight of borehole construction is ignored by donors and NGOs (RWSN Executive Steering Committee, 2010; Mannix *et al.*, 2018; Wanangwa, 2018). Implementing organisations have a responsibility to follow national standards and ensure systems are fit for their purpose, as implementing sub-standard boreholes undermines the policies of the Government of Malawi, and ultimately SDG 6. Problems may similarly arise from inappropriate commissioning of boreholes if water supply quality concerns, notably salinity in parts of alluvial aquifer systems in southern Malawi (Rivett, Budimir, *et al.*, 2019), are ignored or overlooked while prioritising coverage.

The "business as usual" investment into infrastructure that has prioritised the MDG coverage targets over quality of infrastructure is an issue entering the SDG era, especially where it has become evident of premature breakdown within a few years of their installation. Furthermore, the rehabilitation exercises conducted on these assets installed during this timeframe highlight potentially sub-standard infrastructure not exclusively limited to the hand pump (especially where rehabilitation was carried out resulting in partially functional or non-functional supplies—see Figures 4.3 and 4.4). As previously mentioned in Section 4.3.3, rehabilitation is considered the start of a new service.

Our findings, alongside wider evidence cited, suggest there is an underlying issue of infrastructure installation quality that has an impact on functionality and sustainability. While this is most notable of the Afridev hand pump boreholes installed after 2011, there is a risk that this issue has been present across the whole MDG period. These problems pose a risk for Malawi in the transition between the MDGs and SDGs, and while the re-evaluation of O&M dominates discussions, it is imperative that the quality of borehole construction also be improved. The drive to continually provide new assets and implement community-focused hand pump boreholes across Malawi for coverage targets must be reconsidered within monitoring the success of the SDG agenda. This is further complicated by the challenges of CBM and the lack of capacity to contend with the challenges of O&M and CapManEx. Proactive approaches to O&M and CapManEx reduce the risk of breakdowns that require costly rehabilitation to maintain operational levels necessary to the life cycle of the system (Fonseca *et al.*, 2011). However, with the challenges of conducting the necessary CapManEx, rehabilitation is more likely to be needed, and less likely to be conducted within CBM.

4.5.4 Rehabilitation Conducted on MDG Assets

Out of the 844 recorded cases of Afridev hand pump borehole rehabilitation (see Figure 4.5), much of the work was conducted close to the end of the MDG era into the start of the SDGs between 2014 and 2017 (13.74, 15.05, 22.63 and 24.17% of MDG constructed hand pump boreholes, respectively). Between 2000 and 2013 less than 5% of recorded rehabilitation cases were conducted each year.

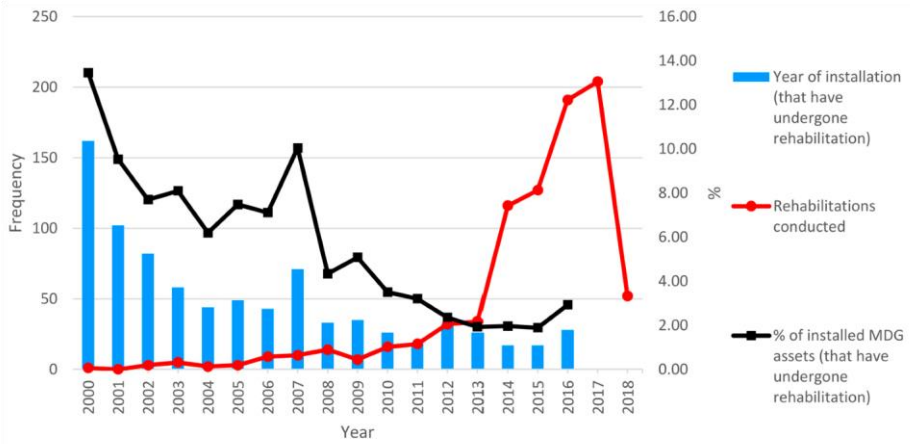

Figure 4.5 Number of rehabilitation exercises conducted on MDG Afridev hand pump boreholes (n = 844).

This data set showing a progressively greater number of rehabilitation exercises targeting early MDG installations (normalised percentage curve, noting the unexplained 2007 peak) further supports the impact depreciation has on the functionality of these assets. This is to be expected, as Afridev hand pumps installed in the boreholes that received regular maintenance from a service provider had typically reached the end of their expected design life. Where no service provider was present (see Figure 4.4), depreciation was more visible. When service delivery ceased over a number of years, rehabilitation should be considered as the start of a new service and a new capital expenditure, an often-neglected cost in pre- and post-construction of rural water supply infrastructure (RWSN Executive Steering Committee, 2010; Mcintyre *et al.*, 2014).

However, the investments that increased the coverage of the MDGs risked masking an underlying issue with further implications concerning the SDGs. When considering life cycle costs, the impacts of sub-standard borehole infrastructure must be considered alongside routine hand pump maintenance. This further supports the need for professional hydrogeological oversight during construction, and proactive approaches in both routine O&M and CapManEx to maintain adequate service delivery and prevent or prolong failure from further depreciation or abandonment of infrastructure (particularly where major repairs through CapManEx are lacking, as indicated by the partial functionality in Figure 4.3). The risk of waiting until major repairs are needed results in rehabilitation, which further leads to reliance of external support to remediate the service delivery.

4.5.5 Reliance on External Support

Malawian policy recommends borehole construction and rehabilitation of water supply systems to the international aid and private sectors (MoAIWD, 2010); however, these organisations often have their own agendas when considering service delivery (Whittington *et al.*, 2009). Further pressures to achieve more sustainable solutions that are less reliant on external support will prove necessary with any decline of international funding (e.g., the substantial reduction of the UK's Department for International Development planned budget for overseas aid in Malawi between 2017 and 2020 (Department for International Development, 2017, 2018)).

The "one-time investment" for donor-funded rural water supplies requires practitioners to follow proper installation standards but only covers the immediate need of rural communities, as it does not provide prospects for sustainability or growth (Whittington *et al.*, 2009; Foster, 2013; Moriarty *et al.*, 2013). Once external support is withdrawn, local government is relied upon to provide support which can be beyond their capacity to maintain the level of support required. Table 4.2 presents the funding actors for the rehabilitation exercises previously explored (see Figures 4.3 and 4.4). Rehabilitation exercises have primarily been provided by NGOs accounting for over 504 (59.72%) of all cases, clearly supporting that reliance on external support for rehabilitation is present in rural Malawi.

Table 4.2 Frequency of actors funding rehabilitation.

Funder	No. of Rehabilitations Conducted	% of Total Rehabilitations Conducted
Community	145	17.18
Local Government	54	6.40
NGO	504	59.72
Politician	52	6.16
Religious Institution	20	2.37
School	12	1.42
Water Point Committee (WPC)	22	2.61
Other	32	3.79
Don't know	3	0.36
Total	844	100

In the previously mentioned cases of sub-standard construction and lack of proactive approaches, repeat rehabilitation is often required to bring a supply back up to operational condition, which is an enormous waste of investment (RWSN Executive Steering Committee, 2010) and an unsustainable solution to depend on for the sector.

A study by Chowns (2015) found that CBM worked as a method, disseminating responsibility from the government and funders to the community, but in practice had failed to deliver any technical or financial benefits. CBM relies on local governments that have limited resources and do not establish efficient support for their communities (Baumann, 2006; Silvestri *et al.*, 2018; Al'afghani, Kohlitz and Willetts, 2019), which often leaves decentralised service providers dependent on external institutions for long-term financial sustainability, such as the private sector or NGOs. While a community may be able to finance and implement minor repairs, major repairs may present more of a challenge due to the substantial costs involved for rural decentralised service delivery. Many communities must rely on external support such as NGOs to provide necessary financial support to bring the hand pump boreholes back to an operational state. A similar situation is found in Zimbabwe, where NGOs are the sole funders of rehabilitation (Kativhu *et al.*, 2018). However, in Malawi, the local governments are expected to provide the support to service providers once external support has left after implementation. With Malawi's own National Water Policy promoting CBM alongside consultation with local governments, necessary and costly rehabilitation exercises are problematic. Notably in Table 4.2, communities have funded rehabilitation in more instances than local governments, meaning local economies and initiatives can assist with the costs of maintenance (Rivett, Halcrow, *et al.*, 2018). This further highlights the financial challenges local governments face in Malawi's rural sector when considering post-construction support, also emphasised by Baumann (2006).

While NGOs have been the primary actors in funding rehabilitation, there are considerable risks associated with relying on external support. It has been previously established in literature that donors and NGOs may ignore or undermine national policies in favour of project-orientated results, resulting in a disregard for government-led priorities for the long-term sustainability of water supply and capacity building/institutional support. Furthermore, rehabilitation that has been conducted on assets at the beginning of the MDGs (see Figure 4.5) where no service provider was present should be considered a poor investment that sacrifices sustainability for coverage. These findings have implications for low-income regions moving into the SDG era, particularly where national policies reflect coverage (Anthonj *et al.*, 2018) and decentralisation of the rural water sector (Marks, Onda and Davis, 2013; Moriarty *et al.*, 2013; Kativhu *et al.*, 2018).

There is no quick fix for rural water supply sustainability and long-term investment planning based on sustainability is required (Whittington *et al.*, 2009; RWSN Executive Steering Committee, 2010; Hutchings *et al.*, 2015). Despite the wide international push from stakeholders to increase coverage in the sector, professionals and practitioners have contributed to the problem of failing water supplies (RWSN Executive Steering Committee, 2010) and decentralisation, most notably CBM, which has contributed to the burden on the rural water supply sector.

4.6 Conclusions

Over the duration of the MDG era, there has been a positive shift in the coverage of rural water supplies. However, the implementation of water supplies has been subject to the influence of national policies and the MDGs that have induced some acceleration of activity to meet coverage targets. The evidence presented indicates that the acceleration towards meeting coverage targets contributes to sustainability challenges within the MDGs, with further implications moving into the SDGs. This provides grounds for water policy guidance updates on minimising the impacts to long-term sustainability.

The drive for decentralisation or "community-led" management of these rural water supplies has left the rural populations of Malawi with the burden of maintaining these assets. However, it is well established that service providers struggle to provide the maintenance and major repairs required to keep services operational sustainably. The reactive approach to the O&M and CapManEx of supplies contributes to the decline of functional assets, which is compounded by the notable effect of depreciating infrastructure across the MDG era. This has produced a growing need for rehabilitation exercises to bring the supplies that were implemented primarily during the early MDG era back to an operational standard. Proactive approaches to adequately maintain these supplies are necessary to prevent or postpone these costly rehabilitation exercises, which are an unsustainable practice due to their reliance on external support and the limited capacity for local governments to fund.

Furthermore, the investments into meeting the coverage targets of the MDGs, in particular those installed after 2011, suggest underlying issues that are not exclusively a product of the hand pump. Non-functionality across newly constructed assets, and some rehabilitation of newly constructed assets, points to a risk of sub-standard quality of infrastructure that could potentially impact assets installed across the MDG timeframe. These risks further contribute to the burden of maintaining assets that are inherently unsustainable at a decentralised level and will have a further impact upon the progress of the SDGs.

This has implications for long-term sustainability transitioning in the SDG 2030 agenda due to the limited communication between NGOs and local governments/service providers, leading to a lack of reporting of reasons for partial functioning or non-functioning services, and ultimately in poorly targeted investments. The resulting decline in service delivery has the potential risk of an increased usage of unimproved supplies that could lead to issues hidden by the MDG coverage targets, such as impacts to the health of the rural population or an increased user burden for a neighbouring improved supply.

These lessons learned from Malawi have significance for other low-income regions, particularly those in SSA that rushed to meet or fell behind MDG 7c by 2015. National policies that focus on coverage and decentralisation of rural water supplies will potentially be subjected to the same challenges as Malawi of sustainably maintaining infrastructure. Moving towards 2030, lessons must be learnt from the evidence in Malawi of the coverage target approach in the MDGs to ensure that low-income regions are not further subjected to the similar risks of unsustainable water supply infrastructure. The evidence points to a burden of maintaining aging assets sustainably, combined with the several occurrences of sub-standard boreholes that have added to the established complexity of managing rural water supplies, as the implementation of assets to meet coverage targets points to justified concerns of sustainability.

It is recommended that conducting the frequent monitoring of water supply assets is essential to the success of the SDGs, and for proactive post-construction support for service providers to achieve sustainable investments. The impact from the notable peak of installations in the late MDGs is not fully evident yet, as the elapsed time is five years. Further research into ongoing monitoring of these assets is required to establish the full impact on communities entering the 2030 agenda, and to improve the performance of service provision at the local level rather than solely measuring it. Further research into proactive approaches at the local level that support the capacity for building is required to address the burden of water supply infrastructure in low-income regions. This is ongoing and will be the subject of subsequent papers.

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4.8 Supplementary Information

Table 4.3 Locations and distribution of Afridev hand pump boreholes installed between 2000–2016 mapped to date by the CJF using the MIS platform mWater (as of January 2019).

District of Malawi	Region of Malawi	n	% of Total Data Set
Balaka	Southern	817	5.47
Blantyre	Southern	1048	7.01
Chikwawa	Southern	967	6.47
Chiradzulu	Southern	530	3.55
Dedza	Central	1130	7.56
Dowa	Central	392	2.62
Karonga	Northern	1	0.01
Kasungu	Central	515	3.45
Likoma	Northern	3	0.02
Lilongwe	Central	2308	15.45
Machinga	Southern	545	3.65
Mangochi	Southern	1724	11.54
Mchinji	Central	29	0.19
Mulanje	Southern	437	2.92
Mwanza	Southern	335	2.24
Mzimba	Northern	17	0.11
Neno	Southern	8	0.05
Nkhotakota	Central	327	2.19
Nsanje	Southern	347	2.32
Ntcheu	Central	808	5.41
Ntchisi	Central	65	0.43
Phalombe	Southern	514	3.44
Salima	Central	177	1.18
Thyolo	Southern	850	5.69
Zomba	Southern	1004	6.72
Border Community/Outside Malawi [1]		45	0.30
Total		14943	100%

[a] These Afridev hand pump boreholes were located across, or on the border of Malawi. These were assets owned by the Government of Malawi and managed by a Malawian Community.

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4.10 Case Study: An Investigation of Community Pooled Resources for Sustainable Handpump Maintenance: The Relationship Between Water User Participation and Saline Water in Kakoma, Malawi

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Keywords: borehole; community management; hand pump; maintenance; Malawi; water quality; salinity; willingness to pay

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[c] **Conceptualisation:** J.P.T.; **Methodology:** J.P.T.; **Data Curation:** J.P.T. and H.S.; **Formal Analysis:** J.P.T.; **Writing (Original draft preparation):** J.P.T.; **Writing (Review and editing):** J.P.T., M.N., K.A.H., A.B.C. and R.M.K.; **Visualisation:** J.P.T.; **Supervision:** A.B.C. and R.M.K.

4.10.1 Background

In rural Malawi, the management and financial responsibilities of water supply currently falls to the communities through the community based management (CBM) approach. Since implementation, it has been recognised that this approach has various failings. To address these shortfalls, a maintenance model, piloted by Water for People, Malawi, has been implemented in a catchment area of Chikwawa, Malawi. The study area is located in the catchment area of Kakoma within the traditional authority (TA) Chapananga, Chikwawa district in Southern Malawi, presented in Figure 4.6. The investigation covered 59 communities, each with a water point committee (WPC) to manage the community Afridev handpump. All 59 WPCs are registered with a single maintenance organisation known locally as a borehole users association (BUA), which utilises a community pooled resource approach.

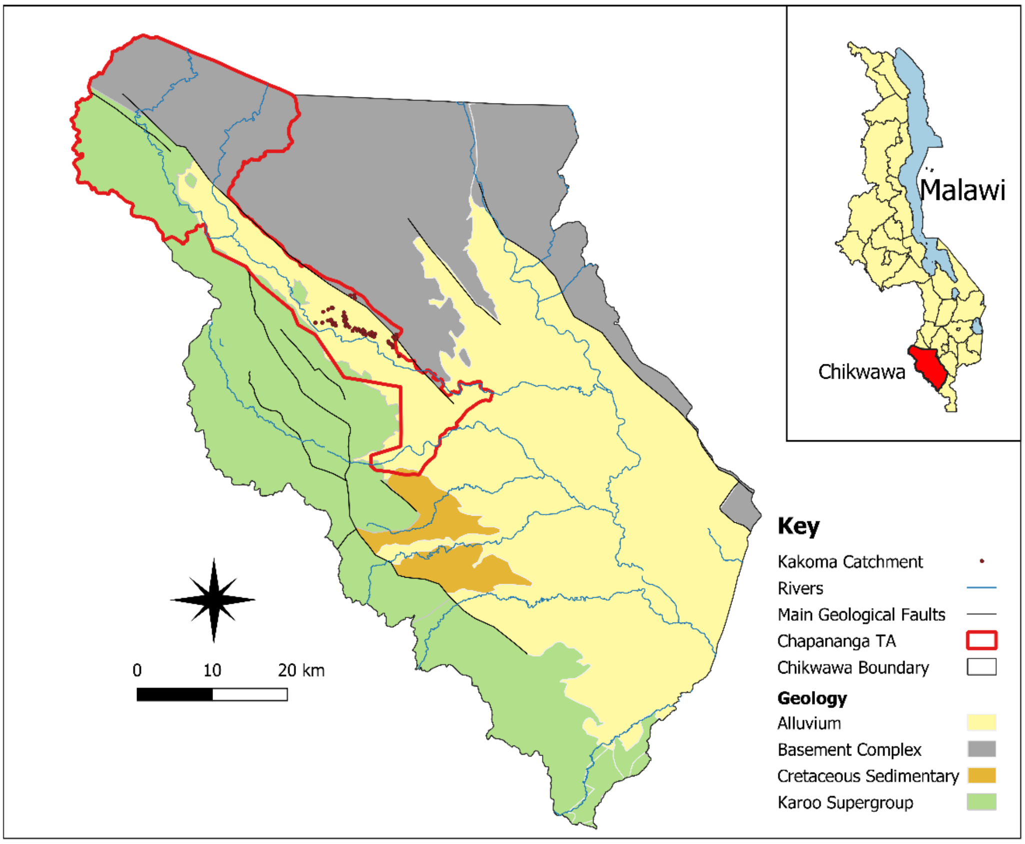

Figure 4.6 Location of study area and geological overview in Chikwawa district.

The BUA catchment area in Chikwawa sits on an alluvial aquifer, in which there are known issues of highly saline groundwater in the area (Monjerezi and Ngongondo, 2012; Rivett, Miller, *et al.*, 2018; Rivett, Budimir, *et al.*, 2019). The implementation of assets in known areas of poor water quality are sub-standard installations that negatively influence the sustainability of services (Truslove *et al.*, 2019). Furthermore, poor water quality and the perception of poor water quality can lead to the abandonment of water supply assets and influence the willingness to pay towards O&M activities. Services can fall into disrepair as the usage of unimproved water sources, over poor quality groundwater sources, increases.

Measuring the salinity of water supply can be indicated by the levels of Total Dissolved Solids (TDS) which incorporates inorganic salts, and the Electrical Conductivity (EC) of water. WHO, 2017a, states: "The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/L". There are no health concerns specified with TDS, however, high levels may impact the acceptability and may become objectionable to water users. There is no designated limit for Electrical Conductivity (EC) by the WHO.

In Malawi, a borehole encountering saline water is defined as a 'defective borehole' and should be sealed off and confined to the strata it is found (Government of Malawi, 2013). Proper reporting of saline groundwater is required to avoid tampering and further implementation of saline assets. The limits in Malawi for saline groundwater are 2000 mg/L concerning TDS and 3500 µS/cm concerning EC (Malawi Bureau of Standards, 2005).

This case study investigates the implementation of saline boreholes in the BUA catchment area, and the impact this has on participation with WPCs and the maintenance model.

4.10.2 Methodology

This case study was conducted alongside the BUA programme piloted by Water for People, Malawi. The free application Kobo Toolbox (http://www.kobotoolbox.org/) was used to collect the GPS coordinates of the Afridev handpump locations under the BUA model, during a site visit in June 2017. Water quality samples were taken from 59 out of 65 water points who had a working supply at the time of audit. There were 6 sites who had no working supply on day of visit. It was not possible to collect a water quality sample and therefore these sites were omitted from the study. Kobo Toolbox was also used to conduct surveys of the handpumps with the assistance of the WPC members present at each site. The names and associated number of each WPC are outlined in Table 4.4. Qualitative data was collected regarding the condition, perceived water quality reported, WPC narratives and maintenance history of the handpumps for each WPC during the survey. Contributing financial resources towards each handpump were investigated. Including water point banks (WPB) that utilise tariffs payed to the water point by the water users to generate interest through micro-loans, and the use of permaculture that utilises wasted water to grow crops to generate an income towards financing the handpump.

Financial books maintained by the Kakoma BUA and Water for People, Malawi were examined. In particular, the number of participating WPCs since implementation and the number of months the WPCs contributed over a year period. Uncertain data was removed with respect to incomplete records and lack of clarity attained from the BUA of contributing WPCs.

Table 4.4 Water quality samples taken from boreholes under the BUA catchment.

Village	Name of WPC	Village	Name of WPC
1	Bankamu	31	Maluwati
2	Batumeyo	32	Manjulo 1
3	Bowasi	33	Manjulo 2
4	Bwinolombwe	34	Manjulo 3
5	Chalowakuti	35	Masamba
6	Chambakata	36	Mindanti
7	Chambakata 2	37	Mlaliki
8	Chamera	38	Mlaliki 2
9	Chikaoneka	39	Moses
10	Chilumpha	40	Ndeule
11	Chimphepo	41	Ndeule 2
12	Chimphepo 2	42	Nkhongono
13	Chingetman	43	Nkosa
14	Chipolopolo	44	Nsaliva 2 (Agnesi)
15	Daus (a.k.a. Dausi 3)	45	Nsika
16	Dausi 1	46	Pataluwo
17	Dausi 2	47	Rice (Lackson 3)
18	Fodya	48	Saikonde 1
19	Gogogo	49	Saikonde 2
20	John	50	Simonzi
21	Jonamu	51	Talavi
22	Kalapilo	52	Timbenao 1
23	Kashoni 1	53	Timbenao 1 (2nd borehole aka Timbenao 3)
24	Kashoni 2	54	Timbenao 2
25	Kashoni 3	55	Timbenao 2 (2nd borehole)
26	Khauni	56	Timvamawa
27	Kulapa	57	Tombondera 2
28	Lackson 1 (Village)	58	Tombondera 3
29	Lackson (Clinic)	59	White (Simonzi 1)
30	Lackson 4/Lackson 2		

A handheld water chemistry probe was used to measure Electrical Conductivity (EC) and Total Dissolved Solids (TDS) during sampling, upon noting many water points were not used as drinking water sources. The dataset was investigated in terms of the Malawian guidelines and WHO guidelines for TDS and EC. A classification system for water quality, outlined in Kempster, van Vliet and Kuhn, 1997, was used to further investigate the TDS and EC measurements in the catchment area, as described in Table 4.5. The locations and salinity measurements, under the aforementioned guidelines for salinity, are assessed to determine the scale of salinity in the study area. Observations between the salinity guidelines and the potential impact in Malawi are discussed.

Table 4.5 Classification system for TDS and EC, adapted from Kempster, van Vliet and Kuhn, 1997.

Classification		TDS (mg/L)		EC (µS/cm)	
Class 0	Suitable for lifetime use, with no adverse health effects on the user.	0-450	Based on taste considerations. No salty taste detectable below this concentration.	0-700	The class limits for electrical conductivity are analogous to those for the TDS, using the approximate conversion ratio of electrical conductivity at 25°C to TDS of 6.5 mg/L.
Class 1	Safe for lifetime use. Water in Class 1 does not cause health effects under normal circumstances.	450-1000	Based on taste concentrations by the World Health Organisation.	700-1500	
Class 2	Defined as that where adverse health effects are unusual for limited short-term period use. Adverse health effects may become more common with prolonged use, or with lifetime use. Suitable for short-term or emergency use only, but not for lifetime use.	1000-2450	Based on health considerations. At this concentration of salts, individuals with impaired renal function, or with immature kidneys, such as infants, are susceptible.	1500-3700	
Class 3	Not suitable for use as drinking water without adequate treatment. Serious health effects may be anticipated, particularly in infants or elderly people with short-term use, and even more so with longer term use.	>2450	Will taste unpleasantly salty and will lead to dehydration and increased thirst.	>3700	

4.10.3 Results

4.10.3.1 Scale of salinity

Table 4.6 shows the classifications of the EC and TDS measurements taken from the 59 water points under the BUA model. There is a strong positive correlation between TDS and EC measurements when investigating salinity.

Table 4.6 Classification distribution for EC and TDS.

Classification*			Total		WPCs Reporting Salinity	
			n	%	n	%
Kempster, van Vliet and Kuhn, 1997	Class 0	EC	0	0.00	0	0.00
		TDS	0	0.00	0	0.00
	Class 1	EC	16	27.12	2	8.00
		TDS	17	28.81	2	8.00
	Class 2	EC	31	52.54	11	44.00
		TDS	30	50.85	11	44.00
	Class 3	EC	12	20.34	12	48.00
		TDS	12	20.34	12	48.00
WHO	Good Quality	TDS	2	3.39	0	0
	Between Good and Unpalatable	TDS	15	25.42	2	8.00
	Unpalatable	TDS	42	71.19	23	92.00
Malawian Standards	Within Limit	EC	47	79.66	13	52.00
		TDS	43	72.88	10	40.00
	Above Limit	EC	12	20.34	12	48.00
		TDS	16	27.12	15	60.00
Total		EC	59	100.00	25	100.00
		TDS	59	100.00	25	100.00

*The linear regression between TDS and EC presents a strong positive correlation of R^2=0.999 ($p<0.001$).

A significant proportion of samples fall within Class 2 and Class 3 for TDS (71.19%) and EC (72.88%). These classifications are not appropriate for regular use as there are significant health concerns and negative user perception at these levels. Notably less than 50% of WPCs in both classifications report salinity at the water point. Less than 30% of the water points investigated are suitable for use (Class 1) with no samples falling under an ideal quality (Class

0). The measurements of EC and TDS for each water point, with respect to classification, Malawi standards and WHO guidelines, are presented in Figure 4.6.

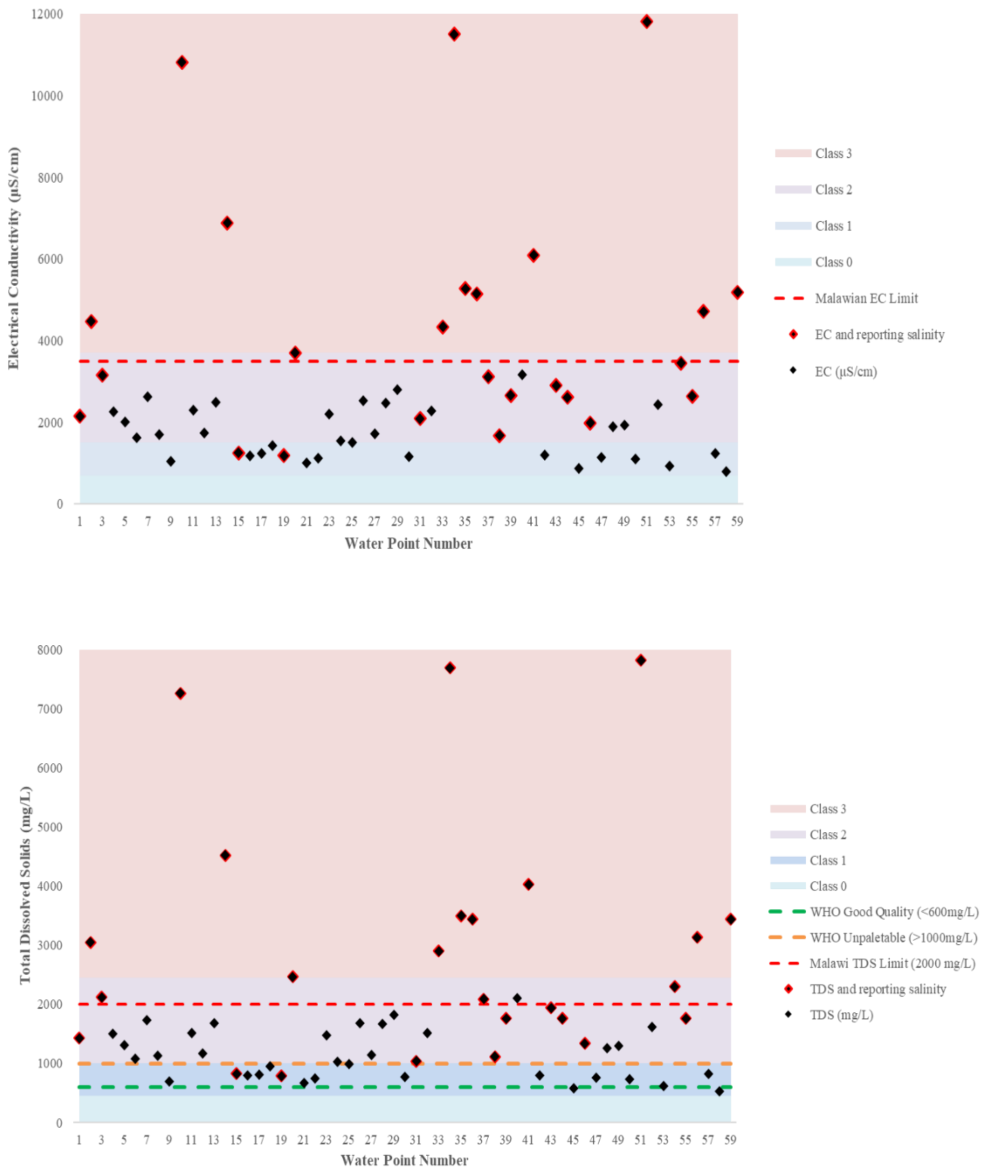

Figure 4.7 Electrical Conductivity (Top) and Total Dissolved Solids (Bottom) at each water point.

The distribution in Figure 4.7 and Table 4.6 shows the perception of saline water increases the higher the classification. The water points in Class 3 express significant high levels of EC and TDS and all reported salinity. Notably, the Malawian limit for EC is on the border between

Class 2 and Class 3. This results in 52.54% of water points that are not fit for purpose (Table 4.5) but are deemed suitable by Malawian Government standards (Malawi Bureau of Standards, 2005). The Malawian limit for TDS is slightly lower within Class 2, however this results in 4 additional water points that are not suitable for purpose.

While the WHO does not provide a guideline for EC, the results of the TDS measurements further suggest the sub-standard nature of these water points due to the aforementioned relationship between EC and TDS. Adhering to these guidelines results in a significant increase in water points that are not fit for purpose. There are 2 water points that are deemed to be 'good quality' by the WHO guidelines (<600mg/L), 15 water points deemed increasingly unpalatable (between 600-1000 mg/L) and 42 water points that are deemed unpalatable by the WHO (>1000 mg/L) and a risk to health. The classification of water points support these distinctions. However, if the Malawian guidelines are adhered to, 43 (72.88%) water points are deemed suitable by TDS standards (<2000 mg/L) and 47 (79.66%) water points by EC standards (<3500 µS/cm).

4.10.3.2 Distribution of salinity

Previous study has shown that salinity does not show a significant trend with the depth of boreholes in the lower Shire River valley where Chikwawa is situated (Monjerezi *et al.*, 2011). However, Monjerezi and Ngongondo (2012), shows that the distribution of salinity varies spatially across the Chikwawa district. The authors further conclude that high TDS levels across the large sections of the district, renders the groundwater unsuitable for domestic and irrigation purposes.

The study area in Chikwawa sits on an alluvial aquifer, in which there are known issues of highly saline groundwater in the area (Monjerezi and Ngongondo, 2012; Rivett, Miller, *et al.*, 2018; Rivett, Budimir, *et al.*, 2019). The Malawi Basement Complex to the north of the catchment, comprised of semi-pelitic gneisses and charnockitic granulites, expresses good quality groundwater away from the saline zones (Monjerezi and Ngongondo, 2012). The following presents the distribution of salinity in Figure 4.8 (TDS Classes), Figure 4.9 (WHO TDS guidelines) and Figure 4.10 (Malawi TDS guidelines).

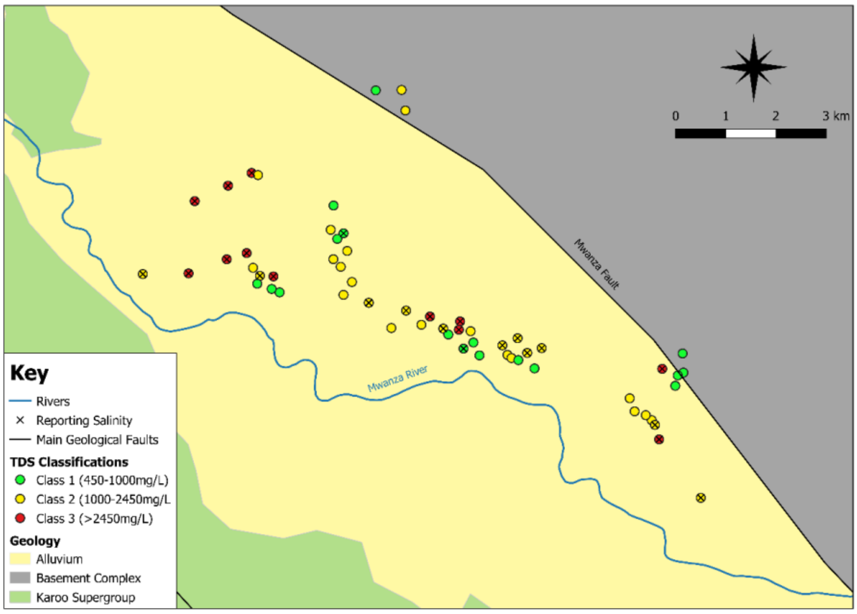

Figure 4.8 Distribution of TDS classes across Kakoma catchment.

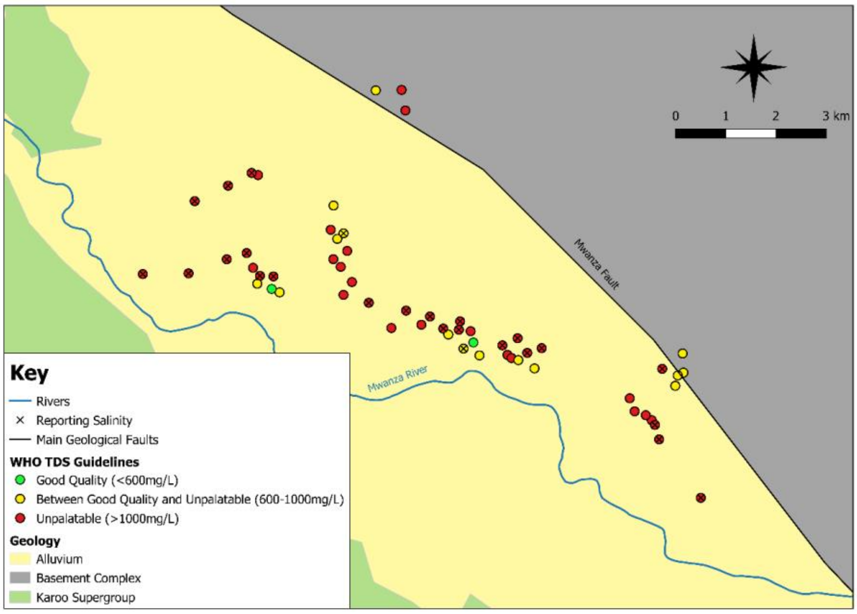

Figure 4.9 Distribution of WHO TDS guidelines across Kakoma catchment.

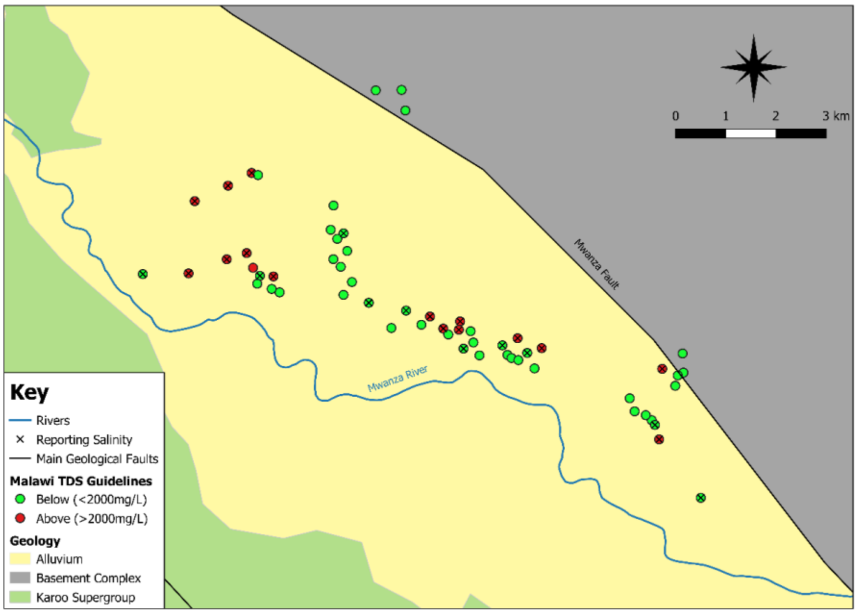

Figure 4.10 Distribution of Malawi TDS guidelines across Kakoma catchment.

While there are no cases of Class 0 in Figure 4.8, there are a proportion of supplies that are potentially safe for long term use (Class 1). However, these may be underutilised by users due to taste considerations as they are increasingly unpalatable as identified by WHO guidelines (Figure 4.9). The remainder of supplies distributed across the site are unfit for use, particularly in the Western section of the site where Class 3 supplies are dominant.

Figure 4.9 expresses a high number of supplies that are unpalatable (>1000mg/L) distributed across the study area under WHO guidelines. Notably, there are only two supplies that are deemed to be deemed good quality (<600mg/L) under WHO guidelines. These are surrounded by supplies with significantly higher saline groundwater that risk health under long term use (Figure 4.8), and users reporting their supplies are saline. It is possible users with or reporting high saline supplies resolve to utilising nearby supplies with lower salinity. Resulting in overuse and an increased burden on maintaining good quality assets.

Several of the supplies found in the Basement Complex lithology are safe for lifetime use (Figure 4.8) but are increasingly unpalatable (Figure 4.9). These supplies are located on or near the Mwanza fault line. Future research is required to understand the role this plays between the good quality groundwater typically found in the Malawi Basement Complex, and the high saline groundwater found in alluvial aquifers.

Figure 4.10 expresses notable differences when compared to Figure 4.8 and 4.9. There are a significant number of supplies that express TDS levels below the Malawian guidelines of 2000mg/L. Supplies that, if assessed under the different methods, are unpalatable and pose significant risks to health over long periods of use (Figure 4.8 - Class 2 and 3). Under the Malawian guidelines the area appears suitable for groundwater exploitation, with few occurrences that exceed suitable TDS levels. Highly saline and unsuitable supplies are therefore hidden when monitoring the access to safe drinking water access. Similarly to Figure 4.8 and 4.9, the Western region of the study area expresses supplies that exceed guidelines. Further suggesting that groundwater exploitation is unsuitable for water supply access in this section of the study area.

4.10.3.3 Decline of participation

The Kakoma BUA financial records identify the WPCs that contributed their fee during a year at the time of audit. Figure 4.11 presents the decline of contributing WPCs and the TDS classification of each water point. Table 4.6 presents supporting statistical information. Water points with both available salinity measurements and data available in the BUA financial records are presented.

Table 4.7 Linear regression for contributing WPCs.

	Contributing WPCs classification				
	Total	Class 0	Class 1	Class 2	Class 3
n	40	0	11	23	6
R^2	0.922	-	0.901	0.924	0.807
p-value	<0.001	-	<0.001	<0.001	<0.001

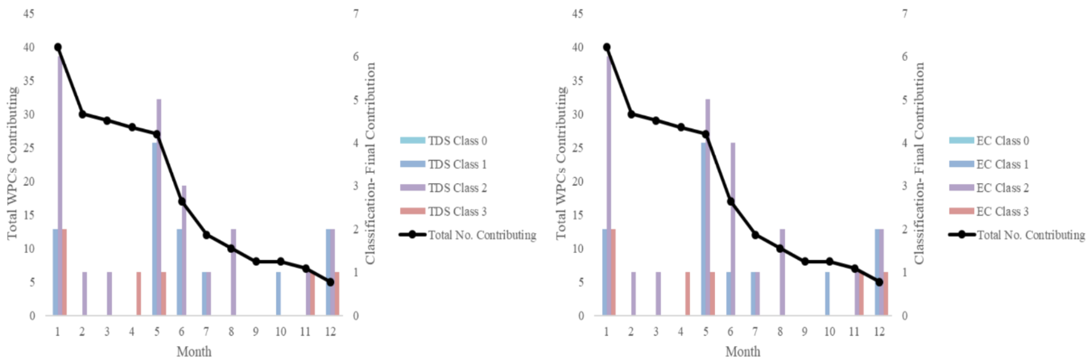

Figure 4.11 Total number of contributing WPCs to BUA by TDS (left) and EC (right) classification

There is a notable decline in WPCs contributing towards the BUA over the 12-month period, from 40 WPCs to 5 WPCs. The largest drop in contributions occur in month 1, 5 and 6, of which Class 2 expresses the largest number of cases where contributions reduced. The high TDS levels at the water points can impact the acceptability for users accessing these supplies (WHO, 2017a). This has a direct impact on water users participating towards the tariff towards WPCs for O&M. This has further implications for the BUA as the lack of contributing WPCs impacts the available financial resources to conduct any repairs for the remaining contributing WPCs.

