UPGro Working Paper (June 2017)

Groundwater and poverty in sub-Saharan Africa

a short investigation highlighting outstanding knowledge gaps

Edited by Prof. Richard Carter

Authors (alphabetical order) : Anthony Baguma, Alfred Bizoza, Richard Carter, Sue Cavill, Stephen Foster, Tim Foster, Guy Jobbins, Rob Hope, Jacob Katuva, Johanna Koehler, Andrew Shepherd, Alexandre Simons

produced on behalf of Skat Foundation (UPGro Knowledge Broker) project number 40805.40-2017; funded by NERC

upgro.org

"There is relatively strong empirical evidence linking improvements in groundwater access for rural agricultural communities to reductions in poverty"
"While reductions in poverty associated with groundwater development are relatively clear, the impact of groundwater problems (over-extraction and quality declines) on poverty is less so"

Moench (2002)

"Hundreds of millions of people in low-income urban settlements rely on wells for drinking and other domestic purposes. Efforts to enhance the quality, reliability and sustainability of these water sources receive little attention, locally and internationally. The implicit justification is that wells do not provide adequate water, but that little can be done to improve these supplies as they are essentially a residual that needs to be eliminated by the continued expansion of piped water systems. For the poorest urban households in many Asian and African countries, however, far from being a small and declining residual, these groundwater sources are vital"

Grönwall et al (2010)

Interviewees (76.2%) felt life had changed for those who had fetched water prior to handpump installation; in particular, less sickness, time saved, better health, good life and less tiredness. However, the installation of a handpump and consequent change in responsibility in fetching water may also have had negative implications. The number of girls and boys aged 5–17 fetching water increased after the installation of a hand pump, resulting from the water source being closer to the village after pump installation, with the work of girls increasing 423% and boys, 480%. This is an observation not previously reported in Malawi. Unfortunately, it was not possible to further examine the impact, but it is likely to affect school attendance, punctuality and stress levels and thus impact adversely on an age group which had previously been less affected by water access issues.

Rieger et al (2016)

PREFACE

The UPGro research programme is working in a variety of rural and urban contexts where the majority of the population would generally be considered by themselves or others to be poor, whether in absolute or relative terms. For some this state of poverty is chronic, for others it is transient. Each of the UPGro projects is investigating groundwater - poverty linkages in different ways.

It may seem obvious that having or gaining access to close, sufficient, reliable, affordable and good quality groundwater (as opposed, to contaminated or seasonal surface water) for drinking and other domestic uses can bring nothing but benefits; or that the loss of such access would have negative implications for poor people. It may seem self-evident that extending access to groundwater for irrigation or livestock watering is a formula for poverty reduction.

There is of course widespread awareness of the ways in which development benefits can be disproportionately appropriated by the relatively well-off. Their position, resources and power enable them to pursue opportunities which are not available to poorer households, and their enjoyment of those opportunities may in some cases further disadvantage the poor. How and to what extent this is the case justifies investigation.

The potential threats to groundwater resources (and in turn to all water users, but especially the poor) which are posed by uncontrolled development or weaknesses in governance and management are well recognised too, not least through reflecting on India's experience. However in predominantly rural sub-Saharan Africa, where domestic water consumption is low (typically less than 1mm per year as a volume per unit land area) and crop irrigation is extremely limited in extent (overall less than 5% of cropped land), it may be thought that such threats lie some way in the future. The growing momentum which is promoting irrigation in general and groundwater irrigation in particular may call this assumption into question.

Our present understanding of the threats to groundwater posed by climate change are far from clear, especially in light of the complex interactions between demographic and land use changes and the detailed unfolding of changes in key weather variables (especially temperature and precipitation). That local water balances are already changing, and that such change is set to continue, is not controversial. However the precise shape of those changes locally, and the implications for groundwater's continuing ability to buffer seasonal and multi-year dry periods are less well understood. They are the subject of investigation in several of the UPGro projects.

Some aspects of groundwater access may be disadvantageous to the poor. In urban settings, large numbers of poor people who occupy unplanned settlements ('slums') cannot access or afford utility-provided piped water, and they resort to lower-cost, more reliable, but highly contaminated shallow groundwater. In rural areas too, shallow groundwater accessed by poorer households in or near river beds or via shallow hand-dug wells may be more contaminated than deeper groundwater which may be accessed by wealthier households. Investigation is needed to ascertain whether or not this is so. It is possible, as one recent study from Malawi has shown that improved groundwater access can increase children's workload substantially.

The interactions between groundwater as a resource, groundwater access (enabled by physical and institutional infrastructure and financial resources), and the actions of those organisations having a mandate to govern and manage groundwater resources and services, have strong implications for the poor. The detailed nature of those implications need to be better understood. This study is a small attempt to further develop that understanding, and to identify promising directions for future research

.

Disclaimer: This work was supported by a NERC International Development Innovation and Impact Award 2017 to the existing Skat Foundation mandate as Knowledge Broker for the UPGro programme. The views expressed are not necessarily those of NERC, DFID, ESRC or Skat Foundation.

UPGro ('Unlocking the Potential of Groundwater for the Poor', https://upgro.org) is a 7-year research programme, funded by the UK Department for International Development (DFID), the Natural Environment Research Council (NERC), and the Economic and Social Research Council (ESRC). It is currently in its second main phase.

The Catalyst Project phase consisted of 15 short research projects, and it ran from 2013 to 2015. The Consortium phase commenced in 2015 and will end in 2019. It consists of five large inter-disciplinary research projects, working in a total of 12 countries in sub-Saharan Africa.

