Environmental Science Water Research & Technology

PAPER

View Article Online
View Journal | View Issue

Cite this: *Environ. Sci.: Water Res. Technol.*, 2020, **6**, 2138

Barriers to handpump serviceability in Malawi: life-cycle costing for sustainable service delivery†

Jonathan P. Truslove, *[a] Andrea B. Coulson, [b] Emma Mbalame[c] and Robert M. Kalin [a]

Received 28th March 2020,
Accepted 26th June 2020

DOI: 10.1039/d0ew00283f

rsc.li/es-water

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 handpumps. 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.

Water impact

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.

1. 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.[1] However, these coverage statistics hide low levels of service and a decline in functionality as systems depreciate.[2–5] 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).[6] 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.[7] The principles of VLOM and handpump standardisation have since been embraced by national policies and sector strategies during the global goals,[6] 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).[8,9] The model is aimed to benefit and empower communities,[10] relies on voluntary participation and the coverage of 100% of O&M costs. The

[a] *Department of Civil and Environmental Engineering, University of Strathclyde, Glasgow G1 1XJ, UK. E-mail: jonathan.truslove@strath.ac.uk, robert.kalin@strath.ac.uk*
[b] *Department of Accounting and Finance, University of Strathclyde, Glasgow G4 0QU, UK. E-mail: a.b.coulson@strath.ac.uk*
[c] *Ministry of Agriculture, Irrigation and Water Development, Government of Malawi, Tikwere House, Lilongwe, Malawi. E-mail: emmambalame@gmail.com*

† Electronic supplementary information (ESI) available. See DOI: 10.1039/d0ew00283f

concept has been widely acknowledged to be an idealistic approach to service delivery that cannot realistically achieve sustainable and reliable services.[11–14]

The implementation of shorter life VLOM handpump solutions to deliver services sooner than later has been a high priority during the MDGs.[15] 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.[16] Handpumps tend to last only 3 to 5 years before premature failure rather than their estimated 15 to 20 year design life,[17,18] with approximately 2 out of 3 handpumps operate at a given time across SSA.[3] 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.[19–21] 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.[4] The original investments and benefits of increasing the coverage of improved supplies are therefore lost for the communities they are intended to serve.[22]

The Afridev handpump, is the most recognised VLOM handpump and the standard in Malawi,[6] where 'village men and women can maintain deep well handpumps, can be locally produced and can still be affordable and reliable'.[23] 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.[16,23] The interventions of preventative maintenance reduce the cost of premature failure and reduce the downtime of service delivery compared to reactive approaches to maintenance.[15] Furthermore, the replacement of handpump components across the shorter life-cycle, compared to a well or borehole, can keep water services working continuously.[7] However, VLOM technologies have not been successful in resolving the maintenance and management issues of CBM that contribute to reduced functionality.[24,25] 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.[26–28]

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.[12,13,29,30] Communities rarely accept true ownership of a system as it is perceived responsibility lies with the implementing government or donor,[31] as O&M costs are frequently deemed 'somebody else's problem'.[3] 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.[12,32] The reality is the community management of water supply requires professionalism and long term external support for sustainable success.[8] 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,[15,16] as focus remains on the short term goals of providing new water facilities.[3] 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.[11,12,14,24,27,33] 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.[3,4,24]

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.

2. Materials and methods

2.1 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.*[20]). 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). 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.[16] As Malawi operates under the CBM approach, service providers under the CBM model (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 interval of wearing parts.[23] Estimated costs of the Afridev were gathered from 6 suppliers and estimators in Malawi.

2.2 Management scenario design

Tariffs are the main financial mechanism for the maintenance of rural water supply assets through the collection of users fees or household contributions.[34,35] 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.[35] 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.[36,37] The distribution of the number of potentially contributing households and the tariff amount under each scenario was investigated. A detailed outline of the tariff scenarios and the conduction of preventative maintenance can be found in the ESI.†

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.[38] 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.[20]

• Non-functionality describes a water point not producing water at the time of audit.

2.3 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.[39] This is most useful for single asset systems, such as handpumps, for considering future investments and alternatives for delivering services.[17] 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 an assumed cost of transport costs and contracts for area mechanics to conduct repairs.[35] 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 the ESI.† The model results were incorporated into the mWater dataset.

2.4 Data analysis

The life-cycle of the Afridev is approximately 10 to 15 years, however this can be affected by many factors.[23] Bonsor *et al.*[40] 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 identifies the current issues reported at the water point at the time of audit. 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.