4.10.4 Discussion

4.10.4.1 Implementation of sub-standard boreholes

The presence of saline groundwater supplies in Malawi are deemed to be 'defective boreholes' (Government of Malawi, 2013). In this case they are to be sealed off to prevent use and contamination of the strata. However, the Malawi Bureau of Standards for drinking water quality are at odds with the wider classification and global guidelines. Concerning the TDS measurements, Malawi standards indicate that 72.88% are deemed suitable for use. However, the WHO indicates 71.19% of water points are significantly and increasingly unpalatable. Class 2 further describes these water points as not suitable for long-term use, only in the short term or for emergency use. The WHO guidelines further indicates 96.61% of these water points are not of 'good quality'. Only 2 cases fall under the WHO limit for 'good quality' (<600 mg/L), with the majority of water points falling within increasingly unpalatable and objectionable categories. Even within the Malawian standards for EC and TDS, there are still notable water points with substantial measurements for salinity. As the TDS and EC measurements were taken as soon as water was produced from the pump, saline measurements may increase with continued use. Good quality sources could become increasingly unpalatable or become a greater risk to community health as pumping continues throughout the day. This provides further evidence of poor siting and practice when commissioning new infrastructure, in favour of the coverage target approach of the MDGs and national policy (Truslove *et al.*, 2019). The standards for EC and TDS in Malawi are therefore too high and risk losing the intended investments and benefits of drinking water supply. Thus posing direct and indirect risks to public health from unimproved source usage (Hunter, MacDonald and Carter, 2010).

4.10.4.2 Risks to health

The implementation of saline supplies may present a direct risk to the community's health. Class 2 and Class 3 for water quality indicates health impacts with prolonged use (Kempster, van Vliet and Kuhn, 1997). A significant proportion of the water points fall within these two categories. WHO guidelines state no health concerns with TDS levels but may influence the acceptability of the water from users. WPCs reporting salinity primarily occurs above TDS levels of 600mg/L. This aligns with the evidence that water quality becomes increasingly unpalatable above this limit. This results in water users avoiding improved water points in favour of unimproved sources.

The Mwanza river in the study area is located South of the study area and close to a significant proportion of increasingly unpalatable water points (Figure 4.9). During the survey it was indicated by several WPCs that the Mwanza was highly utilised as a primary source due to the saline groundwater present across the water points. Drinking water that is collected from the Mwanza impacts community health if it is not boiled or chlorinated prior to use. This source behaviour suggests that the implementation of saline 'improved' sources indirectly increases the use of unimproved sources. Particularly as households commonly obtain water from multiple sources, despite the global monitoring focus on access to one source of water supply (Vedachalam *et al.*, 2017).

4.10.4.3 Willingness to Pay

The presence of salinity affects the acceptability of water use, as outlined by global guidelines and classifications. The majority of cases in the catchment area fall within categories that are known to be increasingly unpalatable for water users, of which the perception of salinity is reported by WPCs. The result is an impact to water users willingness to pay the tariff set for O&M. Saline supplies inevitably increase the risks of water point failure (Foster, Willetts, *et al.*, 2018). The sub-standard installations, that include poor water quality, undermine the O&M capacity of water point governance (Whaley and Cleaver, 2017).

The results further highlight and support notable issues that sub-standard installations create within the CBM context, previously discussed in the chapter. Creating value is important within water user payment behaviour which includes the reliability, accessibility and quality of water service provision (Hoque and Hope, 2019). The implementation of saline supplies inevitably influences the perception of value of that water supply. Water users that prefer unimproved sources over saline supplies shows how the intended benefits and value of improved water supply is lost.

4.11 Conclusions

This case study highlights the impacts of saline water supplies in the Kakoma catchment area in the TA Chapananga within the Chikwawa district of Malawi. The majority of supplies are located on the alluvial aquifer which has known issues of salinity and where groundwater exploitation is unsuitable for drinking water access. Supplies are deemed appropriate under current Malawi water quality guidelines but hide potential impacts and unpalatable drinking water when assessed under international salinity standards. This highlights potential risks to health due to long term use of saline water, or unacceptable taste that leads to unimproved source use through the nearby Mwanza river. These risks are hidden and unaccounted for when monitoring focuses on improved source coverage. Furthermore, high saline content impacts the sustainability of continued water supply. Communities participation in maintaining these supplies decreases, which further risks usage of unimproved sources as the improved saline sources fall into disrepair. Overall the majority of supplies implemented in the study area are unsustainable and unfit for use. However, they will not be identified or resolved under current water quality guidelines in Malawi.

4.12 Acknowledgements

Thanks to Holly Small for assistance and support in data collection during the field investigation. Extended thanks to Water for People, Malawi for discussions and access to resources under the BUA programme, translations in the field and for allowing us to conduct research alongside their BUA programme.

4.13 Thesis Context

This chapter fulfilled RQ 1: Has the drive to meet the success and coverage targets of the Millennium Development Goals (MDG) resulted in low-levels of service and a burden on decentralised service providers? SO 1 is accomplished through a publication in a peer reviewed journal. By demonstrating the implementation of water supplies which have been subjected to the influence of national policies and the MDGs, that have induced some acceleration towards meeting coverage targets. The drive for decentralised management of rural water service providers has left rural populations with the burden of maintaining these assets, who struggle to provide the necessary maintenance and major repairs for sustainable service delivery. Furthermore, the implementation of sub-standard installations has contributed to the challenge of maintaining services. SO 2 demonstrated this issue and is accomplished through the case study in the Kakoma catchment, Chikwawa in Southern Malawi. High saline supplies influence participation with tariffs for O&M and the investigated maintenance model. The findings have implications for Malawian guidelines and policy. Water quality standards, with high thresholds for TDS and EC, may lead to the installation of assets that are unsuitable for use, that further hinder the sustainable development agenda. Further investigation is required to understand the challenges communities face entering the 2030 agenda, and to improve the performance of service provision at the local level rather than solely measuring it. This is accomplished in the next chapter.

CHAPTER 5. LOCALISING SDG 6.1 IN HOUSEHOLD COST RECOVERY TARIFFS

The previous chapter addressed the implementation of water supplies that are influenced by national policies and the global goals to meet coverage targets. Local service providers are left with the burden of sustaining assets that are hindered by a reliance on external support and the implementation of sub-standard installations. This chapter addresses RQ 2: How are global goals reflected in the cost-recovery mechanism for decentralised rural water supply?

Sustainable Development Goal 6 states “ensure availability and sustainable management of water and sanitation for all” and target 6.1 states “Achieve access to safe and affordable drinking water”. Localising this target is key for its fulfilment, however additional challenges may arise for local service providers alongside unsustainable infrastructure addressed in the previous chapter. To investigate the challenge of balancing affordability and maintenance requirements at the local level, service delivery information for boreholes equipped with Afridev handpumps installed across Malawi were extracted from a comprehensive live dataset. The investigation is accomplished through a paper that addresses two specific objectives of the thesis. SO 3: Investigate the variations in decentralised service providers and cost-recovery characteristics for the operations and maintenance of rural water supply assets, and SO 4: Identify service provider consideration when setting tariffs, SDG specific considerations and the significant explanatory predictor variables behind them. This is published in a peer reviewed journal, Sustainability, as follows:

- Truslove, J.P, Coulson, A. B., Nhlema, M., Mbalame, E. and Kalin, R. M. (2020) ‘Reflecting SDG 6.1 in Rural Water Supply Tariffs: Considering “Affordability” Versus “Operations and Maintenance Costs” in Malawi’, *Sustainability*, Multidisciplinary Digital Publishing Institute, 12(2), p. 744. doi: 10.3390/SU12020744

5.1 Paper: Reflecting SDG 6.1 in Rural Water Supply Tariffs: Considering 'Affordability' Versus 'Operations and Maintenance Costs' in Malawi

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Keywords: affordability; borehole; decentralisation; maintenance; management; service delivery; tariff

Truslove, J.P, Coulson, A. B., Nhlema, M., Mbalame, E. and Kalin, R. M. (2020) 'Reflecting SDG 6.1 in Rural Water Supply Tariffs: Considering "Affordability" Versus "Operations and Maintenance Costs" in Malawi', *Sustainability*, Multidisciplinary Digital Publishing Institute, 12(2), p. 744. doi: 10.3390/SU12020744.[d,e]

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[e] **Conceptualisation:** J.P.T; **Methodology:** J.P.T.; **Data Curation:** J.P.T., M.N and R.M.K.; **Formal Analysis:** J.P.T.; **Writing (Original draft preparation):** J.P.T.; **Writing (Review and editing):** J.P.T., A.B.C., M.N., E.M. and R.M.K; **Visualisation:** J.P.T.; **Supervision:** A.B.C. and R.M.K.

5.2 Abstract

Local tariffs in the form of household contributions are the primary financial mechanism to fund the maintenance of rural water supplies in Malawi. An investigation was conducted into the tariffs set by rural service providers to sustain drilled boreholes equipped with Afridev handpumps. A binary logistic regression analysis identified significant explanatory variables for the most common identified considerations when setting tariffs, 'affordability' and 'operations and maintenance (O&M) costs'. The results demonstrate tariffs collected less frequently and usage above the design limit of the Afridev (300 users) had lower odds of considering affordability and higher odds of considering O&M costs, than those collected per month and within the design limit. The results further suggest a recognition by service providers of an increased maintenance challenge. High usage, acquiring spare parts, and the collection of tariffs when repairs are required indicate an increased likelihood of considering O&M costs, conversely to considering affordability. The balance of affordability and sustainable maintenance is a perpetual challenge under decentralised service delivery. Investment into ongoing support and supply chains is required for the financial and operational requirements of water supply, to ensure payments for services does not prevent access to clean water at the local level and to achieve the 2030 agenda.

5.3 Introduction

Investment to increase the coverage of water supply infrastructure has been a key component of global goals, government targets, and projects throughout the aid sector. The Millennium Development Goal (MDG) era set out coverage targets, including target 7c "to halve the proportion of people without sustainable access to safe drinking water and basic sanitation" by 2015. While this target was globally delivered in 2010, areas within Sub-Saharan Africa (SSA) fell behind (WHO/UNICEF, 2010). A global focus for coverage continued into the Sustainable Development Goal (SDG) era in 2015 through goal 6, which aims to "ensure availability and sustainable management of water and sanitation for all". The SDGs focus on coverage also requires the same, if not greater, emphasis on local sustainability to ensure continued service delivery, particularly for rural water supply. While the performance under the MDGs expressed positive progress in rural water supply usage and access at the global level, MDG indicators may hide a low level of local service, which may hinder progress under new SDGs coverage targets (Adank *et al.*, 2016; Truslove *et al.*, 2019).

The SDG agenda makes the commitment to 'leave no one behind', in which attention and priorities are required for disadvantaged groups and the elimination of inequalities for service delivery (United Nations, 2018a). To fulfil this, SDG target 6.1 states "Achieve access to safe and affordable drinking water". This ambitious target moves from "halving the proportion without sustainable access" stated in MDG 7c to 'universal access' and recognises the importance of reducing inequalities as part of sustainable access. Affordability, a key aspect of equity (United Nations Development Programme, 2006), was initially included in the MDG target for water but later removed, as described by Bartram et al. (Bartram *et al.*, 2014). Its importance was subsequently recognised for global SDG targets set post-2015 (WHO/UNICEF, 2015). However, SDG 6.1 still reflects its predecessor (MDG 7c), as focus remains with global coverage of drinking water. Affordability is not reflected by the set indicator (SDG 6.1.1), which states “Proportion of population using safely managed drinking water service”. While the term ‘safely managed’ addresses the quality, availability, and accessibility of an improved source (WHO/UNICEF, 2017a), the affordability of the improved source lacks consideration. This has implications for reducing poverty (SDG 1), particularly in low-income countries due to the synergy between the SDG targets (Mainali *et al.*, 2018; Kroll, Warchold and Pradhan, 2019). Payment for services should not prevent access to clean water, however, there is no commonly agreed approach to defining affordability or its monitoring (United Nations, 2018a).

The efficient operations and maintenance (O&M) of infrastructure investments are key to fulfilling the SDGs. Discussion around the O&M of infrastructure is common in the rural water sector, and efforts into establishing service provision to conduct and finance O&M have been ongoing since the 1980s (Schouten and Moriarty, 2003; Harvey and Reed, 2006a; Moriarty *et al.*, 2013; Hutchings *et al.*, 2015). Technologies, national policies, and sector strategies for rural water supply have embraced the ‘village level operations and maintenance’ (VLOM) approach, most notably the development and standardisation of community handpumps (Baumann and Furey, 2013; Macarthur, 2015). However, the movement and argument that ‘communities are always capable of managing their facilities on their own’ has not solved the issues associated with rural water supply in SSA, with only two out of three handpumps working at a given time (RWSN Executive Steering Committee, 2010). It is widely acknowledged that the community based management (CBM) approach to rural water supply is reaching its limits of what can be achieved through informality and voluntarism (Moriarty *et al.*, 2013; Chowns, 2015a; van den Broek and Brown, 2015), particularly when policy dictates for long-term sustainability. Despite this recognition, CBM continues to be the dominant approach to rural water supply management in the sector, which requires professionalism and long term institutional support to mediate the challenges of participation (Lockwood and Smits, 2011; Hutchings *et al.*, 2015).

It is well established in CBM that O&M is a continuous challenge for rural water service providers, and sustainability as the success is dependent on multi-dimensional factors, i.e., hydrogeological, socio-cultural, financial, and poor infrastructure (van den Broek and Brown, 2015; Hutchings *et al.*, 2017; Kativhu *et al.*, 2017; Bonsor *et al.*, 2018). The infrastructure and management of rural water service delivery are interlinked. Exploring the relationships between systems and influencing factors can improve the understanding of how these relationships contribute to water service delivery and system breakdown (Carter and Ross, 2016; Liddle and Fenner, 2017; Klug *et al.*, 2018). Rural communities and service providers that struggle to provide the required maintenance and major repairs required for operational sustainability will see a decline in service and unreliable sources that undermine the sustainability of service delivery (Foster, 2013; Martínez-Santos, 2017; Kalin *et al.*, 2019; Truslove *et al.*, 2019). This negative feedback loop highlights the need to continually support the community to ensure sustainability (Hutchings *et al.*, 2015; United Nations, 2018a).

The lack of financial resources for O&M is one of the many issues that impact the long-term functionality of an asset. Tariffs are typically the primary financial mechanism to fund maintenance for the sustainability of rural water supply assets, which translate to user fees or household contributions (United Nations, 2018a). Notably, user contributions may reflect payments upon breakdown, as action may only be taken upon water point breakdown (Chowns, 2015a). Tariffs have generally been specified as no more than 3% of household income to reflect affordability within the human right to water. While this benchmark aims to address affordability, this is not guaranteed (Lee, 2011; Holm, Singini and Gwayi, 2016).

Furthermore, tariffs may be set to be affordable for users, but insufficient for sustainable service delivery, that may precipitate a high risk of a cycle of service decline, non-payments by users, and further service deterioration (Lockwood and Smits, 2011).

Acceleration towards the attainment and localizing the SDGs is increasingly important (Editorial, 2019). However, the balance between cost recovery and affordability is a complex dilemma when setting tariffs at the local level. Service providers and communities struggle with this balance in which additional financial mechanisms are required to reconcile from a human rights perspective (WHO, 2017b). This raises the question of the effectiveness of fulfilling SDG 6.1 when the balance of affordability and sustainable maintenance in the rural context are a perpetual challenge.

This study investigates the balance of affordability and O&M costs when tariffs are set by rural water service providers, and how these change over different management contexts. To achieve this, data for service providers and tariff coverage for the O&M of drilled boreholes equipped with Afridev handpumps across Malawi were examined. Variations in decentralised service provisions for these assets and the considerations when establishing tariffs and revenue collection were investigated. A binary logistical regression analysis permitted identification of significant explanatory variables for affordability and O&M cost considerations when setting tariffs at the local level.

5.4 Context, Materials and Methods

5.4.1 Study Context

This study was conducted across rural areas of Malawi. Approximately 84% of the country's 18.6 million people are located in the rural setting, with more than 50% below the poverty line (Government of Malawi, 2018). Groundwater exploitation is the primary water source for the rural communities and is commonly accessed through boreholes fitted with Afridev handpumps.

Like many other low-income countries in SSA, Malawi operates rural water service delivery under the CBM approach. The promotion of this model during the 1980s, as a route towards sustainable water supply access, acts to empower communities, but also requires voluntarily undertaking the management and financial responsibilities of service delivery (Briscoe and de Ferranti, 1988). Through this model, the capital expenditure of implementing rural water supply is covered by external actors while the O&M costs are covered by community based tariffs as a form of cost-recovery (Evans and Appleton, 1993; Fonseca *et al.*, 2013; van den Broek and Brown, 2015). Malawian national policy and guidelines recommend tariffs are calculated by taking the assumed costs of supplying water over the estimated design life of 15 years (e.g., replacement of spare parts, transportation, preventative maintenance contracts, and total replacement) and the number of contributing households to establish a monthly tariff (MoAIWD, 2015).

Malawian national policy is consistent with MDG 7c (MoAIWD, 2005) that states, "To achieve sustainable provision of community owned and managed water supply and sanitation services that are equitably accessible to and used by individuals and entrepreneurs in rural communities for socio-economic development at affordable cost." (MoAIWD, 2010). This also reflects aspects of SDG 6.1. Service providers for decentralised rural water supplies are primarily water point committees (WPCs), who typically contract a local Area Mechanic to conduct repairs out with any routine O&M conducted by the WPCs. The financial provision for O&M is accomplished through the aforementioned household tariffs, in which amount and frequency are agreed upon by the community (MoAIWD, 2005, 2010; Baumann, 2006).

While the policy positively reflects SDG 6.1, there are challenges with balancing affordability and O&M costs at the local level.

5.4.2 Data Collection

The Scottish Government Climate Justice Fund (CJF) Water Futures Programme has been working in partnership with the Government of Malawi since 2011, and currently aims to support the country in the achievement of SDG 6. The programme is evaluating the sustainability of all rural water supply assets in Malawi, in which data are collected and collated through the management information systems (MIS), mWater (www.mwater.co). This is accomplished through a water point functionality survey based on SDG 6 indicators and the Government of Malawi's needs (see www.cjfwaterfuturesprogramme.com).

This study draws upon this dataset, specifically data on the types of service providers managing the assets, financial mechanisms for O&M (primarily in the form of tariffs), and details of the supplied communities. Questions utilised are highlighted in Appendix A. The surveys are subjected to rigorous quality assurance checks to ensure the accuracy of mapped water points and to reject any survey submissions that do not meet these quality checks. This is further described in Miller *et al.*, 2018 and Truslove *et al.*, 2019.

5.4.3 Dataset Sampling

This study investigates the types of decentralised service providers and the variations and trends in tariffs for water point O&M across the 28 districts in Malawi across the MDG period to date. The geographical coverage, primarily across the Southern and Central regions of Malawi, is detailed in the 5.9 Supplementary Information. A subset of 22,316 drilled boreholes equipped with Afridev handpumps was captured from the database for study. The Afridev is an approved technology of the Government of Malawi, and is the dominant handpump through standardisation (ERPF, 2007; Macarthur, 2015), and thus chosen for study. This study focuses on MDG and SDG assets only, therefore, boreholes equipped with Afridevs installed before the beginning of the MDGs were excluded from the study, as this is out with the expected design life of the Afridev. Water points without a date of installation available were also excluded. Taps and piped supplies were excluded, as these fall under water boards primarily in the urban setting (Government of Malawi, 2010; WHO/UNICEF, 2017a). Some 84% of the population of Malawi use boreholes equipped with handpumps; the subset hence considers the dominant improved water supply technology in the rural setting (WHO/UNICEF, 2017a).

5.4.4 Methods

Service provider data was interrogated to explore (a) if the supply had a service provider present for O&M, (b) the breakdown of service providers for O&M, (c) if the service providers set a tariff (which is defined as a user fee or household contribution), and d) the number of water users the water point serves. The tariffs set by the service providers was captured, in relation to (a) the frequency of tariff collection, (b) the variations in the tariff amount, and (c) the costs considered when setting the tariff.

Where the number of users and tariff amount is considered, the raw dataset was consolidated into groups based on similarities in the data. User grouping was stated either above or below the design specification for population using the Afridev (up to 300 users). Where an accurate number is unavailable at the time of audit, the number of users is estimated at approximately 5 members per household (where the statistical average number of members per household in Malawi is 4.4 (National Statistical Office, 2018)). Tariff grouping was chosen within the aforementioned 3% of household income benchmark to reflect affordability, above or below 500 Malawian Kwacha (MWK) (approximately 0.66 USD, where 1 USD = 753.66 MWK, as of July 2019). This equates to 2% of household income in Malawi

(25,000 MWK per month as of 2019), to account for fluctuating household income and inflation, and the median tariff value in the monitoring of the wider CJF dataset.

A binary logistic regression analysis was used to identify significant explanatory variables for 'affordability' and 'O&M costs' considerations when setting tariffs, using the statistical package SPSS (version 26). This allowed determination of the relationship between a dichotomous dependant (affordability considered = yes/no and O&M costs considered = yes/no) and an independent predictor variable (categorical or continuous), while controlling for all other independent variables in the logistic regression model. Unadjusted odds ratio indicates the bivariate relationship between the dichotomous dependent variable and the independent predictor variable. Multivariable adjusted odds ratio allows for the calculation of odds ratios in which the effect of the other independent variables is accounted for. Explanatory variables were selected based on their relevance to sustainability and the rural water service provider context established through the water point functionality survey, domains including:

- Service Delivery—Describing the type of service provider and number of users.
- Operational—Describing the age and functionality of an asset, preventative maintenance, and if spare parts are kept on site.
- Financial & Cost Recovery—Specifying the tariff amount and frequency.
- Geographical—Specifying the region of Malawi.

For the avoidance of doubt where functionality was included, functional describes a water point in operational condition providing water according to design specifications, partially functional describes a water point providing water in a reduced capacity (e.g., repairs required, changes in site, seasonal variations, etc.), and non-functional describes a water point no longer providing water on a regular basis at the time of audit. It is acknowledged in the analysis that the term functionality provides a temporal snapshot indicator for sustainability (Carter and Ross, 2016).

Data was cleaned to remove statistical outliers (e.g., abandoned water points), unlikely values (e.g., tariff amount equals zero where a tariff is reportedly in place), and missing data in the explanatory variables. Furthermore, explanatory variables were tested for multicollinearity by calculating the variance inflation factors. The analysis was designed to identify significant explanatory variables rather than to find a predictive model with the 'best' fit.

5.5 Results and Discussion

5.5.1 Decentralised Service Provision

Table 5.1 shows the breakdown of service providers for rural drilled boreholes equipped with Afridevs, and whether these service providers establish tariffs for the O&M of these community handpumps. Service provision may differ across rural water service delivery areas. While policy states the service providers for rural water supply consist of WPCs and a local Area Mechanic, not all service providers conform to the national policy.

Table 5.1 Breakdown of service providers and the tariffs set, n = 22316.

Service Provider				**Service Provider Variable**			
				w/ Tariff		**w/o Tariff**	
	Variable	*n*	**%**	*n*	**%**	*n*	**%**
Established [1]	No	1162	5.38	-	-	1162	100
	Yes	20,456	94.62	16,796	82.11	3657	17.88
	Total	21,618	100	16,796	77.70	4819	22.30
Where Service Provider Present (*n* = 20,438) [1]				**Service Provider Variable**			
				w/ Tariff		**w/o Tariff**	
	Variable	*n*	**%**	*n*	**%**	*n*	**%**
Single Service Provider	WPC	16,250	79.51	13,644	83.96	2604	16.02
	Area Mechanic	1060	5.19	888	83.77	171	16.13
	Community Members	410	2.01	270	65.85	140	34.15
	Institution	430	2.10	143	33.26	287	66.74
	Other [2]	177	0.87	92	51.98	85	48.02
	Total	18,327	89.67	15,037	82.05	3287	17.94
Multiple Service Providers	=2	1969 [3]	93.27	1638	83.19	331	16.81
	=3	140	7.11	107	76.43	33	23.57
	=4	2	1.43	2	100.00	0	0.00
	Total	2111 [4]	10.33	1747	82.76	364	17.24

[1] Excluding data that indicates no response and don't know. [2] Other service providers of *n* = 20,438: Owner/Private household (*n* = 78, 0.38%), Private contractor or operator (*n* = 59, 0.29%), WUA (*n* = 17, 0.08%), NGO (*n* = 9, 0.04%), Local Government (*n* = 8, 0.04%), Public operator/utilities (*n* = 6, 0.03%). [3] Includes both WPC and Area Mechanic, *n* = 1315 (66.82%). [4] SP > 1 includes either a WPC or Area Mechanic, *n* = 2110 (99.99%).

A small percentage of the dataset (5.38%) lack a service provider for the asset, where service provision has broken down or has not been established at all. CBM is typically attributed to two aspects that dictate the functionality of water supply assets: 'Hardware', which identifies the physical infrastructure, and 'software', which identifies the governance to maintain the physical hardware (Evans and Appleton, 1993). While often treated separately, these are in fact interlinked and important for the overall sustainability of service delivery (Whaley and Cleaver, 2017). The lack thereof resulting in declining functionality and early breakdown without service providers to conduct O&M (van den Broek and Brown, 2015; Whaley and Cleaver, 2017; Truslove *et al.*, 2019).

The presence of service providers alone does not ensure sustainable functionality across the design life of an asset. Of the service providers that are present to conduct O&M (94.62% of the total dataset), 17.88% do not have tariffs set for O&M (Table 5.1). Suggesting a lack of support for service providers to establish a tariff in the first instance or a tariff was set but is no longer present due to impactful factors such as the willingness to pay.

Table 5.1 shows WPCs are widely present in both single service providers and multiple service providers (alongside Area Mechanic) complying with Malawi national policy. Area Mechanics act as the service provider in 5.19% of singular cases where WPCs are not present. Community members also act as the service provider in 2.01% of cases, in which a significant proportion do not set tariffs compared to WPCs and Area Mechanics. The importance of support for governance and sustainability is hence inferred.

Two thirds of institutions (i.e., health facilities, schools, religious organisations) have not established tariffs for their assets (Table 5.1). This is possibly attributed to the more structured approach of institutions when compared to other CBM stakeholders. It is possible O&M funding is within the normal operational budget of these institutions, therefore, tariffs are potentially not required at these sites. If the latter is not the case, under the decentralised CBM policy this would result in inconsistencies within aggregate statistics. Moreover, the lack of tariffs and subsequently O&M of assets could result in an overall decline of service delivery. Support for service providers is essential to ensure an appropriate life-cycle is achieved for water supply assets and to avoid the non-functionality of water points, and decline of serviceability (Whaley and Cleaver, 2017).

Where single service providers are present, the majority conform to the specifications of rural water supply management in Malawi as WPCs make up the majority of service provision (79.51%). Where multiple service providers are present, the WPC or Area Mechanic are one of the established service providers (*n* = 2110, 99.99%). It is assumed a tariff is paid to either one of these, however, the presence of multiple service providers has the potential to create confusion for water users as to whom to pay the tariffs to. This may exacerbate problems associated with willingness to pay by contributing users if clear lines of accountability are not evident. This problem will be compounded if processing charges for tariff collection are levied by individual service providers, essentially duplicating and increasing costs. Establishing service provision that conforms to national policy is important. However, service provision may deteriorate due to various complexities, and in some cases, may not be established in the first instance. Where service provision is present for a rural water supply asset, it may not reflect exactly what is stated within policy and guidelines. As a result, cost recovery through tariffs for O&M and sustainability varies significantly.

5.5.2 Frequency of Tariff Collection

A proactive, preventative approach to maintenance is crucial for ongoing sustainability as emphasised in CBM, but rarely conducted (Chowns, 2015a). The frequency of tariff collection can impact the potential financial resources available to conduct vital O&M and varies across site specific circumstances. Frequency of the tariff collection is therefore an important aspect of the life-cycle costing of rural water supply assets. Table 5.2 presents the distribution of the frequency of tariff collection by the number of users and tariff amount. Where, single frequency refers to a collection by the service provider on a specified occasion (e.g., collection once per month) and multiple frequencies refer to a collection by the service provider on more than one specified occasion (e.g., once per month and when required for repairs). Figures 5.1 and 5.2 indicate the breakdown of single and multiple tariff collection frequencies by the number of users and tariff amount, respectively.

Table 5.2 Frequency of tariff collection by no. of users and tariff amount (n = 22,316).

	No. of Users [1]					
Variable	**Total**		**<=300**		**>300**	
	n	%	*n*	%	*n*	%
Total, *n* [1]	16,670	100	8699	52.18	7971	47.82
Single Frequency	15,938	95.61	8342	52.34	7596	47.66
Multiple Frequencies	732	4.39	357	48.77	375	51.23
	Tariff (MWK) [1]					
Variable	**Total**		**<=500**		**>500**	
	n	%	*n*	%	*n*	%
Total, *n* [1]	16,761	100	15,674	93.51	1087	6.49
Single Frequency	16,023	95.60	14,989	93.55	1034	6.45
Multiple Frequencies	738	4.40	685	92.82	53	7.18

[1] Excluding data that indicates no response and don't know.

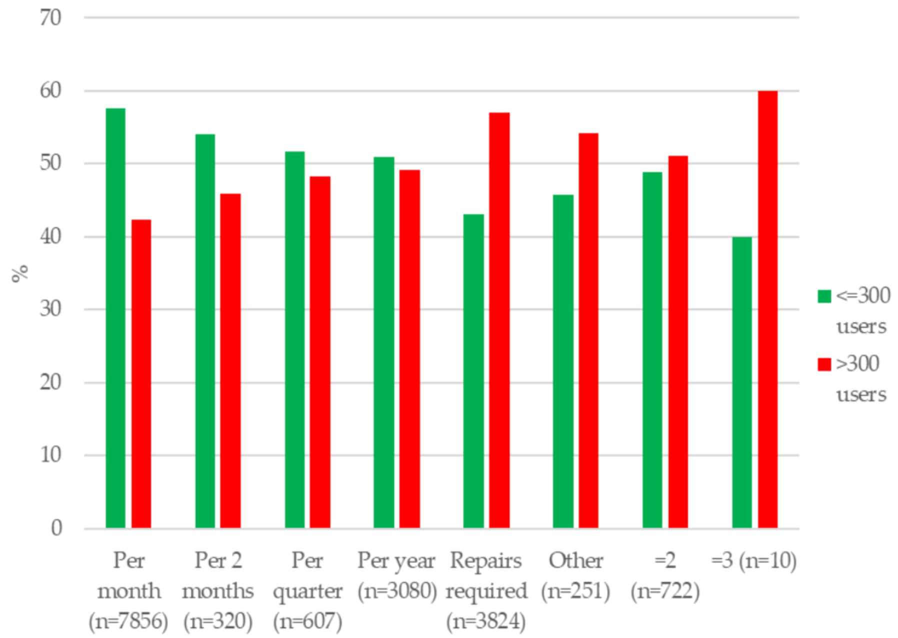

Figure 5.1 Frequency of tariff collection by no. of users.

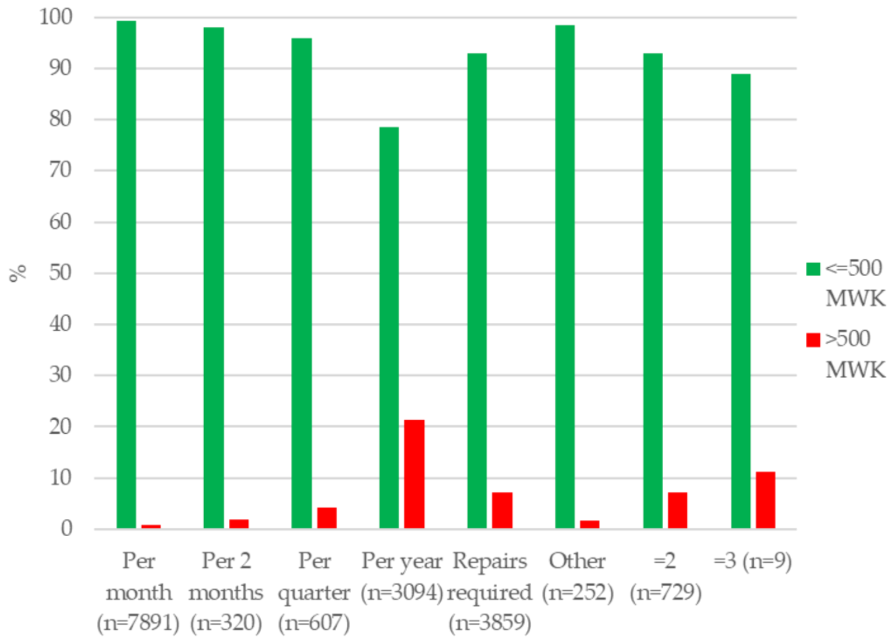

Figure 5.2 Frequency of tariff collection by tariff amount in (MWK). "Other" tariff collection frequencies of n = 16,670 include: Per unit of water—litre/bucket/jerry can (n = 123, 0.74%), Flat fee plus fee per unit (n = 64, 0.38%), Per week (n = 53, 0.32%), Per day (n = 11, 0.07%).

5.5.2.1 Frequency distribution by users

Tariff collection behaviour differs between the two user groups, the first up to the design limit of the Afridev (<=300 users), and the second above the design limit of the Afridev (>300 users). Figure 5.1 demonstrates that as collection becomes less frequent, the distribution between the two user groups moves from a greater weight on <=300 users for more frequent tariffs, to a greater weight on >300 users for collections per year. As users increase, the tariff collection for repairs as required also notably increases. This suggests that as usage increases above the design limit of the Afridev, tariff collection trends towards a reactive approach to maintenance. Usage within the design limit is more reflective of a proactive approach with tariffs collected more frequently. Where multiple tariff collection frequencies occur, weighting trends towards >300 users (Table 5.2 and Figure 5.1).

The number of users at a water point fails to denote that all users contribute, but ideally each user household contributes as defined in Malawian policy (that a tariff is collected per household (MoAIWD, 2010)). Households commonly obtain water from multiple sources despite the global monitoring focus on access to one source of water supply (Vedachalam *et al.*, 2017). Sub-standard installations that are subject to premature breakdown, seasonal variations, and poverty can result in users relying on unimproved or multiple improved sources in other service areas (Tucker *et al.*, 2014; Anthonj *et al.*, 2018; Kelly *et al.*, 2018; Mannix *et al.*, 2018; Truslove *et al.*, 2019). This may contribute to the number of users increases above the design limit of the Afridev (300 users).

Assets that are treated as secondary sources may be treated as free and not receive financial contributions from those users. Furthermore, the perception that a neighbouring community's water supply is free water may impact the willingness to pay of primary users. This impacts the potential financial resources available for O&M, which could attribute to tariffs collected on a reactive basis for maintenance to meet immediate costs to reinstate operations at non-functioning assets when usage is above the intended design. These results underline the shortcomings of single source monitoring, due to the influence multiple source behaviours have for practitioners and stakeholders when establishing and financing service delivery.

5.5.2.2 Frequency distribution by tariff amount

Table 4.2 demonstrates single tariff collection frequencies dominate 95.61%, of which the three most common occurrences are collections 'per month' (47.13%), 'repairs required' (22.94%), and 'per year' (18.48%), as demonstrated in Figure 5.2. Multiple collection frequencies are a minor occurrence with only 4.40% of the total dataset, and only 7.18% of multiple frequencies above 500 MWK.

As tariffs are collected less frequently, the weighting slightly increases to >500 MWK. Figure 5.2 demonstrates 'per year' with the highest weighting above 500 MWK (21.42%). This is to be expected for larger tariffs collected in fewer instances across the life-cycle of the water point to accommodate the annual life-cycle costs. However, as the majority of tariffs collected per year are similar in value to those collected per month, the annualised financial resources available significantly differ. For example, if 500 MWK is collected per month, this cumulatively results in 6000 MWK per annum, compared to a tariff at 500 MWK collected per year. This has implications for the potential financial resources available for O&M across the life-cycle of an asset and could result in premature failure if no maintenance is conducted. This is further complicated by water user's willingness or ability to pay the tariff and pay on time. Therefore, financial contributions may be sought at a time when the need is most apparent to users, such as tariffs collected when repairs are required (Figure 5.2) due to water point failure.

Foster and Hope, 2016, investigates this community behaviour to water point payment over a large timescale and dataset in rural Kenya. Households were not always able to pay towards tariffs, demonstrating a lack of affordability, or were unwilling to contribute. This may be indicative of the complex socio-cultural nature and risk factors for water point sustainability throughout rural SSA (Foster, 2013; Hutchings *et al.*, 2015; Carter and Ross, 2016; Foster, Willetts, *et al.*, 2018). Considerations when setting these tariffs may be inherently different depending on the contextual factors of the rural communities that have implications for sustainability and fulfilling the 2030 agenda. These financial responsibilities and burdens in this complex rural environment require ongoing external support and monitoring (Harvey and Reed, 2006a).

5.5.3 Considerations When Setting Tariffs

Table 5.3 shows the distribution of one or multiple factors that are considered when setting tariffs by the number of users and tariff amount. Figures 5.3 and 5.4 indicate the breakdown of these factors by the number of water users and tariff amount, respectively. It is crucial to identify what factors service providers consider when setting tariffs when reflecting on the country's national policy and the SDG agenda to 'leave no one behind'.

Table 5.3 Considerations when setting tariff by users and tariff amount n = (22,316).

	No. of Users [1]					
Variable	**Total**		**<=300**		**>300**	
	n	%	*n*	%	*n*	%
Total, *n* [1]	16,676	100	8696	52.15	7980	47.85
Single Consideration	12,192	73.11	6289	51.58	5903	48.42
Multiple Considerations [2]	4484	26.89	2407	53.68	2077	46.32
	Tariff (MWK) [1]					
Variable	**Total**		**<=500**		**>500**	
	n	%	*n*	%	*n*	%
Total, *n* [1]	16,737	100	15,651	93.51	1086	6.49
Single Considerations	12,242	73.14	11,473	93.72	769	6.28
Multiple Considerations [2]	4495	26.86	4178	92.95	317	7.05

[1] Excluding data that indicates no response and don't know. [2] Responses include either "Affordability" or "Maintenance" as a consideration, with the exception of *n* = 2 occurrences in "=2" category.

While a single tariff consideration dominates the dataset, multiple considerations also make up a significant proportion (26.89% when users are considered and 26.86% when the tariff amount is considered). In both singular and multiple considerations, the dataset provides valuable insights into what service providers hold most important when setting the tariffs; affordability and maintenance.

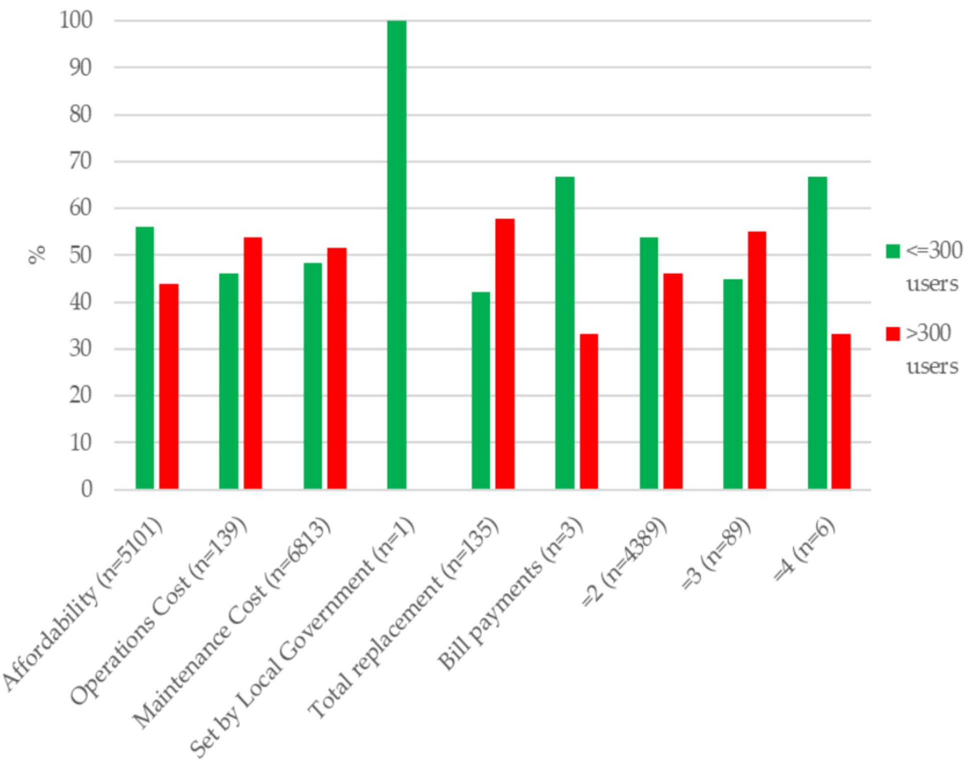

Figure 5.3 Considerations when setting tariffs by no. of users.

