Unlocking the Potential of Groundwater for the Poor

Physical factors contributing to rural water supply functionality performance in Ethiopia

UPGro Hidden Crisis Research Consortium

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Executive Summary

Communal groundwater supplies are the main source of improved water provision for many rural areas in Africa and South Asia, and are likely to remain so for decades to come. Despite the reliance on these sources, it is estimated that the number of poorly functioning water points is 15 to 50% at any one time [1-3] when taking account of quantity, quality, and service reliability. Developing an improved understanding of the poor functionality of these existing supplies is, therefore, a priority in order for future WASH investment to be better targeted, and requires the development of robust interdisciplinary data across the breadth of physical, social and institutional factors that contribute to the functionality of community rural water supply (RWS).

The *Hidden Crisis* project undertook a suite of surveys at local and national levels, to develop a substantial interdisciplinary dataset across three countries to help inform understanding as to where key barriers to sustainability exist and, specifically, how services provided by handpump boreholes can be improved.

The key findings in Ethiopia from these surveys are published over four reports, alongside a final over-arching analysis and report for all three project countries.

This report communicates the findings generated from one of the project surveys – deconstruction and forensic analysis of 50 individual water points in Ethiopia. The report presents the new data generated to Ethiopia's groundwater resource potential; the nature and condition of hand-pump borehole installations; and the significance of both of these factors to service performance.

Based on the evidence collected, the survey results indicate the main physical factors most likely to affect functionality performance within the Ethiopian Highlands are the relatively deep depth to groundwater and the poor condition of handpump components. The impact of these factors to functionality performance can be mitigated through appropriate pump technology choice (e.g. use of deeper handpump boreholes (HPB) lift design), handpump construction, and adequate accessibility to repairs and maintenance capacity with breakdowns.

These factors should not, however, be considered to be the only driving forces of functionality outcomes in these regions of Ethiopia, and the results of this survey need to be examined alongside the wider project findings. Wider institutional arrangements, resources and dynamics, are likely to play a significant role in the implementation of appropriate borehole construction, siting and design; procurement processes; and the management capacity available for water points at national to local levels.

Acknowledgements

Whilst the authors of this report reflect the team directly responsible for undertaking and facilitating the Survey 2 field programme in Ethiopia, 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 team involves an interdisciplinary consortium of established researchers in physical and social sciences from:

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

Contents

1. Introduction to the Hidden Crisis project

The *Hidden Crisis* project is a 5 year (2015-20) research project aimed at developing new evidence and understanding of the complex and multi-faceted causes which underlie the current high failure rates of many new groundwater supplies in Africa. The work focuses specifically on examining the functionality of hand-pump equipped borehole supplies (HPBs) – these being the main form of improved community water supply across rural Africa. The research is focused on three countries – Ethiopia, Uganda and Malawi – in order to examine functionality and performance of groundwater supplies across a range of hydrogeological, climatic and social, institutional and governance environments.

The project undertook a suite of surveys at local and national levels, to develop a substantial interdisciplinary dataset across the three countries to understand where barriers to sustainability exist and, specifically, how services provided by handpump boreholes can be improved.

The five main surveys were designed to collect new data relating to the key physical, social and institutional factors that can contribute to the functionality of community rural water supply (RWS). The surveys included:

1. **Water point functionality survey** – a rapid survey of 200 HPB supplies in each country to provide more nuanced understanding of national statistics and current functionality performance of water services in each of the three countries. The survey employed a tiered approach to define, and measure, the functionality and performance of each HPB and the local water management committee.
2. **Forensic analysis of individual water points** – a detailed survey of 50 HPBs in each country, involving deconstruction of the water points. This generated detailed data on: the local groundwater resource; water point construction and condition; and community management arrangements and dynamics.
3. **Longitudinal surveys** – continuous twelve month surveys conducted at a small number of HPBs (6 -12) in Uganda and Malawi. These surveys were able to document data on temporal changes in individual water point performance experienced across a year; the range of impacts which poor performance or breakdown had to communities; and the multiple mechanisms by which communities manage water points; as well as seasonal groundwater level responses.
4. **Political Economy Analyses** – were aimed at understanding the wider underlying structural factors (historical; institutional; actors) affecting the implementation and maintaining the performance of HPBs within each of the three countries. A series of semi-structured interviews with international, national, regional and woreda level actors and institutions were conducted in each country.

5. **District Sustainability Assessments** – collected data relating to the strength of the enabling environment at the district, and strength of institutional interactions and governance between national and district, and district to local levels. These surveys were conducted through semi-structured interviews and workshops with woreda water offices and stakeholders.

The key findings in Ethiopia from these surveys are published over four reports. These reports will be supplemented in the future by a final over-arching analysis and additional reports providing in-depth analysis in key aspects. The suite of project reports published so far from each of the different surveys are shown in Table 1.

This report communicates the findings generated from the deconstruction and forensic analysis of 50 individual water points in Ethiopia – presenting new data and understanding to Ethiopia's groundwater resource potential; the nature of hand-pump borehole installations; and the significance of both of these factors to service performance.