About 125 researchers are directly engaged in the programme, with numerous other partners and collaborators among Governments, non-Government Organisations, the private sector and the wider natural and social science research communities. The UPGro Knowledge Broker team is led from the Skat Foundation in Switzerland.

This study was proposed, led, managed and administered by the Knowledge Broker team of the UPGro research programme. A team of researchers and consultants drawn from the UPGro projects and beyond undertook the work over a very short period between January and March 2017. This report is the outcome of their work. The main contributors to this report are as follows (in alphabetical order): Anthony Baguma[(1)], Alfred Bizoza[(1)], Richard Carter[(2)], Sue Cavill[(3)], Stephen Foster[(4)], Tim Foster[(5)], Guy Jobbins[(6)], Rob Hope[(7)], Jacob Katuva[(7)], Johanna Koehler[(7)], Andrew Shepherd[(6)], Alexandre Simons[(1)]. The report was assembled and produced by the project manager, Richard Carter (richard@richard-carter.org), on whom rests all responsibility for errors and omissions.

All enquiries concerning this report should be addressed to Sean Furey, Skat Foundation, Switzerland (sean.furey@skat.ch)

Suggested citation:

UPGro (2017) *Groundwater and poverty in sub-Saharan Africa*, UPGro Working Paper, Skat Foundation, St. Gallen, June 2017

Cover photo (Sean Furey, Skat): Young women in Monrovia, Liberia, collecting water from an urban communal handpump (Afridev), February 2013

Contents

Note that longer and more complete versions of section 7.3 and chapter 8 and the powerpoint presentation from the webinar held on 21st March are available from the UPGro Knowledge Broker (contact sean.furey@skat.ch).

Boxes

Figures

Tables

Acronyms and abbreviations

AfGW-Net	African Groundwater Network
AFWA	African Water Association
AICD	Africa Infrastructure Country Diagnostic (World Bank)
ANOVA	Analysis of Variance
AUWSA	Arusha Urban Water and Sanitation Authority
CGIAR	A global agricultural research consortium of 15 research centres
CLTS	Community-led Total Sanitation
CPRC / CPAN	Chronic Poverty Research Centre / Chronic Poverty Advisory Network
DAWASA(CO)	Dar es Salaam Water and Sewerage Authority/Corporation
DFID	Department for International Development
DHS	Demographic Health Surveys
DRC	Democratic Republic of Congo
DRC	Democratic Republic of Congo
EC	Electrical Conductivity
EICV	Enquête Intégrale sur les Conditions de Vie des ménages (Rwanda)
ESPA	Ecosystem Services for Poverty Alleviation
ESRC	Economic and Social Research Council
EWURA	Energy and Water Utilities Regulator (United Republic of Tanzania)
FAO	(United Nations) Food and Agriculture Organisation
FE	Fixed Effects Logit
FHH	Female-headed household
GCRF	Global Challenges Research Fund
GW	Groundwater
GWCL	Ghana Water Corporation Limited
GWOPA	Global Water Operators’ Partnerships Alliance
IAH	International Association of Hydrogeologists
IPAR	Institute of Policy Analysis and Research (Rwanda)
IPCC	Inter-Governmental Panel on Climate Change
IWA	International Water Association
JMP	Joint Monitoring Programme (WHO/UNICEF)
LGWSC	Lukanga Water and Sewerage Company
LWSC	Lusaka Water and Sanitation Corporation
MEA	Millennium Ecosystem Assessment
MICS	Multiple Indicator Cluster Survey(s)
MINIRENA	Ministry of Natural Resources, Republic of Rwanda
Ml/d	Megalitres per day
NERC	Natural Environment Research Council
NISR	National Institute of Statistics Rwanda
ODI	Overseas Development Institute
OLS	Ordinary Least Squares
PRA / PLA	Participatory Rural Appraisal / Participatory Learning and Action
RE	Random Effects Probit
RWF	Rwandan Franc
SDG(s)	Sustainable Development Goal(s)
SMEs	Small and Medium enterprises

SSA	Sub-Saharan Africa
T&S	Travel and subsistence
UNICEF	United Nations Children's Fund
UPGro	Unlocking the Potential of Groundwater for the Poor
WASAC	Water and Sanitation Corporation, Rwanda
WASH	Waster, Sanitation and Hygiene
WEDC	Water, Engineering and Development Centre, Loughborough University
WHO	World Health Organisation
WP	Work Package

The UPGro Consortium Projects

Project	Brief summary	Countries
BRAVE	Modeling and communicating the complex environmental changes in the Sahel region of West Africa to improve the long term planning of groundwater supplies and provide early warnings of groundwater shortages so that the most vulnerable families and communities are more resilient to drought.	Burkina Faso, Ghana
Gro for GooD	Addressing issues of risk and governance of groundwater, with a focus on water security for the poor.	Kwale County, Kenya
GroFutures	Developing the scientific basis and participatory management processes by which groundwater resources can be used sustainably for poverty alleviation.	Benin, Burkina Faso, Ethiopia, Niger, Nigeria, Tanzania, South Africa and Uganda
Hidden Crisis	Develop and apply detailed understanding of inter-linked causes of borehole / handpump failure in SSA.	Ethiopia, Malawi and Uganda.
T-GroUP	Experimenting with practical transition groundwater management strategies for the urban poor in Sub Saharan Africa.	Ghana, Tanzania, Uganda

Summary

Introduction (chapters 1 – 3)

A short study was undertaken in the first quarter of 2017 by the UPGro research programme, to investigate the linkages between groundwater and poverty. The study consisted of four main tasks: a literature review; an overview of UPGro's contribution to the understanding of groundwater-poverty relationships; three sets of analyses of relevant data; and an investigation into groundwater in selected urban settings.