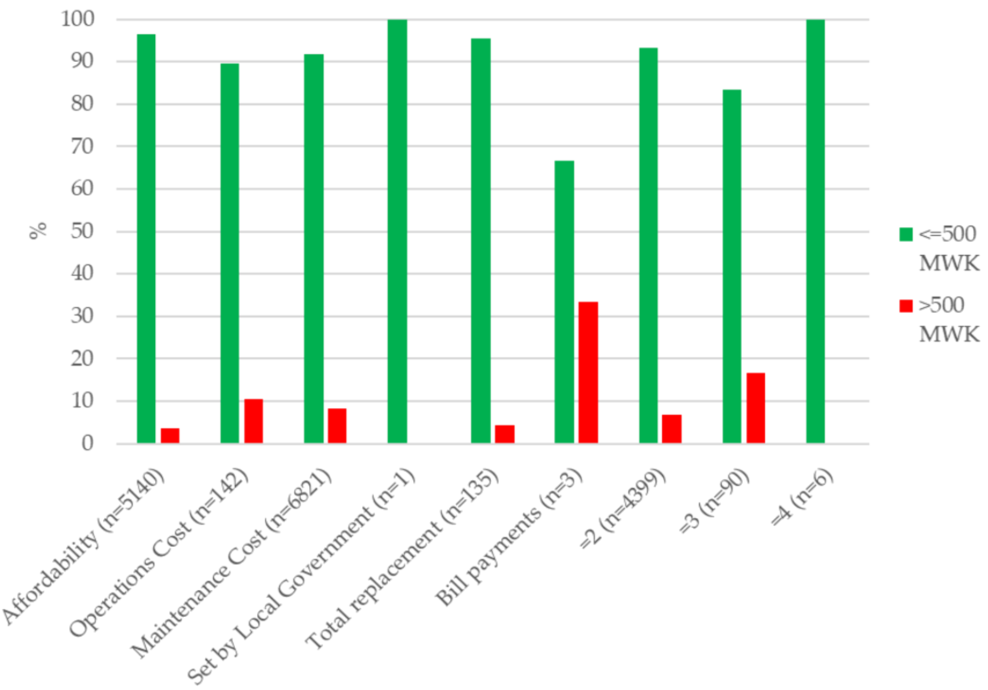

Figure 5.4 Considerations when setting tariffs by tariff amount (MWK).

5.5.3.1 Considering Affordable and Maintenance Driven Tariffs

Affordability and maintenance costs dominate tariff considerations, across user and tariff categories, with affordability being a greater consideration when the population is within design specifications. This trend is reflected where multiple considerations (Figures 5.3 and 5.4 where considerations are '=2') are examined, as the combination of affordability and maintenance costs contribute to the majority of occurrences for users and tariffs (n = 3986 and n = 3995 respectively). These suggest that service providers consider tariffs as sufficient to maintain assets when 'affordable' financial contributions are made from households.

Figure 5.3 demonstrates that maintenance related costs are more considered when usage is above the design limit. O&M costs (which can include both 'operations costs' and 'maintenance costs' considerations) shows a slightly larger split towards >300 users, while affordability indicates ~10% greater weighting towards <=300 users. This suggests that when usage is within the design limit, there is more incentive to ensure willingness to pay of tariffs. With greater use above the design, maintenance costs are more common, resulting from greater wear and tear, and more frequent repairs.

The results present a dominance of tariffs <=500 MWK, as the primary choice for rural water supplies. This suggests that <=500 MWK is what rural service providers consider to be affordable for contributing households, however, the annualised financial resources to cover the maintenance costs in their service delivery area vary significantly (Section 5.4.2.2). Any of the occurrences that express >500 MWK are primarily maintenance based considerations, or where there is more than one consideration when setting the tariff.

5.5.3.2 Considerations for Long Term Sustainability

Total replacement accounts for a small number of the financial considerations recorded (Figures 5.3 and 5.4). Capital Maintenance Expenditure (CapManEx), which accounts for costly major repairs and rehabilitation, is an essential part of the life-cycle of assets which goes beyond routine minor O&M to keep services running (Fonseca *et al.*, 2010; Franceys and Pezon, 2010). These costs are recommended to non-community external support as reflected in Malawian national policy (MoAIWD, 2010) and rely on NGOs for funding (Scanlon *et al.*, 2016; Kativhu *et al.*, 2018; Truslove *et al.*, 2019). Total replacement costs are seldom considered when setting the tariffs (n = 135) with a slightly larger weighting towards >300 users, suggesting the acknowledgement of increased burden on infrastructure from increased usage (Figure 5.3). This small number supports the conclusion that CapManEx/Rehabilitation costs are not a primary concern of service providers. The results endorse the understanding that rehabilitation (excluding maintenance) is regarded as the start of a new service, is not considered in either pre or post construction of assets (RWSN Executive Steering Committee, 2010; Mcintyre *et al.*, 2014). Tariffs at the local level can fulfil O&M requirements, however, these are unlikely to be sufficient for total cost recovery and rehabilitation (United Nations, 2018a). The sustainability of rural water supply is further at risk when rural assets are without appropriate O&M, and prematurely fail after 5 years as described by Baumann, 2006. This results in early rehabilitation to bring the service back up to an operational standard.

The balance of cost recovery and affordable water payments is crucial for fulfilling the SDGs that will require increased financing and development assistance, to bridge the funding gap in low-income countries (Sachs *et al.*, 2019). This has led to affordability schemes throughout the sector to support service delivery. Financing strategies such as microfinance (United Nations, 2018a) and permaculture (Rivett, Halcrow, *et al.*, 2018) can contribute to a reduced financial burden, however, government or external support is fundamental for these to be sustainably successful service delivery initiatives. WHO (WHO, 2017b) describes evidence in

Zimbabwe of affordability schemes, in which the three most common are government subsidies, reduced tariffs for disadvantaged groups, and block tariffs. However, the urban and rural contexts are also important considerations, as is the case in the mix of these affordability schemes. Capital and rehabilitation costs are reportedly covered through government investment, while preventative O&M is financed by water users. While this is described as an 'affordability scheme', it reflects the CBM approach prevalent within Malawi.

The prevalence of 'one time investment' for rural water supplies, as evident here, only cover the immediate need and not sustainability or growth (Whittington *et al.*, 2009; Foster, 2013; Moriarty *et al.*, 2013). These results highlight the importance of modelling service provision and the service delivery context alongside water supply assets to better understand the service delivery (Smits, Rojas and Tamayo, 2013; Fisher *et al.*, 2015; Carter and Ross, 2016) and to assist fulfillment of all aspects of SDG 6.1.

5.6 Binary Logistic Regression – Affordability and O&M

The descriptive statistics for the explanatory variables supporting the binary logistic regression analysis are expressed in Table 5.4. These present the distribution for the most common considerations when setting tariffs; affordability and O&M costs. The results of the binary logistic regression analysis, that allow for the identification of significant explanatory variables of these considerations, are expressed in Table 5.5 (affordability) and Table 5.6 (O&M costs—which include both 'operations costs' and 'maintenance costs').

Table 5.4 Descriptive statistics for considering Affordability and O&M costs across binary logistic regression analysis explanatory variables.

Explanatory Variables	*n*	**% of Total**	**Affordability** *n*	**% Considering Affordability**	**O&M** *n*	**% Considering O&M**
Service Provider						
WPC	11,853	81.95	6189	52.21	8085	68.21
Area Mechanic	757	5.23	478	63.14	347	45.84
Community Members	217	1.50	115	53.00	134	61.75
Institution	86	0.59	48	55.81	55	63.95
Other	79	0.55	51	64.56	48	60.76
Multiple SP	1471	10.17	1055	71.72	1138	77.36
Frequency of Tariff						
Per Month	7327	50.66	4247	57.96	4711	64.30
Per Year	2948	20.38	1497	50.78	2192	74.36
When Required for Repairs	3329	23.02	1695	50.92	2334	70.11
Per 2 Months	317	2.19	183	57.73	200	63.09
Per Quarter	542	3.75	314	57.93	370	68.27
Tariff Amount						
Tariff (Annual)	14,463	100	7936	54.87	9807	67.81
Users						
<=300	8169	56.48	4709	57.64	5371	65.75
>300	6294	43.52	3227	51.27	4436	70.48
Preventative Maintenance						
No	2689	18.59	1373	51.06	1725	64.15
Yes	11,774	81.41	6563	55.74	8082	68.64
Spare Parts Kept on Site						
No	4648	32.14	2609	56.13	2992	64.37
Yes	9815	67.86	5327	54.27	6815	69.43
Functionality						
Functional	11,003	76.08	5876	53.40	7404	67.29
Partially Functional	2964	20.49	1782	60.12	2066	69.70
Non-Functional	496	3.43	278	56.05	337	67.94
Age						
Age (Years)	14,463	100	7936	54.87	9807	67.81
Region						
Southern	7762	53.67	4404	56.74	5429	69.94
Central	6594	45.59	3481	52.79	4308	65.33
Northern	107	0.74	51	47.66	70	65.42

Table 5.5 Unadjusted and Multivariable Binary Logistic Regression when considering Affordability in tariffs for boreholes equipped with Afridev handpumps.

Explanatory Variables	Unadjusted			Multivariable Adjusted		
	OR	**(95% CI)**	***p*-Value [1]**	**OR**	**(95% CI)**	***p*-Value [1]**
Service Provider						
WPC	1	-	-	1	-	-
Area Mechanic	**1.568**	**(1.347–1.825)**	**<0.001**	**1.629**	**(1.394–1.903)**	**<0.001**
Community Members	1.032	(0.788–1.350)	0.820	1.105	(0.840–1.452)	0.476
Institution	1.156	(0.754–1.772)	0.506	1.329	(0.862–2.047)	0.198
Other	**1.667**	**(1.050–2.647)**	**0.030**	**1.658**	**(1.039–2.646)**	**0.034**
Multiple SP	**2.321**	**(2.060–2.614)**	**<0.001**	**2.397**	**(2.121–2.709)**	**<0.001**
Frequency of Tariff [2]						
Per Month	1	-	-	1	-	-
Per Year	**0.748**	**(0.687–0.815)**	**<0.001**	**0.615**	**(0.555–0.682)**	**<0.001**
When Required for Repairs	**0.752**	**(0.693–0.817)**	**<0.001**	**0.598**	**(0.537–0.666)**	**<0.001**
Per 2 Months	0.990	(0.789–1.244)	0.934	0.922	(0.731–1.163)	0.492
Per Quarter	0.999	(0.837–1.192)	0.989	0.890	(0.742–1.068)	0.209
Tariff Amount						
MWK (Annual) [3]	1.000	(1.000–1.000)	0.067	**1.000**	**(1.000–1.000)**	**<0.001**
Users						
<=300	1	-	-	1		-
>300	**0.773**	**(0.724–0.826)**	**<0.001**	**0.764**	**(0.714–0.818)**	**<0.001**
Preventative Maintenance						
No	1	-	-	1	-	-
Yes	**1.207**	**(1.110–1.313)**	**<0.001**	**1.168**	**(1.071–1.273)**	**<0.001**
Spare Parts Kept on Site						
No	1	-	-	1	-	-
Yes	**0.928**	**(0.865–0.995)**	**0.036**	1.029	(0.956–1.109)	0.445
Functionality						
Functional	1	-	-	1	-	-
Partially Functional	**1.315**	**(1.211–1.429)**	**<0.001**	**1.413**	**(1.297–1.539)**	**<0.001**
Non-Functional	1.113	(0.928–1.334)	0.248	1.193	(0.991–1.436)	0.063
Age						
Age (Years)	0.996	(0.991–1.002)	0.219	0.992	(0.987–0.998)	0.209
Region						
Southern	1	-	-	1	-	-
Central	**0.853**	**(0.798–0.911)**	**<0.001**	1.070	(0.994–1.151)	0.072
Northern	0.694	(0.474–1.017)	0.061	0.761	(0.513–1.128)	0.174

[1] Bold represents a statistically significant association ($p < 0.05$), [2] Categories 'other' and 'multiple' omitted due to unpredictable annual tariff, [3] Tariff amounts annualized respective

of tariff collection frequency. 'When required for repairs' was assumed to occur once per year for the purpose of analysis.

Table 5.6 Unadjusted and Multivariable Binary Logistic Regression when considering O&M costs in tariffs for boreholes equipped with Afridev handpumps.

Explanatory Variables	**Unadjusted**			**Multivariable Adjusted**		
	OR	**(95% CI)**	***p*-Value [1]**	**OR**	**(95% CI)**	***p*-Value [1]**
Service Provider						
WPC	1	-	-	1	-	-
Area Mechanic	**0.394**	**(0.340–0.457)**	**<0.001**	**0.366**	**(0.313–0.427)**	**<0.001**
Community Members	**0.752**	**(0.571–0.992)**	**0.044**	**0.738**	**(0.553–0.986)**	**0.040**
Institution	0.827	(0.532–1.286)	0.399	0.724	(0.457–1.147)	0.169
Other	0.722	(0.459–1.135)	0.158	0.738	(0.455–1.195)	0.216
Multiple SP	**1.593**	**(1.401–1.810)**	**<0.001**	**1.531**	**(1.339–1.751)**	**<0.001**
Frequency of Tariff [2]						
Per Month	1	-	-	1	-	-
Per Year	**1.610**	**(1.463–1.771)**	**<0.001**	**2.397**	**(2.127–2.702)**	**<0.001**
When Required for Repairs	**1.303**	**(1.193–1.423)**	**<0.001**	**2.411**	**(2.131–2.727)**	**<0.001**
Per 2 Months	0.949	(0.752–1.198)	0.661	1.204	(0.934–1.551)	0.152
Per Quarter	1.195	(0.991–1.440)	0.063	**1.567**	**(1.282–1.916)**	**<0.001**
Tariff Amount						
MWK (Annual) [3]	**1.000**	**(1.000–1.000)**	**0.010**	**1.000**	**(1.000–1.000)**	**<0.001**
Users						
<=300	1	-	-	1	-	-
>300	**1.244**	**(1.159–1.335)**	**<0.001**	**1.241**	**(1.151–1.338)**	**<0.001**
Preventative Maintenance						
No	1	-	-	1	-	-
Yes	**1.223**	**(1.120–1.336)**	**<0.001**	**1.160**	**(1.056–1.274)**	**0.002**
Spare Parts Kept on Site						
No	1	-	-	1	-	-
Yes	**1.257**	**(1.168–1.354)**	**<0.001**	**1.301**	**(1.200–1.410)**	**<0.001**
Functionality						
Functional	1	-	-	1	-	-
Partially Functional	**1.118**	**(1.024–1.221)**	**0.013**	1.043	(0.949–1.147)	0.378
Non-Functional	1.030	(0.850–1.249)	0.762	1.108	(0.904–1.358)	0.324
Age						
Age (Years)	0.999	(0.993–1.005)	0.798	0.998	(0.992–1.005)	0.645
Region						
Southern	1	-	-	1	-	-
Central	**0.810**	**(0.755–0.869)**	**<0.001**	**0.598**	**(0.551–0.649)**	**<0.001**
Northern	0.813	(0.544–1.214)	0.312	0.921	(0.246–3.448)	0.903

[1] Bold represents a statistically significant association ($p < 0.05$), [2] Categories 'other' and 'multiple' omitted due to unpredictable annual tariff, [3] Tariff amounts annualized respective of tariff collection frequency. 'When required for repairs' was assumed to occur once per year for the purpose of analysis.

5.6.1 Service Delivery – Service Providers and Maintenance

In the multivariable results, Area Mechanics had 1.629 times higher odds of considering affordability (95% CI: 1.394–1.903) and lower odds of considering O&M (OR: 0.366, 95% CI: 0.313–0.427) compared to WPCs when setting tariffs. This may be considered counter intuitive, as the Area Mechanic under CBM policy conduct repairs out with routine O&M, therefore it would be expected O&M costs would be a driving consideration. However, 46.51% of Area Mechanics considered O&M costs, while 63.91% considered affordability (Table 5.4). This can be attributed to the nature of the Area Mechanic in the government structure, as the financial contribution is agreed between the community and the Area Mechanic. Challenges arise as Area Mechanics balance social obligations, resulting in voluntary work, and economic relationships with the community in their service delivery area (Oates and Mwathunga, 2018).

Community members display lower odds of considering O&M costs compared to WPCs in the multivariable regression (Table 5.6). This is further evident from descriptive statistics in Table 4, where 68.21% of WPCs consider O&M compared to the 61.75% of community members. This accords with the literature, where lack of external support and training results in an ineffective system for ensuring quality maintenance and savings for O&M (Harvey and Reed, 2006a; Baumann and Furey, 2013; Moriarty *et al.*, 2013; Chowns, 2015a; Whaley and Cleaver, 2017). Multiple service providers displayed 1.531 times higher odds of considering O&M (95% CI: 1.339–1.751) and 2.397 times higher odds of considering affordability (95% CI:

2.121–2.709) than solely WPCs. Here, multiple service providers primarily consist of both WPCs and Area Mechanics (Table 5.1) who express 71.72% of cases considering affordability compared to 52.21% and 63.14% of solely WPCs or Area Mechanics respectively (Table 5.4).

Conducting preventative maintenance displayed higher odds of considering affordability and O&M costs than when unconducted. This was expected as affordable maintenance and repair is a crucial factor to ongoing functionality, discussed at length by Whaley et al. (Whaley *et al.*, 2019). There is a risk of preventative maintenance being perceived as a redundant exercise to service providers if a water point is operational (Chowns, 2015a; Etongo *et al.*, 2018; Kativhu *et al.*, 2018) as when water supplies are built correctly they can last for years without issue. As depreciation of infrastructure is evident with usage (Baumann, 2006; Foster, 2013; Truslove *et al.*, 2019), preventative maintenance is necessary for the continued sustainability of infrastructure. This is reflected in the regression analysis as users above the design limit had higher odds of O&M cost considerations than below, the inference being that service providers recognize the challenge of meeting the increased maintenance requirements. In the univariable and multivariable analysis, keeping spare parts on site had higher odds of considering O&M costs (Table 5.6) and lower odds of considering affordability in the univariable analysis (Table 5.5), than when spare parts weren't kept on site. This is consistent with evidence, as access to spare parts is a significant factor for the continued functionality and sustainability of waters supply, and crucial for the timely repairs of breakdowns (Harvey and Reed, 2006b; Foster, 2013; Hutchings *et al.*, 2015). These results provide further evidence on the importance of continued post-construction support to achieve and mediate the trade-offs within the SDG agenda. Where, service provider training, preventative maintenance approaches, and supply chains mediate the challenges for sustainable water supply delivery and financing.

5.6.2 Financial Resources – Tariff Frequency, Tariff Amount and Users

Less frequent tariff collections display a notably higher distribution of considering O&M compared to considering affordability (Table 5.4). Tariffs collected per year have lower odds of considering affordability (OR: 0.615, 95% CI: 0.555–0.682) and higher odds of O&M (OR: 2.397, 95% CI: 2.127–2.702) than tariffs collected per month in the multivariable analysis. This suggests less frequent tariffs focus on crucial O&M to ensure continued service delivery when repairs and decline of service delivery may be more evident. A similar trend is presented for the tariff frequency when required for repairs, where there were lower odds of considering affordability (OR: 0.598, 95% CI: 0.537–0.666) and higher odds of considering O&M (OR: 2.411, 95% CI: 2.131–2.727), than tariffs collected per month. This was expected due to the nature of payment upon breakdown when the need for repair is high. The tariff amount displays no association with affordability and O&M costs for both the univariable and multivariable regression. This indicates frequency of collection is the primary association between the tariff and the consideration variables rather than the annualized amount.

Users above the 300-user threshold display lower odds of considering affordability while expressing higher odds of O&M costs being considered than below. When usage is greater than the design limit of the Afridev (300 users), additional wear and tear contributes to depreciation of the infrastructure, particularly when willingness to pay and secondary sources are established problems for collecting financial resources (Section 5.4.2.1). This may attribute to increased odds of considering O&M costs in the set tariffs and decreased odds of affordability compared to usage within the design limit. Furthermore, while there are potentially more households able to contribute towards the O&M of the assets, the increased operational demand results in tariffs reflecting O&M related costs to accommodate the increased wear and tear. This does not suggest that affordability is less relevant or becomes less important as user numbers increase, but rather suggests an increased focus on the O&M costs. This brings into question if the tariffs collected by fewer contributing households are capable of meeting the O&M requirements of the assets. The results thereby suggest that the number of users at a water point can identify potential trade-offs in the financing of services that impact sustainable service delivery and could hinder the fulfilment of the SDGs.

The revenue collected for the maintenance of assets is crucial towards continued functionality (Foster, 2013; Whaley *et al.*, 2019). Communities that have available financial resources available are less reliant on external support (WaterAid, 2011; Whaley *et al.*, 2019). However, annualized financial resources vary significantly, and the regular collection of tariffs are very rarely set to reflect the life-cycle costs of the handpump (Harvey, 2007). Service providers are thus presented with sustainability issues when tariffs do not reflect the life-cycle costs of the water point and households that avoid payments. Understanding how users value water, i.e., reliability, quality, and accessibility, and creating that value is imperative to ensure water payment and deliver sustainable service delivery in the SDGs, rather than solely reducing costs (Hoque and Hope, 2019).

The tariff amount, frequency of collection, and potentially contributing users can dictate the potential financial resources available for O&M. It is recommended that further study investigate how this varies and meets the life-cycle cost of water supply assets. Furthermore, various demographics and disadvantaged groups are notable factors when considering water payments (WAREG, 2017), alongside the willingness to pay the tariffs set by service providers. It is recommended that these contexts be further investigated to identify their significance on rural water service providers considering affordability in the tariffs set. Understanding what tariffs are considered affordable is an important factor for implementing and supporting rural water service delivery and achieving the SDG agenda.

5.6.3 Malawi Assets – Region, Age and Functionality

All three regions of Malawi display a higher distribution of cases considering O&M costs compared to considering affordability in the tariffs that are set (Table 5.4). In the univariable analysis the Central region had lower odds of considering affordability (OR: 0.853, 95% CI: 0.798–0.911) and had lower odds of considering O&M costs in the multivariable analysis (OR:0.598, 95% CI: 0.551–0.649) compared to the Southern region. There is no significant association between the age of the water point asset and considering affordability or O&M costs.

No significant association of considering affordability nor O&M costs was displayed when comparing functional assets and non-functional assets. The multivariable analysis displayed 1.413 times higher odds for considering affordability for partial functionality (95% CI: 1.297–1.539) compared to functionality. Considering affordability when setting tariffs may have an impact on the potential financial resources available for crucial O&M for continued sustainability. However, affordable tariffs do not directly result in a decline of service delivery, as depreciation and sub-standard infrastructure that have higher O&M costs can be attributed to the decline of functional assets across Malawi (Kalin *et al.*, 2019; Truslove *et al.*, 2019). This is further supported by the descriptive statistics in Table 5.4, as partial functionality displays the highest number of cases considering affordability (60.12%) alongside the highest number of cases considering O&M costs (69.70%). This provides evidence of the service delivery challenges faced by rural water service providers who inherently balance affordability and O&M costs when tariffs are set, while maintaining sustainable services.

5.6.4 Limitations

This study was undertaken using a large and detailed dataset. The results presented are statistically significant within the Malawi context. However, in addition to the caveats associated with logistic regression analysis regarding omitted variable bias, the results and interpretations of this study are subject to limitations. First, only data concerning sampling of Afridev handpump boreholes within the MDG period was used. While this considers the dominant improved water supply technology in the rural setting, older systems and other water supply technologies that have variable life-cycle costs were omitted. Second, at the time of evaluation, the Northern region showed less information available compared to the Southern and Central regions of the country. Therefore, it is possible the results are not fully representative of the Northern region. Third, the annualised tariff amount respective of frequency of collection requires an assumption for reactive payments (i.e., when required for repairs) due to the difficulty in predicting water point breakdown. Finally, the functionality of the water points is acknowledged to be a temporal snapshot for sustainability (Section 4.3.4) and can be variable across the life-cycle. This means tariff frequency and amount may also vary according to site specific circumstances.

5.7 Conclusions

Tariffs in the form of household contributions have been the primary financial mechanism for sustainably maintaining rural water supplies, however, balancing affordability and O&M costs at the local level has been challenging. This paper provides insights into the setting of tariffs in Malawi for decentralised rural water supplies, that have implications for monitoring the service provision of assets and ultimately meeting SDG 6.1.

The breakdown of service provision primarily conforms to CBM and Malawian national policy in the form of WPCs. A proportion of water supply assets have no service provider, or no tariff set for O&M, reinforcing the case for universal post-construction support. Tariffs are primarily collected per month, per year, and when required for repairs across rural Malawi. Potential financial resources hence vary across the water points life-cycle, resulting in implications for long term sustainability and maintenance practices. Long term sustainability is further challenged as tariffs are unlikely to be sufficient for maintaining and eventual, or premature, rehabilitation or replacement of assets.

The results of the binary logistic regression analysis demonstrate significant explanatory variables associated with the most common considerations identified by the results, affordability and O&M costs, in both univariable and multivariable adjusted models. Notable drivers behind these considerations include the frequency of tariff collection and the number of users. In particular, less frequent tariffs and usage above the design limit of the Afridev (300 users) had lower odds of considering affordability and higher odds of considering O&M costs, than tariffs collected per month and within the design limit. This highlights the potential trade-offs in the financing of services due to over usage that can hinder the achievement of the SDGs. Considerations are also influenced by the type of service provision. Area Mechanics are less likely to consider the O&M costs and more likely to consider affordability compared to WPCs, while community members are less likely to consider O&M costs compared to WPCs, supporting wider evidence for post-construction support and training. The results further suggest a recognition by service providers of the increased maintenance challenges. Increased usage, conducting preventative maintenance, acquiring spare parts and the collection of tariffs when repairs are required indicate an increased likelihood of considering O&M costs in tariffs. Overall, the balance of affordability and O&M costs is a noticeable challenge throughout the results for the various service providers in the tariffs that are set, that have implications for ensuring sustainable service delivery.

Reflection is required into how affordability is established in Malawi and as an indicator of the SDGs. As MDG 7c disregarded affordability as an indicator, it is crucial for SDG 6.1 to address this indicator by looking outside the established models of rural water supply, such as CBM, and consider the context in which user contributions are established. While there are numerous factors when setting tariffs, the priorities of decentralised service providers may drastically differ across contexts and diverge from the required life-cycle costs of assets. Furthermore, tariffs that are considered affordable in one context may not be considered affordable in another. Successful sustainable services require investment to go beyond solely water access, into the monitoring and supporting of the financial and operational requirements of O&M. This is to ensure payment for services does not prevent access to clean water and breaking the cycle of poverty within the SDG agenda.

Further research should address how the trends in tariffs under decentralised service provision varies socio-geographically and environmentally. Determining the influence local socio-cultural contexts have on service providers is important for establishing affordable financial mechanisms for O&M and reflecting the targets of SDG 6.1.

5.8 Acknowledgements

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5.9 Supplementary Information

Table 5.7 Distribution of Afridev handpump boreholes (n = 22,316) as of 25 April 2019.

Region of Malawi	District of Malawi	*n*	% of Total Data Set
Southern	Balaka	1126	5.05
	Blantyre	1033	4.63
	Chikwawa	1039	4.66
	Chiradzulu	504	2.26
	Machinga	1012	4.53
	Mangochi	2953	13.2
	Mulanje	389	1.74
	Mwanza	337	1.51
	Neno	175	0.78
	Nsanje	327	1.47
	Phalombe	527	2.36
	Thyolo	841	3.77
	Zomba	1363	6.11
	Total of Southern	11,626	52.1
Central	Dedza	1377	6.17
	Dowa	1299	5.82
	Kasunga	1164	5.22
	Lilongwe	3179	14.2
	Mchinji	504	2.26
	Nkhotakota	679	3.04
	Ntcheu	1207	5.41
	Ntchisi	419	1.88
	Salima	646	2.89
	Total of Central	10,474	46.9
Northern	Chitipa	9	0.04
	Karonga	28	0.13
	Likoma	3	0.01
	Mzimba	85	0.38
	Nkhata Bay	14	0.06
	Rumphi	28	0.13
	Total of Northern	167	0.75
No data	-	49	0.22
Total	-	22,316	100

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5.11 Thesis Context

This chapter fulfilled RQ 2: How are global goals reflected in the cost-recovery mechanism for decentralised rural water supply? SO 3 and 4 was accomplished through publication in a peer reviewed journal, by demonstrating the reflection of SDG 6.1 in local tariffs for the continued serviceability of rural water supply in Malawi. The findings highlighted the challenge and drivers behind balancing affordability and O&M costs in local tariffs. These potential trade-offs in the financing of water supply can hinder the achievement of the SDGs, particularly when localising the targets are crucial to their success. Long term sustainability is further challenged as tariffs are unlikely to be sufficient for maintaining and eventual, or premature, rehabilitation or replacement of assets. Further investigation is required into the behaviours towards preventative maintenance and crucial Capital Maintenance Expenditure for continued sustainability of assets. This accomplished in the next chapter.

CHAPTER 6. BEHAVIOURS TOWARDS ROUTINE MAINTENACE AND MAJOR REPAIRS

The previous chapter addressed the challenges decentralised service providers face when balancing affordability and O&M costs in household tariffs for cost recovery. Tariffs that are set vary in terms of frequency and amount, resulting in different potential financial resources across the life-cycle of the water point. Significant explanatory variables identify the likelihood of affordability or O&M costs being considered in the tariffs, which highlights potential trade-offs in the financing of services at the local level. This has the potential to hinder the localising and fulfilment of the SDGs, and the overall sustainability across life-cycle of water supply assets. Particularly when long-term sustainability is seldom considered by service providers. This chapter addresses RQ 3: Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi?

To investigate the behaviours towards routine maintenance and major repairs under decentralised local service delivery, the service providers operational information for boreholes equipped with Afridev handpumps installed across Malawi, were extracted from a comprehensive live dataset. The data, collected in the MIS mWater, was analysed under four tariff scenarios based on the primary collection frequencies identified in the previous chapter. The investigation was accomplished through a drafted paper that address two specific objectives of the thesis. SO 5: Develop scenarios to determine potential financial resources available to service providers under community based management, and SO 6: Identify the current approaches to maintenance and repairs.

- Truslove, J.P, Coulson, A. B. and Kalin, R. M. Behaviours towards life-cycle planning: Routine maintenance and major repairs under community managed handpumps in Malawi. (Drafted)

6.1 Paper: Behaviours Towards Life-Cycle Planning: Routine Maintenance and Major Repairs Under Community Managed Handpumps in Malawi

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6.2 Abstract

Under community management maintaining the serviceability of handpumps is a notable challenge. Essential preventative maintenance is often seen as a redundant exercise as maintenance is conducted on a reactive basis. The costs of major repairs are less understood. These are often neglected across the life-cycle of infrastructure or are left to external stakeholders to conduct. The behaviours towards these exercises were investigated under four tariff scenarios, for a sample size of 21,997 boreholes equipped with Afridev handpumps in Malawi from a large and recent dataset. The investigation separated assets that had gone under rehabilitation and those that had not over the 15 year design life. The findings highlight poor initial capacity building into appropriate cost recovery and maintenance approaches. Total major repair costs increase over the life-cycle under unrehabilitated assets, which consist of low costing replacements that CBM service providers conduct. Post-rehabilitation major repair costs increase, as longer life components such as rods are more commonly replaced. In both cases a reliance on external support is highlighted, as larger costs are primarily covered by NGOs. Proactive tariff scenarios suggest a greater capability of replacement throughout the rods life-cycle compared to reactive tariff scenarios. Unrehabilitated assets replace fewer rods compared to the cases post-rehabilitation, when costs are higher and conducted by NGOs. If short term technologies such as handpumps are continued to be implemented, policy and practitioners must focus on the capacity building of maintenance models that consider the full life-cycle costs of assets. This includes assessments into capable means of meeting the life-cycle requirements of assets.

6.3 Introduction

The delivery of sustainable rural water services requires appropriate financial and maintenance approaches to sustain and repair an asset across its life-cycle (Fonseca *et al.*, 2011). While investment into new infrastructure and rehabilitation programmes has increased the global coverage of improved water supply (Mcintyre *et al.*, 2014; Martínez-Santos, 2017; Huston and Moriarty, 2018; Truslove *et al.*, 2019), capacity building and life-cycle thinking to sustain such services has been lacking (Moriarty *et al.*, 2010, 2013; RWSN Executive Steering Committee, 2010; Fonseca *et al.*, 2011). This focus on Capital Expenditure (CapEx) has led to impulsive investment without any comprehensive planning into the additional costs required (Reddy and Batchelor, 2012).

The Community Based Management (CBM) approach has been seen as the ideal model for service delivery in rural water supply contexts. Not least for its proclaimed 'community empowerment' (Briscoe and de Ferranti, 1988), while relieving responsibilities from governments and external support (van den Broek and Brown, 2015; Whaley and Cleaver, 2017). The well-acknowledged limitations of this one-size-fits-all approach has shown that the promotion of CBM was "a triumph of hope over realism" (WaterAid, 2011). Communities have shown that they are capable with dealing with basic maintenance when professionalism and post-construction support is present (Schouten and Moriarty, 2003; Harvey and Reed, 2006a). However the implementation of shorter life technologies, such as handpumps, incurs frequent costs and maintenance requirements that are beyond communities (Morgan, 1993; Fonseca *et al.*, 2013). The result being maintenance is conducted on a reactive basis and assets are abandoned when just one component fails (Franceys and Pezon, 2010; Chowns, 2015a). The replacement of components before they fail through preventative and timely maintenance is crucial for the continued serviceability of handpumps that reduces the cost of premature failure (Baumann, 2006; Harvey and Reed, 2006b; Foster, 2013; Hutchings *et al.*, 2015). This is often not completed and felt as a redundant exercise by communities (Chowns, 2015a; Etongo *et al.*, 2018; Kativhu *et al.*, 2018). As a result there is a decline in serviceability and premature failure of water supplies that leads to abandonment and lost investment.

The cost-recovery mechanism to fund O&M activities are primarily accomplished through tariffs in the form of household contributions (United Nations, 2018a). The collection of these financial contributions may be insufficient for crucial maintenance to prevent service deterioration (Lockwood and Smits, 2011; Truslove, Coulson, Nhlema, *et al.*, 2020). Furthermore, the long term maintenance is often left to stakeholders outside the community e.g. local or national government, NGOs or donors (Fonseca *et al.*, 2013).

Capital Maintenance Expenditure (CapManEx) describes the costs of sustaining or renewing an existing service (Franceys and Pezon, 2010). Where routine maintenance becomes CapManEx is a matter of the frequency and cost (Franceys and Pezon, 2010). These costs are not widely understood by local and national governments and are not separated in budget planning (Geremew and Tsehay, 2019). In most cases NGOs and Governments allocate rehabilitation budgets at the time of failure rather than the required CapManEx crucial for sustainability (Geremew and Tsehay, 2019). As a result CapManEx is overlooked and under resourced, resulting in failure and abandoned assets (Morgan, 1993; WaterAid, 2011; Fonseca *et al.*, 2013).

This study investigates the preventative maintenance and CapManEx over the 15 year life-cycle of the Afridev, and how these change over different tariff scenarios. To achieve this, data for CBM based service providers for boreholes equipped with Afridev handpumps were examined from a large and recent dataset. Major repairs that were conducted in the last year were investigated over a 15 year period, including the costs, stakeholders who conducted and components replaced during the exercise. This data was interrogated for assets that have been previously rehabilitated and those that have not.

6.4 Methodology

This paper draws upon data associated with service provision, O&M and CapManEx domains, for drilled boreholes equipped with Afridev handpumps installed during the MDG period to date (2000-2019). The data collection took place as part of a wider research programme in evaluating the sustainability of rural water supplies in Malawi (see Kalin *et al.*, 2019). Water supply assets (*n*=121,161) have been evaluated across the country using the management information system (MIS), mWater (www.mwater.co). Data was collected through a water point functionality survey based on sustainability indicators and additional needs of the Malawian government. The age of assets up to the design limit of 15 years old were highlighted. If rehabilitation exercises had been conducted, the age of the Afridev was taken from the date of rehabilitation. Questions utilised in the water point functionality survey are presented in Appendix A.

Service providers under the CBM model (WPCs, Area Mechanics, community members and combinations of the prior) were highlighted. This allowed for a dataset of 21,997 boreholes equipped with Afridev handpumps for the purpose of the study. Four scenarios were investigated based on tariff collection frequency. Scenario A defines tariffs collected 'per month', Scenario B defines tariffs collected 'when required for repairs', Scenario C defines tariffs collected 'per year' and Scenario D defines 'no tariff'.

Under these scenarios, the behaviours towards preventative maintenance were highlighted from the dataset. Where no preventative maintenance was conducted, the reasons why were investigated. Data associated with CapManEx was highlighted if 'major repairs had been conducted in the last year' which concerns repairs costing approximately 50,000MWK or more (where 1 USD = 730 MWK, as of February 2020). The distribution of costs are investigated over the design limit of the Afridev (approximately 15 years) alongside the stakeholders who conducted such repairs by each scenario in each cost category. The components replaced during major repairs are also investigated by each scenario, with a focus on rod replacements over the duration of the Afridev life-cycle. This data was separated into assets without rehabilitation and those that had been rehabilitated (where a rehabilitation exercise consists of a single repair costing more than 1,500,000MWK).

6.5 Results

6.5.1 Behaviours Towards Preventative Maintenance

Every service provider for the Afridev is responsible for the preventative maintenance of the handpump and is therefore entitled to receive regular training from the supplier (ERPF, 2007). However, preventative maintenance can feel a redundant exercise (Chowns, 2015a; Etongo *et al.*, 2018; Kativhu *et al.*, 2018), and continued support for rural communities is lacking under CBM. Table 6.1 presents the breakdown of preventative maintenance conducted across the scenarios specified from the MIS database. This includes explanations as to why preventative maintenance is not conducted across each of the scenarios.

Table 6.1 Preventative maintenance conducted in each scenario (n=21997).

Variable	Scenario A		Scenario B		Scenario C		Scenario D	
	n	%	n	%	n	%	n	%
Yes	7747	79.81	3427	72.47	3176	79.88	1863	51.97
Sometimes	504	5.19	316	6.68	184	4.63	296	8.26
No	1456	15.00	986	20.85	616	15.49	1426	39.78
If preventative maintenance is not conducted (n=5194)[1]								
	n	%	n	%	n	%	n	%
Lack of money	214	12.88	280	23.29	56	8.32	303	18.28
Lack of technical expertise	766	46.12	381	31.70	375	55.72	441	26.60
Parts not available	52	3.13	57	4.74	37	5.50	84	5.07
Lack of understanding	422	25.41	412	34.28	120	17.83	550	33.17
Newly Constructed	113	2.18	13	0.25	31	0.60	96	1.85
Never experienced breakdown	48	0.92	26	0.50	30	0.58	70	1.35
No training	9	0.17	7	0.13	6	0.11	30	0.58
Non-functional	0	0.00	1	0.02	0	0.00	32	0.62
Other	17	0.33	15	0.29	10	0.19	31	0.60
Don’t know	20	1.20	10	0.83	8	1.19	21	1.27

[1] Cases reported can provide more than one answer as to why preventative maintenance is not conducted.

Scenarios with a tariff present a significant percentage of reported cases conducting preventative maintenance compared to the no tariff present. This suggests the presence of financial resources has a positive influence on conducting such operations, as preventative or timely reactive maintenance can reduce the costs of premature failure and downtime of services (Fonseca *et al.*, 2013).

The explanations of why preventative maintenance is not conducted further highlight the lack of support for service providers under the CBM model, with ‘lack of technical expertise’ and ‘lack of understanding’ expressing the highest weighting across the scenarios. Notably proactive scenarios are more weighted towards ‘lack of technical expertise’ (Scenario A – 46.12% and Scenario C – 55.72%) while reactive scenarios are more weighted towards ‘lack of understanding' (Scenario B – 34.28% and Scenario D – 33.17%). Both these factors indicate that the training service providers receive, if any, is insufficient to ensure preventative maintenance is conducted. There is a clear need to build capacity for continuous training and professionalised approaches to maintenance within service delivery, such as the efforts by practitioners outlined by Deal and Furey (2019).