Survey	Survey findings - Project Reports and papers
Water Point Functionality survey	Ethiopia Country Report. Kebede et al. 2017. Capacity of community water management arrangements. Whaley et al. 2019. Measuring functionality and performance levels. Fallas et al. 2018. Need for standard assessment approaches. Bonsor et al. 2018.
Forensic analysis of individual water points	Ethiopia Country Results. This report.
Longitudinal surveys	In preparation
Political Economy Analysis	Ethiopia Findings - PEA report. ODI Report, 2019.
District Sustainability Assessments	Ethiopia Findings - DSA report.

Table 1 – The suite of project reports published so far which communicate the key findings and datasets from each of the different surveys. Further reports and research papers will be published.

2. Functional in Ethiopia 2016 – a review of findings

A first step towards understanding the different drivers of the poor functionality of water points, is to be able to reliably monitor and understand current functionality and the performance of supplies.

The *Hidden Crisis* project undertook a functionality survey of 172 HPBs in Ethiopia in 2016. This was done using a tiered approach for defining and measuring the functionality of supplies, alongside careful statistical survey design[1]. This provided a more nuanced understanding of national statistics and the current functionality of HPBs in Ethiopia and the level of service provided.

More information to the functionality survey approach and results in Ethiopia can be found in the Survey 1 Country Report[2].

Current picture in Ethiopia

At the simplest level of assessment, the survey results indicated 82% of HPBs were working on the day of the survey, in line with national WASH statistics in Ethiopia. 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:

- Only 59% of HPBs provided the design yield of 10 litres per minute
- 45% provided adequate yield and reliability (<1 month downtime within a year).
- 28% of HPB's had adequate yield and reliability, and also passed WHO guidelines of water quality indicators (TTCs and inorganic chemistry) – see Table 2.

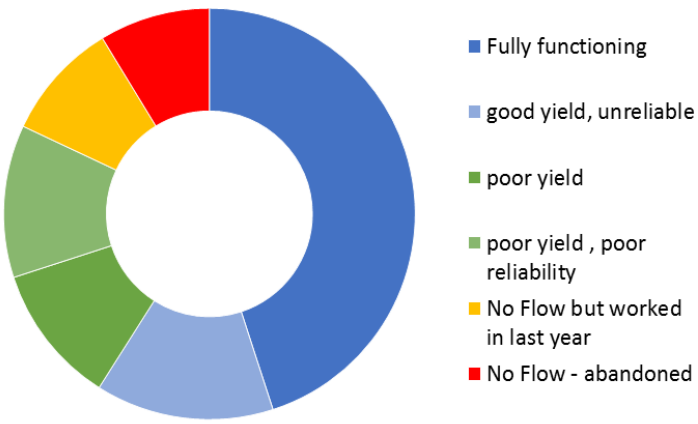


Figure 1 - Functionality performance assessed for boreholes equipped with handpumps within volcanic areas of Ethiopia. The functionality criteria used were: sufficient yield (>10 L/min) on day of survey; and less than 30 days downtime reported for the past year.

[1] UPGro Hidden Crisis Research Consortium. 2018. Project approach for defining and assessing rural water supply functionality and levels of performance. http://nora.nerc.ac.uk/id/eprint/523090/

[2] UPGro Hidden Crisis Research Consortium. 2017. Survey 1 Country Report – Ethiopia. BGS Open Research Report. http://nora.nerc.ac.uk/id/eprint/516998/

The results demonstrate: 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 to bring richer understanding to national monitoring statistics at lower cost.

	Water quality issues (%)			
	None	TTC	Inorganic	Both
Fully functioning	27.5	15.2	2.3	0
Good yield, unreliable	9.9	3.5	0	0.6
Poor yield	7.5	2.9	0.6	0
Poor yield ,poor reliability	7.8	2.4	1.2	0.6
No Flow – not tested			18	

Table 2 – Percentage of the HPBs affected by different types of water quality issues. TTC denotes - thermo-tolerant coliforms (TTC) in excess of the WHO drinking water guidelines.

3. A Forensic survey of 50 individual water points

Understanding where barriers to water point sustainability exist and specifically, how services provided by handpump boreholes could be improved, requires robust interdisciplinary data.

Over the last five years there has been a significant evolution in the WASH sector to better understand the different drivers of poor water supply service performance and sustainability. This has triggered a shift towards approaches that more comprehensively strengthen the leadership, institutions, finances, skills, behaviours, policies, processes and public pressure required to bring about sustained access.

The *Hidden Crisis* project undertook a suite of surveys at local and national levels, to develop a broad and in-depth interdisciplinary dataset to understand where barriers to sustainability exist in each country and, specifically, how services provided by handpump boreholes can be improved.

One of the surveys undertaken was a **forensic analysis of 50 individual water points**. This was aimed at generating detailed data and understanding to the main physical factors most likely to affect functionality performance in each of the three countries. The survey collected detailed data on: the local groundwater resource, and key aspects of water point construction and condition.

The following sections of this report, document the key findings from this survey in Ethiopia.