The literature (chapter 5)

Evidence was sought on four key pillars of human development, namely health, education, livelihoods, and food security. Based on an initial scan of titles of more than 10,000 papers, articles and reports from a range of academic and sector-specific databases were extracted and reviewed. Analysis of relevant, publicly available datasets was also carried out.

The empirical evidence suggests that the majority of people in SSA source their drinking water from groundwater. Around half the population use groundwater point sources and an unknown additional number are served by groundwater-fed utility (piped) supplies. Although access patterns are often country-specific, the level and nature of groundwater access is often determined by household wealth. This is true for both domestic and productive water uses.

Numerous studies document evidence of a relationship between groundwater access and health, education, livelihoods and food security. These benefits generally accrue as water service levels improve (e.g. source protection, treatment, lifting technologies, or proximity of supply). These characteristics in turn are closely correlated with household wealth, suggesting uneven gains across socio-economic strata. Despite the numerous studies considering the wellbeing implications of groundwater access, the vast majority suffer from methodological limitations, and there is a dearth of high quality research unravelling causal linkages and assessing the longer term impacts on poverty trajectories.

Changes and emerging threats to groundwater access, quality, and quantity are also documented in the literature, including geogenic and anthropogenic contamination, climatic change, growing demand, and financial and operational challenges associated with sustaining access. While it is likely that these issues disproportionately impact the poor, few studies have sought to empirically assess their impact on welfare outcomes, and their implications for longer term poverty pathways.

The evidence suggests improved groundwater access can confer a variety of benefits, including for poor households in both urban and rural areas. However, by virtue of disparities in service levels and vulnerability to emerging threats and trends, the poorest households do not necessarily capture an equitable share of the gains, and in some cases groundwater access patterns may reinforce or exacerbate inequalities. Rigorous studies are needed to provide a more robust and nuanced understanding of how groundwater access can benefit the poor and drive long-term changes in poverty trajectories.

The UPGro programme (chapter 6)

All five UPGro projects are working in rural or urban contexts which would generally be characterised as "poor". The five individual projects take a range of definitions or implicit understandings of poverty, and are investigating in a variety of ways how extending, improving or assuring groundwater access may benefit poor people. However the programme as a whole does not have a shared definition or set of indicators concerning poverty, or a common theory of change (how "unlocking the potential of groundwater" may be to the benefit of "the poor"). There would be some value in working towards these, either within the lifetime of the programme or, taking a more inductive approach, at its conclusion.

The rural context (chapter 7)

Six countries in SSA (7.1)

The DHS data for the 6 countries which together make up just over 50% of SSA's rural population shows a general decline in the use of unprotected surface water. Piped water access has expanded in Ethiopia while remaining stagnant elsewhere, and increasing access to protected groundwater is most clearly visible in the expansion of boreholes in Nigeria and Uganda. However, the demographics reached by different sources of water supply varies widely between countries, and the more detailed analysis of Nigeria implies there could be further significant subnational variation within each country. The results from the gender analysis highlight that an accurate assessment of trends on the ground requires contextual analysis, and a finer resolution of detail than is readily available from existing datasets.

Rwanda – panel surveys (7.2)

Analysis of panel data (two rounds, 3 years apart, n=2423) from Rwanda shows a significant reduction in the proportion of people in both extreme poverty and 'moderate' poverty (referenced to national poverty lines). The overall proportion of sampled households with an improved water source did not change over the period. Those below the poverty line are more likely to use unprotected wells (68% more), protected springs (34% more), unprotected springs (48% more) and surface water (45% more), and they are less likely to enjoy piped water (the poor are around 20 times less likely to use piped water). The 'moderately' poor and extremely poor tend to live further from their water source than the non-poor (41% further away), and they spend less on the services of water vendors (39 % of non poor expenditures).

Kenya: Kwale County (7.3)

In the Kenya study, more than 80% of households (n=3349) used groundwater, and they were three times more likely to use groundwater for watering livestock than irrigation. A small fraction of households (6%) were engaging in productive use of groundwater for irrigation. For drinking water, one in eight households perceived the groundwater sources to be affordable while a third found them reliable. Two out of five households found the groundwater sources to be safe and had good taste. Only a fifth of the households relied exclusively on their many groundwater sources with the rest having alternative sources (which could include other groundwater sources). The poorest quintile was less than half as likely as the wealthiest quintile to perceive their drinking water source as affordable or safe, and about 40% less likely to perceive the service as reliable; similarly the poorest quintile was found to be seven times more likely to use shallow (up to 8m depth) groundwater than the wealthiest quintile; the poorest quintile was half as likely to use groundwater for watering livestock; use of groundwater for irrigation was insignificant across all quintiles.

The urban context (chapter 8)

Across the region the proportions of urban populations supplied by utility-provided water services have declined, while increasing proportions of those populations are served by private groundwater wells and boreholes. Those private (self-supply) groundwater sources include unsafe shallow hand-dug wells serving the poor or more expensive, deeper boreholes serving wealthier segments of the population. In the 6 cities included in this study the proportions of utility-supplied water coming from groundwater varied from nil to 100%, while the contribution of self-supply of groundwater varied from very little to magnitudes similar to the volumes of water supplied by the utility. In future it will be necessary to integrate utility and private investments in urban water-supply expansion more effectively, and use both piped and non-piped solutions for safe water-supply provision. This must involve a more extensive roll-out of pro-poor policy and technical units in water utilities. Extensive self-supply may free up utility water for those who cannot access groundwater, or it may undermine the financial viability of those same utilities. Whether it is primarily the well-off, or mainly the poorer quintiles who are most benefiting from groundwater self-supply, the consequences are likely to be disadvantageous to the poor – either in terms of their health, or their inability to access the networked service.