3. Results

3.1 Functionality over life-cycle of the Afridev

The life expectancy of a well or borehole typically exceeds 25 years,[41] while the lifting mechanisms typically have significantly shorter life-spans.[15] 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. Fig. 1 presents the number of recommended replacements of Afridev components across the life-cycle for the worst and best case. 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 1.

A preventative maintenance approach involves the replacement of components before their eventual failure. Fig. 1 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.[18] This is reflected in Fig. 1 as rods and rising main sections typically have a life-cycle of 3 to 5 years[23] 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

Fig. 1 (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.

Table 1 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

case in the sixth year of service. However, Fig. 1 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 Fig. 1 and Table 1. 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 highlight this issue. 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. The presence of a tariff to fund O&M for continued serviceability has a notable impact between the two scenarios.

Fig. 1 and Table 1 describe scenario D as the least effective over the design life of maintaining functional water supply. Scenario A, which conforms to Malawian government guidelines,[35] is described as the most effective as for maintaining functionality. Functionality alone is only the starting point in defining the multi-dimensional issue of service delivery.[38,40] 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,[13] without which decline in service and issues of infrastructure can occur.

3.2 Identifying the importance of life-cycle issues within functionality

The issues of functionality are multi-layered, including variables such as financial, managerial, political and environmental.[25,38,40] Fig. 2 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.

Across Fig. 2, 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.[4,15,25,42,43]

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 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.[44–47] 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 the issue of infrastructure, Fig. 1 described the influence 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,[27,48,49] and predicting functionality.[13,25] Considering how service providers meet the life-cycle needs