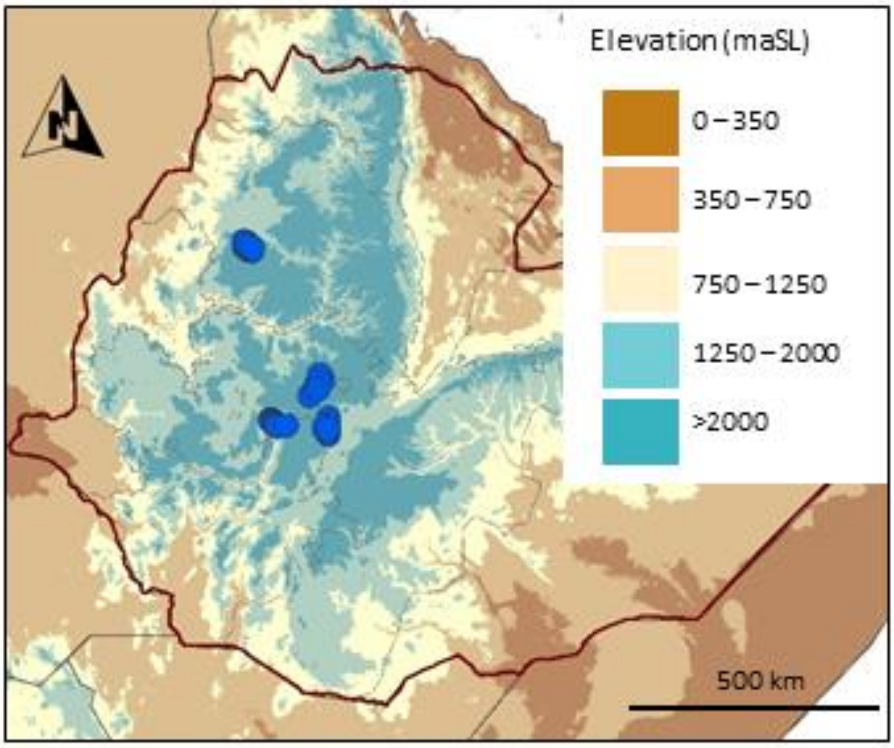


Figure 2 – Location map of sampling sites of the WP Survey in Ethiopia.

Survey design

Site selection. This survey was focused to generating key datasets relating to the main physical factors which can influence HPB functionality and performance – principally assessing the groundwater resource, and HPB construction and condition. Several other surveys were conducted by the project to collect data relating to other possible key factors (governance, institutional capacity, and community dynamics) and are reported separately – see Table 1.

Due to the time intensive nature of the field assessment methods which had to be undertaken at each site in this forensic survey, it was only feasible to investigate 50 HPBs in each country. It was important to ensure this sample included a number of HPBs with a range of performance issues (e.g. yield, reliability) and environmental contexts, as well as some HPBs with adequate functionality.

To achieve this, 50 HPBs were purposively selected from the 172 HPBs originally surveyed in the Water Point Functionality Survey in Ethiopia in 2016 (Survey 1). The purposive sampling approach ensured:

- 50 sites selected in each country (Ethiopia, Uganda and Malawi)
- A range of performance issues were investigated, as identified in Survey 1 (see Table 3) – with as even a distribution of HPBs across each type as possible.
- A range of HPB ages, and local water management arrangement capacities were captured.
- The 50 sites were selected from four to five woredas, to reduce travel time between sites in the survey and maximise the efficiency of survey logistics.

Table 3 shows the HPBs selected for the Forensic Survey in Ethiopia. These sites were located within four woredas – Abeshege, Ejere, Mecha, and Sodo. The physical characteristics of these woredas are shown in Table 4.

Functionality	Number of Survey 1 sites available in four woredas (Abeshege, Ejere, Mecha, Sodo)	Number of sites selected for Forensic Survey
Good yield, good reliability		
Good local WMA	15	5
Poor local WMA	17	5
Good yield, poor reliability		
Good local WMA	4	4
Poor local WMA	6	6
Pood yield, good reliability		
Good local WMA	6	5
Poor local WMA	7	5
Poor yield, poor reliability		
Good local WMA	6	5
Poor local WMA	8	5
No flow in test		
Good local WMA	5	5
Poor local WMA	6	5
Total	80	50

Table 3 – The number and distribution of HPBs selected for the Forensic Water Point analysis in Ethiopia, across four woredas. The acronym 'WMA' denotes Water Management Arrangements.

District	Regional state	Distance from Addis Ababa (km)	Av. Elevation (mamsl)	Mean annual rainfall (mm)	Mean annual temp. (ºC)	Dry months
Abeshege	SNNP	190	1700	1264	17.7	Oct-Mar
Ejere	Oromia	45	2300	1190	16.4	Oct-Feb
Mecha	Amhara	525	2005	1452	20	Nov-Apr
Sodo	SNNP	110	2000	1060	17.2	Oct-Feb

Table 4 – Physical characteristics of the Forensic Survey areas.

Survey dates: The forensic water point survey was conducted in Ethiopia from 6 March to 12 August in 2017. A total of 50 boreholes were investigated across four woredas within three regions: Oromia (Ejere), Southern Nations and Nationalities (Abeshege, Sodo) and Amhara (Mecha) – Figure 2.

Survey methods. The survey dataset includes measurements of the groundwater resource potential, groundwater quality, the downhole construction and condition of handpump components, and borehole construction. These data were collected by a suite of field tests carried out over two days at each site, and required the HPBs to be dismantled. Each water point was re-assembled at the end of the two-day survey by the hand-pump mechanic within the survey team.