A conceptual framework (chapters 4 and 9)

A conceptual framework is presented, linking groundwater users (and their poverty, equity, gender, and well-being) to the groundwater resources, services and institutions which serve them. These are set within the wider social, political, economic, climatic and environmental contexts which influence all other elements of the system. More work is needed to adequately capture the important elements of the system without over-complicating the resulting framework(s). In particular, the interactions and implications for the poor of groundwater as a resource, groundwater as a service, and the institutions and organisations involved in groundwater governance and management need to be unpacked. Furthermore, the social and cultural relationships between poverty, gender and exclusion need to be highlighted.

Methodological limitations of this study

Apart from its brevity, this study has some limitations, both in terms of scope and in terms of its ability to access relevant studies and data. We have made some attempts to disaggregate levels of poverty when examining wealth quintiles, but the dynamic trajectories of poverty for different households and individuals having varying capabilities, combinations of deprivation, and levels of resilience have largely been beyond the reach of this study. Amid that complexity, extending access to groundwater may play very different roles with different individuals and groups.

Knowledge gaps (chapter 10)

Despite the numerous studies considering the wellbeing implications of groundwater access, the vast majority suffer from methodological limitations, and there is a dearth of high quality research unravelling causal linkages and assessing the longer term impacts on poverty trajectories. The assumption is made that improved groundwater access brings benefits to all, while inequalities in those benefits and unintended consequences for the poor tend to be ignored.

Changes and emerging threats to the quality and quantity of groundwater resources and to access, are extensively documented in the literature. While it is likely that these issues disproportionately impact the poor, few studies have sought to empirically assess their impact on welfare outcomes, and their implications for longer term poverty pathways.

The publicly available household survey datasets are informative, but they can only provide limited answers to the questions raised in this work. Household surveys generally ask about the household's main source of drinking water, and so fail to fully address the reality of people's use of multiple sources of water for multiple uses. In this short study, we have analysed panel data for one country (Rwanda) and used longitudinal data from one administrative unit of another country (Kenya), although in the latter we did not explicitly compare across years. In future work it will be important to identify, generate and analyse more such datasets in order to develop a more complete understanding of such poverty dynamics.

Analysis of quantitative data in isolation from understanding of the political economy, social and cultural context, and within-country differences of the countr(y/ies) involved is of limited value. The questions raised for example over the analyses for Nigeria and Uganda (section 7.1) highlight this.

In the urban context, underlying causes of the reductions in utility-derived piped water supply services include those related to demographic change and rates of increase in demand which cannot keep up with investments. However, many aspects of the political economy of specific countries are also strong contributory causes of the difficulties faced by utilities. In attempting to analyse the situation in specific cities, the weaknesses in data availability become even more pronounced. In particular, the proportions of the water supplied by utilities which are groundwater-derived; and the proportions of groundwater consumed which are self-supplied (as opposed to utility-supplied) are not easy to quantify. The implications of self-supply, both for the financial viability of utilities, and for the health of the poor (and to a lesser extent the well-off), are probably highly context-specific, and little known.

In developing conceptual frameworks which can enhance understanding and guide further research, there needs to be some consensus around their scope (for example ecosystem services, water services, or specifically groundwater services), complexity, and relationships to other frameworks (eg livelihoods). Differing approaches to inter-disciplinarity (already subjected to investigation in the UPGro programme, Dobson, 2016) need to be brought into future dialogue over such conceptual frameworks.

Overall, our current state of knowledge in relation to domestic and productive uses of groundwater by the rural and urban poor is deficient in the following ways:

- we do not have complete understanding of the trends in groundwater access, who (in poverty terms) is experiencing those changes, and how the changes are impacting upon them;
- while we know that groundwater access can, in principle, offer a range of benefits to all wealth categories, we have insufficient understanding of how that access brings benefits to the poorest quintiles or groups; nor who, if any, are the losers;
- from a practical point of view therefore, we do not know enough to ensure that the benefits of groundwater access reach the poor without adversely affecting those – perhaps equally poor – who do not have access;
- in the urban context, we do not have sufficient understanding of the benefits and costs of self-supply, specifically those affecting the health of the poor and the financial viability of water utilities;
- while understanding that there will be feedbacks between extending groundwater access, especially for water-thirsty applications such as urban water supply and irrigation, and the quality and quantity of the resource itself, we lack detailed knowledge of the context-specific nature of those impacts.

Next steps (chapter 11)

Discussions will continue in order to articulate a more substantive research proposal, building on the knowledge gaps identified in this report. Further investigations and dialogue will be considered in regard to the urban component of the study, resources permitting.

1 Introduction

On 20th December 2016 the UK Natural Environment Research Council (NERC) wrote to the Skat Foundation (in its capacity as Knowledge Broker for the UPGro Programme) inviting a 'light touch bid' for a short piece of work additional to its knowledge broker mandate, on condition that the proposed activity would (a) add value to UPGro, (b) facilitate development of bids to future research funding calls (especially GCRF and Newton Fund), and (c) be completed and paid for by 31st March.

On 9th January 2017 (the bid deadline) Skat submitted two bids. One of these (the subject of this report) focused on the links between groundwater and poverty (addressing the "for the poor" aspect of the UPGro acronym).

On 24th January Skat was informed that the bid had been successful. On 15th February Skat received a contract amendment permitting this work to go ahead.

The overall objectives of the work are reproduced as Box 1.