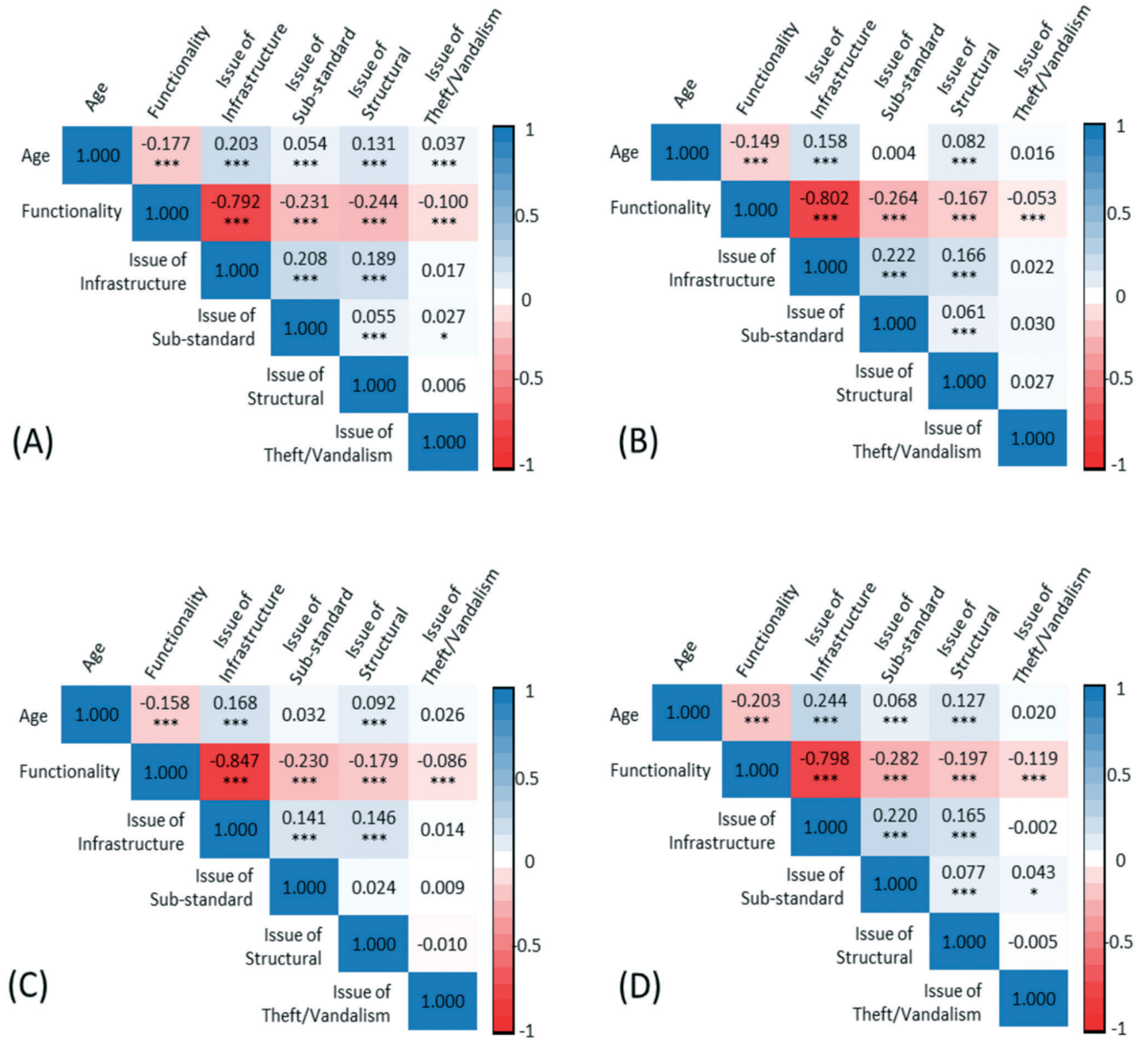

Fig. 2 Correlation matrix showing relationship water point life-cycle characteristics (as binary outcomes) and age within a 15 year design life. Scenario A (top left), scenario B (top right), scenario C (bottom left) and scenario D (bottom right). * Pearson correlation is significant at 0.05. ** Pearson correlation is significant at 0.01. *** Pearson correlation is significant at 0.001.

of infrastructure in a service delivery approach is necessary when moving from a snapshot functionality estimation to continued sustainability of water supply.

3.3 Logistic regression

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 2 presents the descriptive statistics for the logistic regression, Table 3 presents the results for scenario A, Table 4 for scenario B, Table 5 for scenario C and Table 6 for scenario D. The results of the life-cycle cost model was not included in the logistic regression analysis for scenario D.

Table 2 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	—	—

3.3.1. 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 Fig. 2, there is no significant relationship between the other drivers of functionality.

3.3.2. 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.[15] This could also be attributed

Table 3 Scenario A: unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n = 8294)

		Unadjusted			Multivariable adjusted model 1 (R.R)			Multivariable adjusted model 2 (T.OpEx)		
Explanatory variables		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 ($p < 0.05$).

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 Fig. 1, 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.

3.3.3. Forecasted shortfall of financial resources. The forecasted shortfall in Tables 3–5 present a significant association with an issue of infrastructure in the unadjusted and multivariable adjusted models, with the exception R.R multivariable models for scenario A (Table 3) 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

Table 4 Scenario B: unadjusted and multivariable adjusted binary logistic regression where infrastructure issue is reported for boreholes equipped with Afridev handpumps (n = 3743)

		Unadjusted			Multivariable adjusted model 1 (R.R)			Multivariable adjusted model 2 (T.OpEx)		
Explanatory variables		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 sin 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 5 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 ($p < 0.05$).

may other underlying factors that impact either the premature failure of components or the collection of financial resources for O&M. Under scenario C (Table 5), 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 4). 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 for T.OpEx models across the three scenarios (Tables 3–5). 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

Table 6 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 ($p < 0.05$).

infrastructure occurring following a shortfall of financial resources, that increases with the more costs that are considered.

4. 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.

4.1 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.[35] 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.[30,46,48,50,51] 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.[27] The importance of proactive approaches to financial collection has been highlighted by the logistic regression. The results suggest for reactive tariff collection (Table 4), when no preventative maintenance is conducted the likelihood of issues of infrastructure increases compared to when it is conducted. The likelihood in proactive approaches (Tables 3 and 5) are lower or not significant in this case. This suggest proactive collections allow for crucial O&M and fast repairs to be conducted, reducing downtime of water supply.

Notably, keeping spare parts 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,[25,52,53] however the viability of establishing such supply chains is a challenge.[9,54] Limited access to supply chains inevitably increases water point downtime and incurs additional travel costs. Fast repair and reduced downtime contribute towards the reliability of a system.[55]

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 expresses significantly lower odds of an issue of infrastructure occurring than in the southern region. Furthermore, Table 2 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.

