An analysis of hand pump boreholes functionality in Malawi

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Abstract

A survey on the functionality of boreholes equipped with hand pumps was undertaken in five districts in Malawi in 2016. The survey aimed at developing a robust evidence-base of the performance of hand pump boreholes by applying a tiered assessment of functionality: (1) working at the time of survey (2) producing the design yield of the borehole; (3) working for >11 months per year and (4) delivering water quality requirements from the World Health Organisation (WHO). This information would guide sustainable future investments in water and sanitation projects. A stratified two-stage random sampling strategy was adopted. The results from the survey indicate that 74% of hand pump boreholes (HPBs) were working at the time of survey; 66% of HPBs passed the design yield of 10 liters per minute; 55% met the design yield and also experienced less than one month downtime within a year. Only 43% of HPBs met all the functionality requirements including World Health Organisation (WHO) guidelines for drinking water quality. The survey also assessed the village-level Water Management Arrangements at each water point. Results indicate that the majority of the Water Management Arrangements (86%) are functional or highly functional. The initial exploration of the data shows no simple relationship between the physical functionality and Water Management Arrangements.

Key words

Borehole, Functionality, Groundwater, Hand pump, Malawi

1. Introduction

Groundwater provides an estimated 36% of all global domestic water and 42% of agricultural water (Döll et al. 2012) and use is likely to increase due to economic and population growth and climate change (Taylor et al. 2013). Groundwater is a primary source of water for over 70% of the 250 million people living in Southern African Development Community (SADC) region (SADC, 2014). The economy for Malawi largely depends on agriculture. Approximately 80–90% of Malawi's population of 17 million live in rural areas (MoIWD, 2008; GOM/MWP, 2008) and developing water resources is central to socio-economic development (Chiluwe and Nkhata, 2014). Groundwater is widely used across Malawi for both domestic and agricultural purposes (Chavula, 2018). The majority of the people in the rural areas in Malawi significantly depend on groundwater through boreholes and dug wells. According to Sajidu et al., (2013), over 60% of the rural population derive their domestic water requirements from groundwater. The first groundwater development started in the 1930's (MoAIWD, 2017). Boreholes and shallow wells with hand pumps are a relatively low cost method for domestic water supply and generally managed and maintained by communities, often through water user groups. Widespread installation of community boreholes with handpumps started in the 1970s and 80s and continues today. The Sustainable Development Goals (SDGs) have set an agenda for transformational change in water access aiming for secure household connections; however, communal groundwater supplies are likely to remain the main source of improved water supplies for many rural areas in Africa and South Asia for decades to come (Bonsor et al. 2018).

Although groundwater comprises by far the largest water resource in Africa (MacDonald et al. 2012) it has received less attention compared to surface water in terms of governance structures, infrastructure development, research and monitoring (Mechlem, 2016). The status of groundwater infrastructure in Malawi is variable and in many cases, hand pump water sources have broken down sooner than their anticipated design life. In a study conducted in Blantyre district in Malawi (Njalam'mano, 2007), 17% of the wells equipped with hand pumps were out of order. The causes of the hand pump failure are little known.

According to Carter (2016), a commonly quoted estimate of hand pump functionality in some African countries is around 60–65%, a figure which is usually judged to be unacceptably low. Bonsor et al. (2018) reported that estimates of the number of non-functional water points vary from 15 to 50% at any one time between different studies and that this has been the case since 1970s. Poor functionality of water points threatens to undermine progress, and a lack of knowledge of the reasons behind this makes it difficult to recommend improvements and take corrective action. Adding to the challenge of understanding the performance of rural water supplies is the inconsistent definition of what constitutes a functional borehole. Bonsor et al. (2018) reported that the term functionality is often used as a measurable indicator of whether a water point is working at the time of inspection or not, yet this is just one of the six approaches to defining water point functionality. Carter and Ross (2016) also argued that a single binary (functional/non-functional) indicator is insufficient to provide much information about service sustainability.

There is therefore a need to have a standardized approach to assessing functionality to allow for comparison of data from different locations and different times (Bonsor, et al. 2018). It is necessary to be able to reliably monitor current rates of functionality and to have a clear benchmark as to what constitutes a functional water point. Currently, there is no single accepted definition for functionality, although organisations are working towards this as a means of tracking progress towards the SDGs. In this paper we use a tiered definition of functionality developed by the Hidden Crisis project (Bonsor et al. 2018) to develop statistics on the performance of hand pump boreholes in Malawi (Mwathunga et al. 2017).

2. Materials and Methods

The survey of boreholes equipped with hand pumps (HPBs) was undertaken within sedimentary and basement rock in 2016 in Malawi. The aim was to establish data on the different levels of functionality performance of hand-pump equipped boreholes and the performance of the local water management committees. The survey was conducted from 1 September to 9 December in 2016. The survey comprised a total of 200 boreholes across five districts namely: Balaka, Lilongwe Rural, Machinga, Mzimba and Nkhotakota (Figure 1). Physical characteristics of the Districts included in the Survey are summarised in Table 1.