Box 1 Project objectives

Changes in groundwater resources, access and use are taking place throughout sub-Saharan Africa as a consequence of demographic, environmental and economic trends, and infrastructure investments. In the context of the UPGro programme (Unlocking the Potential of Groundwater for the Poor) and the SDGs, **the overall objective** is to identify the extent to which poor people benefit from, or are further marginalised by such changes. The ultimate aim is to contribute to UPGro's impact, "*Sustainably managed groundwater resources support increased water security **for poor people** in Sub-Saharan Africa*".
Specific objectives:

1. The linkages between groundwater and poverty in Africa through systematic literature reviews, consultations and data analysis are understood and conceptualised;
2. A research proposal to further investigate these linkages across the region is developed;
3. The UPGro research networks to those individuals and organisations in the region with a research-, policy- or practice-related interest in poverty reduction are extended.

An important driver for the initiative was the recognition at an UPGro consortium meeting in November 2016 that the programme so far lacks a clear and convincing narrative linking groundwater access to poverty alleviation. This funding opportunity was seen as a chance to begin to address this issue in a systematic manner.

A cautionary note: the work reported here was undertaken in a period of just under 10 weeks, and the main contract for the work was only in place for just over 6 of those weeks. Inevitably it has only been possible to scratch the surface of such a broad and complex topic. Furthermore, the intended research proposal for which this report provides a starting point will require a significantly longer process involving confirmation of partners and detailed design during calendar year 2017. Nevertheless in this study we believe we have identified some important findings, insights and knowledge gaps which can guide future work in this important area.

2 Research questions

It is not clear from existing datasets and syntheses (such as the Joint Monitoring Programme of the World Health Organisation and UNICEF) what exactly is the present status of groundwater access in sub-Saharan Africa, nor what the trends are. In this regard there is probably better data in relation to drinking water than for example for irrigation and other productive uses of water. Furthermore it would be simplistic to assume that simply increasing access to well-managed and reliable groundwater services has direct benefits to the poor, without any concomitant drawbacks, risks, or unintended impacts.

A number of research questions arise therefore, and the list in Box 2 was established at the outset of this project. They are revisited later in the report.

Box 2 Initial broad research questions

1. How has access to different types of domestic water source, and especially those supplied by groundwater changed over the period 1990-2015?
2. To what extent is poverty related to the type of water source (in particular groundwater) used for domestic purposes?
3. How and to what extent does groundwater access for irrigation affect incomes, livelihoods, wellbeing and food security?
4. How and to what extent are changes in groundwater resources (quantity and quality) impacting on the poor?
5. How and to what extent are demographic trends and consequent changes in water demands affecting the poor?
6. How and to what extent do changes in groundwater access affect poverty / wellbeing trajectories (escaping poverty, sustained versus temporary escapes, impoverishment, chronic poverty)?
7. How and to what extent do changes in groundwater access affect vulnerability / security?
8. How and to what extent do changes in groundwater access affect other outcomes (eg education, health, employment)?
9. Who are the winners and losers as access to groundwater changes over time and across wealth / poverty groupings?

It was acknowledged that not all these questions could be addressed in any comprehensive manner in such a short project. However, they helped in a general manner to frame the various scoping investigations which were undertaken.

3 Approach to the project

The project was approached through four substantive tasks (1-4) in which new knowledge, insight and understanding would be generated; and three further tasks (5-7) which would establish the groundwork for a future major research bid. These tasks are set out in Box 3. The methods adopted in tasks 1-4 are set out in greater detail in chapters 5-8 of this report.

Box 3 Tasks proposed at the outset

Task 1 Systematic review of literature on the links between (ground)water access and poverty (desk-based).
We will seek out evidence on the links between changes in groundwater access and the well-being, quality of life and incomes of poor communities, households and individuals. We will synthesise evidence about the impacts of natural and anthropogenic change, and economic and investment trends which affect groundwater access and use, on poor people.
Task 2 Review of emerging data on groundwater and poverty links in the 5 UPGro Consortium projects (desk- and interview-based).
Each of the UPGro Consortium Projects is addressing the issues of poverty within their wider objectives. In this task we will make explicit the nature of the analyses and narratives which are likely to emerge from each project, concerning UPGro's focus on "the Poor".
Task 3 Analysis of data sets on (ground)water access and wealth / poverty (desk-based).
Panel and household survey data sets and syntheses such as that contained in the Joint Monitoring Programme (JMP) of WHO and UNICEF will be analysed to further inform our understanding about who benefits from, and who remains marginalised by, changes in groundwater access.
Task 4 Review of groundwater in the urban context, with a focus on those living in unplanned settlements (desk- and interview-based).
This task will identify the groundwater dependence of select towns and cities in the region, in particular quantifying and drawing out the implications of the dependence of low-income households on self-supplied groundwater.
Tasks 5 and 6 were to consist of (5) a **UK-based workshop** to develop a conceptual framework linking groundwater and poverty, and (6) an **Africa-based workshop** to develop a research proposal. In the final contract these were merged into a series of skype calls and webinars with the same objective of defining the content of a more substantive research proposal. The reasons for this were (a) the difficulty of convening UPGro researchers within the tight time scale of this project (especially given visa difficulties for African colleagues coming to UK), (b) the preference to use most of the T&S funds which were originally budgeted to enhance the findings and insights of the project. In other words the proposal will be more realistic and more cost-effective than what was originally proposed.
Task 7 Extending our groundwater research and policy / practice networks to embrace those with interests in poverty research and action (online).
As the short project progresses we will be actively seeking new collaborators with specific poverty interests and expertise to extend our existing UPGro network of more than 100 research staff and partners.