4.2 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.[2]

Depreciation as assets age inevitably requires major repairs or rehabilitation to maintain an operational level of service across the life-cycle.[16] Further, the importance of O&M reduces the risk of premature failure in the first 5 years under CBM approaches.[18] 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 (Fig. 1). Age therefore constitutes a negative relationship with the functionality of assets, leading to wearing components (Fig. 2). The relationship between the age of infrastructure and decline in functionality is further supported by evidence throughout literature.[4,18,25,42,56,57]

Functionality has previously been discussed as multi-dimensional that is representative of issues at the time of audit.[38,40] 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-cycle must be understood to achieve sustainable services.

When water points are constructed well, they can last for years without issue.[4] 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.[52,58,59] 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.[19] This imposes a negative impact on sustainability, as users are reluctant or unable to contribute towards maintaining unreliable or poor quality resources.[13,51] 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.[59,60] Sub-standard infrastructure fundamentally has a negative effect of the overall functionality of water supply (Fig. 2). Increasing the likelihood of Afridev life-cycle issues occurring (Tables 3–6), 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.

4.3 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 3), the likelihood of an infrastructure issue occurring is lower than the results expressed in Table 5. 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 (see ESI†), 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 4 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 (Fig. 1).

The increased costs result in earlier shortfall and subsequently increase 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.

4.4 Implications for policy and practice

The results of this paper has implications for wider practice and policy. First, is concerning global targets and progress towards the SDGs. Localising the SDGs is increasingly important to fulfil the 2030 agenda.[61] 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.[2,4,5,20,50] This hinders the progress of the wider SDG agenda due to the synergies between the goals.[62,63] It is therefore essential that focus on the coverage of water supply move towards effective service delivery and sustainable O&M services.[25] 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".[64] 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.[19,65,66] Capacity building into life-cycle management is crucial for handpump sustainability that includes spare part access,[53] and proven maintenance systems established alongside infrastructure.[31,67] 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.[20,22]

Finally, rather than solely measuring performance, monitoring rural water supply should strive to improve it.[55] 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 study to collect the water point and management data. Nussbaumer *et al.*[68] 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,[17] supporting the environment for the routine monitoring of assets that allows for improvements in service delivery quality.[69] 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.

4.5 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 supplies. 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,[17] 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, multiple-source use and multiple use sources. 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.

5. 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 to 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.

Conflicts of interest

There are no conflicts of interest to declare.

Acknowledgements

We gratefully acknowledge the funding of this research by the Scottish Government under the Scottish Government Climate Justice Fund Water Futures Programme research grant HN-CJF-03 awarded to the University of Strathclyde. We thank continued direct collaboration with our partner the Government of Malawi Ministry of Agriculture, Irrigation and Water Development (MoAIWD), and implementation partners United Purpose, World Vision, CADECOM, CARE, BAWI and Water for People for their support. In particular, the authors would like to thank BASEFlow for their ongoing technical and logistical support.

References

1 WHO/UNICEF, *Progress on Sanitation and Drinking Water – 2015 Update and MDG Assessment*, World Heal. Organ., 2015, p. 90.

2 M. Adank, J. Butterworth, S. Godfrey and M. Abera, Looking beyond headline indicators: water and sanitation services in small towns in Ethiopia, *J. Water, Sanit. Hyg. Dev.*, 2016, **6**, 435–446.

3 RWSN Executive Steering Committee, *Myths of the Rural Water Supply Sector*, St Gallen, Switzerland, 2010.

4 J. P. Truslove, A. V. M. Miller, N. Mannix, M. Nhlema, M. O. Rivett, A. B. Coulson, P. Mleta and R. M. Kalin, Understanding the Functionality and Burden on Decentralised Rural Water Supply: Influence of Millennium Development Goal 7c Coverage Targets, *Water*, 2019, **11**, 494.

5 P. Martínez-Santos, Does 91% of the world's population really have 'sustainable access to safe drinking water'?, *Int. J. Water Resour. Dev.*, 2017, **33**, 514–533.

6 J. Macarthur, *Handpump Standardisation in Sub-Saharan Africa Seeking a champion*, RWSN, St Gallen, Switzerland, 2015.

7 S. Arlosoroff, G. Tschannerl, D. Grey, J. William, A. Karp, O. Langenegger and R. Roche, *Community water supply : the handpump option*, World Bank, Washington, DC, 1987.

8 P. Hutchings, M. Y. Chan, L. Cuadrado, F. Ezbakhe, B. Mesa, C. Tamekawa and R. Franceys, A systematic review of success factors in the community management of rural water supplies over the past 30 years, *Water Policy*, 2015, **17**, 963–983.