The full suite of field tests carried out at each site in survey are listed in Table 5. Further details to the methods of each of these tests are provided in Appendix 1.

Order initiated	Field test	Day and Time
1	General observations	Day 1 morning
2	Observations and measurements of condition of handpump	Day 1 morning
=2	User survey	Day 1 morning
3	Borehole depth and rest groundwater-level	Day 1 morning
4	Pumping Test	Day 1 afternoon – Day 2 morning
5	Water chemistry field measurements	Day 1 late afternoon
6	Downhole CCTV Survey	Day 2 morning
7	Geological assessment	Day 2 afternoon

Table 5 – The range and order of field assessments undertaken at each site in the WP Survey.

Community engagement. Substantial community engagement and mobilisation was vital to ensure the survey team access the purposively sampled sites with an ethical approach. WaterAid country programmes invested significant effort in liaising with District Water Offices and communities in advance of the Survey visits, ensuring a minimum of two mobilisation visits to each community in the weeks before the Survey team arriving.

Survey team. The Survey Team in Ethiopia was led by Addis Ababa University and WaterAid Ethiopia, and was supported by: BGS and Sheffield University in the UK; national and regional hand-pump mechanics; and Woreda Water Bureaus, who helped facilitate access to communities, and assisted the survey team.

4. Results – Forensic water point survey

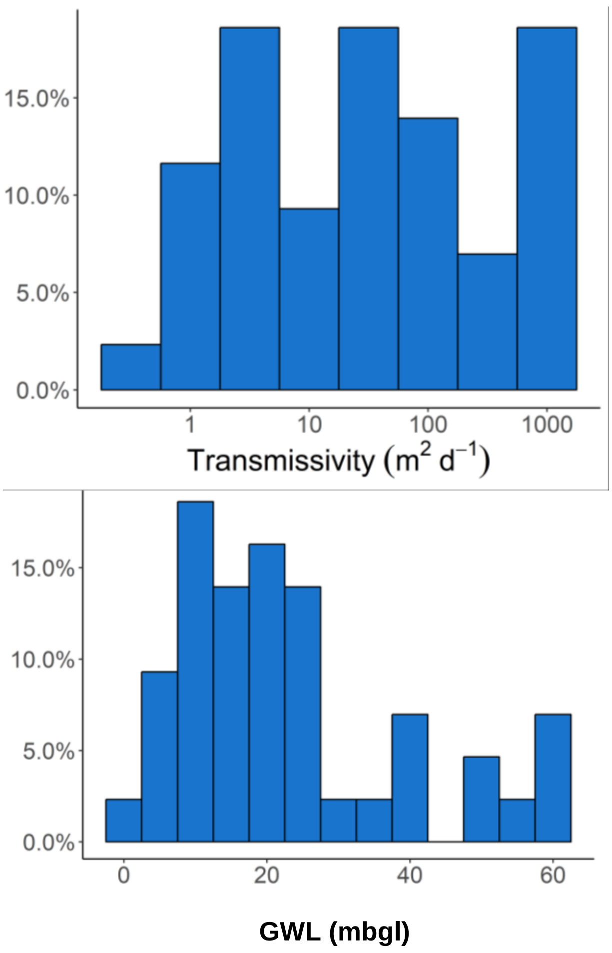
The key data and findings from the Forensic water point survey in Ethiopia are summarised below. These reflect the findings from 50 HPBs examined in the woredas of Abeshege, Ejere, Mecha, and Sodo.

Groundwater resource

Igneous aquifers form the main groundwater resource within the four regions sampled, and are the main aquifer type for the Ethiopia Highlands.

Resource potential

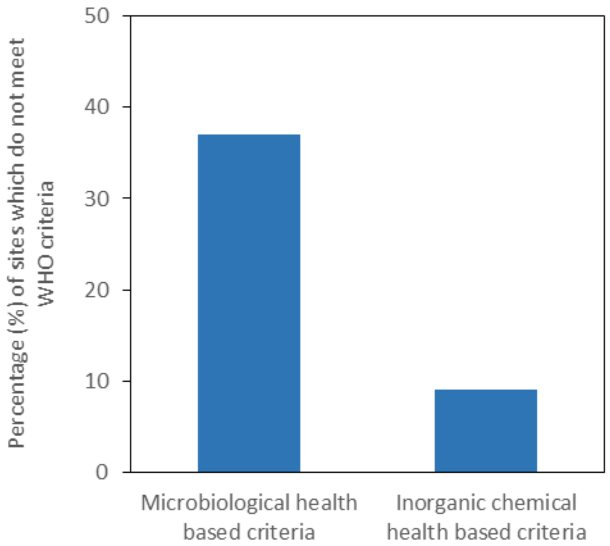
Aquifer yields (as measured by transmissivity) and water-level depths are found to vary considerably across the four regions.



Aquifer transmissivity is measured to be generally high across the regions, with a median and mean value of 26 m^2/d and 177 m^2/d, respectively – Figure 3. The considerable variation of transmissivity values (Figure 3) highlights the heterogeneous nature of the fracture dominated igneous aquifer - Figure 3. Over 90 % of the sites are assessed to have a sufficient aquifer transmissivity (approximately >1.5 m^2/d) to be able to meet the demand of the community water supply.