Table 1 – Physical characteristics of the surveyed districts.

District	Distance from Lilongwe (km)	Av. Elevation (mamsl)	Mean annual rainfall (mm)	Mean annual temp. (ºC)	Dry months	Main geology mapped at surface (Persits et al. 2002)
Balaka	185	620	840	23.1	May-Sept	Basement
Lilongwe Rural	50	1100	734	20.3	May-Oct	Basement
Machinga	225	710	844	22.1	May-Sept	Unconsolidated sediments
Mzimba	240	1200	51	20.1	May-Oct	Basement
Nkhotakota	150	480	48	20.2	May-Oct	Basement

2.1 Site selection

The water points in the survey were chosen by a stratified three-stage random sampling design (Mwathunga et al. 2017). The first stage enables random selection of the districts the survey would be conducted in, then secondly the communities to work in within these districts, and thirdly the water point which was sampled in the communities (if more than one HPB). This approach was used to select 200 HPBs for the survey. Districts were used as primary units and chosen from strata defined with respect to:

- Hydrogeology (sedimentary, basement, volcanic);
- Climate (wet or dry). Based on number of wet months and the total annual rainfall. Climate was classified to be WET if average annual rainfall >800 mm/year, and less than 4 months per year where rainfall <25 mm.
- Poverty (above or below country median). Based on if more than 50% of the population is above or below country median poverty index.

Additional criteria were first applied: (1) the districts must have a minimum of 100 hand pump boreholes, to ensure sufficient sample size pool and reduce bias; and, (2) are accessible to sample (based on ease of access to communities via WaterAid and local partners). Existing national data on Water Point Functionality were then used to optimise the combination and number of strata for the sampling. Table 2 shows the data collected for each district across the three countries to inform the strata.

This stratification improved the sampling efficiency. The relative size of each stratum was calculated using national survey data on water points, and the number of districts to sample scaled accordingly. Using the most efficient stratification, five districts were chosen to work in within Malawi.

Table 2 – Key data sources used to inform the sample stratification

District Data	Data source
Population (rural population)	National Government census data
Number of HPBs	National Government WASH inventories and monitoring
	District Water Offices and
Hydrogeology	Africa Groundwater Atlas - National hydrogeological maps and additional national/regional information and references
Climate	Global datasets – Climatic Research Unit (CRU)
Poverty	National Government statistical offices
	World Resources Institute

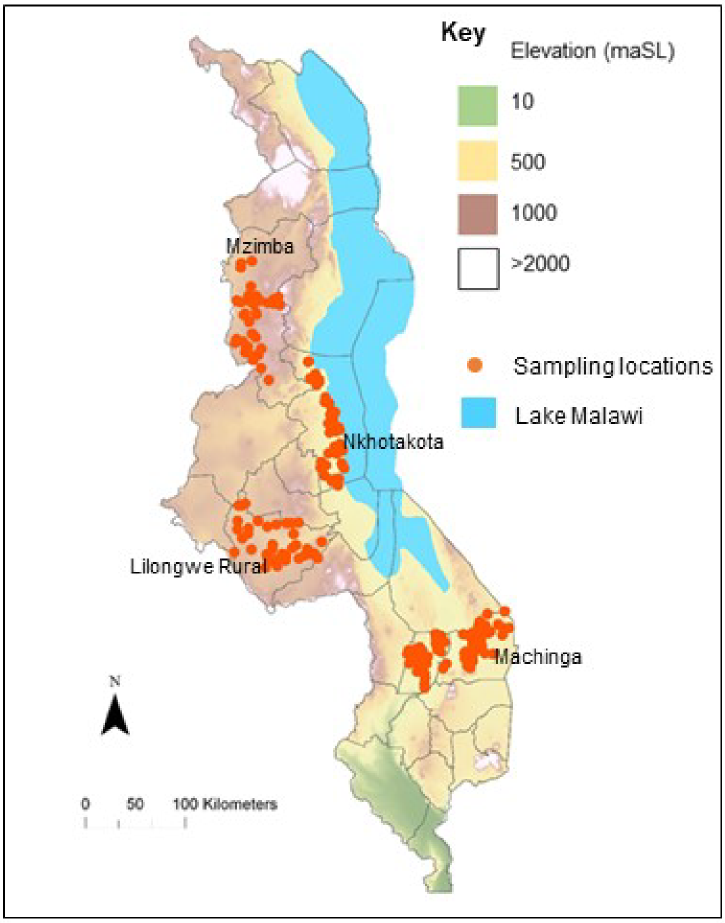

Figure 1 – Location map of sampling sites of the Survey in Malawi in Balaka, Lilongwe Rural, Machinga, Mzimba and Nkhotakota districts.

2.2 Survey methods

At each hand-pump equipped borehole (HPBs) field tests were used to assess water quality, microbiology, yield of the supply, users' perception of the HPB functionality performance, and the experience and capacity of community management arrangements.