4 Towards a conceptual framework

4.1 Water as a contributory factor to poverty alleviation

An important caveat to this entire report, to the UPGro programme, and to all statements about (ground)water and poverty is this: improved access to water is but one of many contributory factors for poverty reduction. The relative importance of (ground)water may be very context-specific and highly variable. The contributions of improved access to education, to health services, to markets and to wider networks of social and economic exchange, among others, make for a complex picture. Furthermore, given that groundwater may represent only one of the multiple sources of water used by many households, the consideration of groundwater and poverty is somewhat artificial.

4.2 Water and land

Groundwater[i] is a natural resource which in many places supplies moisture to wetland ecosystems or provides natural discharges (springs and baseflow) which can be directly used for domestic or productive purposes. However more generally it requires engineering (in the form of wells and boreholes) and technology (in the form of pumps and power supplies), together with continuing governance, management and financing by mandated agencies and water users in order to provide access or water supply services. It is that access, or those services, rather than merely the resource in its undeveloped form which have the potential to alleviate poverty.

It has long been known that stored groundwater far exceeds the volume of surface waters[ii]. It therefore has the potential to buffer short to medium term variations in the balance between recharge[iii] and abstractions to an extent that is only possible for surface waters with artificial reservoir storage. However, in the longer term (a period which depends on the magnitude of groundwater storage and the extent to which abstractions exceed recharge) groundwater storage is susceptible to depletion.

The processes by which a proportion of precipitation enters and then moves through aquifers modify groundwater quality for better or worse. Nevertheless it is generally assumed (with some critical exceptions) that groundwater quality is advantageous, especially for domestic use. But just as with groundwater quantity, the quality of the resource is susceptible to anthropogenic contamination.

Consequently groundwater as a resource, in both its quantity and quality dimensions, is both dynamic and subject to numerous drivers of change. Such drivers include demographic trends (including spatial aspects of such temporal variation), changing demands for water by different users and uses, changes in land use[iv], and global climate change.

Just as the distinction between groundwater and surface water has to be treated with caution (since the two are intimately linked in a dynamic cycle), so it is important to think of water alongside land. This is especially the case when trying to understand and quantify the water balance. How precipitation is partitioned between rapid runoff to watercourses and infiltration to the soil, resulting in evapotranspiration and deep percolation or recharge, is determined as much by soil properties and land use as by precipitation and other weather variables.

Abstractions of groundwater, for rural and urban domestic use, for livestock, for crop irrigation and for industry, and the return flows resulting from these uses, create links between land, its uses, and its underlying aquifers to the quantity and quality of groundwater in those aquifers, and how they change over time. The ownership of land also plays an important role in how groundwater resources are managed and distributed.

4.3 People and poverty

Poverty[v] describes one or more forms of deprivation. At its most fundamental level this may relate to a person's ability to meet their basic needs and so enjoy an acceptable standard of living. Poverty is a symptom, with underlying and wider political, social, economic, institutional and cultural causes.

Poverty places individuals and households at a disadvantage, not just financially, but also from a social point of view. It commonly leads to exclusion, from decision-making, from access to opportunities and services (including water), and from acceptance by better-off and more influential social groups.

Poverty exists in both absolute and relative terms. Poverty may be subject to measurement, but it may (and should) also be explored through 'subjective' perceptions of those who are reckoned by themselves or others to be in a state of poverty. Poverty has multiple dimensions, spanning economic and many non-economic aspects, and it is dynamic in nature.

The dynamic nature of poverty means that households and individuals may be on various trajectories over time. Their poverty may be increasing or reducing, changing in nature, and leading to sustained or only temporary transitions into or out of poverty.

Within households, communities and society, certain categories of individual may be more likely to live in poverty. These include women; those disadvantaged by age, illness, ethnicity, religion, sexual orientation or disability; rural dwellers; and slum-dwellers.

Increasing access to engineered and managed groundwater services may create greater dependencies on organisations (government, private sector, civil society) and services which are external to the household or community. The professionalism of those organisations and the services which they provide are critical if service users are to enjoy the full benefits of improved water access.

Poverty, as a descriptor of individuals, households, communities and society as a whole, is, like groundwater, dynamic and subject to many external influences. These include political and policy choices of governments, national and global economic pressures, and social and cultural trends.

While household water acquisition and management are generally seen as the responsibility of women in SSA (often or usually supported by children), women's meaningful participation in the management and financing of engineered ('improved') groundwater sources cannot be taken for granted. Similarly the ability of women to access groundwater for productive uses may also be constrained by their gender, especially if legal title to land ownership is denied to them.

Societal attitudes to the roles and value accorded to women and children represent an important fault-line within households; while the benefits of groundwater access may be evident at household level, within-household benefits may be far less equitably experienced.

4.4 Groundwater and poverty

Use of groundwater directly (as water for domestic or productive purposes) or indirectly (via ecosystem services and products) has the potential to alleviate poverty or to prevent households falling further into poverty[vi]. Examples of the ways in which poverty may, in principle, be alleviated include those mediated through productive uses of groundwater or groundwater-dependent ecosystems (enabling generation of income, maintenance and increase in consumption, and enhancement of assets). Whether opportunities here represent secure work, or insecure or exploitative labour, is an important question.

Better access to domestic water services in principle offers the potential to save time, which can enhance leisure or create income-generation or educational opportunities, and money which would otherwise be spent on health care (assuming significant health benefits are realised by the poor).

Some external drivers of change impinge both upon groundwater (as a resource and as a service) and upon those living in or close to poverty lines. These include slow- and rapid onset natural disasters such as droughts and floods; and also economic shocks, insecurity and conflict.