The proactive scenarios also express a lower percentage weighting a 'lack of money' compared to the reactive scenarios, reinforcing how preventative approaches can the reduce costs of premature failure. Findings by Olaerts *et al.* (2019), indicate that water users value reliable and fast maintenance services compared to other unreliable improved sources. 'Parts not available' was also highlighted as an issue in a small number of cases, as the spare parts and supply chains for service delivery can influence water point functionality (Foster, 2013; Fisher *et al.*, 2015; Foster, Willetts, *et al.*, 2018).

There is a clear need for additional and continued support for service providers post-construction. When considered why preventative maintenance is not conducted, the most common explanations are 'lack of technical expertise' and 'lack of understanding' in all the scenarios. A lack of understanding the importance of financial resources and preventative maintenance can be further attributed to the inadequate training and support for service providers in the post-construction phase of rural water supply (Baumann and Furey, 2013). The result is service providers adopting an 'if it isn't broke why fix it approach' and a reliance on external support for financial provision. When a community has the financial resources and technical expertise on hand, they are less reliant on such external support (WaterAid, 2011).

6.5.2 Behaviours Towards Major Repairs

6.5.2.1 Major repairs during the life-cycle

The following figures outline major repairs conducted in the last year under the different tariff scenarios for assets with no rehabilitation and assets with rehabilitation. Figure 6.1 presents the costs of major repairs across the life-cycle for assets with no rehabilitation.

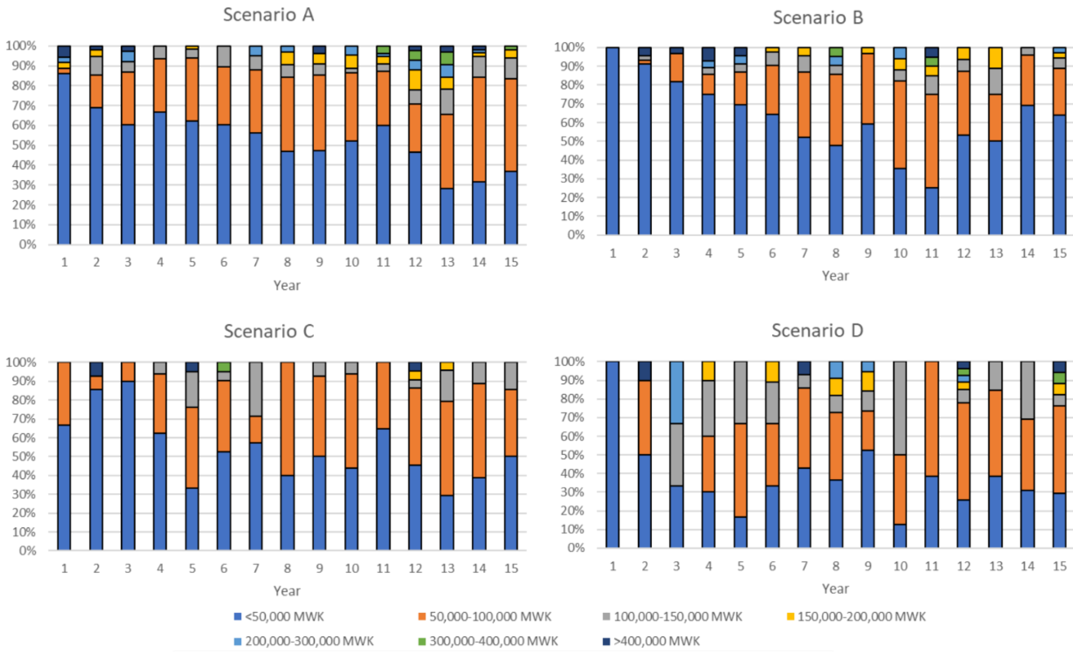

Figure 6.1 Costs of major repairs for assets with no rehabilitation.

The assets with no rehabilitation follow a notable trend across all scenarios. At the beginning of the life-cycle costs express <50,000MWK. The occurrences of these costs decrease as assets age, and more costly major repairs are prevalent.

Over the life-cycle of Scenario A, the increase in costs primarily consists of the next group, 50,000-100,000MWK. There are few occurrences above this group across the life-cycle with the exception of years towards the end of the life-cycle (year 12-13). Scenario B presents a similar trend to Scenario A. However, there is a greater occurrence of lower costing major repairs in the earlier years of the life-cycle. This gradual increase primarily results in 50,000-

100,000MWK between year 3 and year 11. Scenario C expresses costs primarily within the lower two cost groups (<50,000MWK and 50,000-100,000MWK). In the early years (year 1-3) costs fall within <50,000MWK. Post-year 3, there is an increase in costs that result primarily in 50,000-100,000MWK. This occurs in the majority of cases post-year 3, as compared to the gradual increase of costs over the life-cycle displayed in Scenario A and B. Scenario D presents higher costs than the previous scenarios. Following year 1, the number of occurrences in the <50,000MWK category drastically decreases. This results in higher costing repairs, primarily 50,000-100,000MWK and 100,000-150,000MWK, across the life-cycle.

When rehabilitation has been conducted on an asset, it is considered the start of a new service (Franceys and Pezon, 2010). However, rehabilitation exercises result in notable differences in major repairs costs across the life-cycle of the assets. Figure 6.2 presents the costs of major repairs across the life-cycle for assets with rehabilitation.

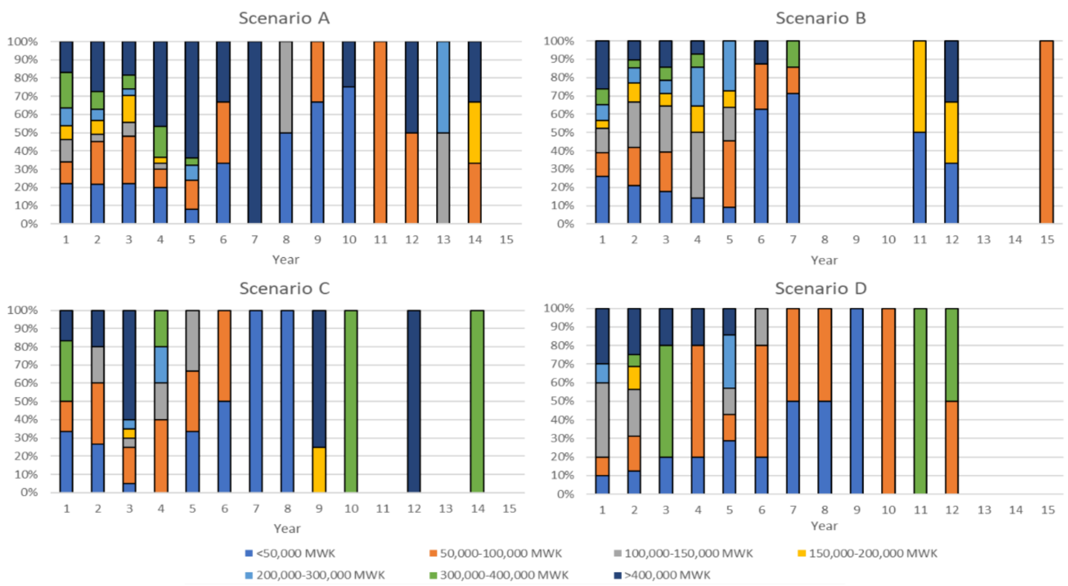

Figure 6.2 Costs of major repairs for assets with rehabilitation.

The assets with rehabilitation express a lower number of occurrences across the life-cycle compared to those with rehabilitation in each scenario (see 6.9 Supplementary Information).

The majority of these occur in the early design life, due to the dataset being taken from the start of the MDGs to date (approximately 20 years). Rehabilitation typically occurs towards the end of the design life of 15 years (highlighting the majority of cases in the early years), however, premature rehabilitation due to improper O&M highlights cases in Figure 6.2 towards the end of the time period.

The costs expressed across the life-cycle are significantly higher compared to unrehabilitated assets. Scenario A presents the largest distribution of cases of major repairs costing >400,000MWK, in the majority of cases between years 1 and 6. Scenario C also presents an increase in cases of >400,000MWK in the first three years, where the majority of major repairs occur over the life-cycle. The major repairs conducted in Scenario B are primarily expressed between year 1 and 7. During this period there is a higher distribution of costs expressed compared to Scenario A and C. However, these costs are significantly higher than the assets without rehabilitation conducted (Figure 6.1). Scenario D follows a similar pattern to Scenario B, although to a lesser extent, as fewer major repairs and a lower cost distribution is expressed.

6.5.2.2 Stakeholders conducting major repairs

Over the course of the life-cycle the major repairs may not be conducted by the service providers responsible for the asset. Table 6.2 presents the stakeholders who conducted major repairs in the last year by the costs of major repairs.

Table 6.2 Stakeholders conducting major repairs by cost groups.

Stakeholder	Costs of major repairs - '000 MWK (%)							
	n	<50	50 - 100	100 - 150	150 - 200	200 - 300	300 - 400	>400
Scenario A								
WPC	343	72.89	23.03	2.33	1.46	0	0	0.29
Area Mechanic	308	42.21	41.23	11.69	2.27	0.65	0.97	0.97
Community Members	34	47.06	41.18	0	2.94	5.88	0	2.94
Local Government	29	10.34	34.48	13.79	10.34	6.9	6.9	17.24
NGO	124	5.65	8.87	4.84	9.68	10.48	16.13	44.35
Private Contractor	34	11.76	32.35	2.94	17.65	11.76	5.88	17.65
WUA	3	100	0	0	0	0	0	0
Other	17	5.88	29.41	17.65	11.76	11.76	0	23.53
Don't Know	2	0	0	0	0	0	50	50
Total	894	46.31	28.75	6.49	4.03	2.8	3.13	8.5
Scenario B								
WPC	239	77.41	15.9	3.77	2.09	0	0.42	0.42
Area Mechanic	223	46.19	32.29	11.66	4.93	4.04	0	0.9
Community Members	20	35	30	30	0	5	0	0
Local Government	5	0	40	20	20	0	0	20
NGO	57	14.04	10.53	8.77	12.28	12.28	15.79	26.32
Private Contractor	9	0	22.22	11.11	0	11.11	0	55.56
Other	16	31.25	37.5	18.75	6.25	6.25	0	0
Don't Know	3	33.33	33.33	0	0	0	0	33.33
Total	572	54.02	23.25	8.92	4.37	3.32	1.75	4.37
Scenario C								
WPC	126	61.9	31.75	5.56	0	0	0	0.79
Area Mechanic	99	38.38	50.51	9.09	1.01	0	0	1.01
Community Members	10	70	10	10	0	10	0	0
Local Government	8	12.5	50	12.5	12.5	0	0	12.5
NGO	41	0	12.2	12.2	4.88	2.44	17.07	51.22
Private Contractor	5	40	20	20	0	0	20	0
Other	4	50	25	25	0	0	0	0
Total	293	43.69	34.81	8.53	1.37	0.68	2.73	8.19
Scenario D								
WPC	78	44.87	41.03	10.26	1.28	1.28	0	1.28
Area Mechanic	90	31.11	44.44	18.89	3.33	1.11	0	1.11
Community Members	7	71.43	14.29	14.29	0	0	0	0
Local Government	10	10	20	20	10	0	20	20
NGO	27	0	14.81	25.93	7.41	11.11	14.81	25.93
Private Contractor	6	16.67	33.33	0	0	0	16.67	33.33
Other	15	26.67	33.33	0	13.33	13.33	6.67	6.67
Total	233	31.76	36.91	15.02	3.86	3	3.43	6.01

In all four scenarios, the costs of major repairs primarily fall within <50,000MWK and 50,000-100,000MWK. The highlighted CBM service providers (WPCs, Area Mechanics and Community Members) primarily conduct repairs within these two cost brackets. WPCs conduct a notably higher distribution <50,000MWK, with the exception of Scenario D. This is due to the higher costs of major repairs occurring across the life cycle. Area Mechanics in all scenarios present a lower percentage conducting major repairs costing <50,000MWK, with larger distributions in the higher costs compared to WPCs. In Scenario C and D, community members present a large number of occurrences in the <50,000MWK group. In Scenario A and B, there is a wider distribution similar to Area Mechanics. However, there are few occurrences of community members conducting major repairs in each scenario.

When considering costs above 100,000MWK, external stakeholders express a larger distribution in all of the scenarios. Local Government and Private Contractors express occurrences across all costs, however there are few occurrences of these stakeholders conducting major repairs in each of the scenarios. Notably, NGOs are the third most common stakeholder to conduct major repairs in all of the scenarios. NGOs express a distribution across all costs with the majority of occurrences in the higher range of costs. In all the scenarios, major repairs costing >400,000MWK are the most common category for NGOs.

6.5.2.3 Replacement of components

Of the major repairs that were conducted in each scenario, the distribution of fast wearing (typical life-cycle of 0-2 years) and longer life components (typical life-cycle 2-15 years depending on component) are presented in Figure 6.3. Results are separated into assets with rehabilitation and no rehabilitation conducted. There are notable differences in the components replaced during major repairs for assets with rehabilitation and those without, indicating the impact a rehabilitation exercise has on future repairs.

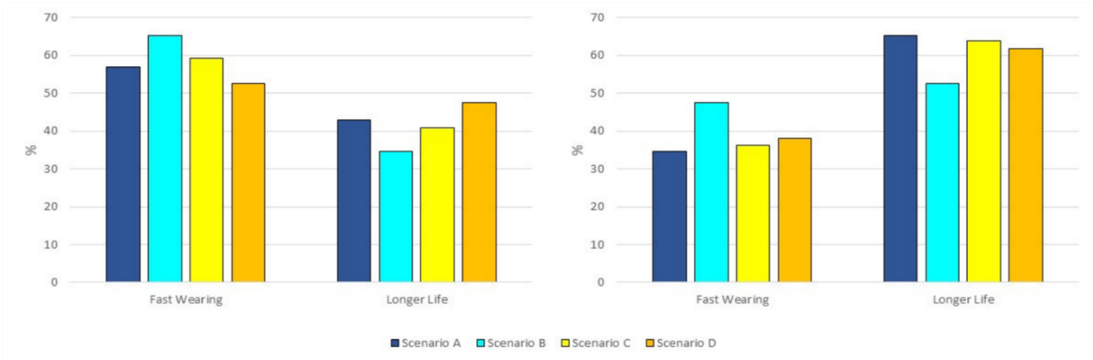

Figure 6.3 Distribution of total replacements by scenario for assets with no rehabilitation (left) and assets with rehabilitation (right).

In all scenarios, assets without rehabilitation favour replacing fast wearing components. Scenario A and C express similar distribution of components replaced (i.e. 57.08% and 59.22% of fast wearing components and 42.92% and 40.78% of longer life components respectively). Approximately two thirds of cases in Scenario B express a distribution towards fast wearing components (65.35%). Scenario D presents a narrower distribution, with 2.54% of cases weighted towards fast wearing components.

In all scenarios, assets with rehabilitation favour replacing longer life components. Approximately two thirds of the cases in Scenario A express a distribution towards longer life components (65.25%). Scenario C and D also present a similar distribution towards longer life components (63.80% and 61.82% respectively). Scenario B presents a narrow distribution between the two types of components, with a weighting of 2.5% towards longer life components.

Figure 6.4 presents the breakdown of components in fast wearing and longer life categories for assets with rehabilitation and assets without rehabilitation.

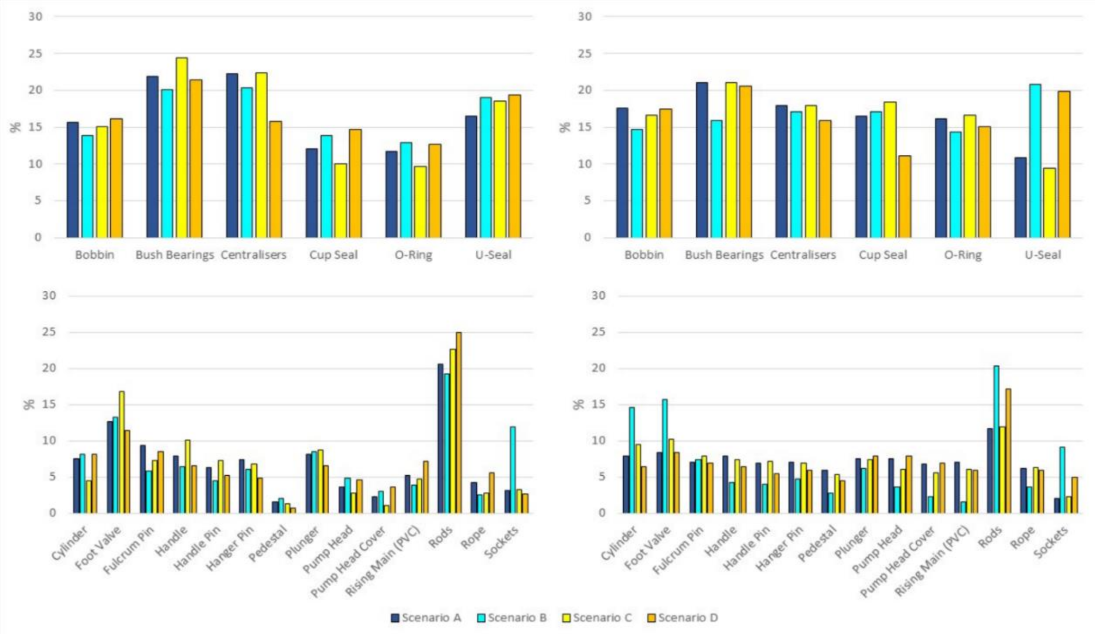

Figure 6.4 Distribution of fast wearing (top) and of longer life (bottom) components by scenario for assets with no rehabilitation (left) and rehabilitation conducted (right).

Of the fast wearing components replaced where no rehabilitation has occurred, all scenarios follow a similar distribution in most component replacements. The three most common components under the fast wearing parts category are: Bush Bearings, Centralisers (where Scenario D presents a lower distribution compared to the other scenarios) and U-Seals. Bobbin's represent approximately 15% of fast wearing components, while Cup-Seals and O-Rings represent between 10% and 15% of cases in all scenarios. Where assets have been rehabilitated, the majority of replacements follow a similar trend, of between 15% and 20% of cases. Notably there is an increase of O-Ring replacements in all scenarios, an increase in Cup-Seal replacements concerning Scenario A, B and C (with a decrease in Scenario D) and a decrease in U-Seal replacements (Scenario A and C).

Of the longer life components replaced, the scenarios follow a similar distribution of replacements, with the exception of a few components. Concerning assets with no rehabilitation, the majority of replacements are below 10% of cases present, with the

Pedestal being the least replaced component. Notable replacements show Sockets are replacement in a larger number of cases in Scenario B than other scenarios, and the Foot Valve presents a larger distribution of replacements than the majority of other components. Assets post-rehabilitation also present the majority of cases below 10%. Notably, there is an increase of Cylinder replacements (Scenario B), a decrease in Foot Valve replacements (Scenario A, C and D) and a slight increase in Pedestal replacements (Scenario A, C and D). Scenario B still presents a large proportion of Socket replacements, although to a lesser extent than assets with no rehabilitation.

Notably, rods are the most common longer life component replaced during a major repair exercise, for assets with and without rehabilitation conducted. This is potentially attributed to multiple rods installed that have the potential to wear or break at different times throughout the life-cycle. The behaviours towards replacements may differ depending on the tariff scenarios across the life-cycle.

6.5.2.4 Replacement of rods

Within the Afridev handpump, rods have a typical life-cycle of 3-5 years before recommended replacement (ERPF, 2007). Rods are a costly component of the Afridev maintenance, in which the number of rods varies depending on the depth of the borehole. The occurrences of rod replacements differ over the life-cycle in each scenario, however, there are notable trends to consider. Figure 6.5 presents the behaviours of each scenario in replacing rods across the life-cycle of the Afridev with no rehabilitation. The number of rods replaced in each year are also highlighted. These are further expressed in 6.9 Supplementary Information.

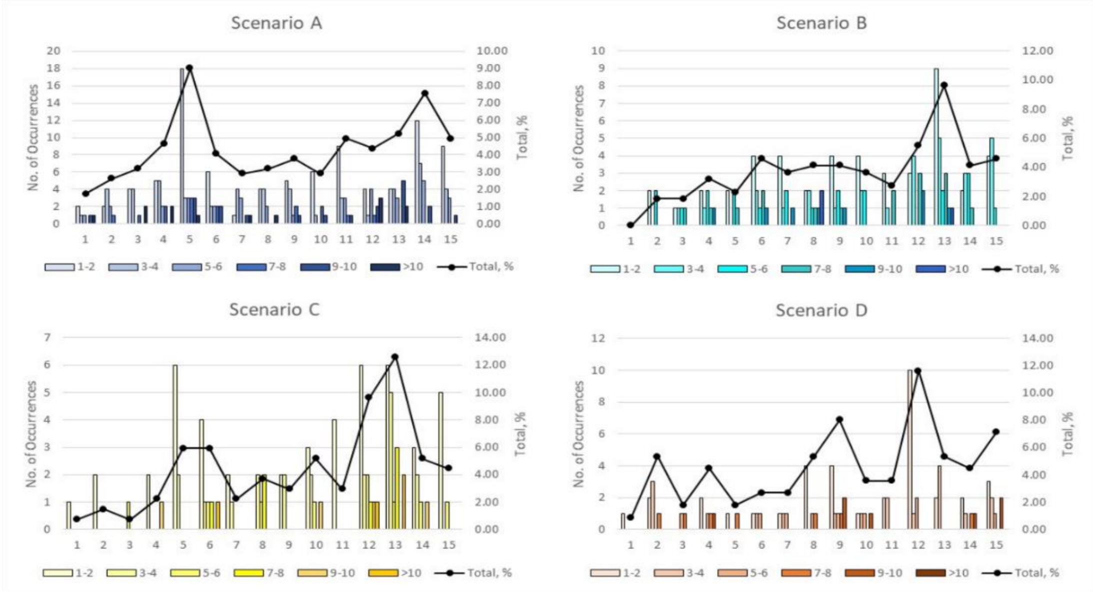

Figure 6.5 Replacement of rods by scenario on assets with no rehabilitation.

Scenario A presents a gradual increase of rod replacements between year 1 and 4 before reaching a peak in year 5 (9.01%). This primarily consists of 1-2 rod replacements. Following year 5, there is a steep decline of replacements until year 7. There is then a gradual increase in replacements towards the end of the Afridev life-cycle. The distribution in Scenario B presents a gradual rise in replacements between year 1 and 6. This is followed by a consistent number of replacements between year 6 and 11, however the number of rods replaced differ each year. There is a steep rise in replacements from year 11 before reaching its peak in year 13 (9.63%). In the early years of the life-cycle under Scenario C there are very few cases of rod replacements, while the later years express the majority of cases. Between years 5 and 6 there is a rise in replacements, before a steep decline in year 7. There is a gradual rise in replacements between years 7 and 11 before greatly increasing in year 12. Between years 12 and 13 the majority of replacements occur (9.63% and 12.59% respectively). There are a very low number of replacements occurring across the life-cycle of the Afridev under Scenario D.

There is a gradual increase of replacements across the life-cycle, with specific increases in years 2, 4, 9 and 12.

Figure 6.6 presents the behaviours of each scenario in replacing rods across the life-cycle of the Afridev with rehabilitation.

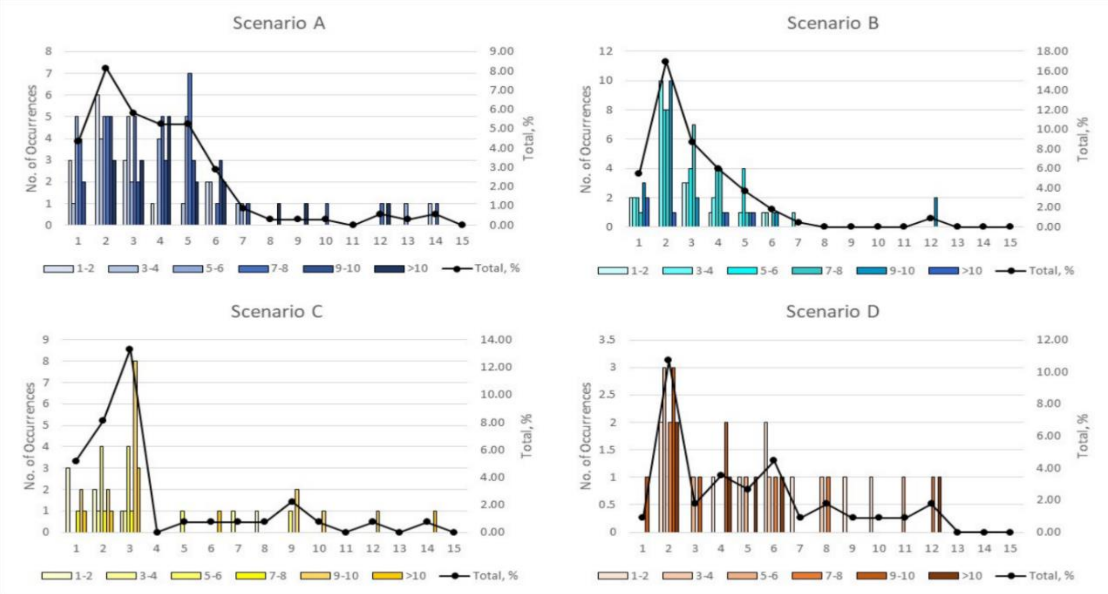

Figure 6.6 Replacement of rods by scenario on assets with rehabilitation.

The rod replacements on assets with rehabilitation present a similar trend over all scenarios. Each scenario presents replacements in the early years of the life-cycle before a decline in the later years. Larger groups of rods replaced in each year are also significantly higher in these years compared to assets with no rehabilitation of the same year (Figure 6.5).

Concerning Scenario A, the majority of replacements occur between year 1 and 5, with year 2 presenting the largest proportion of replacements (8.14%). This is followed by a steep decline before limited replacements towards the end of the life-cycle. Scenario B also expresses a peak in year 2 (16.97%) before a gradual decline of replacements between year 2 and 7. Scenario C presents an increase in the first three years of the life-cycle, reaching a peak in year 3 (13.33%). This is followed by a steep decline and minor replacements over the rest of the life-cycle. Scenario D presents the lowest number of replacements. The largest proportion of replacements occurring in year 2 (10.71%) followed by a steep decline in year 3. There are a consistent number of replacements up to year 12.

6.6 Discussion

6.6.1 Behaviours of scenarios towards unrehabilitated assets

Scenario A (per month) and C (per year) present tariffs collected proactively for the maintenance and repairs of boreholes equipped with Afridev handpumps. These produce different annualised financial resources, however the proactive nature of these scenarios express similar behaviours towards the continued serviceability of the water supply asset. In both scenarios there is a large proportion of the dataset that declare preventative maintenance is conducted at the site. This may be attributed to the continued availability of financial resources to conduct such operations, as suggested by the low response of 'lack of money' in the cases that do not conduct preventative maintenance. The costs of major repairs under these scenarios further supports the positive impact financial resources and conducting preventative maintenance has on continued service. Across the life-cycle of the Afridev, the majority of costs fall into the <50,000MWK and 50,000-100,000MWK categories. The CBM service providers primarily conduct these repairs while external support (primarily NGOs) favour more costly categories (Table 6.2). This suggests the operations by CBM service providers under these scenarios have an ability to conduct major repairs and replacements that favour the life-cycle of the handpump before potential problems occur. This is further expressed by Figure 6.3 where a greater proportion of longer life-components are replaced than those in Scenario B. In particular, the replacement of rods in the early years show an increase during the rods typical life-cycle (3-5 years). This suggests a replacement before the end of the life-cycle to prevent premature failure, typical of a preventative maintenance approach. However, as the costs of major repairs increase, typically towards the end of the life-cycle, the reliance on external support becomes more apparent. While a proactive tariff approach has resulted in a positive behaviour towards major repairs, it does not remove the challenges of conducting such exercises.

The reactive approach to tariff collection (Scenario B) presents different behaviours to the aforementioned proactive scenarios. The collection of tariffs when required for repairs creates problems for a preventative approach to maintenance due to the infrequent and unpredictable nature of collection. This is reflected by the lower number of cases conducting preventive maintenance than Scenario A and C. Moreover, in the cases where no preventative maintenance is reported, 23.29% of cases cited 'lack of money' as the cause. This reactive approach to tariff collection suggests that cheaper, fast wearing components are favoured over longer life components, that potentially hinder continued functionality or result in premature breakdown of water supply. This is expressed in Figure 6.3 where the majority of major repairs consist of fast wearing components (65.35%) and, in the assets with rehabilitation, where the margin between fast wearing and longer life components is significantly lower than the other scenarios. This is further suggested by the replacement of rods over the life-cycle of the Afridev (Figure 6.5) where the majority of rod replacements occur later in the life-cycle. Similar to Scenario A and C, Scenario B presents the CBM service providers as conducting repairs in the <50,000MWK and 50,000-100,000MWK categories with the cases of external support conducting repairs in the more costly categories. However, in the case of NGOs, there is an increased distribution of the costs in the lower categories. This suggests that external support is relied upon even for lower costing major repairs, as collection when required for repairs does not guarantee sufficient financial resources to conduct them.

Where no tariff is collected for O&M (Scenario D), the behaviours and resulting major repairs significantly differ from the previous scenarios. While financial resources may be sourced by the rural service providers from elsewhere, there is no declared financial resources for the O&M of the water supply assets. This may be attributed to the significant proportion of cases where no preventative maintenance is conducted (Table 6.2-39.78%), of which 18.28% of cases declared 'lack of money' as the reason why. The lack of financial resources to conduct vital O&M risks a decline in serviceability, similar to the case in Scenario B. As a result, the costs of major repairs may significantly increase as described by Figure 6.1. There is an increase of cases where major repairs costing 100,000-150,000MWK occur and decrease of repairs <50,000MWK across the life-cycle compared to the other scenarios. In Scenario A, B and C, WPCs have primarily conducted repairs costing <50,000MWK (72.89%, 77.41% and 61.9% respectively). However, Scenario D shows WPCs are more distributed across the costs than previous scenarios. Furthermore, external support (primarily NGOs) are distributed across the major repairs costs, highlighting the reliance on these stakeholders to provide this service. The lack of preventative maintenance may also attribute to the greater occurrence of longer life components being replaced during major repairs compared to the other scenarios (Figure 6.3). This highlights the impact financial resources and preventative maintenance can have on future repairs required for continued functionality.

6.6.2 Impact of rehabilitation on major repairs

Assets that have been rehabilitated express significantly different costs and replacements compared to the assets with no rehabilitation under each scenario. There are a fewer number of major repairs occurring for assets post-rehabilitation, with the majority occurring in the early years of the life-cycle in years 1-6 (Scenario A and D), years 1-7 (Scenario B) and years 1-3 (Scenario C). During this time, more costly repair occurrences significantly rise compared to those without rehabilitation. This suggests that while rehabilitation may be determined to be the start of a new service, the reality is all components may not be replaced under a rehabilitation exercise, that may require replacement soon after. This is reflected by the higher costs of major repairs post rehabilitation under all scenarios that are inevitably conducted by external stakeholders (Table 6.2).

The results highlight that rehabilitation is treated as an exercise to bring an asset back to an operational capacity, rather than the beginning of a new service. However, this is only a temporary solution that does not support sustainable service delivery. In all scenarios the replacement of longer life components are favoured more than fast wearing that risks repeat intervention by external support due to the substantially higher costs involved. This further highlights the inability of revenue collection being sufficient to purchase and replace longer life components (WaterAid, 2011).

The issue of large major repair costs that arise post-rehabilitation highlights the importance of establishing sustainable service delivery, over solely reinstating coverage. The short term gains of rehabilitation still overlook the life-cycle costing aspect required for sustainable services. This is still a coverage attitude rather than supporting the capacity building and service delivery approach to rural water supply. Policy and practitioners have a responsibility to consider the long term impact of potential rehabilitation exercises. Particularly when repeated intervention is required to conduct costly major repairs post 'new service'.

6.6.3 Replacement of Rods

Rods have been described as the most commonly replaced component for both assets with and without rehabilitation conducted under all scenarios. Proactive scenarios (primarily Scenario A) show an increase in the replacement of rods with the rods life-cycle in the first instance, as shown by the increase in years 3-6. This can primarily be conducted by CBM service providers as suggested by the predominantly lower cost brackets during this time period. Furthermore there is a consistent increase of rod replacements following the decline in year 6 that include larger multiples of rods replaced. The replacements in the reactive scenario (Scenario B) suggest that collection 'when required for repairs' is conformed to, due to the consistent and lower number of replacements across the life-cycle.

In all scenarios there are lower multiples of rods replaced across the life-cycle, suggesting that while the replacements can be financed, they may not reflect the full number of rods present. When considering the rod replacements in assets post-rehabilitation, there are a significant number of replacements that include large multiples of rods replaced compared to assets that have not been rehabilitated. This is to be expected when considering the costs expressed during this period, which are primarily conducted by the aforementioned external support.

The number of rods replaced in each scenario suggest replacements are conducted on a needs basis when CBM service providers conduct them. While proactive scenarios in unrehabilitated assets have shown a greater ability to replace rods than reactive scenarios, the lower multiples of rods throughout further highlight the challenge of financing CapManEx at the local level without external support.

6.7 Conclusions

CapManEx remains a challenge as costs are often neglected pre and post construction of water supply assets. This study provides further evidence towards understanding the impact CapManEx can have towards the sustainability and timely replacement of handpump components over the design life.

While CapManEx is a recognised overlooked cost, further lack of initial capacity building is identified through the preventative maintenance behaviours of the four tariff scenarios. In particular a lack of technical expertise and understanding results in no preventative maintenance being conducted by service providers. The occurrences of 'no tariff' (Scenario D) and the significant lack of preventative maintenance conducted under this scenario further indicate poor capacity building into sustainable service delivery.

Rehabilitation has a notable effect on the costs and components that are replaced. While rehabilitation treat the costs as the start of a new service, bringing systems back to an operational use may not result in the replacement of all significant components. Larger major repair costs significantly increase post-rehabilitation that include the increased replacement of longer life components in all scenarios.

Costly major repairs typically encompass longer life components (such as foot valves, rising main sections and rods) are conducted by external stakeholders such as NGOs. Larger multiples of rods are replaced post-rehabilitation when such costs for major repairs are significantly higher, contrary to replacements of lower costs in unrehabilitated assets in the same time-frame. The results highlight that the current service delivery model for rural water supply in Malawi is unable to fully provide the necessary CapManEx that is crucial for continued service without support from external actors.

If short term technologies such as handpumps are continued to be implemented, policy and practitioners must focus on the capacity building of maintenance models that consider the full life-cycle costs of assets. Construction, and notably rehabilitation, further reflects a focus on short term coverage goals rather than the sustainable systems mindset that is needed to provide continued service delivery. This includes assessments and capacity building to ensure cost recovery and maintenance approaches are capable of meeting the life-cycle requirements of assets.

6.8 Supplementary Information

Table 6.3 Scenario A - Costs of major repairs distribution.

Without Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	31	1	0	1	1	0	2	36
2	38	9	5	2	0	0	1	55
3	23	10	2	0	2	0	1	38
4	32	13	3	0	0	0	0	48
5	41	21	3	1	0	0	0	66
6	23	11	4	0	0	0	0	38
7	23	13	3	0	2	0	0	41
8	15	12	2	2	1	0	0	32
9	26	21	3	3	0	0	2	55
10	23	15	1	3	2	0	0	44
11	33	15	2	2	1	2	0	55
12	19	10	3	4	2	2	1	41
13	9	12	4	2	2	2	1	32
14	18	30	6	1	1	0	1	57
15	18	23	5	2	0	1	0	49
Total	372	216	46	23	14	7	9	687
With Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	9	5	5	3	4	8	7	41
2	11	12	2	4	3	5	14	51
3	6	7	2	4	1	2	5	27
4	6	3	1	1	0	5	14	30
5	2	4	0	0	2	1	16	25
6	6	6	0	0	0	0	6	18
7	0	0	0	0	0	0	2	2
8	1	0	1	0	0	0	0	2
9	2	1	0	0	0	0	0	3
10	3	0	0	0	0	0	1	4
11	0	2	0	0	0	0	0	2
12	0	1	0	0	0	0	1	2
13	0	0	1	0	1	0	0	2
14	0	1	0	1	0	0	1	3
15	0	0	0	0	0	0	0	0
Total	46	42	12	13	11	21	67	212

Table 6.4 Scenario B - Costs of major repairs distribution.

Without Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	14	0	0	0	0	0	0	14
2	41	1	1	0	0	0	2	45
3	27	5	0	0	0	0	1	33
4	21	3	1	0	1	0	2	28
5	16	4	1	0	1	0	1	23
6	27	11	3	1	0	0	0	42
7	12	8	2	1	0	0	0	23
8	10	8	1	0	1	1	0	21
9	19	12	0	1	0	0	0	32
10	6	8	1	1	1	0	0	17
11	5	10	2	1	0	1	1	20
12	17	11	2	2	0	0	0	32
13	18	9	5	4	0	0	0	36
14	18	7	1	0	0	0	0	26
15	23	9	2	1	1	0	0	36
Total	274	106	22	12	5	2	7	428
With Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	6	3	3	1	2	2	6	23
2	10	10	12	5	4	2	5	48
3	5	6	7	2	2	2	4	28
4	2	0	5	2	3	1	1	14
5	1	4	2	1	3	0	0	11
6	5	2	0	0	0	0	1	8
7	5	1	0	0	0	1	0	7
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	1	0	0	1	0	0	0	2
12	1	0	0	1	0	0	1	3
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	1	0	0	0	0	0	1
Total	36	27	29	13	14	8	18	145

Table 6.5 Scenario C - Costs of major repairs distribution.

Without Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	2	1	0	0	0	0	0	3
2	12	1	0	0	0	0	1	14
3	9	1	0	0	0	0	0	10
4	10	5	1	0	0	0	0	16
5	7	9	4	0	0	0	1	21
6	11	8	1	0	0	1	0	21
7	4	1	2	0	0	0	0	7
8	4	6	0	0	0	0	0	10
9	7	6	1	0	0	0	0	14
10	7	8	1	0	0	0	0	16
11	11	6	0	0	0	0	0	17
12	10	9	1	1	0	0	1	22
13	7	12	4	1	0	0	0	24
14	7	9	2	0	0	0	0	18
15	7	5	2	0	0	0	0	14
Total	115	87	19	2	0	1	3	227
With Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	4	2	0	0	0	4	2	12
2	4	5	3	0	0	0	3	15
3	1	4	1	1	1	0	12	20
4	0	2	1	0	1	1	0	5
5	1	1	1	0	0	0	0	3
6	1	1	0	0	0	0	0	2
7	1	0	0	0	0	0	0	1
8	1	0	0	0	0	0	0	1
9	0	0	0	1	0	0	3	4
10	0	0	0	0	0	1	0	1
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	1	1
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	1	0	1
15	0	0	0	0	0	0	0	0
Total	13	15	6	2	2	7	21	66

Table 6.6 Scenario D - Costs of major repairs distribution.

Without Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	3	0	0	0	0	0	0	3
2	5	4	0	0	0	0	1	10
3	1	0	1	0	1	0	0	3
4	3	3	3	1	0	0	0	10
5	1	3	2	0	0	0	0	6
6	3	3	2	1	0	0	0	9
7	6	6	1	0	0	0	1	14
8	4	4	1	1	1	0	0	11
9	10	4	2	2	1	0	0	19
10	1	3	4	0	0	0	0	8
11	5	8	0	0	0	0	0	13
12	7	14	2	1	1	1	1	27
13	5	6	2	0	0	0	0	13
14	4	5	4	0	0	0	0	13
15	5	8	1	1	0	1	1	17
Total	63	71	25	7	4	2	4	176
With Rehabilitation								
Year	<50,000 MWK	50,000-100,000 MWK	100,000-150,000 MWK	150,000-200,000 MWK	200,000-300,000 MWK	300,000-400,000 MWK	>400,000 MWK	Total
1	1	1	4	0	1	0	3	10
2	2	3	4	2	0	1	4	16
3	1	0	0	0	0	3	1	5
4	1	3	0	0	0	0	1	5
5	2	1	1	0	2	0	1	7
6	1	3	1	0	0	0	0	5
7	1	1	0	0	0	0	0	2
8	1	1	0	0	0	0	0	2
9	1	0	0	0	0	0	0	1
10	0	1	0	0	0	0	0	1
11	0	0	0	0	0	1	0	1
12	0	1	0	0	0	1	0	2
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
Total	11	15	10	2	3	6	10	57

Table 6.7 Distribution of component replacement for assets with no rehabilitation.