2.2.1 Guidelines for assessing functionality

The following guidelines were used for assessing functionality (Wilson, et al. 2016):

- Functionality should be measured against an explicitly stated standard and population of water points.
- It should be measured separately from the users experience of the service it provides.
- The assessments should be tiered, allowing for further information, but always being able to be reduced to a simple measure.
- A distinction should be made between surveying functionality as a snapshot (e.g. for national metrics) and monitoring individual water point performance (including a temporal aspect).

2.2.2 Defining functionality

The project used the Hidden Crisis guidelines above to assess functionality in terms of different levels of performance. This started with a basic 'working yes/no' definition, and moved to a more detailed understanding of the reliability and yield of supply (Figure 2). The final level introduced water quality to the performance assessment. The project used the following definitions of functionality (Bonsor et al. 2018):

1. **Basic** – is the water point working on day of survey (yes/no)?
2. **Snapshot** – does the water point work and provide sufficient yield (10 L/min) on the day of survey?
3. **Functionality performance** – does the water point provide sufficient yield (10 L/min) on the day of survey, is it reliable (<30 days downtime in last year) or abandoned (not worked in past year)?
4. **Functionality including water quality** – as 3 above and also passes WHO inorganic parameters, and Thermotolerant Coliforms (TTC) standards.

Each of these definitions requires different amounts of data to be collected, and a requisite duration of survey. The 'Basic' and 'Snapshot' assessments reflect the requirements of a widespread national survey assessments, whilst the more performance-focused definitions of 3 and 4 are more relevant to local or regional surveys looking to track the functionality of individual water points or programmes through time.

Standard approaches were used within the Survey to collect different relevant data for each of these definitions.

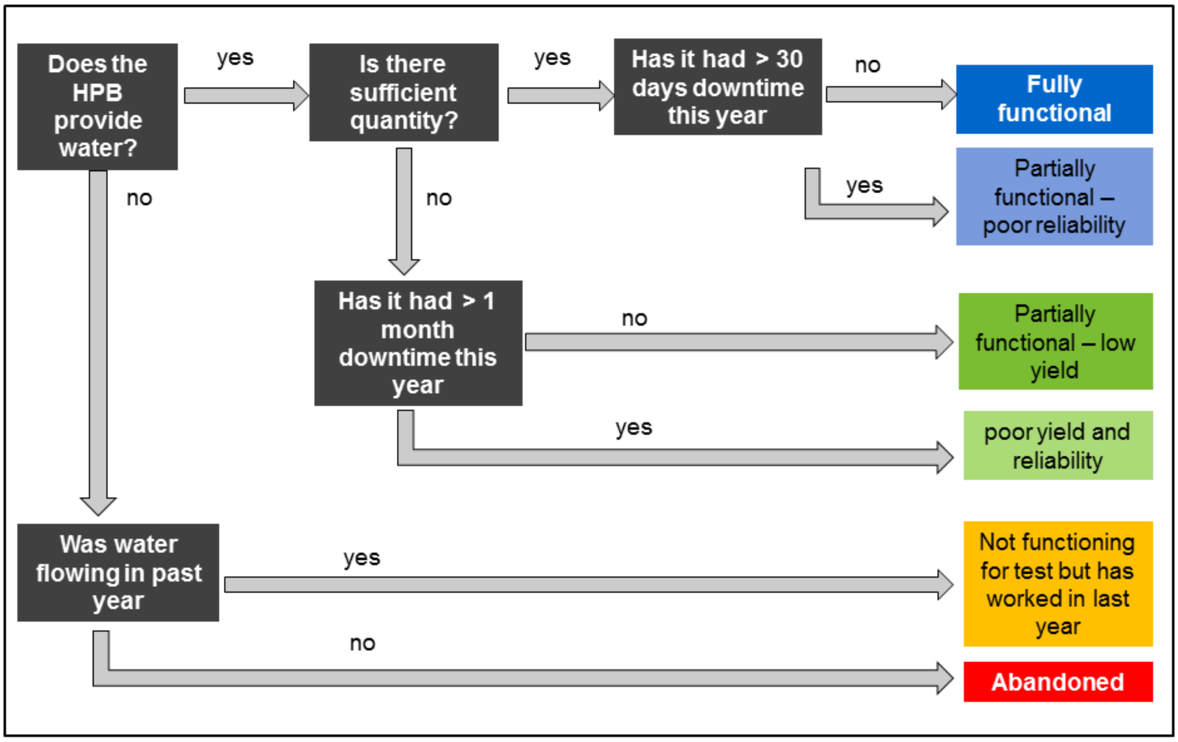

Figure 2 – A schematic diagram showing the different categories of functionality used in the survey analysis. From Bonsor et al. (2018).