Depth to groundwater varied significantly within the four regions, and was on average, relatively deep – mean depth to groundwater being approximately 20 metres below ground level (m bgl). In more than 20% of the HPBs, depth to groundwater was greater than 30 m bgl, which is approaching what is optimal for ensuring the sustainability of handpump mechanisms.

Figure 3 – (Top) Aquifer transmissivity values calculated from pumping test data collected at each of the 50 boreholes; (Bottom) Depth to groundwater (m bgl), measured at each site. The water levels represent a rest water-level following 18 hours of no pumping.



Water Quality.

Inorganic water quality is shown to be good across the sites with only <10% of sites failing WHO standards of water quality indicators – Figure 4. Pathogen contamination was a more significant water quality constraint, with 37% of sites affected, however improved well construction and completion could help improve this issue – Figure 4.

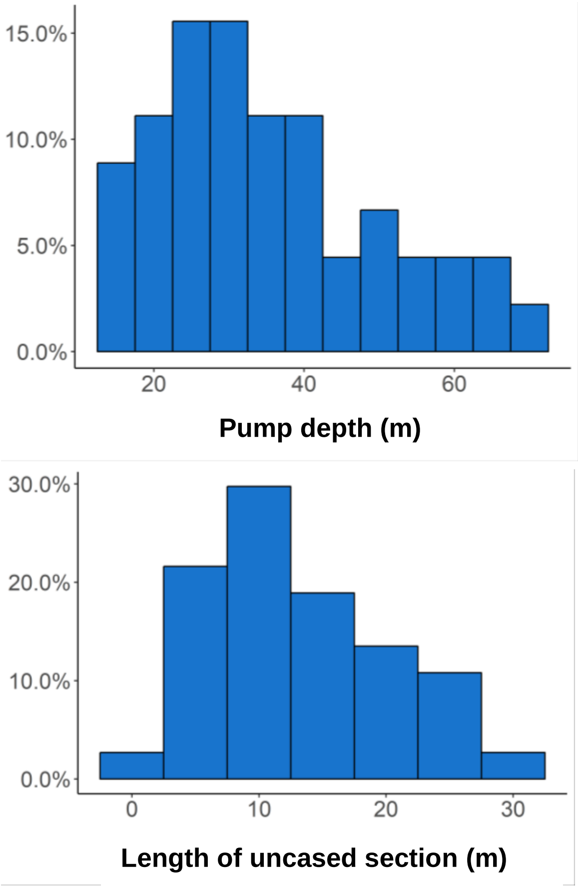
Figure 4 – Proportion of water points in Ethiopia where water quality exceeds WHO drinking water criteria.

Resource resilience – climate and abstraction

The HPBs are assessed to be generally resilient to climate variability for the yields associated with drinking water. At each site, the groundwater sampled is shown to be a mix of modern (<50 years old) and older water, indicating active recharge of several millimetres per year to the aquifers.

Water point construction and condition

Construction

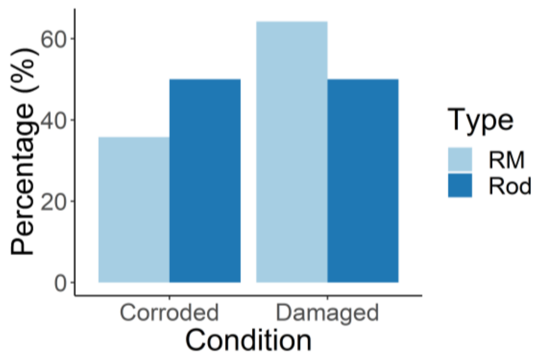


There is a wide range of **borehole depths** observed in the HPBs in Ethiopia – the median depth being approximately 52 m. This most likely to reflects the depth of groundwater across the region. As a result, the **pump depth** is observed to be greater than 40 m bgl in one third of the HPBs – Figure 5.

The length of screen or uncased section in the HPBs was between 5 to 15 m in length in the boreholes, in line with typical rural water supply well design and ensuring a significant range of the aquifer resource is open to the borehole – Figure 5.

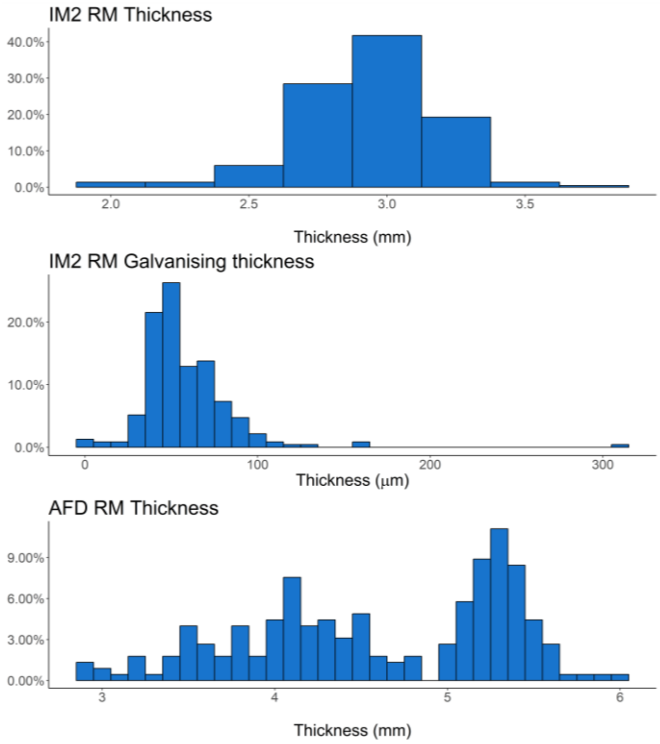
Figure 5 – (Top) the distribution of pump depths in HPBs observed across the four regions in Ethiopia; (Lower) the typical length of screen or uncased sections in HPB construction.