	Scenario A	Scenario B	Scenario C	Scenario D	Total
Fast Wearing	1499	1207	578	341	3625
Longer Life	1127	640	398	308	2473
Total	2626	1847	976	649	6098
			Fast Wearing		
Bobbin	234	167	87	55	543
Bush Bearings	328	243	141	73	785
Centralisers	333	245	129	54	761
Cup Seal	180	167	58	50	455
O-Ring	176	156	56	43	431
U-Seal	248	229	107	66	650
			Longer Life		
Cylinder	85	52	18	25	180
Foot Valve	143	85	67	35	330
Fulcrum Pin	106	37	29	26	198
Handle	89	41	40	20	190
Handle Pin	71	29	29	16	145
Hanger Pin	84	39	27	15	165
Pedestal	18	13	5	2	38
Plunger	92	54	35	20	201
Pump Head	41	31	11	14	97
Pump Head Cover	25	19	4	11	59
Rising Main (PVC)	59	25	19	22	125
Rods	232	123	90	77	522
Rope	47	16	11	17	91
Sockets	35	76	13	8	132

Table 6.8 Distribution of component replacement for assets with rehabilitation.

	Scenario A	Scenario B	Scenario C	Scenario D	Total
Fast Wearing	564	427	223	126	1340
Longer Life	1059	472	393	204	2128
Total	1623	899	616	330	3468
		Fast Wearing			
Bobbin	99	63	37	22	221
Bush Bearings	119	68	47	26	260
Centralisers	101	73	40	20	234
Cup Seal	93	73	41	14	221
O-Ring	91	61	37	19	208
U-Seal	61	89	21	25	196
		Longer Life			
Cylinder	84	69	37	13	203
Foot Valve	89	74	40	17	220
Fulcrum Pin	74	35	31	14	154
Handle	83	20	29	13	145
Handle Pin	73	19	28	11	131
Hanger Pin	75	22	27	12	136
Pedestal	63	13	21	9	106
Plunger	80	29	29	16	154
Pump Head	80	17	24	16	137
Pump Head Cover	72	11	22	14	119
Rising Main (PVC)	74	7	24	12	117
Rods	124	96	47	35	302
Rope	66	17	25	12	120
Sockets	22	43	9	10	84

Table 6.9 Scenario A rod replacements.

Without Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	2	2	4	5	18	6	1	4	5	6	9	4	4	12	9
3-4	1	4	4	5	3	2	4	4	4	1	3	1	4	7	4
5-6	1	2	0	2	3	2	3	2	1	0	3	4	3	5	3
7-8	0	1	1	2	3	2	0	0	2	2	1	1	0	0	0
9-10	1	0	0	0	3	2	1	0	1	1	1	2	5	2	1
>10	1	0	2	2	1	0	1	1	0	0	0	3	2	0	0
Total, n	6	9	11	16	31	14	10	11	13	10	17	15	18	26	17
Total, %	1.74	2.62	3.20	4.65	9.01	4.07	2.91	3.20	3.78	2.91	4.94	4.36	5.23	7.56	4.94

With Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	3	6	3	1	0	2	0	0	0	0	0	0	0	0	0
3-4	1	4	5	0	1	2	1	0	0	0	0	0	0	1	0
5-6	5	5	2	4	5	0	1	0	0	0	0	0	1	0	0
7-8	4	5	5	5	7	1	0	0	0	1	0	1	0	1	0
9-10	2	5	2	3	3	3	1	0	0	0	0	0	0	0	0
>10	0	3	3	5	2	2	0	1	1	0	0	1	0	0	0
Total, n	15	28	20	18	18	10	3	1	1	1	0	2	1	2	0
Total, %	4.36	8.14	5.81	5.23	5.23	2.91	0.87	0.29	0.29	0.29	0.00	0.58	0.29	0.58	0.00

Table 6.10 Scenario B rod replacements.

Without Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	0	2	1	2	2	4	4	2	4	4	3	3	9	2	4
3-4	0	0	1	1	0	2	1	2	1	2	1	4	5	3	5
5-6	0	2	1	2	2	1	2	1	2	2	0	0	2	3	1
7-8	0	0	1	1	1	2	0	1	1	0	2	3	3	1	0
9-10	0	0	0	1	0	1	1	1	1	0	0	2	1	0	0
>10	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0
Total, n	0	4	4	7	5	10	8	9	9	8	6	12	21	9	10
Total, %	0.00	1.83	1.83	3.21	2.29	4.59	3.67	4.13	4.13	3.67	2.75	5.50	9.63	4.13	4.59

With Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	2	0	3	1	0	1	0	0	0	0	0	0	0	0	0
3-4	2	10	3	2	1	1	1	0	0	0	0	0	0	0	0
5-6	2	8	4	4	4	0	0	0	0	0	0	0	0	0	0
7-8	1	8	7	4	1	1	0	0	0	0	0	0	0	0	0
9-10	3	10	2	1	1	1	0	0	0	0	0	2	0	0	0
>10	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0
Total, n	12	37	19	13	8	4	1	0	0	0	0	2	0	0	0
Total, %	5.50	16.97	8.72	5.96	3.67	1.83	0.46	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00

Table 6.11 Scenario C rod replacements.

Without Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	1	2	0	2	6	4	2	0	2	3	4	6	6	3	5
3-4	0	0	0	0	2	1	1	2	2	2	0	2	5	2	0
5-6	0	0	1	0	0	1	0	1	0	1	0	2	1	1	1
7-8	0	0	0	0	0	1	0	2	0	0	0	1	3	0	0
9-10	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0
>10	0	0	0	0	0	1	0	0	0	0	0	1	2	0	0
Total, n	1	2	1	3	8	8	3	5	4	7	4	13	17	7	6
Total, %	0.74	1.48	0.74	2.22	5.93	5.93	2.22	3.70	2.96	5.19	2.96	9.63	12.59	5.19	4.44

With Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	3	2	1	0	0	0	0	1	0	0	0	0	0	0	0
3-4	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0
5-6	0	4	4	0	1	0	0	0	1	0	0	0	0	0	0
7-8	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
9-10	2	2	8	0	0	0	0	0	2	1	0	1	0	0	0
>10	1	1	3	0	0	1	0	0	0	0	0	0	0	1	0
Total, n	7	11	18	0	1	1	1	1	3	1	0	1	0	1	0
Total, %	5.19	8.15	13.33	0.00	0.74	0.74	0.74	0.74	2.22	0.74	0.00	0.74	0.00	0.74	0.00

Table 6.12 Scenario D rod replacements.

Without Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	1	2	0	2	1	1	1	4	4	1	2	10	2	2	3
3-4	0	3	0	0	0	1	1	0	1	1	2	1	4	1	2
5-6	0	0	1	1	0	1	1	1	1	1	0	2	0	0	1
7-8	0	1	1	1	1	0	0	1	1	0	0	0	0	1	0
9-10	0	0	0	1	0	0	0	0	2	1	0	0	0	1	2
>10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, n	1	6	2	5	2	3	3	6	9	4	4	13	6	5	8
Total, %	0.89	5.36	1.79	4.46	1.79	2.68	2.68	5.36	8.04	3.57	3.57	11.61	5.36	4.46	7.14

With Rehabilitation															
No. of rods	Year														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	0	2	0	1	1	2	1	0	1	1	0	0	0	0	0
3-4	0	3	0	0	0	1	0	1	0	0	0	0	0	0	0
5-6	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0
7-8	0	2	0	0	0	1	0	1	0	0	0	1	0	0	0
9-10	1	3	1	2	0	0	0	0	0	0	0	0	0	0	0
>10	0	2	0	1	1	1	0	0	0	0	0	1	0	0	0
Total, n	1	12	2	4	3	5	1	2	1	1	1	2	0	0	0
Total, %	0.89	10.71	1.79	3.57	2.68	4.46	0.89	1.79	0.89	0.89	0.89	1.79	0.00	0.00	0.00

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6.10 Thesis Context

This chapter fulfilled RQ 3: Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi? SO 5 and SO 6 are accomplished in a drafted paper for a peer reviewed journal. By demonstrating the variations in preventative maintenance behaviours and costs of major repairs under different tariff scenarios over the life-cycle of the Afridev handpump, through interrogating the 'big data' collected in the mWater dataset, the findings highlight a lack of initial capacity building into appropriate cost recovery and maintenance approaches. While lower costing major repairs can be conducted by CBM service providers, these primarily consist of fast wearing parts. The replacement of high cost significant components are less common. Rehabilitation has a notable effect as higher costing major repairs then increase costs post-rehabilitation as the replacement of other longer life components also become more common. In cases pre and post rehabilitation, higher costing major repairs are left to external support, primarily NGOs. This further represents a coverage attitude rather than supporting the capacity building and service delivery approach to rural water supply.

The behaviours towards rod replacement, in particular, suggest the presence of financial resources contributes to more effective life-cycle planning. However, while proactive tariff scenarios show replacement towards the end of the rods life-cycle in the first instance, compared to reactive scenarios, these primarily consist of lower multiples of rods. Larger multiples are replaced when major repair costs are higher, where external support is required and typically post-rehabilitation.

Appropriate life-cycle planning is essential for the continued functionality of water supply, however, appropriate capacity building for local service providers is lacking. The struggle to accommodate the technical and financial life-cycle requirements of handpumps accompanied by barriers created at the outset (i.e. assets subject to seasonality and poor water quality) may prevent sustainable access to improved sources. This is discussed in the next chapter.

CHAPTER 7. BARRIERS TO HANDPUMP LIFE-CYCLE SERVICEABILITY

The previous chapter addressed the behaviours of community based service providers towards preventative maintenance and CapManEx, under different tariff scenarios. Major repairs by community service providers prioritise lower costs over the life cycle which favour fast wearing components over longer life components. Inefficient life-cycle planning results in a reactive approach to maintenance and reliance on external support following breakdown, that could result in abandonment should just one component fail. This chapter addresses two research questions of the thesis. RQ 3: Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi? and RQ 4: How can a proactive approach to monitoring identify and target increased risk to handpump breakdown?

To investigate the variables contributing to the decline of functionality, infrastructure (condition at time of audit) and service provision (financial and operational) information for boreholes equipped with Afridev handpumps installed across Malawi were extracted from a comprehensive live big dataset. A life-cycle cost model was developed to highlight the costs across the design life of the Afridev handpump in a best and worst case scenario. Furthermore, the potential year in which a financial shortfall would occur is investigated under the tariff scenarios highlighted in the previous chapter. A logistic regression approach was taken to identify significant variables associated with an issue of infrastructure. The investigation is accomplished through a paper that addresses three specific objectives of the thesis. SO7: Develop an LCC model of the Afridev handpump operations and maintenance requirements, to be used as proxy indicators for real world monitoring data. SO 8: Identify the LCC element (i.e. issue of infrastructure) within the temporal snapshot monitoring indicator, functionality. SO 9: Identify significant explanatory predictor variables (e.g. domains relevant to service delivery and LCC model proxy indicators) behind the LCC element occurring. This is published in a peer reviewed journal, Environmental Science: Water Research & Technology, as follows:

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7.1 Paper: Barriers to Handpump Serviceability in Malawi: Life-Cycle Costing for Sustainable Service Delivery

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7.2 Abstract

The implementation of handpumps has contributed to increased improved water access. However, 'universal access' as the metric for success within Sustainable Development Goal (SDG) 6, potentially conceals fundamental barriers for sustainable services and hinders SDG 6 target success. Tariffs, in the form of household contributions, are the most common form of financial provision for the maintenance of rural water supplies. However, the annualised financial resources significantly vary across local contexts. Four tariff scenarios (collected per month, when required for repairs, per year and no tariff) were investigated across the life-cycle of 21,997 Afridev handpumps in Malawi. Known local costs for Afridev components from suppliers in Malawi were used to determine the potential shortfall in financial resources over the handpumps 15-year design life. Domains that influence functionality, such as the operations, maintenance and quality of infrastructure, were also investigated to identify significant factors impacting the sustainability of the handpump. Logistic regression indicates sub-standard installations (i.e. seasonality and poor water quality), structural damage to civil works, no preventative maintenance, lack of spare parts on site and a shortfall in potential financial resources were significantly associated with the poor status of infrastructure (broken or worn components) over the life-cycle of the Afridev. The findings highlight the burden placed on rural communities of maintaining inherently unsustainable assets that inevitably hinders lasting service delivery and benefits for rural communities in the SDG period and beyond.[i]

[i] **Water Impact Statement:** Maintaining serviceability across the life-cycle of handpumps remains a challenge for local service providers. This study highlights barriers faced by local service providers in maintaining handpumps for rural water supply in Malawi. Factors associated with broken or worn parts during a handpumps life-cycle include a shortfall in financial resources, no preventative maintenance, access to spare parts on site and poorly installed infrastructure.

7.3 Introduction

Over two decades, investments into increasing the coverage of improved water supplies saw the Millennium Development Goal (MDG) for water met by 2010, and 91% of the global population with access to an improved source by the end of the MDGs in 2015 (WHO/UNICEF, 2015). However, these coverage statistics hide low levels of service and a decline in functionality as systems depreciate (RWSN Executive Steering Committee, 2010; Adank *et al.*, 2016; Martínez-Santos, 2017; Truslove *et al.*, 2019). This creates a major challenge for the Sustainable Development Goals (SDGs) in which 'universal access' has become the metric for success.

Handpumps have played a fundamental role in increasing access to safe water for rural populations across Sub-Saharan Africa (SSA) (Macarthur, 2015). During the International Decade for Drinking Water and Sanitation in the 1980's, the concept of village level operations and maintenance (VLOM) was conceived through the idea that if handpumps were easier to maintain, communities could be responsible for them (Arlosoroff *et al.*, 1987). The principles of VLOM and handpump standardisation have since been embraced by national policies and sector strategies during the global goals (Macarthur, 2015), to underpin the sustainability of rural water supplies. Post-construction, the vast majority of these services are managed under a demand responsive community based management approach (CBM) (Lockwood and Smits, 2011; Hutchings *et al.*, 2015). The model is aimed to benefit and empower communities (Briscoe and de Ferranti, 1988), relies on voluntary participation and the coverage of 100% of O&M costs. The concept has been widely acknowledged to be an idealistic approach to service delivery that cannot realistically achieve sustainable and reliable services (Harvey and Reed, 2006a; Moriarty *et al.*, 2013; Whaley and Cleaver, 2017; Whaley *et al.*, 2019).

The implementation of shorter life VLOM handpump solutions to deliver services sooner than later has been a high priority during the MDGs (Fonseca *et al.*, 2013). The focus on capital expenditure (CapEx) in rural water supply coverage can lead to investment decisions favouring cheaper infrastructure, leading to premature major repairs and breakdowns (Franceys and Pezon, 2010). Handpumps tend to last only 3 to 5 years before premature failure rather than their estimated 15 to 20 year design life (Baumann, 2006; Fonseca *et al.*, 2011), with approximately 2 out of 3 handpumps operate at a given time across SSA (RWSN Executive Steering Committee, 2010). Furthermore, poor siting, poor construction and improper design for the local context results in poor service delivery in terms of water supply availability and quality (Bonsor *et al.*, 2015; Kalin *et al.*, 2019; Lapworth *et al.*, 2020). This contributes to sustainability challenges at the local level, which has been particularly evident by the acceleration to meet the coverage targets of the MDGs, and a risk in the SDGs (Truslove *et al.*, 2019). The original investments and benefits of increasing the coverage of improved supplies are therefore lost for the communities they are intended to serve (Hunter, MacDonald and Carter, 2010).

The Afridev handpump, is the most recognised VLOM handpump and the standard in Malawi (Macarthur, 2015), where 'village men and women can maintain deep well handpumps, can be locally produced and can still be affordable and reliable' (ERPF, 2007). Preventative maintenance is a core aspect of the Afridev design which encompasses the act of regular checks at fixed time intervals and the replacement of components ideally before they have failed (ERPF, 2007; Franceys and Pezon, 2010). The interventions of preventative maintenance reduce the cost of premature failure and reduce the downtime of service delivery compared to reactive approaches to maintenance (Fonseca *et al.*, 2013). Furthermore, the replacement of handpump components across the shorter life-cycle, compared to a well or borehole, can keep water services working continuously (Arlosoroff *et al.*, 1987). However, VLOM technologies have not been successful in resolving the maintenance and management issues of CBM that contribute to reduced functionality (Baumann and Furey, 2013; Foster, 2013). While preventative maintenance is the most cost effective solution over the life-cycle of infrastructure, and the CBM approach incorporates preventative maintenance into the responsibilities of rural water service providers, the reality is preventative maintenance is seldom undertaken. Poor management, lack of financial resources or the 'if it is not broke why fix it' approach, are commonly attributed to the lack of conducting preventative maintenance at the local level (Chowns, 2015a; Etongo *et al.*, 2018; Kativhu *et al.*, 2018).

Donors and NGOs released of responsibility for ongoing O&M, while continuing to proclaim empowerment of the communities served, has made CBM a compelling model throughout its political history since the 1980s (Blaikie, 2006; van den Broek and Brown, 2015; Whaley and Cleaver, 2017; Whaley *et al.*, 2019). Communities rarely accept true ownership of a system as it is perceived responsibility lies with the implementing government or donor (Morgan, 1993), as O&M costs are frequently deemed 'somebody else's problem' (RWSN Executive Steering Committee, 2010). Despite the lack of evidence for the continuation of CBM for rural water supply, it has persisted as the popular paradigm for service delivery across SSA in attempts to achieve SDGs.

The physical infrastructure and governance arrangements throughout the life-cycle of the Afridev are not separate entities but are interlinked when it comes to sustainability (Evans and Appleton, 1993; Whaley and Cleaver, 2017). The reality is the community management of water supply requires professionalism and long term external support for sustainable success (Hutchings *et al.*, 2015). The CapEx of new rural water supplies typically requires donors or external stakeholders. External funders are further required over the design life of handpumps due to frequent capital maintenance expenditure (CapManEx) i.e. major repairs and rehabilitation. This is unlikely to be planned for in the rural context over the short life-cycles (Franceys and Pezon, 2010; Fonseca *et al.*, 2013), as focus remains on the short term goals of providing new water facilities (RWSN Executive Steering Committee, 2010). Furthermore, the general lack of external support and training post-construction results in an ineffective system for ensuring quality maintenance and savings for O&M (Harvey and Reed, 2006a; Baumann and Furey, 2013; Moriarty *et al.*, 2013; Chowns, 2015a; Whaley and Cleaver, 2017; Truslove, Coulson, Nhlema, *et al.*, 2020). The challenges of CBM reinforce the need for a holistic service delivery approach and not for one-time investments, commonly adopted by NGOs and donors (RWSN Executive Steering Committee, 2010; Baumann and Furey, 2013; Truslove *et al.*, 2019).

The common theme across research is that the CBM approach and focus on coverage leaves little understanding or capacity to accommodate service delivery in the long term. The purpose of this paper is to investigate if rural service providers meet the life-cycle cost requirements of the Afridev under the current cost-recovery mechanism. The decline in functionality over the 15-year design life is investigated and the various drivers behind this indicator are identified, with a focus on impact to the life-cycle costing. Finally, the significant variables associated with issues of infrastructure over the Afridev design life are identified (i.e. broken and worn components). These findings highlight the barriers to continued serviceability in rural Malawi that will continue to burden communities and hinder progress towards the SDG 6 under current coverage target and CBM approaches.

7.4 Materials and Methods

7.4.1 Data Collection and Sampling

The data collection took place as part of a wider research programme in evaluating the sustainability of rural water supplies in Malawi (see Kalin *et al.*, 2019). Water supply assets (*n*=121,161) have been evaluated across the country using the management information system (MIS), mWater (www.mwater.co). Information was collected through a water point functionality survey based on sustainability indicators and additional needs of the Malawian government. This paper draws on the survey data associated with the service delivery of drilled boreholes equipped with Afridev handpumps in the context of rural Malawi, focussing on assets installed during the MDG period to date (2000-2019). Questions utilised in the paper are outlined in Appendix A. Domains include:

- Operational: Preventative maintenance, spare parts kept on site and major repairs conducted.
- Financial & cost recovery: Tariff amount and frequency.
- Service Delivery: Service provider type and number of users.
- Condition of water supply: Functionality status of water supply and issues at time of audit.
- Geographical: Region of Malawi.

The age of assets up to the design life of 15 years old were highlighted. If rehabilitation exercises had been conducted, the age of the Afridev was taken from this date, as rehabilitation is considered the start of a new service (Franceys and Pezon, 2010). As Malawi operates under the CBM model, service providers under the CBM approach (Area Mechanics, Community Members, WPCs and combinations of the prior) were highlighted. This presented a dataset of 21,997 boreholes equipped with Afridev handpumps.

The life-cycle of the Afridev was investigated in relation to the replacement intervals of components and associated costs for spare parts. The primary source for replacement intervals was the 'Installation and Maintenance Manual for the Afridev Handpump' in which Annex III describes the quantity of parts per pump, approximate lifetime and the recommended replacement intervals of wearing parts (ERPF, 2007). Estimated costs of the Afridev were gathered from 6 suppliers and estimators.

7.4.2 Management Scenario Design

Tariffs are the main financial mechanism for the maintenance of rural water supply assets through the collection of user fees or household contributions (MoAIWD, 2015; United Nations, 2018a). National policy and guidelines recommend tariffs are set by taking assumed costs across the handpump life-cycle over the estimated 15 year design life, and the number of contributing households to provide a monthly tariff (MoAIWD, 2015). The costs include, but not limited to, replacement of spare parts, transportation, preventative maintenance contracts and total replacement.

To determine the potential financial resources available for the O&M across the Afridevs life-cycle, four tariff frequency scenarios were investigated. Collection per month (Scenario A), when required for repairs (Scenario B), per year (Scenario C) and no tariff (Scenario D). Scenario C also reflects harvest seasonal payments, whereby principal corps such as maize are generally harvested and marketed in Malawi between April and June (Ellis and Manda, 2012; FAO, 2015). The distribution of the number of potentially contributing households and the tariff amount under each scenario was investigated. The potential annual financial resources under each scenario for O&M was calculated using the following matrix:

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} = A_{ij} \tag{1}$$

Where, a = Potential financial resources (MWK), m = Set tariff group (MWK), n = No. of potentially contributing households' group. The household and tariff amounts are presented in Table 7.1.

Table 7.1 Household and tariff amount grouping.

Value	m (MWK)	n (households)
1	<=100	15
2	>100 & <=200	30
3	>200 & <=300	45
4	>300 & <=400	60
5	>400 & <=500	75
6	>500 & <=600	90
7	>600 & <=700	105
8	>700 & <=800	120
9	>800 & <=900	-
10	>900 & <=1000	-
11	>1000 & <=2000	-

The model was run for a low, medium and high value in each of the tariff groups (i.e. for group >100 and <=200 MWK, the values 101MWK (low), 150MWK (medium) and 200MWK (high) were applied). The potential financial resources across the 15 year period were determined using the following steps:

$$\begin{gathered} Step\ 1 = y_1 \ = (cA)_{ij} \\ Step\ 2 = y_2 \ = y_1 + (cA)_{ij} \\ \vdots \\ Step\ n = y_{n+1} \ = y_n + (cA)_{ij} \end{gathered} \tag{2}$$

Where, y_n = Year n of the life-cycle, A = Potential Financial Resources Matrix, i = Set tariff (MWK), j = No. of potentially contributing households and c = Frequency of Tariff based on the designated scenario (scalar) specified as: Scenario A multiplying the matrix by 12;

Scenario B was determined based on the results of the life-cycle model. If a component was replaced in a given year in the Afridev life-cycle, then the matrix is applied; Scenario C required no scalar; Scenario D was omitted as no other financial information was available.

The annualised potential financial resources for each scenario were weighed against the cumulative costs of the Afridev across the 15 year design life for best and worst case models, further discussed in the following section (7.3.3). The minimum, average and maximum year of potential shortfall was determined for each scenario. This is presented in 7.9 Supplementary Information.

The functionality of Afridev handpump boreholes up to 15 years old was investigated in relation to the previously defined scenarios to determine trends across the design life. The term 'functionality' has been used by studies to represent the performance or reliability of a water point, however this only represents a snapshot at the time of audit (Carter and Ross, 2016). Abandoned water points were omitted from the study as the root cause of failure is not fully known. For the avoidance of doubt in the context of the study:

- Functionality is used to describe a water point operating to design specifications.
- Partial functionality is a water point producing water but in a reduced capacity. For example, in need of repair, poor water quality or periodic decline in groundwater levels (Kalin *et al.*, 2019).
- Non-functionality describes a water point not producing water at the time of audit.

7.4.3 Life-Cycle Assessment Model Design

The components of the Afridev were assigned an expected life-cycle range and a cost as previously discussed. The life-cycle cost approach identifies and quantifies the costs over the life-cycle using the present value technique (Woodward, 1997). This is most useful for single asset systems, such as handpumps, for considering future investments and alternatives for delivering services (Fonseca *et al.*, 2011). The best case (highest expected life span) and worst case (lowest expected life-span) scenarios were examined over a 15 year period. For example, a pump-rod assembly has an expected life-cycle of 3 (worst case) to 5 years (best case).

An average cost for each component was applied to be representative of each of the Afridev suppliers. These costs were then applied over the 15-years design life of the Afridev for two life-cycle models: life-cycle of replacing components under recommended repairs (R.R) and total operations expenditure (T.OpEx). T.OpEx included assumed costs for transport and contracts for Area Mechanics to conduct repairs (MoAIWD, 2015). The costs of Afridev components may vary across the socio-geographical context, however they can provide insights into how service providers under CBM meet the costs over the design life. The potential financial resources under each scenario were calculated per annum and cumulatively over a 15 year period against the annual life-cycle costs of the Afridev, in the best and worst case for each of the two models. The results of this analysis are found in 7.9 Supplementary Information. The model results were incorporated into the mWater dataset.

7.4.4 Data Analysis

The life-cycle of the Afridev is approximately 10 to 15 years, however, this can be affected by many factors (ERPF, 2007). Bonsor *et al.*, 2018, states "Defining and measuring functionality is only a starting point" and water point failure is a multi-dimensional issue. Therefore, functionality alone as an indicator is insufficient when determining the linkage between serviceability and the life-cycle of infrastructure. The aforementioned mWater database allows for the current issues reported at the water point at the time of audit to be identified.

The correlation between functionality and current issues reported are investigated. These variables describe:

- Functionality: as binary variable either functional or partially/non-functional.
- Issues of infrastructure: as a binary variable yes/no. Describes worn out parts, broken parts or low water pressure.
- Issue of sub-standard: as a binary variable yes/no. Describes seasonality, irregular flow or poor water quality.
- Issue of structural: as a binary variable yes/no. Describes damage to civil works, reported theft of handpump components or vandalism of the water point.
- Age of water supply: as a continuous variable.

Finally, a binary logistic regression analysis was conducted to determine the likelihood of 'issues of infrastructure' occurring should a service provider experience a financial shortfall during the life-cycle of the Afridev, using the statistical package SPSS (version 26). Explanatory variables included operational, service delivery, geographical and functionality domains established through the water point functionality survey, and the results of the life-cycle cost model. Explanatory variables were tested for multicollinearity by calculating the variance inflation factors. The analysis was designed to identify significant explanatory variables rather than to find a predictive model of 'best' fit.

7.5 Results

7.5.1 Distribution of households and tariffs

Tariffs are the primary financial mechanism to finance the necessary O&M requirements for rural water points in the form of household contributions or user fees (United Nations, 2018a). The potential financial resources available to a service provider can be determined by the tariff amount, the frequency of collection and the number of contributing households.

Table 7.2 describes the groupings of user and tariff amount. Figure 7.1 presents the distribution of potentially contributing households and the grouping of tariff amounts with respect to the tariff collection frequency scenarios.

Table 7.2 User and tariff amount grouping.

Value	No. of Users Group	No. of Households Group	No. of Tariffs (MWK)
1	>0 & <= 75	15	<=100
2	>75 & <=150	30	>100 & <=200
3	>150 & <=225	45	>200 & <=300
4	>225 & <=300	60	>300 & <=400
5	>300 & <=375	75	>400 & <=500
6	>375 & <=450	90	>500 & <=600
7	>450 & <=525	105	>600 & <=700
8	>525 & <=600	120	>700 & <=800
9	>600	>120	>800 & <=900
10	-	-	>900 & <=1000
11	-	-	>1000 & <=2000
12	-	-	>2000

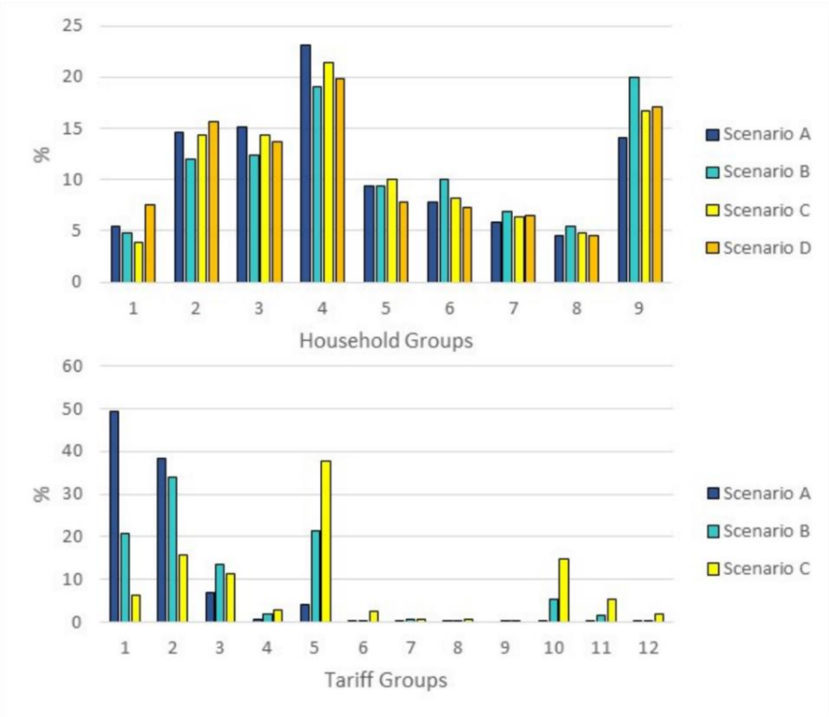

Figure 7.1 Household groups (above) and tariff groups (below) by tariff collection scenarios.

The trend of household groups is consistent across all four scenarios. User groupings primarily fall within the design limit, with the largest distribution in group 4 (approximately 60 households). The distribution sharply declines following this group with a notable increase in the final group in all scenarios (above 120 households). As households commonly obtain water from multiple sources, it is possible that these water points are considered secondary sources. Hence the large proportion of cases in the final grouping (greater than double the Afridev design limit of 120 households). Households utilising multiple water points may not financially contribute to all water points. Therefore, usage above the design limit of the Afridev may not receive tariffs from all recorded households, impacting the potential financial resources available for O&M.

When concerning the tariff amount the distribution of the scenarios is more pronounced, primarily falling in groups 1-5 and 10-12. Firstly, Scenario A primarily falls within the first two tariff groups with significantly lower occurrences above group 5 (approximately 500 MWK). This is to be expected due to the frequent collection of tariffs, thus important for the tariff to be an affordable amount when collected per month. Scenario B similarly falls within 500 MWK (groups 1-5). The larger distribution of tariffs compared to Scenario A could be attributed to the variations of costs associated with each repair, and therefore higher tariffs may be considered for more costly repairs as the Afridev ages. Scenario C primarily falls within group 5 (approximately 500MWK) due to the infrequency of the collection period when compared to Scenario A. However, financial resources per annum would significantly differ between the scenarios to meet the required O&M costs during the life-cycle of the Afridev handpump. Finally, scenario D presents cases where no tariff has been set by the service provider. Table 7.3 presents the reported explanations why no tariff has been set.

Table 7.3 Reasons why no tariff is set (Scenario D).

Variable	n	%
External Support	642	18.09
Lack of training	1313	37.00
Lack of understanding	20	0.56
Enough money or other forms of community fundraising	313	8.82
Reluctance to pay	299	8.42
Non-functional/Unreliable water point	128	3.61
Lack of coordination/Negligence	172	4.85
Perception water is free	67	1.89
Poor water quality	26	0.73
New water point or have yet to experience breakdown	167	4.71
Ask community for contributions when needs arises	376	10.59
Other	26	0.73

Lack of training for the service provider is the most common reported reason why no tariff is set in the rural areas (37%). Other variables in Table 7.3 can also be associated with lack of training, such as; lack of understanding (0.56%), lack of coordination/negligence (4.85%), new water points or have yet to experience breakdown (4.71%) and ask community for contributions when needs arise (10.59%). Other forms of financing have also been reported. External support from institutions, local government or NGOs attributes to 18.09% of cases. However, there may be a perception that the responsibility falls with someone else (RWSN Executive Steering Committee, 2010; Koehler *et al.*, 2018), resulting in a lack of financing and O&M. Enough money or other forms of community fundraising attributes to 8.82% of cases which raises the question if this is sufficient for O&M costs across the life-cycle of infrastructure. It is well recognised throughout studies that external support and continued training of service provision is essential to the continued service delivery of the water supply at the community level (Harvey and Reed, 2006a; Whittington *et al.*, 2009; RWSN Executive Steering Committee, 2010; Foster, 2013). These variables of poor capacity building at the local level further highlight the inappropriateness of the standardised CBM model for rural water supply.

The willingness to pay by community members is well-recognised factor in rural water supply. While this can affect scenarios with an established tariff, in the case of Scenario D the willingness to pay can potentially be attributed to the collapse of a financial mechanism. In Table 7.3 this can be attributed to two areas: the condition of the water point (Non-functional/Unreliable (3.61%) and poor water quality (0.73%)) and socio-cultural characteristics (perception water is free (1.89%) and reluctance to pay (8.42%)).

Firstly, the non-functional/unreliable assets indicate the water point is not producing water as is intended. While it is possible that the lack of understanding (how the financial mechanism influences continued service delivery of assets) may be a contributing factor, poor construction or improper siting of water points directly contributes to premature failure. The poor water quality variable highlights this, as saline water was the most common of the reported cases in the mWater dataset.

Secondly, the perception of water and the quality of service provision contributes to the premature failure of water points and management. The cases of reluctance to pay are attributed to poverty and inability to pay in the communities. It is also attributed to a mistrust in the service provider or from previous interference with the collected financial resources. Previous studies have also supported these findings in willingness to pay (van den Broek and Brown, 2015), reinforcing the understanding that CBM has reached its limit as an appropriate method for service delivery.

It is clear infrastructure and management requires continued support and monitoring to ensure sustainable services at the local level (RWSN Executive Steering Committee, 2010;

Carter and Ross, 2016). The reasons behind why no tariffs are in place are useful narratives when understanding and supporting the wider local contexts, which has been absent from traditional CBM approaches.

7.5.2 Functionality over life-cycle of the Afridev

The life expectancy of a well or borehole typically exceeds 25 years (Driscoll, 1986), while the lifting mechanisms typically have significantly shorter life-spans (Fonseca *et al.*, 2013). The Afridev handpump has an estimated design life of approximately 10 to 15 years. However, insufficient O&M to replace components and depreciation results in a reduction in the operational lifespan of the handpump.

The relationship between O&M and continued serviceability is well established. Therefore the concept of functionality over the life-cycle of assets can provide insights into the sustainability of an asset. Figure 7.2 presents the number of recommended replacements of Afridev components across the life-cycle for the worst and best case scenarios. The reported functionality, partial functionality and non-functionality of the 21,997 boreholes equipped with Afridev handpumps for a 15 year age range is plotted with regards to the four aforementioned tariff scenarios. This presents the relationship between life-cycle, management and serviceability, and is further expressed in Table 7.4.

Table 7.4 Linear regression of functionality by scenarios.

Scenario	Functionality	*n*	%	Age: 1 (%)	Age: 15 (%)	R^2	p-value
A	F	7570	77.98	88.45	68.24	0.769	<0.001
	PF	1803	18.57	9.37	28.24	0.812	<0.001
	NF	334	3.44	2.18	3.53	0.394	0.012
B	F	3309	69.97	82.20	61.07	0.787	<0.001
	PF	1185	25.06	15.25	34.02	0.751	<0.001
	NF	235	4.97	2.54	4.92	0.197	0.097
C	F	3068	77.16	84.59	62.00	0.771	<0.001
	PF	799	20.10	13.36	34.50	0.755	<0.001
	NF	109	2.74	2.05	3.50	0.298	0.035
D	F	2315	64.57	82.56	42.76	0.844	<0.001
	PF	803	22.40	8.37	36.55	0.779	<0.001
	NF	467	13.27	9.07	20.69	0.648	<0.001

Figure 7.2 (A) Number of replacements over 15-year design life (left) and proxy cost of replacements each year (right). (B) Functionality (left), partial-functionality (middle) and non-functionality (right) of scenarios over the 15-year design life of the Afridev.

A preventative maintenance approach involves the replacement of components before their eventual failure. Figure 7.2 shows that these recommended replacements occur every year in either a best or worst case scenario. This reflects the understanding that shorter life-span technologies require earlier maintenance for continued serviceability. Handpumps in particular are estimated to only last 3 to 5 years out of their 15 year design life without O&M (Baumann, 2006). This is reflected in Figure 7.2 as rods and rising main sections typically have a life-cycle of 3 to 5 years (ERPF, 2007) and have the largest incurred cost of components due to the number installed.

A gradual increase in the number of recommended replacements occurs before a marked increase in the worst case in the sixth year of service. However, Figure 7.2 reflects the replacements under a preventative maintenance approach and does not reflect instantaneous breakdown, due to an inability to replace components at the end of an approximated life-cycle. It does however reflect a risk of service decline should components continue to wear and the inadequate O&M behaviours by service providers. This is reflected in the scenario functionality distributions in Figure 7.2 and Table 7.4. There is a notable decline in functionality as infrastructure ages over the design life of the Afridev, however this does not necessarily result in non-functionality. All scenarios express a significant linear decline in functionality across the life-cycle, with Scenario A and Scenario C expressing higher levels of functionality compared to Scenario B and Scenario D. However, the decline in functionality results in a significant linear rise in partial functionality across the design life. With the exception of Scenario D, there is no significant linear rise in non-functionality resulting from the decline in functionality.

There are two notable points in the design life in Scenario B and Scenario D, highlighting this trend. At the established years when handpumps tend to fail (between year 3 and 5), both scenarios experience a notable drop in functionality. However, Scenario B expresses a rise in partial functionality while Scenario D expresses a rise in both partial and non-functionality during this period. Therefore, the presence of a tariff to fund O&M for continued serviceability has a notable impact between the two scenarios.

Figure 7.2 and Table 7.4 describe Scenario D as the least effective over the design life of maintaining functional water supply. Scenario A, which conforms to Malawian government guidelines (MoAIWD, 2015), is described as the most effective for maintaining functionality. Functionality alone is only the starting point in defining the multi-dimensional issue of service delivery (Carter and Ross, 2016; Bonsor *et al.*, 2018). In the context of service delivery across the Afridev design life, the aforementioned decline in functionality indicates the presence of a tariff does not guarantee continued service. Financial arrangements and affordable maintenance and repair are key drivers that contribute to the speed of repair under CBM (Whaley *et al.*, 2019). Without which decline in service and issues of infrastructure can occur.

7.5.3 Identifying importance of life-cycle issues within functionality

The issues of functionality are multi-layered including variables such as financial, managerial, political and environmental (Foster, 2013; Carter and Ross, 2016; Bonsor *et al.*, 2018). Figure 7.3 presents the correlation between functionality and variables related to the reported condition of physical infrastructure identified from the results of the water point functionality survey.

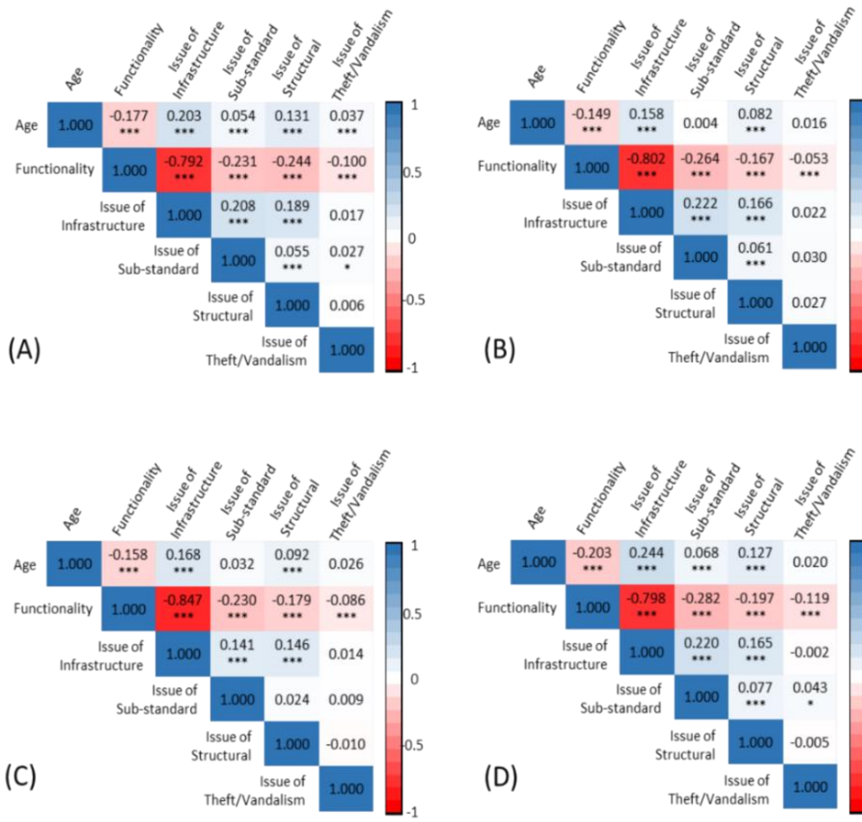

Figure 7.3 Correlation matrix showing relationship water point life-cycle characteristics (as binary outcomes) and age within a 15-year design life. Scenario A (top left), scenario B (top right), scenario C (bottom left) and scenario D (bottom right). * Pearson correlation is significant at 0.01. *** Pearson Correlation is significant at 0.001.