2.3 Water quality analysis

To collect a representative sample, stagnant water from handpump boreholes was pumped to waste for 1-2 minutes. pH, turbidity, alkalinity and epecific electrical conductivity (SEC) were measured on site as these parameters easily change with time. Two samples for dissolved inorganic chemistry (for anions and cations) were filtered in the field (<0.45 micron) and were stored in airtight bottles. Ion chromatography was used to measure major anions. Inorganic chemical analysis was undertaken by CSIRO Land and Water Analytical Services, in Adelaide, South Australia. For a detailed description of methods see Lapworth et al. (2020).

Microbial water quality analysis was undertaken using TTCs, which indicate faecal contamination. Water samples were collected using sterilized 250 ml sample bottles. Samples were sotred in a cool box in the filed prior to processing. TTCs were analysed using membrane filtration techniqueusing Membrane Lauryl Sulphate broth as a selective culture medium. Processed samples were then incubated at 44°C for 24 hours after which cream to yellow colonies greater than 1 mm in diameter were counted and expressed as TTCs per 100 ml.

2.4 Water Management Arrangements

A social survey of the village-level water management arrangements was also carried out at each water point. A core aspect of the social-science component of the Hidden Crisis project is to not assume that all local management functions are performed solely by the formally appointed water point committee. Instead, the focus of the research had been broadened to include all local actors and institutions who may play a part in managing HPBs. This is why the term water management arrangement (WMA), which includes the water point committee but is not limited to it was used. For a detailed description of the methodology see Whaley et al. (2019).

The project developed a definition of a WMA. This definition lists 8 different attributes that need to be present to a greater or lesser extent if the WMA is to be considered 'functioning' as follows:

1) Authoritative leadership exists;
2) Has the capacity to make and enforce decisions, including on rules-in-use;
3) Collects or sources, manages, and accounts for funds;
4) Undertakes and secures maintenance work;
5) Represents all users in a way that ensures equitable access to the water supply;
6) Recognised as legitimate by both users and the local governance structure;
7) Is aware of its own role and responsibilities and the roles and responsibilities of others;
8) Is linked to other relevant stakeholders and institutions.

A structured social survey was designed with a total of 23 questions that addressed the 8 attributes of a WMA, where each question could be ranked between 1 (lowest) and 3 (highest). The survey was divided into 4 categories of questions: (1) Finance; (2) Maintenance and Repair; (3) Decision making, rules, and leadership; and (4) External Support. The quality of the Water Management Arrangements was then assessed by placing each into 4 categories depending on total score.

Scores	Functionality of WMA
Scores mostly 1s	Non existent
Scores 1s and 2s	Weak
Scores mostly 2s and 3s	Functional
Scores mainly 3s	Highly Functional

3. Results and Discussion

3.1 HPB Functionality

A summary of the functionality survey findings in Malawi are summarised in Table 3. This provides a breakdown of the proportion of HPBs identified across the different levels of functionality performance. Using a binary ('yes / no') definition of functionality, based on if the HPB produces any water at the time of the survey, 74% of hand pump boreholes (HPBs) are assessed functional at any one time. This is broadly in line with the national water inventory statistics from national-level functional surveys (MoWDI 2012, SPR, 2016). However, the more detailed survey assessment approaches conducted in the work which include assessments of water point yield and reliability show a significant proportion of these HPBs have performance issues: only 66% of HPBs surveyed passed the design yield of 10 liters per minute; 55% met the design yield and also had less than one month downtime within a year – Figures 3-6.

Table 3: Summary of survey results in Malawi

Functionality performance level	% pass
Basic – working (yes/no)	74
Snapshot – provides sufficient yield (10 L/min)	66
Functionality performance – sufficient yield and reliability (<30 days downtime in last year)	55
Functionality including water quality (passes WHO inorganic parameters, and TTC)	43

The 'Basic' and 'Snapshot' assessments shown in Table 3 reflect the requirements of national survey assessments, whilst the more performance-focussed definitions use more detailed assessment approaches that are relevant to local or regional surveys looking to track the functionality of individual water points or programmes through time. In the context of this work, water quality is considered a service issue rather than strictly functionality.

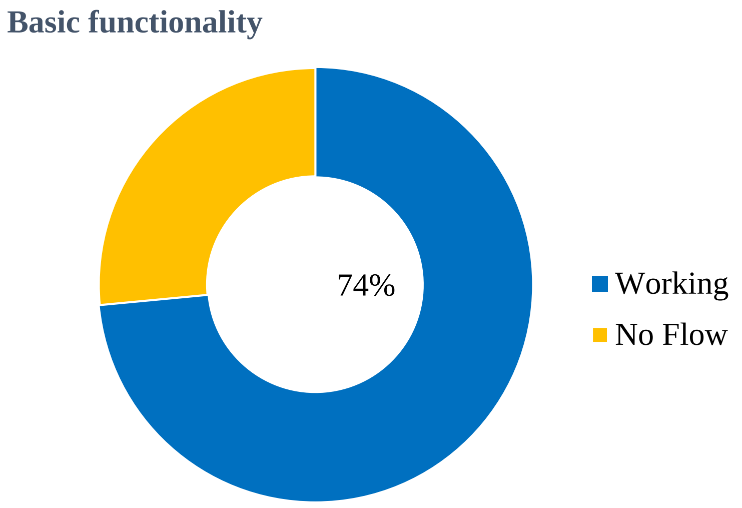

Figure 3 – Functionality assessed as working or not working.