Condition



Corrosion and general damage affected handpump components in 50% of the HPBs surveyed. Damage was defined to include evidence of significant wear – for example components which were bent, or cracked. Rising main sections and pump rods were shown to be equally affected by damage or corrosion, with 25% being in poor condition across the sites – Figure 6.

Figure 6 – Percentage of Rising Main (RM) or pump rods which were observed to be damaged or corroded in HPBs in Ethiopia.



Handpump components were found to have variable material competency (either as a result of corrosion, or manufacturing variability) making damage of the components more likely. Significant variation (±15%) in the thickness of rising main sections, was measureable in the India Mark II (Galvanised Iron (GI)) and Afridev (uPVC) handpumps surveyed – Figure 7. Over 60% of the India Mark II handpumps surveyed, had a rising main thickness below the handpump specification (3.25 mm ±0.2 mm).

The galvanised thickness of India Mark 2 rising mains also varied considerably, again due to corrosion or manufacturing variability. Over 55% of GI measured were less than the India Mark II specification (70-80 µm).

Figure 7 – (Top) Distribution of Rising Main section thicknesses measured in India Mark II hand pumps in Ethiopia; (Middle) Distribution of Galvanising thickness on Rising Main sections in India Mark II hand pumps; (Lower) Distribution of Rising Main (RM) thickness in Afridev handpumps.

Overall individual HPB results

The individual findings from the Forensic water point survey in Ethiopia are summarised below for each of the HPBs – Table 6. This provides an insight to how different physical factors combine at individual HPBs in Ethiopia.

		Groundwater resource				Water Point construction and condition		
		Resource potential (T >1.5 m^2/d)	Depth to ground-water <20 m	Water Quality Passes WHO inorganic standards	Resource resilience	Pump depth >35 m	Corrosion /damage hand-pump	Length screen /open section >10 m
Abeshege	EAE01	Y	N	Y	Y	N	Y	N
	EAE02	Y	Y	Y	Y	Y	N	UKN
	EAE03	Y	N	Y	Y	N	Y	Y
	EAE04	Y	N	Y	Y	N	Y	UKN
	EAE07	Y	N	Y	Y	Y	Y	N
	EAE08	N	N	Y	Y	N	Y	N
	EAE10	Y	N	Y	Y	N	Y	UKN
	EAE11	Y	Y	Y	Y	N	Y	Y
	EAE12	N	N	Y	Y	N	Y	Y
	EAE13	N	N	Y	Y	N	Y	Y
	EAE14	Y	N	Y	Y	N	Y	Y
	EAE15	UKN	UKN	Y	Y	N	Y	UKN
	EAE19	Y	N	Y	Y	Y	Y	N
Ejere	EEJ02	Y	Y	Y	Y	Y	Y	Y
	EEJ06	Y	Y	Y	Y	Y	Y	Y
	EEJ09	Y	Y	Y	Y	Y	Y	Y
	EEJ10	Y	Y	Y	Y	Y	N	Y
	EEJ16	Y	Y	Y	Y	N	Y	Y
	EEJ17	Y	N	Y	Y	N	N	Y
	EEJ18	N	UKN	Y	Y	N	N	UKN
	EEJ20	N	N	Y	Y	Y	Y	Y
Mecha	EME01	Y	Y	Y	Y	Y	Y	N
	EME02	Y	Y	Y	Y	Y	Y	N
	EME03	Y	Y	Y	Y	N	Y	N
	EME05	Y	Y	Y	Y	N	Y	N
	EME07	Y	Y	Y	Y	Y	N	Y
	EME08	Y	Y	Y	Y	Y	Y	Y
	EME09	Y	Y	Y	Y	Y	N	Y
	EME10	Y	N	Y	Y	Y	Y	N
	EME12	Y	Y	Y	Y	Y	Y	Y
	EME13	Y	N	Y	Y	N	Y	Y
	EME15	Y	Y	Y	Y	N	N	Y
	EME18	Y	Y	Y	Y	N	N	Y
Sodo	ESD01	Y	Y	Y	Y	Y	Y	UKN
	ESD03	Y	Y	Y	Y	Y	N	Y
	ESD04	Y	N	Y	Y	N	N	Y
	ESD08	Y	N	N	Y	N	Y	Y
	ESD09	Y	Y	N	Y	Y	N	N
	ESD10	Y	N	N	Y	N	Y	Y
	ESD11	Y	N	N	Y	Y	N	UKN
	ESD13	UKN	Y	Y	Y	Y	N	UKN
	ESD16	Y	N	Y	Y	Y	Y	N
	ESD17	Y	N	Y	Y	N	Y	N
	ESD19	Y	N	Y	Y	N	Y	Y
	ESD20	Y	N	Y	Y	N	Y	N

Table 6 – Individual findings from the Forensic water point survey in Ethiopia. Y – Denotes the measured value meets the criteria shown in the column heading; N – denotes the measured value does not meet the criteria; UKN – means the criteria wasn't measured. Green shading denotes good or adequate conditions for HPB functionality performance; Yellow shading denotes where the physical factors may affect HPB functionality performance.