9 H. Lockwood and S. Smits, *Supporting Rural Water Supply moving towards a Service Delivery Approach*, Practical Action Publishing Ltd., Rugby, 2011.

10 J. Briscoe and D. de Ferranti, *Water for Rural Communities - Helping People Help Themselves*, The World Bank, Washington D.C, 1988.

11 P. Moriarty, S. Smits, J. Butterworth and R. Franceys, Trend in rural water supply: Towards a service delivery approach, *Water Altern.*, 2013, **6**, 329–349.

12 L. Whaley and F. Cleaver, Can 'functionality' save the community management model of rural water supply?, *Water Resour. Rural. Dev.*, 2017, **9**, 56–66.

13 L. Whaley, D. J. MacAllister, H. Bonsor, E. Mwathunga, S. Banda, F. Katusiime, Y. Tadesse, F. Cleaver and A. MacDonald, Evidence, ideology, and the policy of community management in Africa, *Environ. Res. Lett.*, 2019, **14**, 085013.

14 P. A. Harvey and R. A. Reed, Community-managed water supplies in Africa: sustainable or dispensable?, *Community Dev. J.*, 2006, **42**, 365–378.

15 C. Fonseca, S. Smits, K. Nyarko, A. Naafs and R. Franceys, *Financing capital maintenance of rural water supply systems: current practices and future options*, 2013.

16 R. Franceys and C. Pezon, *Services are forever: The importance of capital maintenance (CapManEx) in ensuring sustainable WASH services Briefing Note 1b*, The Hague, The Netherlands, 2010.

17 C. Fonseca, R. Franceys, C. Batchelor, P. Mcintyre, A. Klutse, K. Komives, P. Moriarty, A. Naafs, K. Nyarko, C. Pezon, A. Potter, R. Reddy and M. Snehalatha, *Life-cycle costs approach: costing sustainable services*, 2011.

18 E. Baumann, Do operation and maintenance pay?, *Waterlines*, 2006, **25**, 10–12.

19 H. Bonsor, N. Oates, P. Chilton, R. C. Carter, V. Casey, A. MacDonald, R. Calow, R. Alowo, P. Wilson, M. Tumutungire and M. Bennie, *A Hidden Crisis: strengthening the evidence base on the sustainability of rural groundwater supplies-results from a pilot study in Uganda*, 2015.

20 R. M. Kalin, J. Mwanamveka, A. B. Coulson, D. J. C. Robertson, H. Clark, J. Rathjen and M. O. Rivett, Stranded Assets as a Key Concept to Guide Investment Strategies for Sustainable Development Goal 6, *Water*, 2019, **11**, 702.

21 D. J. Lapworth, A. M. MacDonald, S. Kebede, M. Owor, G. Chavula, H. Fallas, P. Wilson, J. S. T. Ward, M. Lark, J. Okullo, E. Mwathunga, S. Banda, G. Gwengweya, D. Nedaw, S. Jumbo, E. Banks, P. Cook and V. Casey, Drinking water quality from rural handpump-boreholes in Africa, *Environ. Res. Lett.*, 2020, **15**, 64020.

22 P. R. Hunter, A. M. MacDonald and R. C. Carter, Water Supply and Health, *PLoS Med.*, 2010, **7**, e1000361.

23 K. ERPF, *Afridev: Installation and Maintenance Manual for the Afridev Handpump, (Revision 2-2007)*, Rural Water Supply Network, St Gallen, Switzerland, 2007, vol. 2.

24 E. Baumann and S. Furey, *How Three Handpumps Revolutionised Rural Water Supplies A brief history of the India Mark II/III, Afridev and the Zimbabwe Bush Pump Rural Water Supply Network Field Note No 2013-1*, St Gallen, Switzerland, 2013.

25 T. Foster, Predictors of Sustainability for Community-Managed Handpumps in Sub-Saharan Africa: Evidence from Liberia, Sierra Leone, and Uganda, *Environ. Sci. Technol.*, 2013, **47**, 12037–12046.