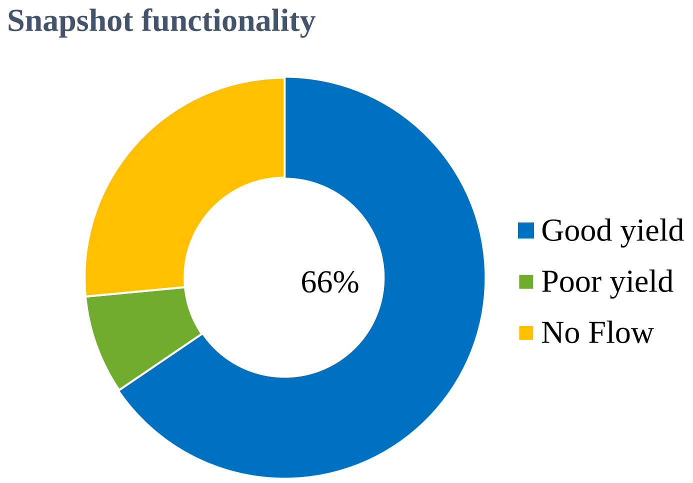

Figure 4 – Functionality assessed as working with sufficient yield (10 L/min)

Functionality performance

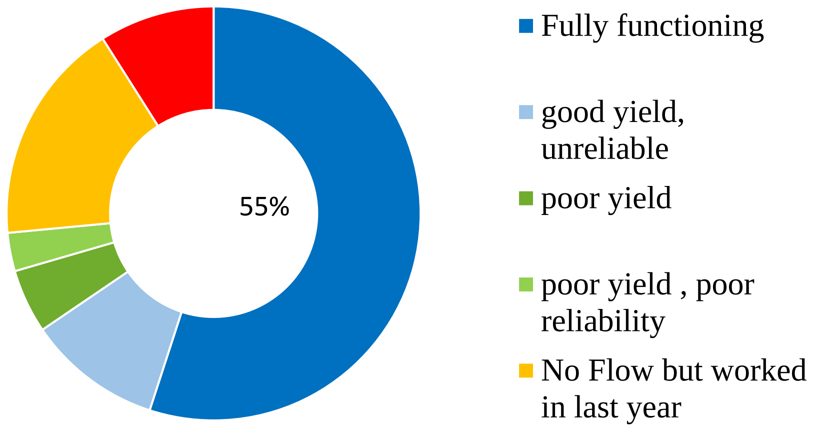

Figure 5 – Functionality performance – sufficient yield (>10 L/min) and reliability (<30 days downtime in the last year).

Functionality performance – including water quality

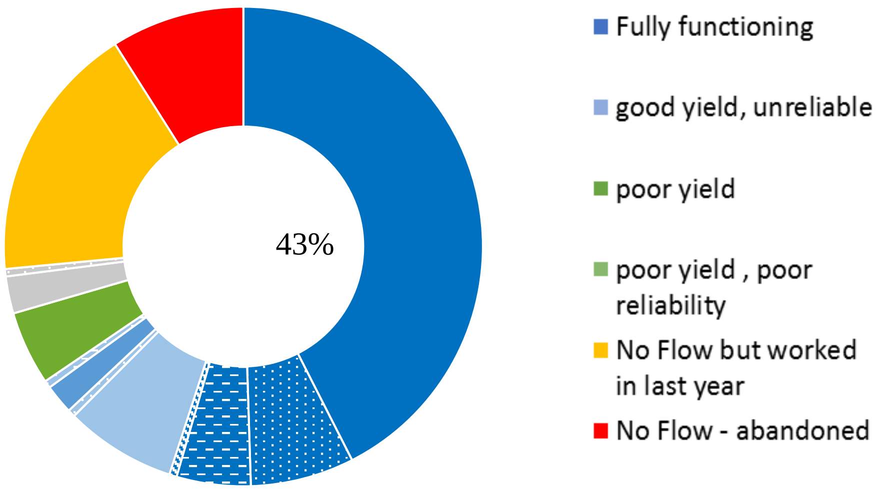

Figure 6 – Functionality performance, including water quality.

Key: Failure to meet WHO inorganic water quality guidelines denoted by stipple overlay; failure to meet WHO TTC guidelines denoted by line overlay; failure to meet both denoted by dashed overlay.

As well as indicating a much greater range in the quantity and reliability of HPBs than discerned by binary assessments of water point functionality, the survey results provide insight to the water quality provided by HPBs. Table 4 and Figure 7 provide the main findings to water quality provided by the HPBs. Inorganic water quality is shown to be good across the majority sites with only 16% of sites failing WHO guidelines for key water quality indicators (F, Mn, NO_3) – Figure 7. Pathogen contamination, as measured by TTC concentrations also affected 16% of sites, however improved well construction and completion could help improve this issue (Lapworth et al. 2020).