4.5 Scale issues

Broad but abstract principles, and generalised links between groundwater and poverty, need to be made concrete through examining particular places and populations. This implies that we can examine the linkages at various spatial scales – from very local to national and beyond – and by placing either a defined groundwater body, or a defined population, centre-stage.

From a hydrological viewpoint, when dealing primarily with surface water, the dilemma of whether to work with catchment boundaries or administrative boundaries inevitably arises. In the case of groundwater, which may or may not follow topographical (surface water) catchment boundaries, this situation is accentuated.

From a poverty perspective, it may be appropriate to explore groundwater-poverty linkages at a variety of scales, from individual to household to administrative unit to national scale. Poverty itself needs to be disaggregated by depth, by dynamic trajectories, and by its multi-dimensional aspects.

In either case, in drawing a boundary around a population or a groundwater resource unit which is of interest, there has to be a recognition of the 'porosity' of that boundary – and of the 'fuzziness' of the distinction between what is inside and outside of the box.

Just as there are spatial scale issues to consider in the examination of groundwater-poverty linkages, so too temporal scale matters. Recent groundwater research (Taylor et al, 2013) shows clearly the importance of infrequent extreme events in determining aquifer recharge in the semi-arid tropics, so implying that decadal rather than annual time scales are more important. The appropriate time-scales for examining poverty and poverty transitions may not always match those most suited to examining groundwater resources and groundwater services.

4.6 Conceptual frameworks

In developing a conceptual framework for this research, a few principles are relevant. A useful (in the sense of mapping ideas and providing a checklist of key features) conceptual framework of a complex system should:

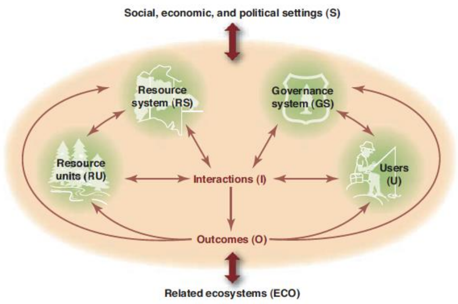
- represent the most important components or aspects and their important linkages, even if not including all their detail;
- be shown in graphical form with an accompanying explanatory narrative which acknowledges limitations both in terms of understanding and of representation;
- be readily appreciated and understood (and therefore not be over-complex);
- be open to the inclusion of new insights as they arise.

In this study we have not undertaken a comprehensive evaluation of conceptual frameworks, although some reviews and papers have been consulted and considered. In particular we have utilised the review by Keane (2016), and papers by Fisher et al (2014) and CGIAR (2015).

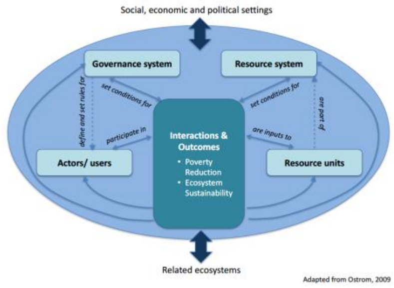
Early in this short project a number of candidate conceptual frameworks were considered by the project team. Figure 1 shows the starting points and early evolution of these frameworks.

Figure 1 Initial candidate conceptual frameworks

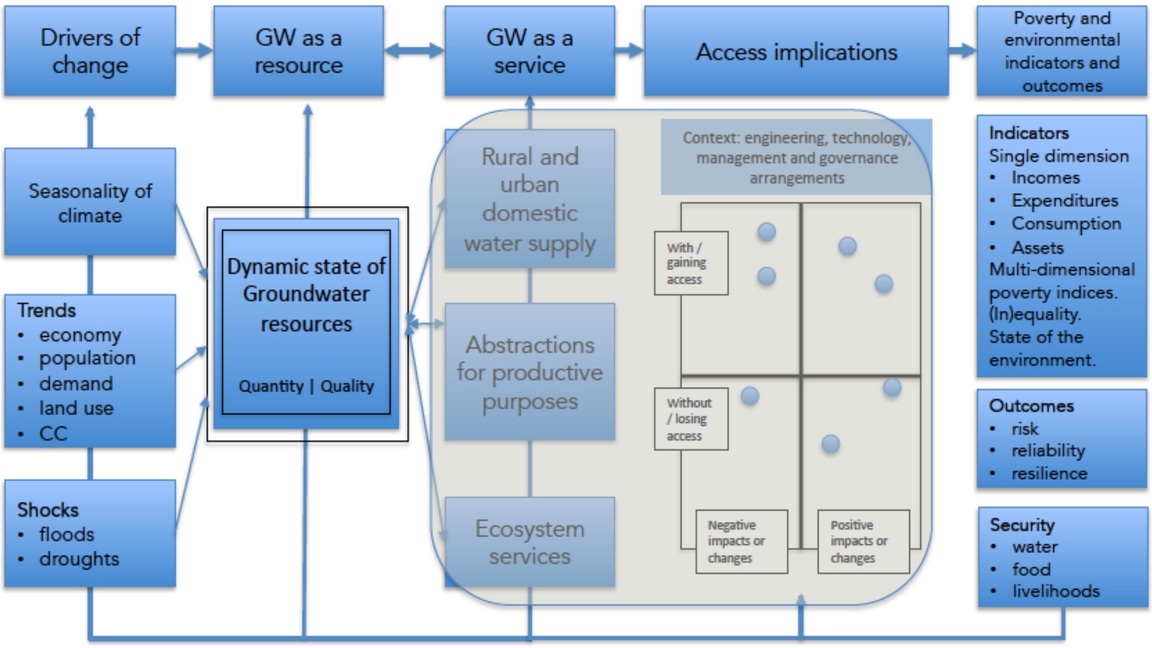
(a) From Ostrom (2009)