Across Figure 7.3, the four scenarios follow similar trends and present minor variations in the correlation between investigated variables. The depreciation of infrastructure is highlighted by the negative correlation between age and functionality, and between age and issue of infrastructure. This is supported by further findings highlighting this effect and the challenge local service providers face of sustaining infrastructure over its life-cycle (Baumann and Danert, 2008; Fonseca *et al.*, 2013; Foster, 2013; Fisher *et al.*, 2015; Truslove *et al.*, 2019).

The issue of sub-standard service is negatively correlated with functionality in all scenarios. This could be attributed to the seasonal aspect of the category in which no water is produced at certain times of the year and potentially at the time of audit. However, this correlation may highlight a wider issue. Sub-standard services show a positive correlation with an issue of infrastructure in all scenarios. Unreliable water points through either poor initial drilling, seasonal variations, poor water quality and user perception can impact the willingness to pay and collection of financial resources for crucial O&M (Foster and Hope, 2016, 2017; Kativhu *et al.*, 2017; Olaerts *et al.*, 2019). This further impacts the serviceability of infrastructure and highlights a wider concern of sustainability in low-income countries.

The strongest relationship out of all the variables shows a negative correlation between functionality and the issue of infrastructure, the life-cycle element. While all four scenarios present similar correlations between functionality and infrastructure, Figure 7.2 described the influence of household contributions can have on sustaining infrastructure across the Afridev life-cycle. This reflects the findings of other studies highlighting the importance of finances and affordable maintenance and repairs when delivering CBM (Whittington *et al.*, 2009; Carter, Harvey and Casey, 2010; Chowns, 2015a), and predicting functionality (Foster, 2013; Whaley *et al.*, 2019). Considering how service providers meet the life-cycle needs of infrastructure, in a service delivery approach, is necessary when moving from a snapshot functionality estimation to continued sustainability of water supply.

7.5.4 Significant explanatory variables for life-cycle issues

The following tables present the results of the binary logistic regression analysis for an issue of infrastructure reported at the Afridev handpump borehole. Here explanatory variables reflect the interlinking 'hardware' and 'software' aspects of rural water supply established through the water point functionality survey. The results of the life-cycle cost model are included in the regression analysis. The multivariable logistic regression analysis was run for two life-cycle cost models using the estimated costs of Afridev components. Model 1 determined the year of shortfall for scenarios meeting 'Recommended Repairs' (R.R) and

Model 2 determined the year of shortfall meeting 'Total Operations Expenditure' (T.OpEx). While the costs used to determine the shortfall are estimations, the results can provide proxy indicators and insights into the risks associated with failing to meet the life-cycle requirements. Table 7.5 presents the descriptive statistics for the logistic regression, Table 6.6 presents the results for Scenario A, Table 7.7 for Scenario B, Table 7.8 for Scenario C and Table 7.9 for Scenario D. The results of the life-cycle cost model are not included in the logistic regression analysis for Scenario D.

Table 7.5 Descriptive statistics for variables included in logistic regression.

Explanatory Variables	**S.A (*n*=8294)**		**S.B (*n*=3743)**		**S.C (*n*=3240)**		**S.D (*n*=2890)**	
	n	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Sub-standard								
Yes	646	7.79	463	12.37	218	6.73	413	14.29
Structural								
Yes	378	4.56	239	6.39	110	3.40	136	4.71
Theft/Vandalism								
Yes	30	0.36	19	0.51	9	0.28	27	0.93
Service Provider								
WPC	7208	86.91	3214	85.87	2883	88.98	2345	81.14
Area Mechanic	325	3.92	159	4.25	92	2.84	108	3.74
Community Members	102	1.23	69	1.84	37	1.14	129	4.46
Multiple	659	7.95	301	8.04	228	7.04	308	10.66
Preventative maintenance conducted								
Yes	6634	79.99	2731	72.96	2621	80.90	1498	51.83
Sometimes	407	4.91	232	6.20	137	4.23	240	8.30
No	1253	15.10	780	20.84	482	14.88	1152	39.86
Spare Parts on site								
Yes	5584	67.33	2241	59.87	2301	71.02	1076	37.23
Major repairs in last year								
Yes	731	8.81	409	10.93	227	7.01	181	6.26
Region								
Southern	5888	70.99	1374	36.71	1382	42.65	1064	36.82
Central	2033	24.51	1875	50.09	1314	40.56	1574	54.46
Northern	373	4.50	494	13.20	544	16.79	252	8.72
Shortfall on/after age								
R.R	650	4.84	2825	75.47	1739	53.67	-	-
T.OpEX	4071	49.08	3026	80.84	2255	69.60	-	-

Table 7.6 Scenario A: Unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n=8294).

Explanatory Variables		Unadjusted			Multivariable adjusted Model 1 (R.R)			Multivariable adjusted Model 2 (T.OpEx)		
		OR	(95% CI)	p-value	OR	(95% CI)	p-value	OR	(95% CI)	p-value
Sub-standard	Yes	**4.407**	**(3.739-5.195)**	**<0.001**	**4.205**	**(3.548-4.984)**	**<0.001**	**4.183**	**(3.522-4.967)**	**<0.001**
Structural	Yes	**5.489**	**(4.430-6.801)**	**<0.001**	**4.866**	**(3.898-6.074)**	**<0.001**	**4.213**	**(3.368-5.270)**	**<0.001**
Theft/Vandalism	Yes	1.757	(0.835-3.699)	0.138	1.449	(0.645-3.255)	0.369	1.208	(0.533-2.737)	0.650
Service Provider	WPC	-	-	**0.002**	-	-	0.542	-	-	0.463
	Area Mechanic	**1.444**	**(1.136-1.835)**	**0.003**	1.000	(0.771-1.298)	0.998	1.014	(0.780-1.319)	0.915
	Community Members	**1.697**	**(1.127-2.557)**	**0.011**	1.377	(0.894-1.196)	0.147	1.426	(0.921-2.210)	0.112
	Multiple	1.056	(0.879-1.269)	0.559	0.985	(0.812-1.196)	0.882	1.027	(0.845-1.248)	0.791
Preventative maintenance conducted	Yes	-	-	**<0.001**	-	-	**0.015**	-	-	**0.024**
	Sometimes	1.153	(0.919-1.448)	0.218	1.067	(0.840-1.356)	0.596	1.047	(0.821-1.334)	0.712
	No	**1.333**	**(1.166-1.524)**	**<0.001**	**1.236**	**(1.070-1.427)**	**0.004**	**1.224**	**(1.059-1.415)**	**0.006**
Spare Parts on site	Yes	**0.709**	**(0.639-0.787)**	**<0.001**	**0.817**	**(0.731-0.914)**	**<0.001**	**0.830**	**(0.742-0.929)**	**0.001**
Major repairs in last year	Yes	**1.865**	**(1.590-2.188)**	**<0.001**	**1.764**	**(1.489-2.089)**	**<0.001**	**1.745**	**(1.471-2.070)**	**<0.001**
Region	Southern	-	-	**<0.001**	-	-	**<0.001**	-	-	**<0.001**
	Central	**0.614**	**(0.541-0.696)**	**<0.001**	**0.654**	**(0.573-0.747)**	**<0.001**	**0.667**	**(0.583-0.762)**	**<0.001**
	Northern	1.038	(0.822-1.312)	0.753	1.043	(0.813-1.337)	0.742	1.135	(0.883-1.458)	0.323
Shortfall on/after age (Avg. year)	R.R	**1.318**	**(1.106-1.572)**	**0.002**	1.121	(0.929-1.354)	0.232	-	-	-
	T.OpEX	**2.171**	**(1.959-2.405)**	**<0.001**	-	-	-	**1.982**	**(1.780-2.208)**	**<0.001**

Bold represents statistically significant association (p<0.05)

Table 7.7 Scenario B: Unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n=3743).

Explanatory Variables		Unadjusted			Multivariable adjusted Model 1 (R.R)			Multivariable adjusted Model 2 (T.OpEx)		
		OR	(95% CI)	p-value	OR	(95% CI)	p-value	OR	(95% CI)	p-value
Sub-standard	Yes	**3.781**	**(3.092-4.624)**	**<0.001**	**3.632**	**(2.938-4.491)**	**<0.001**	**3.547**	**(2.872-4.381)**	**<0.001**
Structural	Yes	**3.773**	**(2.875-4.951)**	**<0.001**	**2.892**	**(2.167-3.859)**	**<0.001**	**2.957**	**(2.218-3.943)**	**<0.001**
Theft/Vandalism	Yes	1.840	(0.746-4.541)	0.186	1.536	(0.562-4.204)	0.403	1.608	(0.587-4.410)	0.356
Service Provider	WPC	-	-	**0.007**	-	-	0.115		-	0.101
	Area Mechanic	0.775	(0.542-1.108)	0.162	0.829	(0.554-1.241)	0.362	0.802	(0.537-1.196)	0.279
	Community Members	1.516	(0.934-2.458)	0.092	1.226	(0.731-2.055)	0.440	1.210	(0.721-2.029)	0.471
	Multiple	**1.386**	**(1.088-1.766)**	**0.008**	**1.318**	**(1.016-1.710)**	**0.037**	**1.317**	**(1.015-1.708)**	**0.038**
Preventative maintenance conducted	Yes	-	-	**<0.001**	-	-	**<0.001**	-	-	**<0.001**
	Sometimes	1.186	(0.891-1.580)	0.242	1.089	(0.791-1.500)	0.602	1.089	(0.791-1.499)	0.603
	No	**2.098**	**(1.782-2.470)**	**<0.001**	**1.830**	**(1.532-2.186)**	**<0.001**	**1.856**	**(1.554-2.217)**	**<0.001**
Spare Parts on site	Yes	**0.608**	**(0.530-0.699)**	**<0.001**	**0.784**	**(0.670-0.917)**	**0.002**	**0.785**	**(0.672-0.918)**	**0.002**
Major repairs in last year	Yes	**0.797**	**(0.636-1.000)**	**0.050**	0.850	(0.659-1.096)	0.210	0.853	(0.662-1.099)	0.219
Region	Southern	-	-	**<0.001**	-	-	**<0.001**	-	-	**<0.001**
	Central	**0.549**	**(0.473-0.637)**	**<0.001**	**0.676**	**(0.573-0.799)**	**<0.001**	**0.675**	**(0.572-0.797)**	**<0.001**
	Northern	1.010	(0.818-1.246)	0.929	1.156	(0.992-1.451)	0.210	1.175	(0.937-1.474)	0.163
Shortfall on/after age (Avg. year)	R.R	**2.314**	**(1.936-2.765)**	**<0.001**	**2.164**	**(1.793-2.612)**	**<0.001**	-	-	-
	T.OpEX	**2.401**	**(1.965-2.933)**	**<0.001**	-	-	-	**2.245**	**(1.818-2.771)**	**<0.001**

Bold represents statistically significant association (p<0.05)

Table 7.8 Scenario C: Unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n=3240).

Explanatory Variables		Unadjusted			Multivariable adjusted Model 1 (R.R)			Multivariable adjusted Model 2 (T.OpEx)		
		OR	(95% CI)	p-value	OR	(95% CI)	p-value	OR	(95% CI)	p-value
Sub-standard	Yes	**3.018**	**(2.277-3.999)**	**<0.001**	**2.878**	**(2.134-3.882)**	**<0.001**	**2.810**	**(2.081-3.796)**	**<0.001**
Structural	Yes	**4.482**	**(3.050-6.587)**	**<0.001**	**3.519**	**(2.335-5.305)**	**<0.001**	**3.404**	**(2.258-5.131)**	**<0.001**
Theft/Vandalism	Yes	1.750	(0.437-7.015)	0.430	1.281	(0.301-5.451)	0.737	1.373	(0.324-5.809)	0.667
Service Provider	WPC	-	-	**<0.001**	-	-	**<0.001**	-	-	**<0.001**
	Area Mechanic	0.839	(0.492-1.432)	0.520	**0.388**	**(0.212-0.709)**	**0.002**	**0.398**	**(0.217-0.731)**	**0.003**
	Community Members	1.567	(0.770-3.189)	0.216	1.105	(0.492-2.482)	0.808	1.191	(0.527-2.690)	0.675
	Multiple	**2.002**	**(1.503-2.665)**	**<0.001**	**1.614**	**(1.189-2.192)**	**0.002**	**1.641**	**(1.207-2.230)**	**0.002**
Preventative maintenance conducted	Yes	-	-	**0.001**	-	-	0.268	-	-	0.365
	Sometimes	0.823	(0.528-1.283)	0.390	0.688	(0.431-1.098)	0.117	0.714	(0.445-1.146)	0.163
	No	**1.465**	**(1.177-1.823)**	**0.001**	1.033	(0.815-1.310)	0.788	1.015	(0.800-1.288)	0.900
Spare Parts on site	Yes	**0.555**	**(0.466-0.661)**	**<0.001**	**0.602**	**(0.499-0.726)**	**<0.001**	**0.601**	**(0.498-0.726)**	**<0.001**
Major repairs in last year	Yes	**1.546**	**(1.149-2.080)**	**0.004**	**1.626**	**(1.160-2.229(**	**0.004**	**1.551**	**(1.117-2.154)**	**0.009**
Region	Southern	-	-	**<0.001**	-	-	**<0.001**	-	-	**<0.001**
	Central	**0.321**	**(0.264-0.392)**	**<0.001**	**0.363**	**(0.295-0.447)**	**<0.001**	**0.358**	**(0.291-0.441)**	**<0.001**
	Northern	**0.620**	**(0.492-0.783)**	**<0.001**	**0.583**	**(0.456-0.745)**	**<0.001**	**0.588**	**(0.459-0.753)**	**<0.001**
Shortfall on/after age (Avg. year)	R.R	**1.696**	**(1.430-2.011)**	**<0.001**	**1.626**	**(1.358-1.948)**	**<0.001**	-	-	-
	T.OpEX	**2.285**	**(1.859-2.807)**	**<0.001**	-	-	-	**2.166**	**(1.746-2.686)**	**<0.001**

Bold represents statistically significant association (p<0.05)

Table 7.9 Scenario D: Unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n=2890).

Explanatory Variables		Unadjusted			Multivariable adjusted		
		OR	(95% CI)	p-value	OR	(95% CI)	p-value
Sub-standard	Yes	**3.474**	**(2.803-4.307)**	**<0.001**	**3.271**	**(2.618-4.087)**	**<0.001**
Structural	Yes	**4.765**	**(3.276-6.932)**	**<0.001**	**3.810**	**(2.577-5.633)**	**<0.001**
Theft/Vandalism	Yes	0.950	(0.425-2.123)	0.901	0.679	(0.290-1.588)	0.372
Service Provider	WPC	-	-	0.249	-	-	0.845
	Area Mechanic	1.422	(0.962-2.102)	0.077	1.094	(0.716-1.672)	0.678
	Community Members	1.099	(0.760-1.588)	0.617	0.881	(0.595-1.303)	0.525
	Multiple	0.908	(0.704-1.170)	0.456	0.936	(0.711-1.233)	0.640
Preventative maintenance conducted	Yes	-	-	**0.008**	-	-	0.095
	Sometimes	**1.398**	**(1.056-1.851)**	**0.019**	**1.396**	**(1.033-1.888)**	**0.030**
	No	**1.238**	**(1.053-1.456)**	**0.010**	**1.051**	**(0.883-1.250)**	**0.575**
Spare Parts on site	Yes	**0.536**	**(0.454-0.633)**	**<0.001**	**0.579**	**(0.486-0.691)**	**<0.001**
Major repairs in last year	Yes	**1.627**	**(1.201-2.203)**	**0.002**	1.370	(0.984-1.906)	0.062
Region	Southern	-	-	**<0.001**	-	-	**<0.001**
	Central	**0.587**	**(0.499-0.692)**	**<0.001**	**0.704**	**(0.591-0.840)**	**<0.001**
	Northern	0.858	(0.647-1.138)	0.288	0.874	(0.646-1.182)	0.382

Bold represents statistically significant association (p<0.05)

7.5.4.1 Relationship with current issues

The results of the logistic regression analysis, across all four scenarios, show that issues of infrastructure have significant likelihood of occurring should sub-standard characteristics and structural issues at the water point be present. Water users may not contribute or utilise water points that are deemed sub-standard, either due to the quality of water discharged or no water available seasonally. There is no significant association expressed between an issue of infrastructure and theft or vandalism at the water point. While this explanatory variable has presented a minor correlation with Functionality in Figure 7.3, there is no significant relationship between the other drivers of functionality.

7.5.4.2 Location and service provision

The type of service provider does not express a significant relationship with the issue of infrastructure in the multivariable models for all scenarios. In Scenario A, the odds of an issue of infrastructure present are higher in Community Members and Area Mechanics compared to WPCs in the unadjusted model. This suggests that the type of service provision under CBM is not the primary driver when it comes to sustaining infrastructure but may be associated by the O&M actions taken.

The multivariable regression results for Scenario A and B present a significant association between preventative maintenance and an issue of infrastructure. The odds of an issue of infrastructure are more likely to occur when preventative maintenance is not conducted compared to when it is. This is to be expected as preventative maintenance is crucial across the life-cycle of the Afridev to ensure continued serviceability. This relationship is present in the unadjusted models for Scenario C and D. Notably, the results describe that spare parts kept on site has a significant relationship with the issue of infrastructure. Across the unadjusted and multivariable models for all scenarios, the odds of infrastructure issues are lower when spare parts are kept on site compared when they are not. This highlights the importance of a proactive approach to O&M within service delivery across the life-cycle of the Afridev.

Infrastructure issues present higher odds of occurring if major repairs have been conducted in the last year across the unadjusted and multivariable models. While it would be assumed that conducting major repairs would result in lower odds of infrastructure issues, the shorter life spans of handpumps and cheaper water supply infrastructure, results in premature service decline (Fonseca *et al.*, 2013). This could also be attributed to the established challenge of service providers conducting major repairs. The circumstances of the repairs vary across the life-cycle of the Afridev, as described in Figure 7.2. Therefore the associated costs significantly differ across life-cycle years. The point at which OpEx becomes CapManEx may be the accumulation of replacing cheaper fast wearing components rather than the replacement of components with typically longer life-cycles.

7.5.4.3 Forecasted shortfall of financial resources

The forecasted shortfall in Table 6.6-6.9 present a significant association with an issue of infrastructure in the unadjusted and multivariable adjusted models. With the exception of R.R multivariable models for Scenario A (Table 7.6) which are significant in the unadjusted models. This highlights that while the scenario has the potential to finance the life-cycle requirements of the Afridev in the majority of cases, there may be additional underlying factors that impact either the premature failure of components or the collection of financial resources for O&M. Under Scenario C (Table 7.8), there is a significant association between the results of the life-cycle cost model and an issue of infrastructure present in the unadjusted and multivariable models. This suggests the earlier year of shortfall under this scenario increases the likelihood of an issue of infrastructure occurring.

This trend is reflected in Scenario B (Table 7.7). All models suggest an issue of infrastructure is more than twice as likely to occur following a shortfall under Scenario B. This highlights the embedded issues associated with a reactive approach to maintenance. While the need for financial contributions is at its greatest to continue service delivery, there is no guarantee of the willingness to pay when a water point is non-functional. This increases the likelihood of an infrastructure issue and declining functionality. The multivariable results show an issue of infrastructure is approximately twice as likely to occur following a shortfall in the T.OpEx models across the three scenarios (Table 7.6-7.9). This is to be expected as the increase in costs over the life-cycle will undoubtably result in an earlier year of shortfall. Overall, the forecasted shortfall in the life-cycle cost model shows an increased likelihood of an issue of infrastructure occurring following a shortfall of financial resources, that increases with the more costs that are considered.

It is noted that the life-cycle cost model is not fully representative of the reality of rural service delivery under the CBM model. However, the proxy costs provide indications of how likely issues of infrastructure occur following a forecasted shortfall under various financial strategies. This supports further evidence that the CBM model is inappropriate for meeting the financial requirements of service delivery.

7.6 Discussion

The results of this study provide further understanding into establishing financial provisions for O&M within decentralised service provision, and the barriers to providing sustainable services across an assets life-cycle under CBM policy, prevalent throughout low-income countries.

7.6.1 Influence of service provision

Potential financial resources available for O&M are significantly different between each scenario. The variations of tariff amount and collection, outlined by the scenarios, describes the reality at the local level diverges from policy guidelines (MoAIWD, 2015). The result is significant variations in the potential annualised financial resources for conducting O&M. Distributions in the number of potentially contributing households indicate water points are commonly treated as secondary sources. This is attributed to the substantial proportion of cases reporting usage above the design limit of the Afridev (300 users). Contrary to the global monitoring focus on single usage, households in low-income and middle countries commonly obtain water from multiple sources (Whittington *et al.*, 2009; Tucker *et al.*, 2014; van den Broek and Brown, 2015; Foster and Hope, 2016; Vedachalam *et al.*, 2017). The increased usage can attribute to additional wear and tear of the Afridev resulting in premature breakdown and increased O&M cost requirements.

While Scenario A, B and C have suggested a large proportion conduct preventative maintenance, the reality is this exercise is seldom conducted (Chowns, 2015a). The importance of proactive approaches to financial collection has been highlighted by the logistic regression models. The results suggest for reactive tariff collection (Table 7.7), when no preventative maintenance is conducted the likelihood of issues of infrastructure increases compared to when it is conducted. The likelihood in proactive approaches (Table 7.6 and Table 7.8) are lower or not significant in this case. This suggests proactive collections allow for crucial O&M and fast repairs to be conducted, reducing downtime of water supply.

Notably, keeping spare parts kept on site has shown to be a significant explanatory factor for reducing the likelihood of an issue of infrastructure occurring across all scenarios. This conforms to previous studies on the association between continued water point serviceability and access to spare parts (Baraki and Brent, 2013; Foster, 2013; Foster, Willetts, *et al.*, 2018). However, the viability of establishing such supply chains is a challenge (Harvey and Reed, 2006b; Lockwood and Smits, 2011). Limited access to supply chains inevitably increases water point downtime and incurs additional travel costs. This is significant for sustainable access, when fast repairs and reduced downtime contributes towards the reliability of a system (Thomson and Koehler, 2016).

This may also attribute to the notable findings regarding the geographical location of the Afridev handpump boreholes. In the unadjusted and multivariable adjusted models, the Central region of Malawi express significantly lower odds of an issue of infrastructure occurring than in the Southern region. Furthermore, Table 7.5 shows that 'no tariff' (Scenario D – 54.46%) and 'when required for repairs' (Scenario B – 50.09%) are more dominant in the Central region than the proactive collections. This may indicate that assets in the Central region have greater access to the drivers that reduce issues of infrastructure, such as supply chains. More research into the regional disparity of establishing supply chains and post-construction service delivery is required.

7.6.2 Quality of water point

The quality of infrastructure is crucial for sustainability, and despite the global monitoring focus on coverage, indicators do not represent the reality faced by local service providers and hide low levels of service (Adank *et al.*, 2016).

Depreciation as assets age inevitably requires major repairs or rehabilitation to maintain an operational level of service across the life-cycle (Franceys and Pezon, 2010). Further, the importance of O&M reduces the risk of premature failure in the first 5 years under CBM approaches (Baumann, 2006). This is evident from the results as the decline in functionality as assets age results primarily in a reduced service rather than asset failure. However, the importance of available financial resources is hence inferred over the investigated period

(Figure 7.2). Age therefore constitutes a negative relationship with the functionality of assets, leading to wearing components (Figure 7.3). The relationship between the age of infrastructure and decline in functionality is further supported by evidence throughout literature (Baumann, 2006; Foster, 2013; Fisher *et al.*, 2015; Cronk and Bartram, 2017; Klug *et al.*, 2018; Truslove *et al.*, 2019).

Functionality has previously been discussed as multi-dimensional that is representative of issues at the time of audit (Carter and Ross, 2016; Bonsor *et al.*, 2018). Functionality, as a sole indicator, is therefore insufficient to understand what intervention and decisions are required at the local level outside its temporal characteristics. The narratives behind functionality at the local level and how these impact Afridev life-cycles must be understood to achieve sustainable services.

When water points are constructed well, they can last for years without issue (Truslove *et al.*, 2019). This is not the case in many water points where poor siting or considerations for seasonal fluctuations in groundwater, results in sub-standard boreholes impacting the sustainability of the handpump, financial arrangements and service provision (Foster, Willetts, *et al.*, 2018; Kelly *et al.*, 2018). This issue of sub-standard infrastructure primarily occurs at the outset of implementing water supply for reasons such as poor siting, poor construction and inappropriate design (Bonsor *et al.*, 2015). This imposes a negative impact on sustainability, as users are reluctant or unable to contribute financially towards maintaining unreliable or poor quality resources (Tucker *et al.*, 2014; Whaley *et al.*, 2019). The willingness to pay towards unreliable systems reduces available resources to conduct vital O&M and attributes to the increased usage at higher quality water points. As multiple source use is a common behaviour among water user (Foster and Willetts, 2018). Sub-standard infrastructure fundamentally has a negative effect of the overall functionality of water supply (Figure 7.3). Increasing the likelihood of Afridev life-cycle issues occurring (Table 7.6-7.9), due to insufficient O&M practices and the aforementioned user behaviour towards such assets. Known issues of sub-standard infrastructure can therefore be considered an indicator of underlying risks to meeting the life-cycle requirements of the Afridev.

7.6.3 Shortfall in financial resources

The potential financial resources available to meet the financial requirements of O&M were found to be significantly different. The result is an earlier shortfall in financial resources, which can impact the serviceability and sustainability of the water point. Accounting for the various costs during the life-cycle inevitably means an earlier shortfall in financial resources. The proxy costs used in the model allows for an indication of the capacity of each scenario under a proactive approach to financing the necessary O&M, which is expected of communities under rural water policy. This further emphasises the burden placed on communities under a coverage approach to policy and global targets, and a CBM approach to service provision.

Scenario A (per month) and Scenario C (per year) present a proactive collection of financial resources. The differences in the logistic regression results highlight the impact of potential annualised resources in meeting the two cost models. There is no significant relationship in the R.R multivariable model concerning Scenario A, as the potential annualised financial resources meet the cost requirements in a substantial number of cases. In the unadjusted models (Table 7.6), the likelihood of an infrastructure issue occurring is lower than the results expressed in Table 7.6. In all models, the results of the logistic regression presents a higher likelihood of infrastructure issues occurring following a shortfall in Scenario C than Scenario A. Tariffs are typically set lower under collection per month than per year (Figure 7.1), however the potential annualised resources indicates an important relationship between the frequency of collection and breakdown of handpumps.

Scenario B (when required for repairs) presents a reactive collection of financial resources. Table 7.7 expresses a significant relationship between shortfall and an issue of infrastructure in all models, in which each model suggests an issue is approximately twice as likely to occur. This is primarily due to the insufficient cumulative financial resources available to potentially fund the required repairs in all models. Overall suggesting a shortfall within 3 to 5 years. The results further support the understanding that handpumps only last 3 to 5 years without appropriate O&M, shown by the steep decline in functionality during this period (Figure 7.2).

The increased costs result in earlier shortfall and subsequently increased the likelihood of infrastructure issues. This has implications for setting tariffs and further reflects the need for support if sustainability is to be acquired at the local level. The drive for coverage of hardware and poor monitoring indicators has resulted in deeper issues of sustaining services. It is unlikely national and SDG targets will be met until the life-cycle of assets are treated as a long term investment that requires continued support. Rather than the one-time investment approach for rural water supply that has become the normality in delivering policies.

7.6.4 Implications of policy and practice

The results have implications for wider practice and policy. First, is concerning global targets and progression towards the SDGs. Localising the SDGs is increasingly important to fulfil the 2030 agenda (Editorial, 2019). The indicators used in global monitoring have significant shortcomings in describing the reality of rural water supply services. For example, an 'improved' water source fails to denote the quality of the service, multiple source use and the service provision to maintain it. Hence while global targets may be described as on track, they may potentially hide low levels of service (Adank *et al.*, 2016; Martínez-Santos, 2017; Vedachalam *et al.*, 2017; Kalin *et al.*, 2019; Truslove *et al.*, 2019). This hinders the progress of the wider SDG agenda due to the synergies between the goals (Mainali *et al.*, 2018; Kroll, Warchold and Pradhan, 2019). It is therefore essential that focus on the coverage of water supply move towards effective service delivery and sustainable O&M services (Foster, 2013). The SDGs risk creating more of the same if the short term reward of implementing improved coverage continues. The results and wider evidence prove sustainable services are more than a one off investment.

Second, Malawi's national policy goal for rural water services states "to achieve provision of community owned and managed water supply and sanitation services" (MoAIWD, 2005). The advocation of this approach and method of cost recovery contradicts the widely accepted shortcomings of CBM over the last three decades. The results suggest the current service delivery model in rural Malawi is inadequate for maintaining inherently unsustainable infrastructure. The method of cost-recovery is questionable for poor communities who struggle to finance minor repairs and afford rehabilitation exercises (Montgomery, Bartram and Elimelech, 2009; Bonsor *et al.*, 2015; Mcnicholl, Hope and Money, 2019). Capacity building into life-cycle management is crucial for handpump sustainability that includes spare part access (Baraki and Brent, 2013), and proven maintenance systems established alongside infrastructure (Morgan, 1993; Foster, McSorley and Willetts, 2019). Professionalised approaches to maintenance is a priority, to avoid losing the intended benefits of water supply for rural populations and for investments across the sector (Hunter, MacDonald and Carter, 2010; Kalin *et al.*, 2019).

Finally, rather than solely measuring performance, monitoring rural water supply should strive to improve it (Thomson and Koehler, 2016). This includes the capacity around maintaining sustainable service provision, accountability when installing sub-standard infrastructure and proactive maintenance and supply chain arrangements. The MIS mWater was used in this study to collect the water point and management data. Nussbaumer *et al.* (2016), states systems such as these can "facilitate coordination between the different stakeholders involved in borehole exploitation, build up a strong water quality and levels database, and increase transparency.”. Incorporating a life-cycle cost approach for targeted water points and data driven investment is entirely possible through MIS (Fonseca *et al.*, 2011). Supporting the environment for the routine monitoring of assets that allows for improvements in service delivery quality (Dickinson, Knipschild and Magara, 2017). Monitoring performance and indicators are well understood to be temporal snapshots. However, these snapshots can be used to understand the narrative behind the indicator and inform data driven decisions to ensure long term sustainability.

7.6.5 Limitations

The results are subject to a number of caveats. First, are the results and assumptions made in the life-cycle cost model. While noting the barriers towards the payment of tariffs, the model assumes financial resources are available throughout the life-cycle according to the scenario specifications. Proxy costs of Afridev components are used by taking an average of the quotes from suppliers. While this allows for a representation of the costs in Malawi, costs inevitably vary depending on the local context. The present value approach was used due to its usefulness in considering future investments (Fonseca *et al.*, 2011), particularly for the scope of this study. However, this does not include the variations of future inflation that other methodologies might include. Furthermore, an average year of potential shortfall was taken for the purpose of this study. As previously discussed, components may last past their design life or prematurely fail due a number of factors out with the life-cycle cost approach assumptions.

Second, is the monitoring of performance at the time of audit. This provides a snapshot of the performance and service provision which may indeed vary temporally due to individual local contexts. Breaking down the multi-dimensional indicator, functionality, again reflects issues at the time of audit which may be resolved or occur following the monitoring period.

Estimations are limited in identifying the primary users of the water point and if they contribute towards O&M. Due to the aforementioned multiple-source behaviours of communities. However, these narratives have the potential to provide a starting point in assessing sustainability.

Finally, the variables included in the logistic regression analysis do not cover the exhaustive list of all the potential influential factors associated with handpump sustainability and the life-cycle of components. Issues not controlled for, in the multivariable analysis, include; technical expertise in maintenance and repairs, established supply chains, financial management accountability and transparency, quality of borehole construction, presence of external post-construction support, levels of user participation, poverty, and multiple-source use. Other site specific socio-cultural barriers may also be in place that hinder wider participation and water source access. Further site specific hydrogeological characteristics were not factored into the model.

7.7 Conclusions

The implementation of handpumps has contributed to increased improved water access across SSA. Maintaining these assets to the end of their design life, that may be inherently unsustainable from the outset, remains a challenge in the rural water sector. The metric for success in the global goals have transitioned from halving 'the proportion of people without sustainable access' to 'universal access'. This risks concealing fundamental barriers to sustainable services that hinder the success of SDG 6 and national policies.

Malawi operates under the CBM approach to rural water supply, however there are distinct variations in tariff collection frequency impacting the annualised financial resources for O&M. Preventative maintenance is reportedly conducted in the majority of cases where tariffs are set, and a decreased amount when there is no tariff. Factors influencing a lack of maintenance and tariffs highlight a wider post-construction issue of capacity building and lack of continued support at the local level.

Preventative maintenance and the presence of a tariff does not guarantee a continued service as there is a decline in functionality as handpumps age over the life-cycle in all scenarios. The issues of infrastructure across the life-cycle of the Afridev was found to be the highest correlated variable when investigating the multi-dimensional indicator, functionality. The logistic regression results suggest the likelihood of an infrastructure issue occurring increases when preventative maintenance is not conducted, when there is a shortfall in financial resources in both life-cycle models (R.R and T.OpEx), when structural issues (e.g. damage to civil works) are also present and when there is sub-standard infrastructure (e.g. poor water quality and subject to seasonality). These further highlight the burden placed on rural communities of maintaining inherently unsustainable assets with issues that could be remediated from the outset. Notably when spare parts are kept on site there is a lower likelihood of issues of infrastructure occurring. This further supports the importance of capacity building and establishing supply chains for spare parts post-construction to reduce the time between breakdown and repair.

It is clear that the drive for improved access in the MDGs and SDGs has not delivered the intended results. Focus on coverage in the global targets and policies risk favouring the short term reward of new infrastructure rather than the long-term investment required, creating barriers in achieving sustainable services. The enforcement of CBM in Malawi and other low-income countries further hinders any lasting sustainability progress and benefits for rural communities. Moving forward in the SDG's decade of action (2020-2030), successful sustainability will require adapting approaches from the lessons learnt from the MDGs and SDGs to date. Global targets and rural water sector policies must consider the narratives behind the services and look beyond the coverage approach as a metric for success if benefits are to be seen when monitoring SDG progress at the local level. Acknowledging the barriers that hinder serviceability, through monitoring current assets, must progress to informing investments into capacity building and improving service delivery. The implementation of new infrastructure must include appropriate siting, capacity building that promotes continual preventative maintenance and life-cycle costing alongside rural water access.

7.8 Acknowledgements

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7.9 Supplementary Information

Table 7.10 Life-cycle of Afridev components and estimated costs from suppliers for a borehole of 30m depth.

Afridev component	No. installed	Life-cycle (Years)		Supplier 1 (MWK)	Supplier 2 (MWK)	Supplier 3 (MWK)
		Worst	Best			
Head (Full Assembly – Cover, Case, Bolts, Spout)	1	10	15	N/A	34600	N/A
Handle Assembly	1	10	15	N/A	N/A	N/A
Rodhanger Assembly	1	5	8	4946	N/A	N/A
Fulcrum Pin Assembly	1	5	8	3935	N/A	N/A
Fulcrum Pin Bush-Bearings	2	1	2	675	N/A	N/A
Hanger Pin Assembly	1	5	8	3035	N/A	N/A
Hanger Pin Bush Bearings	2	1	2	675	N/A	N/A
Pedestal	1	10	15	N/A	20000	N/A
Rods (3m)	9	3	5	8432	7500	N/A
Bottom Rod (3m)	1	3	5	N/A	15000	N/A
Rod Centralisers	9	2	3	562	N/A	N/A
Rising main pipe (3m)	9	3	5	5958	N/A	N/A
Top Sleeve	1	3	5	675	N/A	N/A
Flapper	1	3	5	450	N/A	N/A
Socket (Double End)	8	3	5	N/A	1200	600
Rising Main Centralisers	8	3	5	675	N/A	N/A
Cylinder Assembly	1	5	8	40022	N/A	N/A
Plunger Body	1	3	5	6970	N/A	N/A
Cup Seal (U-seal)	1	2	3	337	N/A	N/A
Plunger Bobbin	1	2	3	337	N/A	N/A
Foot Valve Body	1	3	5	N/A	N/A	N/A
O-ring	1	2	3	225	N/A	N/A
Foot Valve Bobbin	1	2	3	337	N/A	N/A
Cone Flange	1	10	15	N/A	N/A	N/A
Compression Cone	1	5	8	1349	N/A	N/A
Rope	1	10	15	N/A	6500	N/A
Area Mechanic Contract (Operations)	1	-	-	3373	N/A	N/A
Transport costs (Operations)	1	-	-	1124	N/A	N/A

*where 1USD = 738.64 MWK as of 9th of December 2019.

Table 7.10 cont. Life-cycle of Afridev components and estimated costs from suppliers for a borehole of 30m depth.

Afridev component	Supplier 4 (MWK)	Supplier 5 (MWK)	Supplier 6 (MWK)	Average Cost (MWK)
Head (Full Assembly – Cover, Case, Bolts, Spout)	N/A	44500	69500	49533
Handle Assembly	N/A	36500	42500	39500
Rodhanger Assembly	N/A	4650	N/A	4798
Fulcrum Pin Assembly	N/A	4250	6950	5045
Fulcrum Pin Bush-Bearings	N/A	475	450	533
Hanger Pin Assembly	N/A	3975	3950	3653
Hanger Pin Bush Bearings	N/A	475	450	533
Pedestal	N/A	N/A	N/A	20000
Rods (3m)	N/A	11500	9000	9108
Bottom Rod (3m)	N/A	N/A	N/A	15000
Rod Centralisers	N/A	466	450	493
Rising main pipe (3m)	N/A	6500	6950	6469
Top Sleeve	N/A	1200	N/A	937
Flapper	N/A	1200	N/A	825
Socket (Double End)	N/A	1200	1150	1038
Rising Main Centralisers	N/A	490	N/A	582
Cylinder Assembly	N/A	45000	59500	48174
Plunger Body	N/A	6800	9500	7757
Cup Seal (U-seal)	N/A	220	450	336
Plunger Bobbin	N/A	360	N/A	349
Foot Valve Body	N/A	3200	2950	3075
O-ring	N/A	110	N/A	167
Foot Valve Bobbin	N/A	360	N/A	349
Cone Flange	N/A	4500	6950	5725
Compression Cone	N/A	3000	2950	2433
Rope	N/A	6500	7500	6833
Area Mechanic Contract (Operations)	N/A	N/A	N/A	3373
Transport costs (Operations)	N/A	N/A	N/A	1124

*where 1USD = 738.64 MWK as of 9th of December 2019.

Table 7.11 Life-cycle cost of Afridev over 15-year design life.

Worst Case					
Year	Occurrences	R.R Cost (MWK)	Cumulative R.R Cost (MWK)	T.OpEx Cost (MWK)	Cumulative T.OpEx Cost (MWK)
1	2	2133	2133	6630	6630
2	7	7603	10064	12100	25359
3	11	172088	178527	176584	220673
4	7	7603	186459	12100	428087
5	7	66236	252695	70733	706234
6	16	177042	426440	181539	1165920
7	2	2133	428573	6630	1632235
8	7	7603	436504	12100	2110650
9	11	172088	604967	176584	2765650
10	19	181040	786335	185536	3606186
11	2	2133	788468	6630	4453352
12	16	177042	962213	181539	5482056
13	2	2133	964346	6630	6517390
14	7	7603	972277	12100	7564824
15	16	233116	1201768	237613	8849871

Best Case					
Year	Occurrences	R.R Cost (MWK)	Cumulative R.R Cost (MWK)	T.OpEx Cost (MWK)	Cumulative T.OpEx Cost (MWK)
1	0	0	0	0	0
2	2	2133	2133	6630	6630
3	5	5471	7603	9967	23226
4	2	2133	9736	6630	46453
5	9	169955	179691	174452	244131
6	7	7603	187294	12100	453909
7	0	0	187294	0	663687
8	7	66236	253530	70733	944198
9	5	5471	259001	9967	1234676
10	11	172088	431088	176584	1701739
11	0	0	431088	0	2168802
12	7	7603	438692	12100	2647965
13	0	0	438692	0	3127127
14	2	2133	440824	6630	3612920
15	21	285443	726267	289940	4388651

*Where R.R = Recommended Repairs and T.OpEx = Total Operations Expenditure.