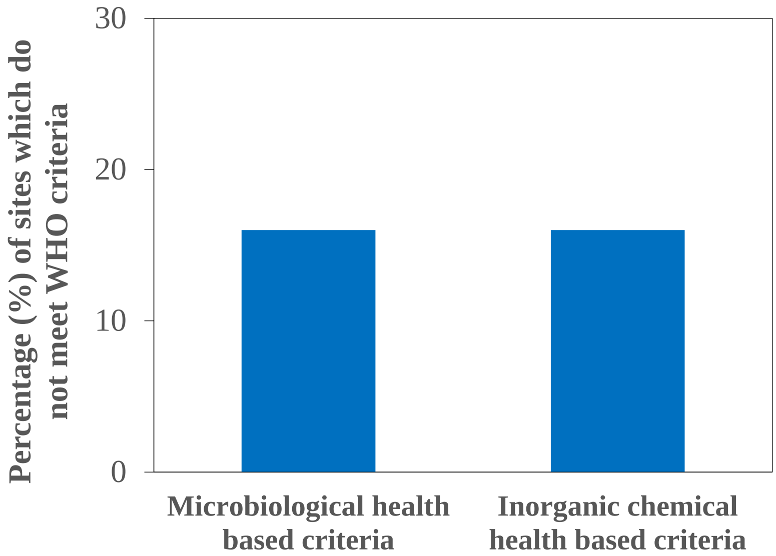

Figure 7 – Proportion of water points surveyed in Malawi where water quality exceeds WHO drinking water guidelines.

Table 4 – Percentage of the HPBs affected by different types of water quality issues across the different functionality performance categories .

	Water quality issues (%)			
	none	TTC	Inorganic	both
fully functioning	42.5	7.0	5.0	5.0
good yield, unreliable	7.5	0.5	2.0	0.5
poor yield	5.0	0	0	0
poor yield ,poor reliability	2.5	0.5	0	0
no Flow – not tested		9.0		

To meet the Sustainable Development Goal 6, there is need for water to be safe and reliable. Based on the findings of this more detailed survey, only 43% of HPBs (Figure 6) meet the requirements of the SDG6 in their entirety Improving the functionality performance of existing basic community supplies, such as HPBs, is therefore a critical part of the investment needed to achieve SDG6 in Malawi, as well as in many parts of sub-Saharan Africa, where reliance of community groundwater supplies is likely to continue for decades to come. However, results from Malawi are more favourable across all catergories than those from Ethiopia (Kebede et al. 2017) and Uganda (Owor et al, 2017).

The findings from this survey highlight the significant impact that different definitions have to the functionality rates recorded; and binary definitions mask the significant performance issues which affect a large proportion of HPBs. There is, therefore, significant value in using good statistical design to surveys, so that more detailed assessments can be used bring richer understanding to national monitoring statistics at low cost. Statistical design can be used to gain maximum information for limited resources. A binary functionality assessment can be undertaken rapidly for an entire domain – for example a district, region, or even country. By using a stratified two or three staged randomised sampling approach, the number of sites to be visited for the more detailed assessments can be reduced substantially. This sample can then be used to estimate more detailed functionality behaviour for the entire domain. Investment in good survey design can therefore save time and money and give more confidence in the data produced.

3.2 Water management arrangements

The survey indicated the vast majority of the Water Management Arrangements (WMA) (86%) were functional or highly functional, but also indicated some differences in the different aspects, or dimensions, of management capacity – for example, the strong difference between Maintenance and Repair and the much lower scores for External Support - Figures 8 and 9.

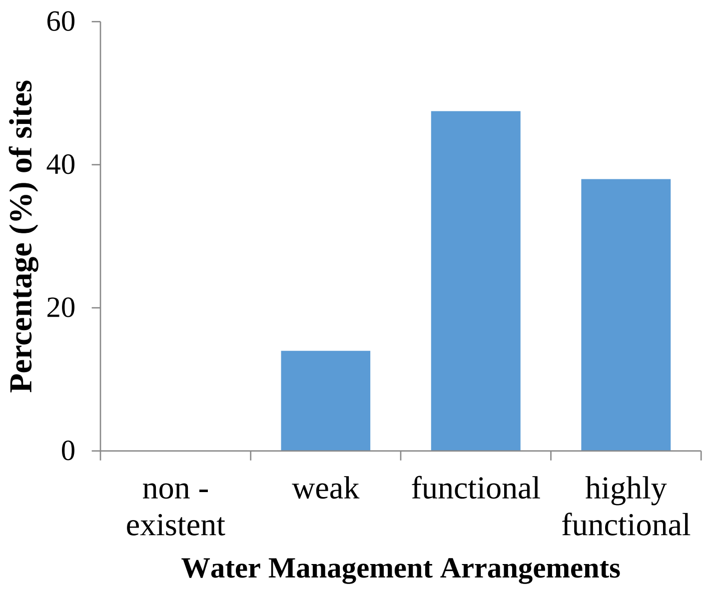

Figure 8 – Percentage of sites assessed to have non-existent, weak, functional or highly functional Water Management Arrangements.