26 T. Kativhu, D. Mazvimavi, D. Tevera and I. Nhapi, Implementation of Community Based Management (CBM) in Zimbabwe: The dichotomy of theory and practice and its influence on sustainability of rural water supply systems, *Phys. Chem. Earth*, 2018, **106**, 73–82.
27 E. Chowns, Is Community Management an Efficient and Effective Model of Public Service Delivery? Lessons from the Rural Water Supply Sector in Malawi, *Public Adm. Dev.*, 2015, **35**, 263–276.
28 D. Etongo, G. H. Fagan, C. Kabonesa and R. B. Asaba, Community-Managed Water Supply Systems in Rural Uganda: The Role of Participation and Capacity Development, *Water*, 2018, **10**, 1271.
29 P. Blaikie, Is Small Really Beautiful? Community-based Natural Resource Management in Malawi and Botswana, *World Dev.*, 2006, **34**, 1942–1957.
30 M. van den Broek and J. Brown, Blueprint for breakdown? Community Based Management of rural groundwater in Uganda, *Geoforum*, 2015, **67**, 51–63.
31 P. Morgan, Maintenance, the key to handpump survival, *Waterlines*, 1993, **11**, 2–4.
32 B. Evans and P. Appleton, *Community Management Today: The Role of Communities in the Management of Improved Water Supply Systems*, Delft, The Netherlands, 1993.
33 J. P. Truslove, A. B. Coulson, M. Nhlema, E. Mbalame and R. M. Kalin, Reflecting SDG 6.1 in Rural Water Supply Tariffs: Considering 'Affordability' Versus 'Operations and Maintenance Costs' in Malawi, *Sustainability*, 2020, **12**, 744.
34 United Nations, *Sustainable Development Goal 6 Synthesis Report on Water and Sanitation*, United Nations, New York, 2018.
35 MoAIWD, *Rural Water Supply Operation and Maintenance Series 1: Community Based Management (O&M Refresher Course) Training Manual*, Ministry of Agriculture, Irrigation and Water Development, Lilongwe, 2015.
36 FAO, *Review of food and agricultural policies in Malawi*, Rome, Italy, 2015.
37 F. Ellis and E. Manda, Seasonal Food Crises and Policy Responses: A Narrative Account of Three Food Security Crises in Malawi, *World Dev.*, 2012, **40**, 1407–1417.
38 R. C. Carter and I. Ross, Beyond 'functionality' of handpump-supplied rural water services in developing countries, *Waterlines*, 2016, **35**, 94–110.
39 D. G. Woodward, Life cycle costing-theory, information acquisition and application, *Int. J. Proj. Manag.*, 1997, **15**, 335–344.
40 H. Bonsor, A. MacDonald, V. Casey, R. Carter and P. Wilson, The need for a standard approach to assessing the functionality of rural community water supplies, *Hydrogeol. J.*, 2018, **26**, 367–370.
41 F. Driscoll, *Groundwater and Wells*, Johnson Screens, St. Paul, Minnesota, 2nd edn, 1986.
42 M. B. Fisher, K. F. Shields, T. U. Chan, E. Christenson, R. Cronk, H. Leker, D. Samani, P. Apoya, A. Lutz and J. Bartram, Understanding handpump sustainability: Determinants of rural water source functionality in the Greater Afram Plains region of Ghana, *Water Resour. Res.*, 2015, **51**, 8431–8449.
43 E. Baumann and K. Danert, *Operation and Maintenance of Rural Water Supplies in Malawi Study Findings*, 2008, pp. 1–60.
44 L. Olaerts, J. Walters, K. Linden, A. Javernick-Will and A. Harvey, Factors Influencing Revenue Collection for Preventative Maintenance of Community Water Systems: A Fuzzy-Set Qualitative Comparative Analysis, *Sustainability*, 2019, **11**, 3726.
45 T. Kativhu, D. Mazvimavi, D. Tevera and I. Nhapi, Factors influencing sustainability of communally-managed water facilities in rural areas of Zimbabwe, *Phys. Chem. Earth*, 2017, **100**, 247–257.
46 T. Foster and R. Hope, A multi-decadal and social-ecological systems analysis of community waterpoint payment behaviours in rural Kenya, *J. Rural Stud.*, 2016, **47**, 85–96.
47 T. Foster and R. Hope, Evaluating waterpoint sustainability and access implications of revenue collection approaches in rural Kenya, *Water Resour. Res.*, 2017, **53**, 1473–1490.
48 D. Whittington, J. Davis, L. Prokopy, K. Komives, R. Thorsten, H. Lukacs, A. Bakalian and W. Wakeman, How well is the demand-driven, community management model for rural water supply systems doing? Evidence from Bolivia, Peru and Ghana, *Water Policy*, 2009, **11**, 696.
49 R. C. Carter, E. Harvey and V. Casey, *User financing of rural handpump water services*, IRC Symp., 2010.
50 S. Vedachalam, L. H. MacDonald, S. Shiferaw, A. Seme, K. J. Schwab and O. behalf of P. investigators, Underreporting of high-risk water and sanitation practices undermines progress on global targets, *PLoS One*, 2017, **12**, e0176272.
51 J. Tucker, A. MacDonald, L. Coulter and R. C. Calow, Household water use, poverty and seasonality: Wealth effects, labour constraints, and minimal consumption in Ethiopia, *Water Resour. Rural. Dev.*, 2014, **3**, 27–47.
52 T. Foster, J. Willetts, M. Lane, P. Thomson, J. Katuva and R. Hope, Risk factors associated with rural water supply failure: A 30-year retrospective study of handpumps on the south coast of Kenya, *Sci. Total Environ.*, 2018, **626**, 156–164.
53 Y. A. Baraki and A. C. Brent, Technology transfer of hand pumps in rural communities of Swaziland: Towards sustainable project life cycle management, *Technol. Soc.*, 2013, **35**, 258–266.
54 P. A. Harvey and R. A. Reed, Sustainable supply chains for rural water supplies in Africa, *Proc. Inst. Civ. Eng. - Eng. Sustain.*, 2006, **159**, 31–39.
55 P. Thomson and J. Koehler, Performance-oriented Monitoring for the Water SDG – Challenges, Tensions and Opportunities, *Aquat. Procedia*, 2016, **6**, 87–95.
56 R. Cronk and J. Bartram, Factors Influencing Water System Functionality in Nigeria and Tanzania: A Regression and Bayesian Network Analysis, *Environ. Sci. Technol.*, 2017, **51**, 11336–11345.
57 T. Klug, R. Cronk, K. F. Shields and J. Bartram, A categorization of water system breakdowns: Evidence from Liberia, Nigeria, Tanzania, and Uganda, *Sci. Total Environ.*, 2018, **619–620**, 1126–1132.
58 E. Kelly, K. F. Shields, R. Cronk, K. Lee, N. Behnke, T. Klug and J. Bartram, Seasonality, water use and community management of water systems in rural settings: Qualitative