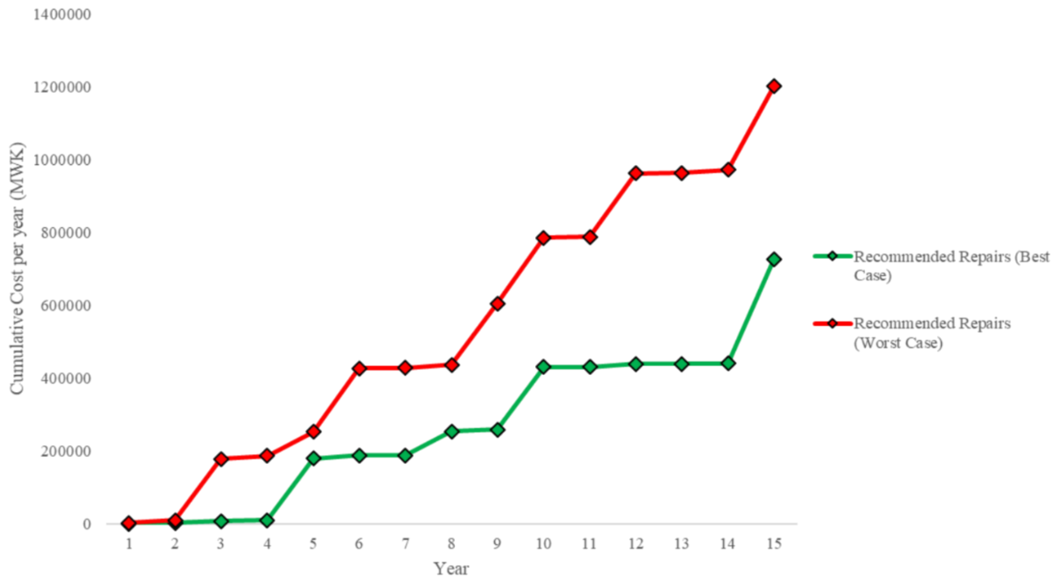

Figure 7.4 Recommended Repairs cumulative costs (MWK).

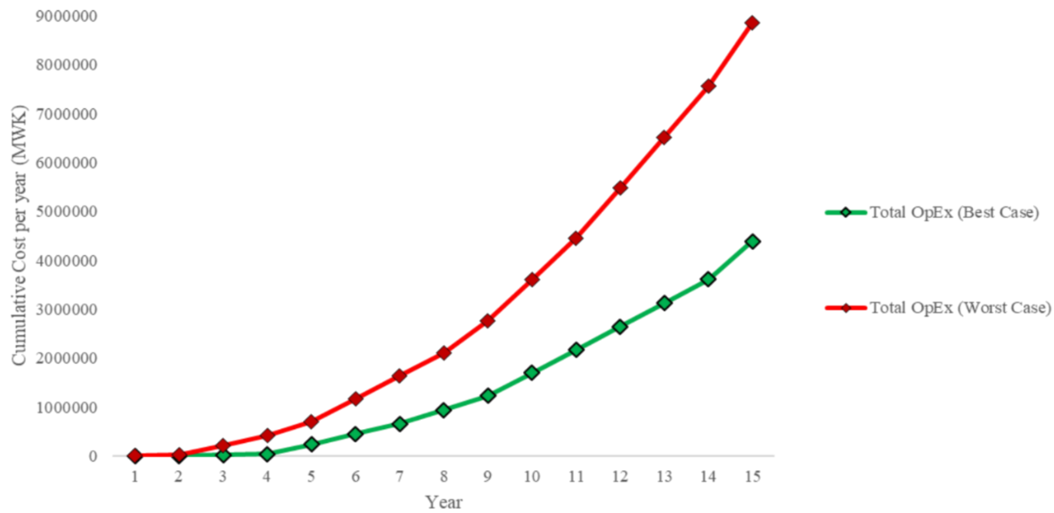

Figure 7.5 Total Operations Expenditure (T.OpEx) cumulative costs (MWK).

Table 7.12 Scenario A – Recommended Repairs (R.R) projected year of shortfall.

Household Group	Year of Shortfall	Tariff Group 1	2	3	4	5	6	7	8	9	10	11
1	Min	1	3	-	-	-	-	-	-	-	-	-
	Avg	3	5	-	-	-	-	-	-	-	-	-
	Max	5	10	-	-	-	-	-	-	-	-	-
2	Min	1	-	-	-	-	-	-	-	-	-	-
	Avg	4	-	-	-	-	-	-	-	-	-	-
	Max	10	-	-	-	-	-	-	-	-	-	-
3	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-
4	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-
5	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-
6	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-
7	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-
8	Min	-	-	-	-	-	-	-	-	-	-	-
	Avg	-	-	-	-	-	-	-	-	-	-	-
	Max	-	-	-	-	-	-	-	-	-	-	-

* Where “-“ represents no shortfall within the 15 year design life of the Afridev

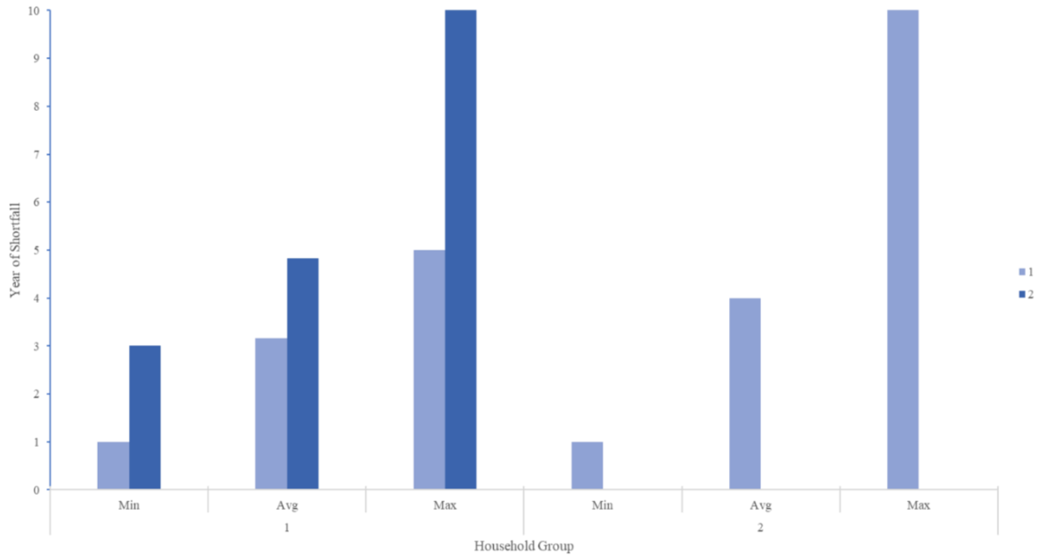

Figure 7.6 Scenario A – R.R forecasted year of shortfall.

Table 7.13 Scenario A – Total Operations Expenditure (T.OpEx) projected shortfall.

Household Group	Year of Shortfall	Tariff Group										
		1	2	3	4	5	6	7	8	9	10	11
1	Min	1	3	3	3	3	4	5	5	6	6	-
	Avg	3	4	4	5	5	6	7	7	8	8	-
	Max	5	5	6	6	7	8	9	10	10	11	-
2	Min	1	3	3	5	6	6	7	8	-	-	-
	Avg	3	4	6	7	8	9	10	12	-	-	-
	Max	5	6	8	10	11	12	14	15	-	-	-
3	Min	1	3	5	6	7	-	-	-	-	-	-
	Avg	3	6	7	9	11	-	-	-	-	-	-
	Max	6	8	10	12	15	-	-	-	-	-	-
4	Min	1	3	6	7	-	-	-	-	-	-	-
	Avg	3	6	9	11	-	-	-	-	-	-	-
	Max	6	10	12	15	-	-	-	-	-	-	-
5	Min	1	4	6	-	-	-	-	-	-	-	-
	Avg	4	7	10	-	-	-	-	-	-	-	-
	Max	7	11	15	-	-	-	-	-	-	-	-
6	Min	1	5	-	-	-	-	-	-	-	-	-
	Avg	4	8	-	-	-	-	-	-	-	-	-
	Max	8	12	-	-	-	-	-	-	-	-	-
7	Min	1	5	-	-	-	-	-	-	-	-	-
	Avg	4	9	-	-	-	-	-	-	-	-	-
	Max	9	14	-	-	-	-	-	-	-	-	-
8	Min	1	6	-	-	-	-	-	-	-	-	-
	Avg	5	10	-	-	-	-	-	-	-	-	-
	Max	10	15	-	-	-	-	-	-	-	-	-

* Where "-" represents no shortfall within the 15 year design life of the Afridev

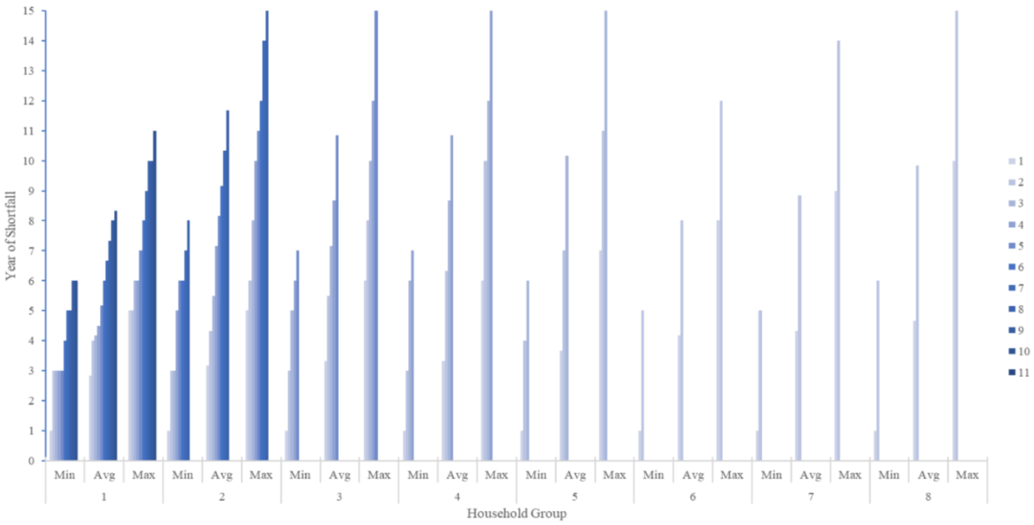

Figure 7.7 Scenario A – T.OpEx forecasted year of shortfall.

Table 7.14 Scenario B – Recommended Repairs (R.R) projected shortfall.

Household Group	Year of Shortfall	Tariff Group										
		1	2	3	4	5	6	7	8	9	10	11
1	Min	1	1	2	2	2	2	2	3	3	3	3
	Avg	2	2	3	3	3	3	4	4	4	4	4
	Max	2	3	3	3	3	4	5	5	5	5	5
2	Min	1	2	2	2	3	3	3	3	3	3	3
	Avg	2	3	3	4	4	4	4	4	4	4	4
	Max	3	3	4	5	5	5	5	5	5	5	5
3	Min	1	2	2	3	3	3	3	3	3	3	3
	Avg	2	3	4	4	4	4	4	4	4	4	4
	Max	3	4	5	5	5	5	5	5	5	5	5
4	Min	1	2	3	3	3	3	3	3	3	3	3
	Avg	2	3	4	4	4	4	4	4	4	4	4
	Max	3	5	5	5	5	5	5	5	5	5	5
5	Min	1	2	3	3	3	3	3	3	3	3	3
	Avg	2	4	4	4	4	4	4	4	4	4	4
	Max	3	5	5	5	5	5	5	5	5	5	5
6	Min	1	2	3	3	3	3	3	3	3	3	3
	Avg	2	4	4	4	4	4	4	4	4	4	4
	Max	4	5	5	5	5	5	5	5	5	5	6
7	Min	1	3	3	3	3	3	3	3	3	3	3
	Avg	3	4	4	4	4	4	4	4	4	4	5
	Max	5	5	5	5	5	5	5	5	5	5	7
8	Min	1	3	3	3	3	3	3	3	3	3	3
	Avg	3	4	4	4	4	4	4	4	4	4	5
	Max	5	5	5	5	5	5	5	5	5	5	7

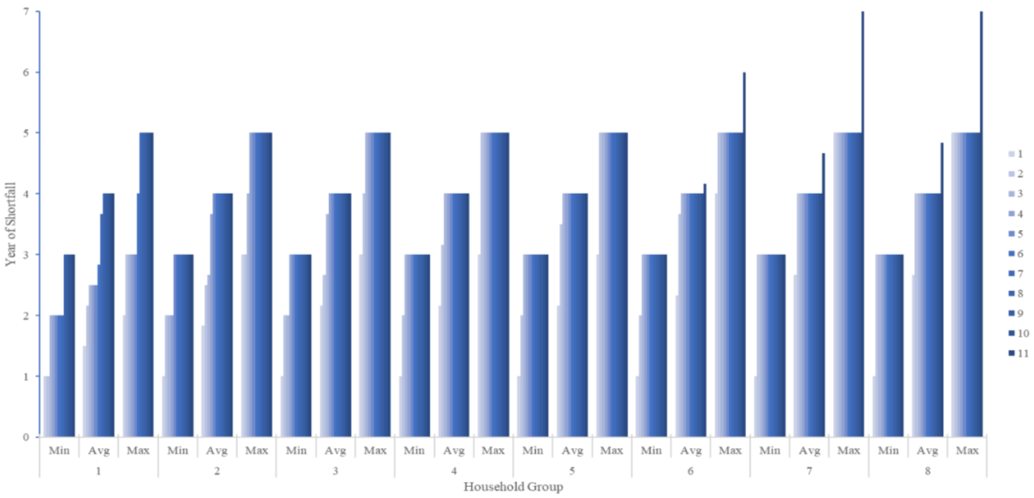

Figure 7.8 Scenario B – R.R forecasted year of shortfall.

Table 7.15 Scenario B – Total Operations Expenditure (T.OpEx) projected shortfall.

Household Group	Year of Shortfall	Tariff Group 1	2	3	4	5	6	7	8	9	10	11
1	Min	1	1	1	1	1	2	2	2	2	2	2
	Avg	2	2	2	2	2	3	3	3	3	3	3
	Max	2	2	2	2	3	3	3	3	3	3	4
2	Min	1	1	1	2	2	2	2	2	2	3	3
	Avg	2	2	2	3	3	3	3	3	3	4	4
	Max	2	2	3	3	3	3	3	4	4	4	5
3	Min	1	1	2	2	2	2	3	3	3	3	3
	Avg	2	2	3	3	3	3	4	4	4	4	4
	Max	2	3	3	3	3	4	4	4	4	4	5
4	Min	1	1	2	2	2	3	3	3	3	3	3
	Avg	2	2	3	3	3	4	4	4	4	4	4
	Max	2	3	3	4	4	4	4	5	5	5	5
5	Min	1	2	2	2	3	3	3	3	3	3	3
	Avg	2	3	3	3	4	4	4	4	4	4	4
	Max	3	3	3	4	4	4	5	5	5	5	5
6	Min	1	2	2	3	3	3	3	3	3	3	3
	Avg	2	3	3	4	4	4	4	4	4	4	4
	Max	3	3	4	4	4	5	5	5	5	5	5
7	Min	1	2	2	3	3	3	3	3	3	3	3
	Avg	2	3	3	4	4	4	4	4	4	4	4
	Max	3	3	4	4	5	5	5	5	5	5	5
8	Min	1	2	2	3	3	3	3	3	3	3	3
	Avg	2	3	3	4	4	4	4	4	4	4	4
	Max	3	4	4	5	5	5	5	5	5	5	5

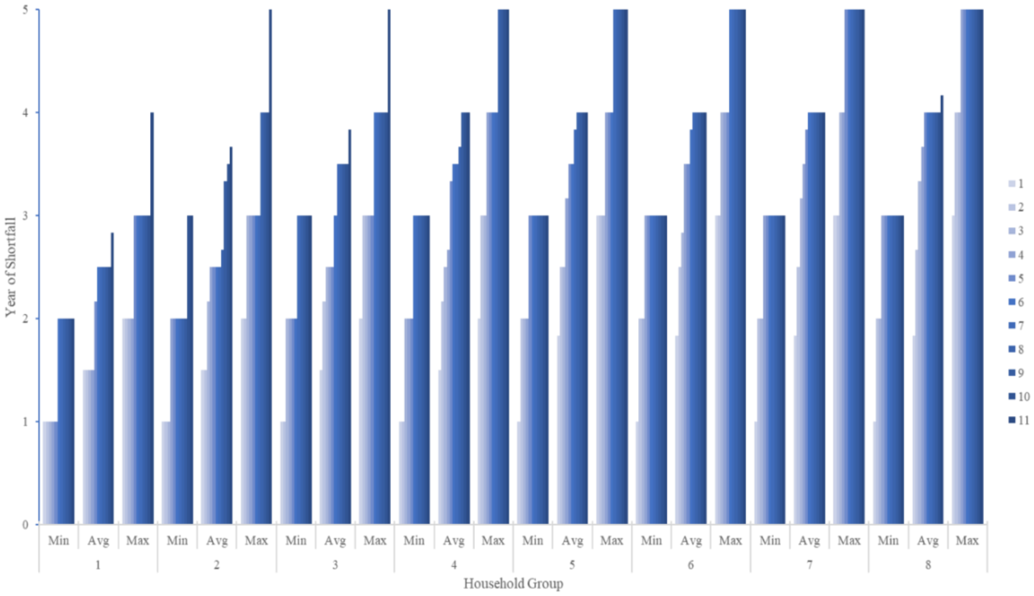

Figure 7.9 Scenario B – T.OpEx forecasted year of shortfall.

Table 7.16 Scenario C – Recommended Repairs (R.R) projected shortfall.

Household Group	Year of Shortfall	Tariff Group										
		1	2	3	4	5	6	7	8	9	10	11
	Min	1	1	2	2	3	3	3	3	3	3	3
1	Avg	2	3	4	4	4	4	4	4	4	4	4
	Max	3	5	5	5	5	5	5	5	5	5	5
	Min	1	2	3	3	3	3	3	3	3	3	-
2	Avg	2	4	4	4	4	4	4	4	4	4	-
	Max	5	5	5	5	5	5	5	5	5	5	-
	Min	1	2	3	3	3	3	3	3	3	3	-
3	Avg	3	4	4	4	4	4	4	5	7	7	-
	Max	5	5	5	5	5	5	5	10	10	15	-
	Min	1	3	3	3	3	3	3	3	-	-	-
4	Avg	3	4	4	4	4	5	7	8	-	-	-
	Max	5	5	5	5	5	10	10	15	-	-	-
	Min	1	3	3	3	3	3	-	-	-	-	-
5	Avg	3	4	4	4	5	7	-	-	-	-	-
	Max	5	5	5	5	10	15	-	-	-	-	-
	Min	1	3	3	3	3	-	-	-	-	-	-
6	Avg	3	4	4	5	7	-	-	-	-	-	-
	Max	5	5	5	10	15	-	-	-	-	-	-
	Min	1	3	3	3	-	-	-	-	-	-	-
7	Avg	3	4	4	6	-	-	-	-	-	-	-
	Max	5	5	5	10	-	-	-	-	-	-	-
	Min	1	3	3	3	-	-	-	-	-	-	-
8	Avg	3	4	5	7	-	-	-	-	-	-	-
	Max	5	5	10	15	-	-	-	-	-	-	-

* Where "-" represents no shortfall within the 15 year design life of the Afridev

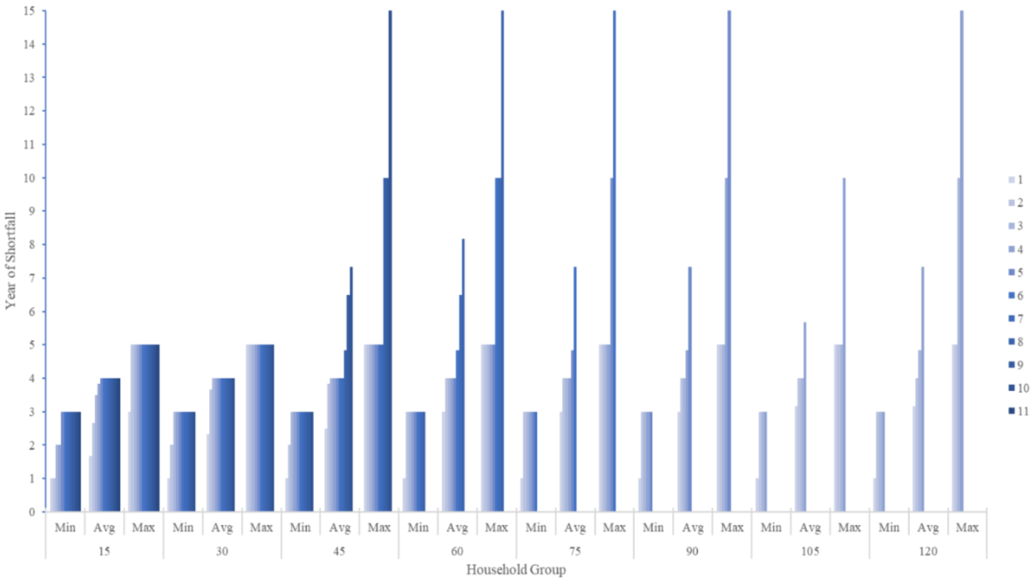

Figure 7.10 Scenario C – R.R forecasted year of shortfall.

Table 7.17 Scenario C – Total Operations Expenditure (T.OpEx) projected shortfall.

Household Group	Year of Shortfall	Tariff Group 1	2	3	4	5	6	7	8	9	10	11
1	Min	1	1	1	1	1	2	2	2	2	3	3
	Avg	2	2	2	2	2	3	3	3	4	4	4
	Max	2	2	3	3	3	4	4	5	5	5	5
2	Min	1	1	1	2	2	3	3	3	3	3	3
	Avg	2	2	3	3	4	4	4	4	4	4	4
	Max	2	3	4	5	5	5	5	5	5	5	6
3	Min	1	1	2	3	3	3	3	3	3	3	3
	Avg	2	3	3	4	4	4	4	4	4	4	5
	Max	3	4	5	5	5	5	5	5	5	5	7
4	Min	1	1	2	3	3	3	3	3	3	3	3
	Avg	2	3	4	4	4	4	4	4	4	5	6
	Max	3	5	5	5	5	5	5	5	6	6	9
5	Min	1	2	3	3	3	3	3	3	3	3	4
	Avg	2	3	4	4	4	4	4	5	5	5	7
	Max	3	5	5	5	5	5	6	6	6	6	10
6	Min	1	2	3	3	3	3	3	3	3	4	4
	Avg	2	4	4	4	4	4	5	5	5	6	7
	Max	4	5	5	5	5	6	6	6	7	7	11
7	Min	1	2	3	3	3	3	3	4	4	4	4
	Avg	2	4	4	4	4	5	5	5	6	6	8
	Max	4	5	5	5	6	6	6	7	7	8	12
8	Min	1	2	3	3	3	3	3	4	4	5	5
	Avg	2	4	4	4	4	5	5	6	6	7	9
	Max	5	5	5	5	6	6	7	8	8	9	13

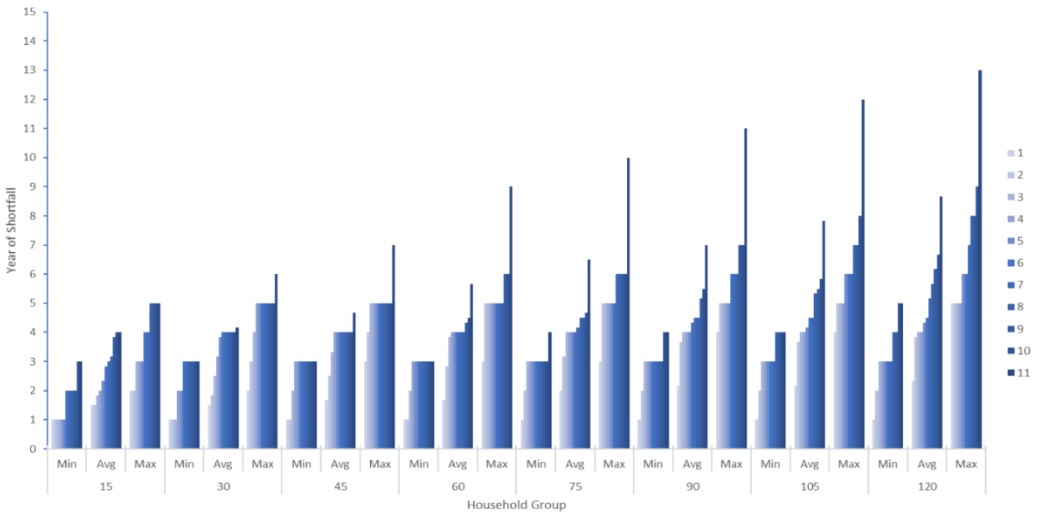

Figure 7.11 Scenario C – T.OpEx forecasted year of shortfall.

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7.11 Thesis Context

This chapter fulfilled RQ 3: Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi? and RQ 4: How can a proactive approach to monitoring identify and target increased risk to handpump breakdown? SO 7, SO 8 and SO 9 are accomplished through a submitted paper to a peer reviewed journal.

The findings, from interrogating the 'big data' collected in the mWater dataset, highlighted that functionality decreases over the design life of the Afridev. Where a tariff is present, non-functionality is reduced over the life-cycle. Where there is no tariff, non-functionality is more common over the life-cycle. A life-cycle cost model for the Afridev handpump was developed to identify potential shortfalls in financial resources when meeting the costs of replacing Afridev handpump components, across the life-cycle.

Logistic regression analysis demonstrated significant explanatory variables associated with the occurrence of broken or worn components that contribute to a decline in service. Service provision, the quality of infrastructure and a shortfall in financial resources are significantly associated with broken or worn components. Together, these are the most correlated issues for predicting functionality. Incorporating a life-cycle cost approach for targeted water point data and data driven investment is important to support the environment, for the routine monitoring of assets that allows for improvements in quality of services. This is entirely possible through the introduction of a Management Information System (MIS). The primary data source for the findings across the results chapters has been the monitoring information collected in the MIS mWater. The use of MIS alongside a life-cycle and systems mindset is important to improve past investment and plan for future service delivery.

Moving beyond coverage as the metric for success to a life-cycle systems approach is crucial for the sustainability of rural water supply assets in low-income countries and supporting the achievement of the 2030 agenda. This is discussed in the next chapter.

CHAPTER 8. MORE THAN INDICATORS: LIFE-CYCLE PRINCIPLES TO INFORM ASSET MANAGEMENT

8.1 Introduction

The previous chapter addressed the significant explanatory variables associated with broken or worn components that contribute to a decline in service across the life-cycle of the Afridev handpump. From the life-cycle cost model proxy indicators were produced to identify when a shortfall in financial resources would occur, using the present value technique across four tariff scenarios (Scenario A – collected per month, Scenario B – collected when required for repairs, Scenario C – collected per year and Scenario D – no tariff). The results of the logistic regression analysis suggested a shortfall in financial resources increased the likelihood of worn out or broken parts (described as an issue of infrastructure) occurring. The increased likelihood for this failure was also true when sub-standard infrastructure was present, structural damage was present, lack of preventative maintenance was conducted, and major repairs conducted in the last year. Notably, further support for establishing effective supply chains is justified by the presence of spare parts on site, reducing the likelihood of an issue of infrastructure occurring across the design life.

This chapter addresses RQ 4: How can a proactive approach to monitoring identify and target increased risk to handpump breakdown? Monitoring and identifying the drivers behind service decline is crucial for the fulfilment of the SDGs. However, they must be more than solely providing indicators for a database. They must be used to facilitate stakeholder accountability and support asset management (WaterAid, 2011). The database can be used to provide feedback data and inform proactive changes to the current behaviours towards service delivery.

The purpose of this chapter is to discuss how the findings of the thesis, systematically analysed from the monitoring 'big dataset', can be used to improve service delivery across the life-cycle of rural water supply. In particular, how the key themes and challenges in the previous chapters allow for the 'learning and adaptation' in rural water asset management. The discussion addresses SO 10: Evaluate how techniques (LCCA) and monitoring (MIS) can assist in data driven investment/intervention decisions to move from a coverage approach to fulfil the SDGs, to a service delivery approach for sustainable systems.

The use of 'big data' has presented crucial findings that are relevant to the global and local contexts of sustainable service delivery through the outcomes of this thesis. Phone based data collection in particular has seen increased popularity in assembling local water point data and large datasets (Manyika *et al.*, 2011; Taylor and Schroeder, 2015; Dhoba, Nyawasha and Nyamuranga, 2017; Dickinson, Knipschild and Magara, 2017). Acquiring large scale datasets can provide important indicators for policies and interventions, given challenges and lack of capacity to collect country-wide data, particularly in low-income countries (Jerven, 2013). Taylor and Schroeder (2015), note the importance of understanding the local contexts when data science informs development policy. A theme prevalent throughout the findings of the thesis. The authors further acknowledge the immense potential a 'big dataset' has in improving the understanding of the needs of low-income countries for responsive and targeted policies.

This chapter will adopt a system thinking mindset, which moves from linear problem solving to understand how different factors impact a wider system (Liddle and Fenner, 2017). To accomplish this, the system boundaries identified by Huston and Moriarty (2018), and presented in Table 8.1, are drawn upon, to reduce the complexity of analysing water, sanitation and hygiene (WASH) systems.

Table 8.1 Nine WASH system boundaries, adapted from (Huston and Moriarty, 2018) for the context of water supply.

	Components	Definition
1	Monitoring	Acquisition, management and distribution of information to manage services effectively and adapt to change.
2	Planning	Planning to achieve policies, fulfilling life-cycle costs and budgeting.
3	Finance	Funding mechanism to sustain and fund services over their entire life-cycle.
4	Infrastructure	Water supply hardware and the asset management ability to develop and maintain.
5	Institutions	Roles in the organisational structure and the capacity to perform the role.
6	Water Resources Management	Water source for services and management of quality and abstraction.
7	Policy and Legislation	Vision for the sector and how to achieve it.
8	Regulation and Accountability	Mechanisms to hold decision makers, service providers and interested stakeholders to account.
9	Learning and Adaptation	Capacity to learn and feedback to adapt to maintain progress.

Monitoring the system and its boundaries through the MIS mWater, has been key (throughout the thesis findings) in helping to understand the quality and challenges of service delivery. As the SDGs enter the 'decade of action (2020-2030)' it is imperative that monitoring goal achievements include indicators on the current behaviours towards asset management.

8.2 Learning and Adapting Asset Management across Service Delivery Life-Cycle

8.2.1 Planning and implementing quality infrastructure

Increasing access to safe drinking water has been a primary driver in the global goals. The MDGs aimed to 'halve the proportion without access' (United Nations General Assembly, 2000), while the SDGs drive to 'leave no one behind' (United Nations, 2015), through the coverage approach prevalent throughout global goals and local policy (Chapter 4). The drive to increase access to water, can favour cheaper technologies that can contribute to poor quality services that are more likely to be replaced than repaired (Franceys and Pezon, 2010). The installation of sub-standard infrastructure, prevalent throughout the findings, risk implementation that leads to failure (Bonsor *et al.*, 2015), and lost investment. Monitoring water point data can be harnessed to inform new programmes, target interventions to existing services and identifying the key drivers through which to plan maintenance approaches and prevent failure (Dickinson, Knipschild and Magara, 2017; Miller *et al.*, 2018).

Monitoring the spatial implementation of infrastructure allows for an insight into the potential coverage of water supply but can also provide insights into proper siting due diligence. The siting of infrastructure without proper insight into the hydrogeological conditions of the coverage area has been identified as a significant factor into the failure of water supply assets across SSA by prior research (Nussbaumer *et al.*, 2016; Martínez-Santos *et al.*, 2017; Bonsor *et al.*, 2018; Mannix *et al.*, 2018). This is further identified in the thesis where sub-standard infrastructure contributes to the increased likelihood of breakdown (Chapter 4 and 7). Infrastructure that is unreliable undermines a communities ability to sustain itself (Whaley *et al.*, 2019), leaving assets vulnerable to breakdown, risks abandonment during periods of seasonality or permanently, and fails to adhere to the global goals target of sustainable management and access.

This is also the case for proper siting of water that is of a sufficient quality to be abstracted for use. Chapter 4 addressed the impact high saline water points have on communities. Poor quality water results in poor participation with mechanisms designed to maintain the handpumps and opt for unimproved source use, impacting community livelihood. While boreholes equipped with handpumps are the standard approach to water supply in Malawi they may not be the most appropriate technology in the service delivery area. Improper siting or lack of due diligence when investing into access, have led to establishing boreholes in areas where salinity is a known issue. Again the investment into cheap CapEx technologies such as handpumps, leads to poor quality services when short term targets are favoured over long term goals.

Ensuring quality infrastructure is implemented involves holding (implementing) stakeholders to account for the services they provide, to avoid trading long term sustainability targets for cheap and poor quality services. Monitoring the investments into infrastructure allows for stakeholders to be held to account for the quality of services they provide. This includes both spatial and temporal parameters to ensure infrastructure yield and quality is fit for purpose. An MIS, such as mWater, has the potential to provide the live database required to accomplish such accountability for previous and future assets. It also allows for the learning and adaption required to identify service delivery areas at risk due to sub-standard infrastructure, and the appropriateness of technologies to deliver safe and reliable services.

8.2.2 Capacity building to sustain services

Achieving a sustainable service requires more than a one-time investment. Infrastructure requires maintenance and the institutional capacity to perform it. In Malawi, the preferred method of government policy supported by other stakeholders is to defer responsibilities to communities. However, reflection of 30 years of CBM has shown community management is limited in its capacity to maintain services, without some form of support and professionalised service delivery (Lockwood and Smits, 2011; Hutchings *et al.*, 2015).

The findings in this thesis further suggest institutional support and capacity building in Malawi is lacking when establishing service delivery. Service provision is essential for continued sustainability and the lack of such, significantly reduced services compared to those with service providers (Chapter 4). Even where local service providers are established, strengthening their ability to perform the roles are questionable. The lack of service providers capacity is evident where, community members are service providers, under the policy that recommends WPCs, for water point management (Chapter 5), no preventative maintenance was conducted (Chapter 6), and no tariffs were present (Chapter 7). The findings indicate where capacity is lacking and thus suggest where there is a need to target investment to maintain service delivery. However, when priorities focus on coverage, such as the rehabilitation conducted on assets with no service providers (Chapter 4), interventions only temporarily resolve the cycle of non-functionality. Coverage without the capacity building into institutional support to maintain it, can result in usage over the recommended capacity for the Afridev handpump (Chapter 5 and 7). Additional wear and tear has the potential to accelerate breakdown and increase the usage of other sources, or the use of unimproved sources. Monitoring the usage of water sources can allow better understanding of multiple source use but also where service delivery is at risk from overcapacity.

The standardisation of Afridev use for all rural water supply places an even greater weight on institutional capacity building. The Afridev does not come without crucial O&M at the local level. However, it has placed supply chains at the centre of investment decisions for sustainability, through its demonstration as a locally produced, affordable and reliable VLOM handpump (Baumann and Furey, 2013). Handpump breakdown is less likely to occur when spare parts are available on site (Chapter 7). However, behaviours pointed towards favouring fast wearing components when major repairs were conducted (Chapter 6). Investment into service delivery must adopt appropriate life-cycle planning that includes the establishment of supply chains, so timely access can reduce downtime (Thomson and Koehler, 2016). Building capacity into Afridev supply chains is essential to the sustainability of water supply access in rural Malawi. Identifying service providers that have conducted repairs and have local knowledge of the spare parts that are available on site, can potentially indicate current capacity of supply chains and where targeted supply chains are required.

Poor life-cycle planning, the lack of institutional support and lack of financial capacity are common themes across the findings of the thesis. Service providers commonly opt for reactive approaches to maintenance and financial mechanisms. Reactive collection of financial resources are more likely to be driven by O&M costs, while more frequent proactive approaches are more likely to consider affordability (Chapter 5). However, while service providers commonly resolve to this approach, the reality is it is not cost effective or sustainable for service delivery in the long term (Chapter 7). As a result, service providers struggle to maintain different priorities in the financial mechanisms set (Chapter 5). This is primarily due to the lack of capacity to meet such life-cycle costs (Chapter 7) and the behaviours towards payment (van den Broek and Brown, 2015; Foster and Hope, 2017), and repairs (Chapter 6). Understanding the life-cycle of technologies and the individual components, such as rods and rising mains, are important for life-cycle planning and financing. A lack of life-cycle planning results in a heavy reliance on external support across the life-cycle requirements of infrastructure. Monitoring performance can be used to indicate where capacity building is required.

8.2.3 Better understanding of CapManEx

CapManEx is often overlooked within life-cycle cost planning by service providers and governments (Franceys and Pezon, 2010; Geremew and Tsehay, 2019). A knowledge of the costs of replacing or rehabilitating water supplies are crucial for achieving continued services and return of investment (Franceys and Pezon, 2010). The lack of understanding, financial means and life-cycle planning inevitably means that services are left to prematurely fail. Monitoring the behaviours towards these costs allows an understanding of the current capacity to meet CapManEx and also how to facilitate investments towards meeting them.

The focus on CapEx when implementing new assets has the potential to increase the CapManEx requirements and frequency across the life-cycle through the installation of cheaper technologies (Fonseca *et al.*, 2013). The increased premature failure and depreciation of assets (Chapter 4) and the local behaviours of waiting until failure of a system (Moriarty *et al.*, 2013; Etongo *et al.*, 2018; Kativhu *et al.*, 2018; Whaley *et al.*, 2019), result in a reliance on external support. Particularly, for CapManEx when rehabilitation (Chapter 4) and high costing major repairs (Chapter 6) are concerned. While the costs of rehabilitation is deferred to international aid and private sectors (MoAIWD, 2010), major repairs are left to community service providers. However, long-term maintenance is seldom considered. This is demonstrated in Chapter 5 where tariffs consider routine O&M costs but fail to accommodate appropriate life-cycle cost planning in the tariff amount and frequency. Chapter 7 further demonstrated the current financial mechanism is insufficient as few scenarios are capable of meeting the full design life before a shortfall. Suggesting an increase in the likelihood of potential breakdown. The initial lack of planning, building institutional capacity and financial provision is evident by local service provider behaviours towards CapManEx (Chapter 6). Cheaper major repairs are favoured over the design life with fast wearing parts prioritised. Longer life components, of which failure can result in non-functional or abandoned assets, depend on externally conducted high costing major repairs.

The findings further illustrate that CapManEx is overlooked from the outset and not appropriately planned for across the design life by both implementing stakeholders and communities. Implementing stakeholders favour cheaper CapEx to increase cover, while local service providers favour cheaper CapManEx to sustain it. The initial trade-off risks increasing the inability of local service providers to maintain serviceability over the design life. This may not result in the most cost effective investment as external support returns prematurely.

To better adapt and understand CapManEx, immediate response approaches could be integrated into current behaviours when CapManEx occurs. Innovative approaches such as smart handpump technologies (Goodall *et al.*, 2016; FundiFix, 2017; Swan *et al.*, 2018), have the potential to provide immediate feedback to reduced serviceability that could improve CapManEx understanding. The incorporation of smartphones for real-time monitoring of services allow for spatial and temporal data collection (Batchelor, 2013), such as through mWater. This can further improve the understanding of CapManEx and optimisation of resources. It is crucial that the monitoring of such leads to a change in behaviours and strengthening of institutional capacity to meet the CapManEx requirements.

These findings allow for a better understanding of the behaviours towards CapManEx in the rural context. Installing a new borehole and handpump, without appropriate life-cycle considerations, is a huge waste of investment when considering service delivery. Investments into service delivery can therefore be targeted towards improving the life-cycle of assets rather than waiting for asset failure and maintaining the 'one-time investment' behaviours of new coverage. This further justifies the importance of monitoring and understanding the requirements of CapManEx within asset management.

8.3 Learning and Adapting in the SDGs Decade of Action

8.3.1 Monitoring more than coverage in SDG 6

Progress has been made towards the SDG goal for water, but this progress remains too slow to meet the 2030 deadline (Ortigara *et al.*, 2018). SDG 6 makes significant advancement on all aspects of water over the MDG water goal, however, the headline indicators of water supply coverage risk masking poor levels of service (Cronk, Slaymaker and Bartram, 2015; Martínez-Santos, 2017). Monitoring has been ongoing over the last 20 years. What can be learned, is to adapt approaches in the decade of action (2020-2030) to maintain progress towards the 2030 agenda.

"What [Sustainable Development Goal 6 Synthesis Report on Water and Sanitation] makes clear is that we must tackle weak funding, planning, capacity and governance of water and sanitation services as a top priority…. Data and smart technologies must be embraced so interventions can be as effective as possible and progress tracked over time."