Further exploration and analysis of this data by the project team and published by Whaley et al. 2019, show no strong relationship between the capacity of WMAs and the functionality of HPBs. Of the four management dimensions, affordable maintenance and repair was the best predictor of borehole functionality. However, access to external support for regular maintenance which is essential to the efficacy of community WMA was often found not to go hand in hand with capacity for maintenance and repairs (Figure 9). The relationship between capacity of community based WMAs and HPB functionality is therefore, complex and multifaceted, and further research is needed to better understand the efficacy of community based water management capacity to sustaining HPB functionality by itself (Whaley et al. 2019).

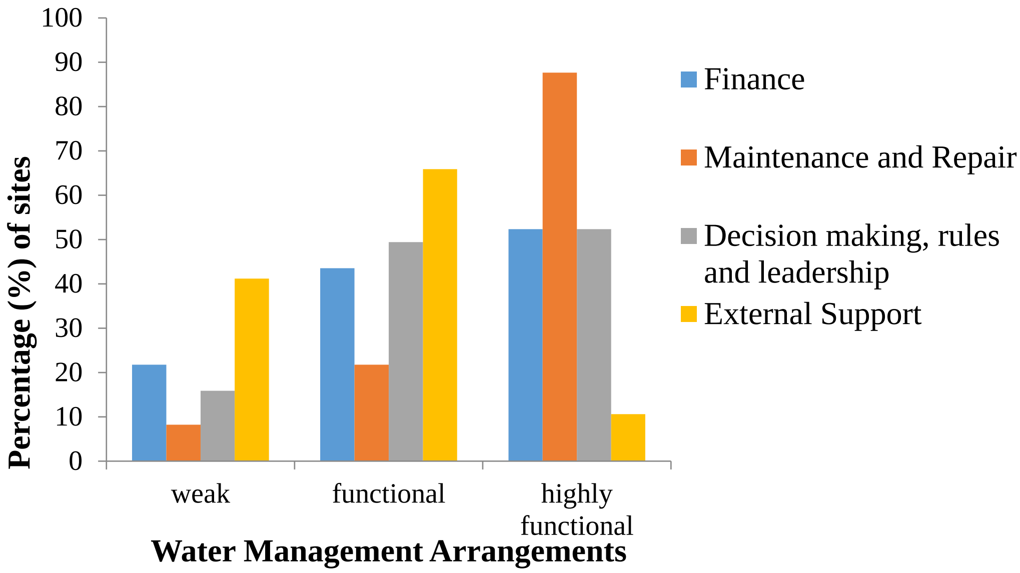

Figure 9 – Percentage of HPBs with different Water Management Arrangements.

4. Conclusions

The study has presented a new tiered approach to defining and assessing of the functionality of hand pump boreholes that takes into account sufficient yield, reliability (less than 30 days of down time in a year) and health-based water quality indicators. Using a binary (‘yes/no’) definition of functionality, 74% of hand pump boreholes (HPBs) are assessed functional at any one time. This is broadly in line with the national water inventory statistics from national-level functional surveys. However, when taking account of the level of service provided (in terms of quantity, reliability, and quality), the number of HPBs with adequate functionality was considerably lower. The findings from this survey, therefore, highlight the significant impact that different definitions have to the functionality rates recorded; and binary definitions mask the significant performance issues which affect a large proportion of HPBs. The work has shown good statistical design to surveys can be used to enable more detailed assessments to be undertaken to bring richer understanding to national monitoring statistics at relatively low cost.

Acknowledgements

Whilst the authors of this report reflect the team directly responsible for undertaking and facilitating the Survey field programme in Malawi, the design of the field research programme, and the definitions of functionality presented are the joint work of the whole *Hidden Crisis* project team. The project was funded by UKRI Grant NE/M008606/1 The project team involves an interdisciplinary consortium of established researchers in physical and social sciences from:

- British Geological Survey
- Sheffield University
- Overseas Development Institute
- Flinders University, Australia
- Addis Ababa University, Ethiopia
- Makerere University, Uganda
- University of Malawi
- Ministry of Irrigation and Water Development, Malawi
- Ministry of Water and Environment, Uganda
- Ministry of Water, Irrigation and Energy, Ethiopia
- WaterAid UK and country programmes (Ethiopia, Uganda and Malawi)

References

Bonsor, H., MacDonald, A. M., Casey, V., Carter, R. and Wilson, P. (2018). *The need for a standard approach to assessing the functionality of rural community water supplies. Hydrogeology Journal*, 26: Issue 2: 367–370. https://doi.org/10.1007/s10040-017-1711-0

Carter, R. C, and Ross, I. (2016). *Beyond 'functionality' of hand pump- supplied rural water services in developing countries.* https://www.developmentbookshelf.com/doi/pdf/10.3362/1756-3488.2016.008.