5. Summary of findings

Below are the main findings from the forensic analysis of 50 water points in the Ethiopian Highlands as part of the Hidden Crisis UPGro project:

1. The resource potential (aquifer transmissivity) is found to be sufficient to support HPB drinking water demands in over 90% of HPBs, and all the HPBs are assessed to be generally resilient to climate variability for the yields associated with drinking water and handpumps.
2. Depth to groundwater varied significantly across the regions, and despite an average groundwater depth of 23 m bgl, over 20% of the sites have a depth to groundwater greater than 30 m bgl. Correspondingly, around 15% of HPBs had a pump installation depth of ≥40 m and less than 5 m water column above the pump, which is at, or close to the operational capacity of the handpumps.
3. Inorganic water quality is shown to be good across the sites with only <10% of sites failing to meet WHO water quality standards. Organic water quality exceeds WHO drinking water standards in 25% of the HPBs surveyed, however, this could be improved with borehole construction.
4. Poor condition of handpump components was observed in 50% of HPBs examined. This was more of a problem for India Mk II pumps and associated with corrosion. Over 55% of the India Mark II handpumps surveyed had a rising main thickness and/or galvanised coating thickness, below the handpump specification.

Based on the evidence collected, the main physical factors most likely to affect functionality performance within the Ethiopian Highlands are shown to be the relatively deep depth to groundwater and the poor condition of handpump components. The impact of these factors to functionality performance can be mitigated through appropriate pump technology choice (e.g. use of deeper HPB lift design), handpump construction, and adequate accessibility to repairs and maintenance capacity with breakdowns.

These factors should not, however, be considered to be the only driving forces of functionality outcomes in these regions of Ethiopia, and the results of this survey need to be examined alongside the wider project findings. Wider institutional arrangements, resources and dynamics, are likely to play a significant role in the implementation of appropriate borehole construction, siting and design; procurement processes; and the management capacity available for water points at national to local levels.

Appendix 1 – Summary of Survey 2 field methods

The range of field tests used to collect the physical science data, reported in this Country Report – are listed in the Table 1A below, and summarised below.

Order initiated	Field test	Day and Time
1	General observations	Day 1 morning
2	Observations and measurements of condition of handpump	Day 1 morning
=2	User survey	Day 1 morning
3	Borehole depth and rest groundwater-level	Day 1 morning
4	Pumping Test	Day 1 afternoon – Day 2 morning
5	Water chemistry field measurements	Day 1 late afternoon
6	Downhole CCTV Survey	Day 2 morning
7	Geological assessment	Day 2 afternoon

Table 1A – The range of field assessments undertaken at each site in Survey 2, alongside the order they were conducted.

1. General observations

Key general information relating to the geography of the site and the handpumped borehole (HPB) were captured by visual observation on arrival to each village. The co-ordinates of site locations were based on the location of the water point, and measured with a hand-held Global Positioning System (GPS) using the WGS84 co-ordinate system.

Observations were made to the basic functionality of the HPB at each site. A rapid stroke test was conducted as the basic assessment on arrival to the HPB, to assess if the water was 'working', or 'not working'. This was conducted by operating five full strokes of the handpump lever to see if any water at all (of any quality) was provided by the HPB. A visual observation and record was made of any discoloration of the water.

2. Observations and measurements of handpump condition

2.1 Above ground handpump components

Visual observation of the head-works recorded the condition of the pump head, spout, handle, and the top and bottom flange, and the handpump platform. Observations were also made to the presence of surrounding drainage to the site were made, alongside the number and proximity of latrines to the handpump, presence of fencing or wall around the handpump, and any visible sources of local pollution.

2.2 Below ground handpump components

The general condition of the rising main pipes and pump rods was assessed by visual inspection and measurement of each pipe section as they were removed from the borehole and laid out on the ground surface. Each section was labelled and placed in sequential order on the ground on plastic sheeting, and a photograph taken of each pipe and rod section.

The following measurements and observations were made of each section of Rising main pipe, and pump rod, from every handpump:

- Length of each component section – using an 8 m measuring tape.
- Diameter of each pipe section – using Vernier callipers
- Weight of each component section – using digital hand held Kern weighing scale.
- General condition of each section and thread – was recorded by visual inspection, with the condition reported against six defined categories of condition (Good / Corroded / Worn / Cracked / Biofilm / Discoloured / Scaling). A digital microscope photograph was taken of the worst condition observed within each section, using a hand held Ash vision ion 4.3" digital microscope.
- Thickness of Rising Main pipes and Galvanising thickness – using an ultrasonic and magnetic thickness gauge, respectively.

The condition of other downhole components such as, couplers, the pump cyclinder, plungers and seals were made by visual inspection and observations and reported as free text on the field survey form.