(United Nations, 2018a)

The findings of the thesis clearly supports the top priority of water supply in the SDG synthesis reports. Localising the SDGs is crucial for their success (Editorial, 2019), however, the lack of capacity in the community hinders this aim. Service providers have shown the challenge of balancing affordability and O&M costs for sustainability in the financial mechanisms in place (Chapter 5). Which hinder the affordable and sustainable aspects of the SDG agenda. Particularly when long term sustainability is a minor consideration. Monitoring affordability has no commonly agreed approach, which increases the importance of monitoring the priorities of rural service providers when it comes to SDG localising success.

The behaviours towards establishing financial mechanisms and planning, are impacted by the number of users utilising a source (Chapter 5), as multiple source use is a well-established practice (United Nations Development Programme, 2006; Foster and Willetts, 2018). Monitoring user behaviours towards source use is necessary to establish the capacity required at the local level. The serviceability of water supply is at risk if multiple source use is not considered within regular monitoring practices. Usage above the capacity of the Afridev is common (Chapter 5 and 7) which has the potential to increase wear and tear and impact primary user behaviours. This risk to low level service in Malawi may further increase and remain overlooked if the capacity of improved sources is not considered. Low-income countries may also face similar challenges where handpumps are standardised, and global monitoring continues to focus on single source use (Vedachalam *et al.*, 2017).

The sustainable management aspect of the SDGs are further hindered by the lack of planning and funding that results in the evident sub-standard infrastructure that has been implemented to date (Chapter 4 and 7). While there may be coverage of improved sources, user behaviours towards such sub-standard assets may lead to prefer unimproved sources over improved source coverage, without any real indication that this has occurred. Furthermore, the nature of coverage can be temporal if infrastructure is susceptible to seasonality. Again unimproved source use may increase during periods of seasonality if improper planning, siting and capacity does not accommodate this issue. Overall, successful monitoring and action requires a political commitment to this.

8.3.2 Data driven policies

Malawian water policy dictates its vision for the rural water sector. Continuous monitoring is crucial to ensure its vision is being achieved but also to understand how that vision impacts the sector.

First, the implementation of sub-standard infrastructure, discussed throughout the findings of the thesis, supports the importance of monitoring when it comes to regulating the sector. National policy dictates the construction and rehabilitation of water points to international aid and the private sector (MoAIWD, 2010). In parallel with the coverage targets of the global goals, the focus on implementing water supply has taken precedent over its quality. Poor regulation and lack of accountability for these interested stakeholders means policy goals are hindered and it is the rural communities who are burdened. The case study findings in Chapter 4 highlighted how monitoring can reinforce the regulation and accountability of interested stakeholders. It can also reduce the reputational risk for stakeholders when assets prematurely fail (Dickinson, Knipschild and Magara, 2017). It also highlighted how policy and regulation can learn and adapt to the supply quality and management challenges at the local level. The thresholds set for salinity reinforce poor siting practices by implementing stakeholders that result in assets that are not fit for purpose. Furthermore, in areas of known salinity such as the district of Chikwawa (Monjerezi and Ngongondo, 2012; Rivett, Budimir, *et al.*, 2019), supplies above the government thresholds are still being implemented. Supplies that should be classed as a defective borehole by Malawi's own Water Resources Act (Government of Malawi, 2013). While it may be seen as a successful increase in access to water supply, the reality is the supplies fail to deliver any real benefit, and encourages unimproved source use that negatively impact livelihood (Hunter, MacDonald and Carter, 2010; Tucker *et al.*, 2014; Anthonj *et al.*, 2018).

Second, the decentralisation of rural water supply management through the CBM approach has been regarded as ineffective across international studies. The reliance on this model absolves funders and governments of responsibility while failing to delivery any technical or financial benefits. While implementing stakeholders are failing to deliver quality infrastructure, that exacerbates the challenges of management. The monitoring of such challenges at the local level allows for an insight into measures to remediate and support communities. External support is necessary throughout rural Malawi for the sustainability of assets. Monitoring allows stakeholders to understand where capacity building is required and hold stakeholders to account where it has not been undertaken. This is evident where no service provision (Chapter 4 and 5), no tariff (Chapter 4 and 6) and no preventative maintenance approaches (Chapter 6) are established, all of which are required by national policy and crucial to sustainability. Monitoring is more than just abiding by the policy but understanding where the shortcomings in policy are present. For example, the 'one size fits all approach' of CBM expresses significantly different management scenarios that vary due to local contextual drivers across the regions of Malawi that impact life-cycle sustainability (Chapter 5-7). The findings and wider evidence support the understanding that rural service delivery requires a more systematic approach that incorporates appropriate life-cycle planning and monitoring, rather than continuing the sole dissemination of management to communities.

8.4 Filling the Knowledge Gaps

The collection of information on Malawi's rural water supply sector, through the MIS mWater, provides valuable insights into local service delivery. Monitoring, the 'acquisition, management and distribution of information to manage services effectively and adapt to change' (Table 8.1), has aided in fulfilling the overall knowledge gaps identified in the literature review (Chapter 2). The thesis identifies:

- The focus on monitoring the increase of water supply access may hide low levels of service. Service decline is notable as systems age, that may be further affected by sub-standard installations, as reliability and operational status are not accounted for in success targets (Knowledge Gap 1).
- High thresholds for salinity in Malawi contribute to the installation of water supply systems in high saline areas, that are deemed unfit for use by international standards. These have underlying impacts towards achieving safe source access, due to negative community behaviours towards saline sources (Knowledge Gap 2).
- Localising the SDGs is crucial for their success. Understanding the considerations when setting tariffs by local service providers, provide insights into what affordability looks like in the local context and the drivers behind it (Knowledge Gap 3).
- Functionality as an indicator encompasses various factors that influence its status. Issues of infrastructure have shown to be the highest correlated factor. The research has identified the drivers behind this factor, which is crucial for life-cycle planning (Knowledge Gap 4).
- There is a focus on investment into water supply infrastructure, however, investments into the 'software' to manage assets is lacking. Capacity building into

establishing and training WPCs is not always accomplished and in some cases no service provider is present. Furthermore, financing O&M significantly varies across local contexts that is insufficient to accommodate life-cycle requirements in most cases (Knowledge Gap 5).

- The initial lack of planning and building institutional capacity, and financial provision, is evident by local service provider behaviours towards the maintenance requirements of infrastructure. Long-term maintenance is seldom considered as cheaper major repairs are favoured over the design life, with fast wearing parts prioritised. Longer life components, of which failure can result in non-functional or abandoned assets, depend on externally conducted high cost major repairs (Knowledge Gap 6).

8.5 Summary

This chapter fulfilled RQ 4: How can a proactive approach to monitoring identify and target increased risk to handpump breakdown? SO 10 is accomplished through the discussion, that the findings of the thesis can be used to improve service delivery across the life-cycle of rural water supply. Monitoring is crucial for the effective management of water supply services. Learning and adapting allows for data driven decisions that progresses towards sustainable service delivery. The comprehensive live dataset collected in the MIS mWater has allowed for the identification of key themes and challenges of sustaining infrastructure across the design life in Malawi's rural water supply sector. This chapter draws upon system boundaries associated with the findings of the thesis, to aid the discussion on how monitoring promotes the learning and adaption in rural asset management in Malawi. As the SDG's move into the 'decade of action', adapting approaches from the lessons learnt over the last 20 years of monitoring is increasingly important.

Capacity building into the planning, infrastructure, financing and institutional arrangements of rural water supply infrastructure have been acknowledged as lacking. Initial CapEx has been the primary investment in the life-cycle planning of infrastructure. However, the capacity and financial ability to maintain serviceability under decentralised management in Malawi, has not delivered the sustainability as intended. Understanding and monitoring the shortcomings of service delivery is essential to feedback and strengthen the associated system boundaries. Including the institutional capacity of CBM, establishing targeted supply chains, and the accountability of stakeholders to ensure proper siting of new infrastructure. Overlooked aspects of life-cycle planning, such as CapManEx, also requires continuous monitoring to improve the sectors understanding of its occurrences.

Malawi's national policy defers responsibility of water supply construction and rehabilitation to international aid and the private sector. However, monitoring the trends and behaviours towards these exercises suggest poor planning and quality of service delivery, to establish water supplies that are both affordable and sustainable. The monitoring of which can aid the understanding of the impact stakeholders actions have on the local communities, accountability for poor practices and fulfilment of policy objectives. This also allows for data driven policy changes to new understandings such as the limitations of current management models (e.g. CBM) or unsuitable areas for boreholes (e.g. saline groundwater). The importance of data driven considerations are also true for SDG monitoring. The localisation of the SDGs is crucial for their success. However, they are encumbered by the local challenges of rural service providers and poor quality infrastructure. True representation of rural service provision may be misrepresented if the lessons of the MDGs and SDGs to date are not fed back into monitoring strategies. Services creating a burden on the rural communities they are intended to serve must be addressed in the 'decade of action', if the legacy of the SDGs will truly 'leave no one behind'.

CHAPTER 9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Restatement of Aim of Objectives

The aim of the research was to investigate the influence the global goals in the MDG period and subsequent SDG period, have on maintaining rural community water supply across their life-cycle in low-income countries. The thesis accomplishes this aim through a series of research questions and specific objectives, which are addressed progressively in each chapter, as described in Figure 9.1.

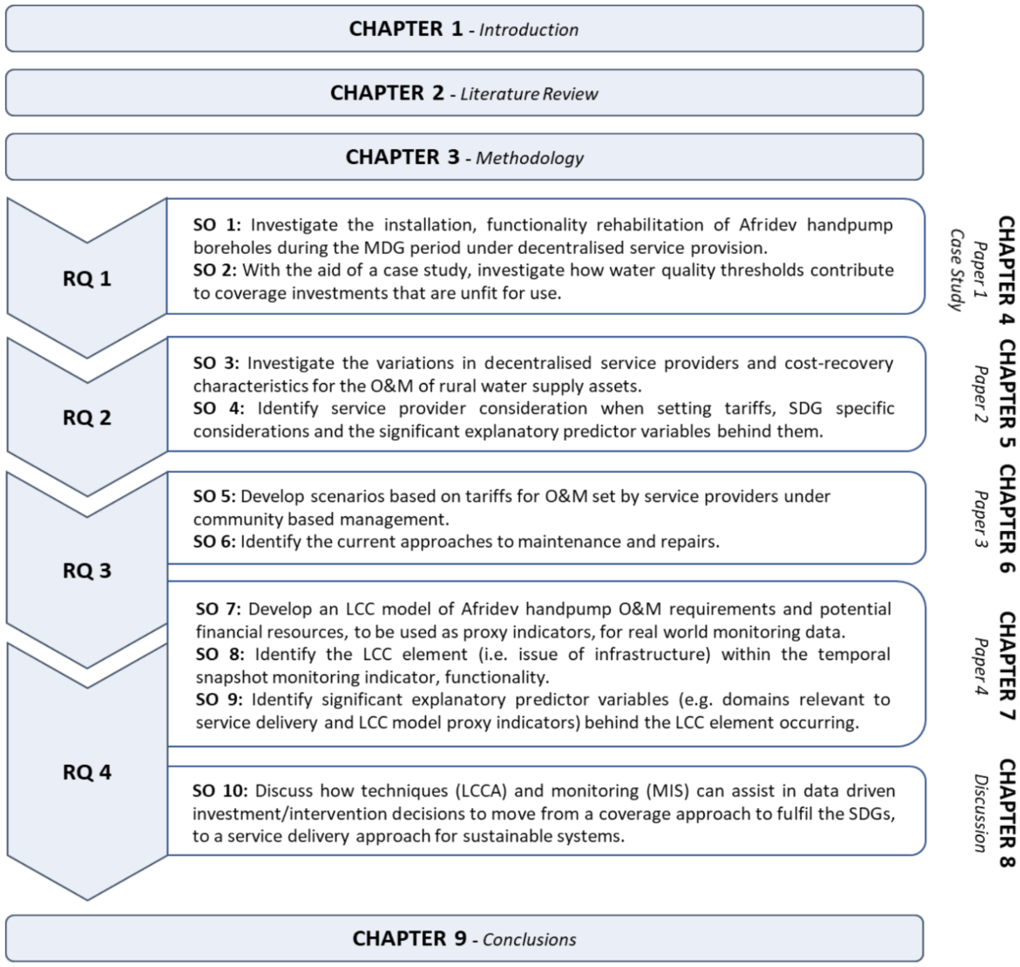

Figure 9.1 Roadmap of thesis outlining research questions, objectives and content of chapters.

Chapter 2 provides literature relevant to the thesis aim and identifies gaps in knowledge to be answered. A comprehensive live management information system, regression analysis and life-cycle cost approach principles were then utilised to interrogate the domains associated with implementing decentralised rural water supply (e.g. service delivery, operational, cost-recovery, condition of infrastructure). The following specific objectives address the knowledge gaps and overall thesis aim as follows:

- SO 1 was met through a peer reviewed publication in Chapter 4 and addressed Knowledge Gap 1. The reliability and operational status of systems, hidden by coverage statistics, are identified by investigating the installation, functionality and rehabilitation of Afridev handpump boreholes during the MDG period under decentralised service provision.
- SO 2 was met through a case study in Southern Chikwawa, Malawi in Chapter 4 and addressed Knowledge Gap 2. Assets that are unfit for use under international standards, but not deemed problematic under Malawian standards, are identified by investigating salinity thresholds.
- SO 3 was met through a peer reviewed publication in Chapter 5 and addressed Knowledge Gap 3. The variations in financial resources and management are identified by investigating decentralised service providers and cost-recovery characteristics for the operations and maintenance of rural water supply assets.
- SO 4 was met through a peer reviewed publication in Chapter 5 and addressed Knowledge Gap 3. Reflecting and localising SDG 6 is identified by investigating service provider considerations when setting tariffs, SDG specific considerations and the significant explanatory predictor variables behind them.

- SO 5 was met through a drafted paper in Chapter 6 and addressed Knowledge Gap 5. Scenarios are developed to be used in the life-cycle analysis based on tariffs for O&M set by service providers under community based management.
- SO 6 was met through a drafted paper in Chapter 6 and addressed Knowledge Gap 6. Current approaches to maintenance and repairs are identified by interrogating decentralised rural water service delivery data collected through the MIS mWater.
- SO 7 was met through a submitted paper in Chapter 7 and addressed Knowledge Gap 5 and 6. O&M requirements and potential financial resources, to be used as proxy indicators for real world monitoring data, are identified by developing an LCC model of the Afridev handpump.
- SO 8 was met through a submitted paper in Chapter 7 and addressed Knowledge Gap 4. Information on the temporal snapshot indicator for monitoring asset quality (functionality), collected through the MIS mWater, is interrogated to identify significant drivers and the LCC element of the Afridev (i.e. issue of infrastructure).
- SO 9 was met through a submitted paper in Chapter 7 and addressed Knowledge Gap 4. Significant explanatory predictor variables (e.g. domains relevant to service delivery and LCC model proxy indicators) behind the LCC element occurring, are identified through logistic regression analysis.
- SO 10 was met through Chapter 8. The discussion on moving from a coverage approach to a service delivery approach is aided by systems thinking methodology to highlight how techniques (LCCA) and monitoring (MIS) can assist in data driven decisions.

The impact of this research is to support data driven decisions and policy. Particularly to promote long term delivery of sustainable services, contrary to the short term achievement of increasing coverage, as the global goals move into the ‘decade of action’.

9.2 General Conclusions

Chapter 4 addressed the first research question 'Has the drive to meet the success and coverage targets of the Millennium Development Goals (MDG) resulted in low-levels of service and a burden on decentralised service providers?' through specific objectives one and two. It was concluded that the influence of national policies and global goals contributed to the acceleration of water supply installations to meet coverage targets. The drive for decentralised management of these supplies has left communities with the burden of sustaining services. Reactive approaches to maintenance contribute to declining services. These require costly and premature rehabilitation exercises to bring services back to an operational standard, of which external support is relied upon to accomplish. The premature decline in services indicates sub-standard infrastructure quality is implemented due to the drive to meet coverage targets. This is further highlighted by the conclusions of the case study. Groundwater supplies are implemented in areas of known salinity that have the potential to impact the health of communities. Malawian water quality thresholds for salinity are significantly higher than the threshold for suitable use under the WHO. This results in installations which are unfit for long term use. Communities do not use or participate in maintaining these supplies, which risks increased usage of unimproved supplies that further impacts health. The implementation of sub-standard installations during the MDGs and drive for the short term success of a coverage target approach, points to justified concerns of sustainability. Thus, further investigation is required to understand the challenges communities face entering the 2030 agenda, and to improve the performance of service provision at the local level rather than solely measuring it.

Chapter 5 addressed the second research question 'How are global goals reflected and highlight challenges in the cost-recovery mechanism for decentralised rural water supply?' through specific objectives three and four. It was concluded the potential financial resources, through the collection of household tariffs, vary across the water points life-cycle resulting in implications for long term sustainability and maintenance practices. Furthermore, balancing affordability and O&M costs has been challenging. Considering these factors, in the tariffs set, are influenced by drivers at the local level which highlights potential trade-offs based on local contexts. These hinder the achievement of the SDGs, particularly when localising the targets are crucial to their success. Long term sustainability is further challenged as tariffs are unlikely to be sufficient for maintaining and eventual, or premature, rehabilitation or replacement of assets.

Chapter 6 addressed the third research question 'Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi?' through specific objectives five and six. The CapManEx element of water supply life-cycles is an often neglected cost pre and post construction. It was concluded that there is poor capacity building for service providers to accommodate ongoing maintenance requirements from the outset. The CBM service delivery model for rural water supply is unable to fully provide the necessary CapManEx without the support from external stakeholders. Low costing major repairs are primarily conducted by communities which encompass low costing fast wearing parts. Costly major repairs significantly increase post-rehabilitation that typically encompass longer life components, such as rods, and are conducted by external actors such as NGOs. If short term technologies such as handpumps are continued to be implemented, policy and practitioners must focus on the capacity building of maintenance models that consider the full life-cycle costs of assets. This includes assessments and capacity building to ensure cost recovery and maintenance approaches are capable of meeting the life-cycle requirements of assets.

Chapter 7 addressed the third research question 'Can the life-cycle requirements of rural water supply be met under decentralised management in Malawi?' through specific objective seven. The fourth research question 'How can a proactive approach to monitoring identify and target increased risk to handpump breakdown?' is also addressed through specific objectives eight and nine. It was concluded that maintaining rural water supply assets to the end of their design life, may be inherently unsustainable from the outset. Significant explanatory variables (i.e. sub-standard infrastructure, structural damage, no preventative maintenance and a shortfall in financial resources) are associated with the occurrence of broken or worn handpump components that contribute to a decline in service delivery in all tariff scenarios investigated. Capacity building into appropriate life-cycle planning and establishing supply chains are notable factors in improving the serviceability of water supply assets post-construction and reduce the time between breakdown and repair. Focus on coverage in the global targets and policies, risk favouring the short term reward of new infrastructure rather than the long-term investment required, creating barriers in achieving sustainable services.

Chapter 8 addressed the fourth research question 'How can a proactive approach to monitoring identify and target increased risk to handpump breakdown?' through specific objective ten. The chapter discussed the main lessons of the thesis in the context of system boundaries to show how monitoring promotes the learning and adaption for rural water asset management in Malawi. Initial CapEx into coverage has been the primary rural water supply investment, while capacity building into the planning, infrastructure, financing and institutional arrangements have been lacking in the sector. Malawi's national policy defers responsibility of water supply construction and rehabilitation to international aid and the private sector. However, monitoring the trends and behaviours towards these exercises suggest poor planning and quality of service delivery, to establish water supplies that are both affordable and sustainable. Monitoring water supply assets can aid the understanding of the impact stakeholders actions have on the local communities, accountability for poor practices and fulfilment of policy objectives. This allows for data driven policies and true representation of rural service provision in the global goals if the legacy of the SDGs will truly 'leave no one behind'.

9.3 Future Research and Policy Recommendations

9.3.1 Future Research

The recommended areas for future research to build and lead from the findings of the thesis are summarised as follows:

- **Comparative low-income country analysis:** The conclusions of the thesis have clear implications for the sustainability of decentralised rural water supply, which may not be exclusive to Malawi alone. The implications of the coverage target approach in the global goals may also be present in other low-income countries, that are also groundwater dependant, focus on coverage in national policies and promote decentralisation for rural water supply. Further research is required to investigate the extent if issues identified in the thesis are present in other low-income countries, to explore if the legacy of the global goals is a trend or country specific. This includes services that are implemented in the SDGs to date to determine if the attitude towards coverage has remained the same since the MDGs.
- **Comparative analysis into other handpump technologies for groundwater supplies:** While the life-cycle model that was developed for Chapter 7 of the thesis provided proxy indicators for Afridev handpumps, other handpump technologies present in Malawi were outside the scope of the study. Exploration into other technologies, such as the India MKII/III, elephant pump and bush pump, is necessary to understand

how the findings of the thesis are reflected in scenarios that use other handpump technologies.

- **Investigation into the quality of current infrastructure to ensure accountable and reliable services:** Sub-standard installations have been demonstrated as having a detrimental impact to the sustainability of service delivery. Assets that are subject to seasonal variations may risk successful climate reliant communities, while assets that are installed in areas of known water quality issues (i.e. salinity) may risk community health. Further exploration into the casual factors (i.e. siting, hydrogeological analysis and construction) that result in poor quality services can be used to inform data driven policies and accountability measures of future investments. Service delivery assessments of known poor quality services are necessary to remediate issues that may be impactful presently and in the future.
- **Capacity building into local service delivery:** The capacity of local communities to sustain water supply infrastructure across the design life is a significant issue in the findings of the thesis. Under CBM, appropriate life-cycle financing and planning has been found to be lacking across the scenarios investigated. Further work is required into supporting and building the capacity at the local level beyond the CBM model in Malawi. This includes assessments into current capacity and the establishment of sufficient supply chains within service delivery areas.
- **Monitoring and advancing the localisation of the SDGs:** Chapter 5 demonstrated that localising the SDGs is crucial for their success. In the case of affordability, its establishment requires further research into the casual factors that contribute to affordable supplies, such as how affordability relates to the household level and local contexts. This includes the casual linkages to SDGs such as poverty, education and health. User behaviours towards multiple and unimproved sources further implicates

the success if remained unconsidered in SDG monitoring. Understanding how casual factors impact targets within the SDGs allows for appropriate monitoring and targeted systematic investment.

9.3.2 Impact to Policy and Data Driven Decisions

The impact from this research is to support data driven decisions and policy. These areas are summarised as follows:

- **Accountability measures for sustainable service delivery:** Malawi has seen an increase in improved source access across the global goals. However, declining serviceability, sub-standard installations and a lack of capacity building to sustain services have been common themes throughout the results of the thesis. Accountability measures are necessary to ensure cheap and poor quality services are not implemented over long term sustainability, as dictated by Malawi's national policy. An MIS as standard monitoring practice has the potential to provide the live database required to accomplish such accountability measures for previous and future water supply assets, and the maintenance services in place to sustain them.
- **Changes to salinity thresholds in water quality guidelines:** Chapter 4 demonstrated the impact of the high salinity thresholds in Malawi. Policy states that saline boreholes are defective, however, few supplies meet this criterion under current standards. These assets are not deemed problematic under current water quality guidelines. However, these assets act as a driver for community source behaviours, and under international standards (i.e. WHO) are unfit for use and a risk to health. Identifying 'defective' boreholes and risk areas can be aided by lowering Malawi's salinity thresholds to conform to WHO standards. This can also aid accountability measures for new installations, drive action towards data driven decisions and

appropriate water service delivery decisions where groundwater exploitation is unsuitable.

- **Re-thinking 'community owned and managed water supply' in policy:** The limitations of CBM are well documented in literature and the results of this thesis. Community participation is a prerequisite for sustainability. However, community ownership and management of water supply does not translate into their sustainability. This is problematic, as evidence presented on 'community owned and manged water supply' contradicts the 'sustainable provision' aspect of Malawi's policy. Rural water service delivery requires a more systematic approach that incorporates appropriate life-cycle planning and monitoring, rather than continuing the sole dissemination of management to communities. Therefore, Malawi's water policy requires reflecting the establishment of professionalised service delivery alongside community participation, if 'sustainable provision' is to be achieved.
- **Incorporating monitoring to improve service delivery as standard practice, rather than solely measuring it:** MIS has allowed for an understanding of the burden on rural communities and potential areas of need. The information collected can aid data driven decisions at the national, district and community level. This includes data driven policies to improve serviceability under decentralised services, suitable technologies for service delivery areas, climate resilient communities and understanding the casual linkages with additional community challenges (i.e. health and poverty). Furthermore, monitoring allows for assessment for spatial and temporal variations in life-cycle planning for current and new services. This includes building a greater understanding of CapManEx for Malawi and stakeholders globally. Exploring the casual factors measured through MIS allows interventions to be

considered at different stages in the life-cycle of water supply in response to factors that negatively impact service delivery.

9.4 Final Remarks

Coverage has been a fundamental aspect to the success of the MDGs, SDGs and national policies for water supply. However, the last two decades of investment have not delivered the results for the rural communities they are intended to serve. Limited capacity to accommodate the life-cycle responsibilities and challenges under decentralised management hinders long term sustainability and benefits for rural communities. Addressing the sustainability burden on decentralised rural water supply in Malawi, requires moving beyond coverage as a metric for success. The SDGs decade of action (2020-2030) requires attention towards capacity building, localising the goals, causal linking factors and risks relating to sustaining services. The principles of life-cycle costing and MIS can allow for the data driven decisions required to ensure sustainable and continued services to deliver the intended benefits to rural communities.

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APPENDIX A. mWATER SURVEY QUESTIONS

This section describes the water point survey questions used in the Water Point Functionality Survey by the Climate Justice Fund Water Futures Programme. Data was collected in the MIS mWater. The questions utilised in each thesis chapter are described in the following tables.

Table A.1 mWater Survey Questions for Chapter 4

Survey Question	**Specified Description and/or variable**
Water Point linked to this survey	• The water point by which the survey questions relate to.
Type of Water Point	• Borehole or tube well
Type of pump/lifting device	• Afridev
Date of installation	• Is between 01/01/2000 and 31/12/2016
Functional Status of the Water Point	• Functional: Water point is in good working condition and regularly provides water according the specifications in the original design. • Partially functional but in need of repair: Water point provides water on a regular basis (possibly in a reduced capacity) but repairs are needed due to some maintenance issue or change in conditions at the site. • Not functional: Water point is no longer providing water on a regular basis. This could be due to maintenance issues, changes in water availability or quality, or problems with access to the water point. • No longer exists: The water point can no longer be found at the original site or has been decommissioned.
Has the Water Point been rehabilitated?	• Yes • No • Where a rehabilitation is considered any single upgrade costing more than 1,500,000MWK.
Year which the water point was rehabilitated	• Is between 01/01/2000 and 31/12/2016
Who paid for rehabilitation?	• Community • Local Government • NGO • Politician • Religious institution • School • Water Point Committee • Other • Don’t Know

	• None
Is there a service provider responsible for the O&M of this water point?	• Yes • No • Don't Know

Table A.2 mWater Survey Questions for Chapter 5

Survey Question	**Specified Description and/or variable**
Water Point linked to this survey	• The water point by which the survey questions relate to.
Administrative Region/District of Malawi Water Point is located	• Southern (Balaka, Blantyre, Chikwawa, Chiradzulu, Machinga, Mangochi, Mulanje, Mwanza, Neno, Nsanje, Phalombe, Thyolo, Zomba) • Central (Dedza, Dowa, Kasunga, Lilongwe, Mchinji, Nkhotakota, Ntcheu, Ntchisi, Salima) • Northern (Chitipa, Karonga, Likoma, Mzimba, Nkhata Bay, Rumphi)
Type of Water Point	• Borehole or tube well
Type of pump/lifting device	• Afridev
Date of installation	• Is between 01/01/2000 and present (25/4/2019)
Functional Status of the Water Point	• Functional: Water point is in good working condition and regularly provides water according the specifications in the original design. • Partially functional but in need of repair: Water point provides water on a regular basis (possibly in a reduced capacity) but repairs are needed due to some maintenance issue or change in conditions at the site. • Not functional: Water point is no longer providing water on a regular basis. This could be due to maintenance issues, changes in water availability or quality, or problems with access to the water point. • No longer exists: The water point can no longer be found at the original site or has been decommissioned.
Is there a service provider responsible for the O&M of this water point?	• Yes • No • Don't Know
What type of service provider	• Water Point Committee • Area or Water Mechanic • Community members • Institution • Local Government • NGO • Owner/Private household • Private contractor or operator • Public operator (utilities) • Water Users Association (WUA)

Is there a tariff or user fee for water use from the improved water point?	• Yes • No
How much is the tariff/user fee? (in MWK)	• Specified value in MWK
How often is the tariff/user fee collected?	• Flat fee plus fee per unit • Per unit of water (litre, bucket, jerry can) • Per day • Per week • Per month • Per 2 months • Per quarter • Per year • When required for repairs • Don't Know
What costs were considered when setting the tariff or user fee?	• Affordability • Operations costs • Maintenance costs • Total replacement cost for the system • Set by local government • Bill payments
How many people use this water point?	• Specified value. If no answer, take the number of households using the water point and multiply by 5.
Does the service provider keep any spare parts for the water point?	• Yes • No
Is preventative maintenance performed on the water point?	• Yes • No • Sometimes

Table A.3 mWater Survey Questions for Chapter 6

Survey Question	**Specified Description and/or variable**
Water Point linked to this survey	• The water point by which the survey questions relate to.
Type of Water Point	• Borehole or tube well
Type of pump/lifting device	• Afridev
Date of installation	• Is between 01/01/2000 and present (10/10/2019)
Functional Status of the Water Point	• Functional: Water point is in good working condition and regularly provides water according the specifications in the original design. • Partially functional but in need of repair: Water point provides water on a regular basis (possibly in a reduced capacity) but repairs are needed due to some maintenance issue or change in conditions at the site. • Not functional: Water point is no longer providing water on a regular basis. This could be due to

	maintenance issues, changes in water availability or quality, or problems with access to the water point. • No longer exists: The water point can no longer be found at the original site or has been decommissioned.
Is there a service provider responsible for the O&M of this water point?	• Yes • No • Don't Know
What type of service provider	• Water Point Committee • Area or Water Mechanic • Community members • Institution • Local Government • NGO • Owner/Private household • Private contractor or operator • Public operator (utilities) • Water Users Association (WUA)
Is there a tariff or user fee for water use from the improved water point?	• Yes • No
How much is the tariff/user fee? (in MWK)	• Specified value in MWK
How often is the tariff/user fee collected?	• Flat fee plus fee per unit • Per unit of water (litre, bucket, jerry can) • Per day • Per week • Per month • Per 2 months • Per quarter • Per year • When required for repairs • Don't Know
Does the service provider keep any spare parts for the water point?	• Yes • No
Is preventative maintenance performed on the water point?	• Yes • No • Sometimes
If preventative maintenance is not conducted, what is stopping you from carrying out preventative maintenance?	• Lack of money • Lack of technical expertise • Parts not available • Lack of understanding • Other (please specify) • Don't Know
Has the Water Point been rehabilitated?	• Yes • No

	• Where a rehabilitation is considered any single upgrade costing more than 1,500,000MWK
Year which the water point was rehabilitated	• Is between 01/01/2000 and present (10/10/2019)
Have major repairs been completed on the water point in the past year?	• Yes • No • Don't Know
Which Afridev parts were repaired/replaced?	• Afridev Pump Replacement • Apron • Bobbin • Bush Bearings • Cement • Centralisers • Civil works • Cup seal • Cylinder • Foot valve • Fulcrum pin • Gasket • Gate valve • Handle • Handle pin • Hanger pin • O-ring • Pedestal • Pipe • Plunger • Pump head • Pump head cover • Rising main (PVC) • Rods • Rope • Security system • Sockets • U-seal
If rods have been replaced, how many rods were replaced?	• Specified value
Who did the repair?	• Area Mechanic • Community • Local Government • NGO • Private Contractor • Water Point Committee • Water User Association (WUA) • Other • Don't Know

How much did the repairs/upgrade cost (in MWK)?	• Less than 50,000 • 50,000-100,000 • 100,000-150,000 • 150,000-200,000 • 200,000-300,000 • 300,000-400,000 • More than 400,000

Table A.4 mWater Survey Questions for Chapter 7

Survey Question	**Specified Description and/or variable**
Water Point linked to this survey	• The water point by which the survey questions relate to.
Type of Water Point	• Borehole or tube well
Type of pump/lifting device	• Afridev
Date of installation	• Is between 01/01/2000 and present (10/10/2019)
Functional Status of the Water Point	• Functional: Water point is in good working condition and regularly provides water according the specifications in the original design. • Partially functional but in need of repair: Water point provides water on a regular basis (possibly in a reduced capacity) but repairs are needed due to some maintenance issue or change in conditions at the site. • Not functional: Water point is no longer providing water on a regular basis. This could be due to maintenance issues, changes in water availability or quality, or problems with access to the water point. • No longer exists: The water point can no longer be found at the original site or has been decommissioned
Is there a service provider responsible for the O&M of this water point?	• Yes • No • Don't Know
What type of service provider	• Water Point Committee • Area or Water Mechanic • Community members • Institution • Local Government • NGO • Owner/Private household • Private contractor or operator • Public operator (utilities) • Water Users Association (WUA)
Is there a tariff or user fee for water use from the improved water point?	• Yes • No
How much is the tariff/user fee? (in MWK)	• Specified value in MWK

How often is the tariff/user fee collected?	• Flat fee plus fee per unit • Per unit of water (litre, bucket, jerry can) • Per day • Per week • Per month • Per 2 months • Per quarter • Per year • When required for repairs • Don't Know
If there is no tariff, why is there no tariff or user fee?	• Committee has had no training • Committee has more than enough money saved for maintenance • External support • Other (please specifiy)
How many people use this water point?	• Specified value. If no answer, take the number of households using the water point and multiply by 5.
Does the service provider keep any spare parts for the water point?	• Yes • No
Is preventative maintenance performed on the water point?	• Yes • No • Sometimes
What is the current problem?	• Broken parts • Irregular supply • Low water flow (low water pressure) • Meter problem • Newly constructed • Poor water quality (salty, bad taste/colour • Other contamination) • Seasonal shortages • Structural problems (civil works) • Theft/Vandalism • Worn out parts, Other (please specify)
Are there times of the year when water is not available from this source due to seasonal variation?	• Yes • No • Don't Know
Have major repairs been completed on the water point in the past year?	• Yes • No • Don't Know
Has the Water Point been rehabilitated?	• Yes • No • Where a rehabilitation is considered any single upgrade costing more than 1,500,000MWK
Year which the water point was rehabilitated	• Is between 01/01/2000 and present (10/10/2019)

APPENDIX B. LIST OF RESEARCH PUBLICATIONS, ACTIVITIES AND ENGAGEMENTS

Table B.1 Peer-reviewed journal papers

Year	Citation
2017	Rivett, M.O., Halcrow, A.W., Schmalfuss, J., Stark, J.A., **Truslove, J.P.**, Kumwenda,S., Harawa, K.A., Nhlema, M., Songola, C., Wanangwa G.J., Miller, A.V.M. & Kalin, R.M. (2018) 'Local scale water-food nexus: Use of borehole garden permaculture to realise the full potential of rural water supplies in Malawi', Journal of Environmental Management. Elsevier Ltd, 209, pp. 354–370. doi: 290 10.1016/j.jenvman.2017.12.029
2019	**Truslove, J.P.**, Miller, A.V.M., Mannix, N., Nhlema, M., Rivett, M.O., Coulson, A.B. Mleta, P. & Kalin R.M. (2019) 'Understanding the Functionality and Burden on Decentralised Rural Water Supply: Influence of Millennium Development Goal 7c Coverage Targets', Water. Multidisciplinary Digital Publishing Institute, 11(3), p. 494. doi: 10.3390/w11030494.
2020	**Truslove, J.P.**, Coulson, A.B., Nhlema, M., Mbalame, E. & Kalin, R.M. (2020) 'Reflecting SDG 6.1 in Rural Water Supply Tariffs: Considering "Affordability" Versus "Operations and Maintenance Costs" in Malawi', Sustainability. Multidisciplinary Digital Publishing Institute, 12(2), p. 744. doi: 10.3390/SU12020744.
	Truslove, J.P., Coulson, A.B., Mbalame, E. and Kalin, R.M. (2020) 'Barriers to handpump serviceability in Malawi: life-cycle costing for sustainable service delivery', Environmental Science Water Research & Technology. Royal Society of Chemistry, 2020, 6, pp. 2138-2152. doi.org/10.1039/D0EW00283F.

Table B.2 Research field work and data collection

Date	Location	Objectives and Description
March 2017 (1 week)	Malawi	1. Establishing context for governance structure and challenges of CBM for rural water supply in Malawi. • Engagement with District Government. • Engagement with BUA leaders for communities in Chithumba and Kakoma, Chikwawa.
May-July 2017 (7 weeks)	Malawi	1. Investigate the challenges associated with maintaining rural water supply under the CBM and BUA model in Malawi. • Investigation conducted in the BUA Kakoma catchment, Chikwawa. • Surveys to WPCs and BUA members. • Identify EC and TDS levels of water produced from handpumps.

	• Investigate the successes and failures of community owned and managed permaculture to finance handpump maintenance. • Engage with Water for People and WUA board members to investigate the setup of WUAs in peri-urban areas of Malawi, to be included in a peer-reviewed publication. 2. Findings from field work to aid and refine interrogation of national data collected through the mWater platform, to evaluate the sustainability of community management rural water supply.

Table B.3 Poster presentations

Year	**Event**
2016	Truslove, J.P. (2016) 'Methodology Framework for Assessing Rural Water Supply in Developing Countries, Chartered Institution of Water and Environmental Management (CIWEM) Scottish Water Research Poster Competition, 30th November 2016.
2017	Truslove, J.P. (2017) "Exploring the Sustainability of Water Points through Local Circular Economy and Preventative Maintenance for Rural Community Integrated Water Resources Management in Malawi". Early Careers Hydrogeologists' Conference, University of Strathclyde, 1st September 2017.
2018	Truslove, J.P., Small, H., Nhlema, M., Harawa, K. A., Coulson, A. B. and Kalin, R (2018) "An investigation of community pooled resources for sustainable handpump maintenance: The relationship between water user participation and saline water", Water and Health: Where Science Meets Policy 2018, University of North Carolina, 29th October – 2nd November 2018.
2019	Truslove, J.P. (2019) 'Falling short of "sustainable access", why coverage is a poor metric for success in SDG 6.1'. Early Careers Hydrogeologists' Conference, University of Leeds, poster presentation 25th October 2019

Table B.4 Oral Presentations

Year	**Event**
2017	'Local Circular Economy and Preventative Maintenance for Rural Communities Integrated Water Resource Management in Malawi', First Year PhD Conference, University of Strathclyde, 25th October 2017
2018	'Local Circular Economy and Preventative Maintenance for Rural Communities Integrated Water Resource Management in Malawi', Malawi Delegate's visit to Scotland hosted by Climate Justice Fund: Water Futures Programme, University of Strathclyde, 26th January 2018
2018	The Scottish Engineering Leadership Award 2017-2018. Invitation to present at a question and answer session on engineering disciplines at Grange Primary School, 22nd March 2018
2018	'Local Circular Economy and Preventative Maintenance for Rural Communities Integrated Water Resource Management in Malawi', Malawi Delegate's visit to Scotland hosted by Climate Justice Fund: Water Futures Programme, University of Strathclyde, 23rd April 2018

2018	Earth Day, Glasgow City Chambers. Invitation for oral presentation and panel discussion on Climate Justice, climate adaptation and resilience, and sustainable development, 20th April 2018
2018	'Sustainable Cost Modelling for Preventative Maintenance of Water Points: The Maintenance Burden of Rural Water Supply Infrastructure', Malawi Delegate's visit to Scotland hosted by Climate Justice Fund: Water Futures Programme, University of Strathclyde, 16th July 2018

Table B.5 Conference attendance

Year	Event
2017	(29th March) Strathclyde Vertically Integrated Project (VIP) for Sustainable Development Conference
2017	(1st September) Early Careers Hydrogeologists' Conference, University of Strathclyde
2018	(28th March) Strathclyde Vertically Integrated Project (VIP) for Sustainable Development Conference
2018	(20th April) Earth Day, Glasgow City Chambers & University of Glasgow.
2018	(6th June) StrathWide 2018 - 2nd Annual Strathclyde Research Conference.
2018	(26th October) Global Engineering Congress 2018, Institution of Civil Engineers.
2018	(29th October – 2nd November) Water and Health: Where Science Meets Policy 2018, University of North Carolina.
2019	(27th April) Strathclyde Vertically Integrated Project (VIP) for Sustainable Development Conference
2019	(25th October) Early Careers Hydrogeologists' Conference, University of Leeds.