evidence from Ghana, Kenya, and Zambia, *Sci. Total Environ.*, 2018, **628–629**, 715–721.

59 D. J. MacAllister, A. M. MacDonald, S. Kebede, S. Godfrey and R. Calow, Comparative performance of rural water supplies during drought, *Nat. Commun.*, 2020, **11**, 1–13.

60 T. Foster and J. Willetts, Multiple water source use in rural Vanuatu: are households choosing the safest option for drinking?, *Int. J. Environ. Health Res.*, 2018, **28**, 579–589.

61 Editorial, Delivering on sustainable development, *Nat. Sustain.*, 2019, 2, 783.

62 B. Mainali, J. Luukkanen, S. Silveira and J. Kaivo-oja, Evaluating Synergies and Trade-Offs among Sustainable Development Goals (SDGs): Explorative Analyses of Development Paths in South Asia and Sub-Saharan Africa, *Sustainability*, 2018, **10**, 815.

63 C. Kroll, A. Warchold and P. Pradhan, Sustainable Development Goals (SDGs): Are we successful in turning trade-offs into synergies?, *Palgrave Commun.*, 2019, **5**, 140.

64 MoAIWD, *National Water Policy*, Lilongwe, 2005.

65 D. Mcnicholl, R. Hope and A. Money, *Performance-based Funding for Reliable Rural Water Services in Africa*, 2019.

66 M. A. Montgomery, J. Bartram and M. Elimelech, Increasing Functional Sustainability of Water and Sanitation Supplies in Rural Sub-Saharan Africa, *Environ. Eng. Sci.*, 2009, **26**, 1017–1023.

67 T. Foster, B. McSorley and J. Willetts, Comparative performance evaluation of handpump water-supply technologies in northern Kenya and The Gambia, *Hydrogeol. J.*, 2019, **27**, 535–551.

68 D. Nussbaumer, I. Sutton, A. Parker, D. Nussbaumer, I. Sutton and A. Parker, Groundwater Data Management by Water Service Providers in Peri-Urban Areas of Lusaka, *Water*, 2016, **8**, 135.

69 N. Dickinson, F. Knipschild and P. Magara, *Harnessing Water Point Data To Improve Drinking Water Services*, 2017.