3. Borehole depth and rest groundwater-level

Once all the handpump components were removed the total borehole depth was measured using a surveyors tape attached to a plumb line, alongside a manual dip measurement of the static groundwater-level in the borehole.

4. User Survey

A water point user survey was conducted at each site to collect data on the reliability, performance (quantity and quality) and breakdown history of the HPB, based on user recall and perception. This survey was conducted in the vicinity of the water point, with community water point users. The questions were designed to uncover increasingly depth of information for each aspect of performance of the water point – particularly to the breakdown history, and the nature and timescales of repairs (e.g. number of breakdowns in the last year, month and week; the number of days downtime in the last year; length of individual downtime, and types of breakdown).

5. Pumping Test

The Survey 2 dataset provides data from 142 pumping tests conducted within each of the boreholes at the Survey 2 sites after removal of the handpumps. This field method provides time series data of the groundwater-level response (drawdown and recovery) to a 2.5 hour pumping period at each site. The tests pump (i.e. stress) the borehole beyond the normal level of demand experienced as a result of routine usage of the HPB by the community. The time series data generated enable the transmissivity of the surrounding aquifer resource to the HPB, and the potential yield of the borehole, to be subsequently calculated.

The pumping tests were designed and scheduled in the survey, so that they were able to have a minimum 2.5 hour pumping phase in line with best practice, and a complete recovery of water-levels was monitored within each borehole over 20 hours. Generally, the average pumping rate at each site was 0.8-1 L/s. Manual dip water-level measurements were made throughout the pumping phase, and the first hour of recovery. High-frequency (15 second intervals) groundwater-level measurements were made throughout the entire period of the test (24 hours) by the pressure transducers installed the borehole.

Water chemistry field measurements

Groundwater quality field measurements, and water sampling were undertaken at each site to gather evidence to:

1. Examine the reasons for HPB corrosion and assess the corrosivity of aquifer water at each site.
2. Assess the general groundwater chemistry and microbiology within the aquifer at each site
3. Determine the residence times of groundwater which will allow investigation of recharge dynamics for each individual HPB.

All groundwater quality field measurements and water sampling were undertaken towards the end of the pumping phase of the pumping test at each site. This ensured that the groundwater quality field measurements were taken after the borehole was purged and the groundwater sampled was reflective of aquifer resource.

Field measurements of water chemistry

The water chemistry parameters recorded by Survey 2 are summarised in Table 1B alongside the associated field-based analytical methodologies.

Laboratory analysis of groundwater chemistry

The full suite of groundwater samples collected for laboratory analysis during Survey 2 is shown in Table 1C.

Analyte	Analytical method	Units of measurement	Detection Limit	Sample count
pH	Probe	pH units	n/a	143
Specific Electrical Conductivity (SEC)	Probe	μScm^{-1}	<10	143
Redox Potential (Eh)	Probe	mV	<0.1	143
Dissolved Oxygen (DO)	Probe	$mg\ L^{-1}$	<0.1	143
Temperature	Probe	^{o}C	<0.1	143
Turbidity	Probe	NTU	<0.01	143
Tryptophan-like Fluorescence (TLF)	Probe	ppb	<0.1	93
Chromophoric dissolved organic carbon (CDOM)	Fluorometer (TLF probe)	ppb	<0.1	93
Alkalinity	Digital titration	$mg\ L^{-1}\ CaCO_3$	<0.05	143
Total Iron	Digital colorimeter	$mg\ L^{-1}$	<0.02	131
Ecoli	Aquagenx bags	$MPN\ L^{-1}$	<1	143

Table 1B – Field-based analytical methodologies and analytes.

Groundwater sample collected for laboratory analysis	Description	Sample count
F/A and F/UA (30mL LDPE)	Filtered acidified and filtered un-acidified samples for: major and trace inorganic chemistry, iodine, NPOC, alkalinity	143
F/UA (30mL LDPE)	Filtered un-acidified sample for stable isotopes ($\delta^{18}O$ and $\delta^{2}H$)	140
CFC (brown glass bottle)	Chlorofluorocarbon sample (CFC-11, CFC-12)	142
SF_6 (clear glass bottle)	Sulfur hexafluoride sample	142
Noble gas (copper tube)	Noble gas sample (He, Ne, Ar, Kr, Xe)	18

Table 1C – Groundwater samples collected for laboratory analysis.

Downhole CCTV survey

Downhole CCTV surveys were used to collect information about the construction and condition of each borehole. These surveys were conducted by lowering a borehole camera fitted with a calibrated cable and integrated light source down each borehole.

Undertaking the CCTV survey required two field staff – one person to operate the camera, and one person to record key observations on the survey form. Key observations made by the surveys included the location and depth of: casing and screen intervals in the boreholes, open-hole sections, and the location and depth of any visible inflows. Information was also recorded about the condition of the borehole – for example, the depth and location of any corrosion, discolouration, staining or encrustation of the screen and casing.

8. Geological assessment

A geological field assessment was conducted in the locality of each HPB site – making observations of any rock outcrops exposed to record data on the rock type present and its features (weathering, fractures, inclusions, hardness, grain size). Wider observations to the site topography, local land use and drainage features, were also included within the assessment.

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