Chavula, G.M.S. (2018). *Malawi Country Report on the Water, Energy and Food (WEF) Nexus*. A Malawi Country Report submitted to SADC as part of the SADC - EU Project on **"**Fostering Water, Energy and Food Security Nexus Dialogue and Multi-Sector Investment in the SADC Region." Lilongwe.

Chiluwe, Q. W. and Nkhata, B. (2014). *Analysis of water governance in Malawi: Towards a favourable enabling environment?* Journal of Water, Sanitation and Hygiene for Development, 04.2. IWA Publishing

Döll, P., Hoffman-Dobrev, H., Portmann, F.T., Siebert, S., Eicker, A., Rodell, M., Strassburg, G., Scanlon, B, R. (2012*). Impact of water withdrawals from groundwater and surface water on continental water storage variations. J. Geodyn*. 59–60, 143–156

GOM/MWP. (2008). *Integrated Water Resources Management/Water Efficiency (IWRM/WE) Plan 2008–2012.* Ministry of Irrigation and Water Development. MWP/CIDA. Lilongwe

Kebede, S, MacDonald, A.M., Bonsor, H.C., Dessie, N, Yehualaeshet, T, Wolde, G, Wilson, P, Whaley, L, Lark, RM. (2017). UPGro Hidden Crisis Research Consortium, Survey 1 Country Report – Ethiopia. British Geological Survey (BGS) Open Report, OR/17/024, pp 17

Lapworth, et al (2020). Drinking water quality from rural handpump-boreholes in Africa. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/ab8031

MacDonald, A.M., Bonsor, H.C., Dochartaigh, B.É.Ó. and Taylor, R.G. (2012). Quantitative maps of groundwater resources in Africa. Environmental Research Letters, 7(2), p.024009.

Mechlem, K. (2016). Groundwater Governance: The Role of Legal Frameworks at the Local and National Level-Established Practice and Emerging Trends. *Water* 8, 347; DOI:103390/W8080347. MDPI. www.mdpi.com/journal/water.

MoAIWD. (2017). *National Water Resources Master Plan*. Annex 2: Groundwater Resources. Ministry of Agriculture, Irrigation and Water Development. Republic of Malawi.

MoIWD. (2008). Water and Sanitation Sector: Joint Sector Review Report. Ministry of Irrigation and Water Development.

Ministry of Water Development and Irrigation (MoWDI). 2012. Malawi Sector Performance Report 2011: Irrigation, Water and Sanitation, 106pp

Mwathunga, E, MacDonald, A.M, Bonsor, H.C., Chavula, G., Banda, S., Mleta, P., Jumbo, S. G. Gwengweya, Ward, J., Lapworth, D., Whaley, L., Lark, R.M. (2017). *UPGro Hidden Crisis Research Consortium, Survey 1 Country Report* – Malawi. British Geological Survey (BGS) Open Report, OR/17/046

Njalam'mano, J.B.J. (2007). *Current status and management of hand pump equipped water facilities in Blantyre rural district, Malawi. A case study of Kapeni and Lundu traditional authorities.* MSc Thesis. Sweden.

Owor, M., MacDonald, A.M., Bonsor, H.C., Okullo, J., Katusiime, F., Alupo, G., Berochan, G., Tumusiime, C., Lapworth, D., Whaley,L., Lark, R.M. (2017). UPGro Hidden Crisis Research Consortium – Survey 1 Country Report – Uganda. British Geological Survey (BGS) Open Report, OR/17/029, pp 18.

SADC. (2014). Southern African Development Community. *Sustainable Groundwater Management in SADC Member States Project.* Resettlement Policy Framework (RPF) RP1581.

Sajidu, S., Monjerezi, M., Ngongoro, C., Namangale, J. (2013). *Malawi Country Water Resource Profile Report.* University of Malawi (UNIMA).

SPR. (2016). *Malawi Government 2016/2017 Sector Performance Report for Irrigation*. Water and Sanitation Sector.

Taylor, R.G., Scanlon, B., Döll, P., Rodell, M., Van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J.S., Edmunds, M. and Konikow, L. et al. 2013. Ground water and climate change. Nature climate change, 3(4), pp.322-329. https://doi.org/10.1038/nclimate1744

Whaley, L., MacAllister, D.J., Bonsor, H., Mwathunga, E., Banda, S., Katusiime, F., Tadesse, Y., Cleaver, F., MacDonald, A. (2019) Evidence, ideology, and the policy of community management in Africa. *Environmental Research Letters*, 14 (8), 085013. https://doi.org/10.1088/1748-9326/ab35be

Wilson, P., Bonsor, H.C., MacDonald, A.M., Whaley, L., Carter, R.C., Casey, V. (2016). *UPGro Hidden Crisis Research consortium: unravelling past failures for future success in rural water supply—initial project approach for assessing rural water supply functionality and levels of performance.* British Geological Survey (BGS) Open report OR/16/044.