(b) Hope (2017), after Ostrom (2009)



(c) Carter (this project)



The dynamic state of groundwater quantity and quality, over seasonal and decadal cycles and over the long-term, is affected by the climate; trends in GNI, population size, residence (rural and urban) and wealth; corresponding water demands; changing land use patterns and anthropogenic climate change. Investments in public water supply and in abstractions for agriculture and industry enhance access for some, while returning degraded non-consumptive flows which contaminate the groundwater resource. The groundwater-surface water interactions which take place in wetland ecosystems help to determine the state of and changes in the ecosystem services enjoyed by human beings. Access or lack of access to groundwater services may have both positive and negative impacts on individuals, households and communities. The blue circles in the access-impact matrix represent different context-specific examples and cases of such relationships. Competition for or cooperation over access may exacerbate or enhance benefits to different segments of the population. Access has to be seen in the context of engineering and technology, local management and wider governance arrangements. At the highest level (the right hand side of the diagram), groundwater access may reduce risk, enhance reliability and increase resilience and security for some, while perhaps worsening the situation, in relative or absolute terms, for others. A number of feedback loops exist, as changing access to services may contribute to competition, pollution and drivers of change. Every aspect in the framework is dynamic.

This study was too short to permit development and adoption of a common conceptual framework by all those working on it. Instead a framework is proposed in section 10 which attempts to summarise the linkages which have emerged from this work.

5 Literature review

5.1 Summary

This literature review aims to identify and summarise current evidence linking access to groundwater with poverty and wellbeing in sub-Saharan Africa (SSA). The review synthesises literature exploring: (a) longitudinal and socio-economic patterns in access to groundwater; (b) the relationships between groundwater access and poverty/wellbeing; and (c) emerging groundwater trends and their impacts on poverty and wellbeing. In addition to multidimensional measures of poverty and wellbeing, evidence was sought on four key areas of human development: health, education, livelihoods, and food security. Based on an initial scan of titles of more than 10,000 papers, articles and reports from a range of academic and sector-specific databases were extracted and reviewed. Analyses of relevant publicly available datasets were also carried out.

The empirical evidence examined suggests the majority of people in SSA source their drinking water from groundwater. Around half the population use groundwater point sources and an additional but unknown number are served by groundwater-fed piped supplies. Although access patterns differ from country to country, the levels and nature of groundwater access are strongly determined by household wealth. This is true for both domestic and productive water uses.

Numerous studies document evidence of a relationship between groundwater access and positive outcomes relating to health, education, livelihoods and food security. The benefits generally accrue as water service levels improve (e.g. source protection, treatment, lifting technologies, and proximity of supply). These characteristics in turn are closely correlated with household wealth, suggesting uneven gains across socio-economic strata. Despite the numerous studies which consider the implications of groundwater access in SSA, the majority suffer from methodological limitations, and there is a dearth of high quality research unravelling causal linkages and assessing the longer term impacts on poverty trajectories.

Changes and emerging threats to groundwater quality, quantity and access are also documented in the literature. While it is likely that these issues disproportionately affect the poor, few studies have sought to empirically assess their impact on welfare outcomes and longer term poverty pathways.

In summary, the available evidence suggests improved groundwater access can confer a variety of benefits, including for poor households in both urban and rural areas. However, by virtue of disparities in service levels and vulnerability to emerging threats and trends, the poorest households do not necessarily capture an equitable share of the gains, and in some cases groundwater access patterns may reinforce or exacerbate inequalities. Rigorous studies are needed to provide a more robust and nuanced understanding of how groundwater access can benefit the poorest households and drive long-term changes in poverty trajectories.

5.2 Methodology

Academic databases and sector-specific digital libraries were searched using a broad set of key words pertaining to (a) poverty impacts, (b) water access, and (c) African country names (see Appendix A1 for detailed search methodology). Databases searched included Web of Science; WEDC Conference Papers; World Bank; British Geological Survey; Rural Water Supply Network; International Water Management Institute; and UNICEF/WHO Joint Monitoring Programme. A separate search of Web of Science for water-related systematic reviews was also conducted, as these papers tended not to include references to Africa or African countries in their title or abstract, and were therefore not captured in the initial search. Where references of interest within documents were identified, these papers were located and reviewed. Sector-specific databases generally did not allow complex search strategies, and so in several cases it was more expedient to filter by key terms and/or scan all titles. In total, more than 10,000 titles were reviewed, the vast majority of which were returned by the Web of Science search (8,959).

The original intention of this review was to be systematic, however given the time constraints and large body of literature to survey it might more aptly be considered a scoping of the literature. The review was conducted in a condensed timeframe (i.e. search, review and write-up were completed within 12 days), and hence there was insufficient time to thoroughly read all papers of interest. It is probable that some relevant studies are not included in the review. Similarly, time constraints precluded a comprehensive search of several other relevant databases, including Scopus, IRC International Water and Sanitation Centre, FAO, CGIAR, and International Livestock Research Institute.

A key challenge in conducting the review is that many studies assessing the impacts of water supply improvements do not specify whether the ultimate source is groundwater, surface water or rainwater. Instead most adopt dichotomous categorisations such as improved/unimproved, protected/unprotected, and piped/non-piped. Studies also adopt research designs and analytical strategies with varying levels of rigour, and in the timeframe it was not possible to critically assess the quality of each study reported. It should also be noted that the findings presented may reflect a degree of publication bias. Non-significant results pertaining to ground(water) are less likely to be included in a title or abstract, and therefore may not be captured in the literature searches.

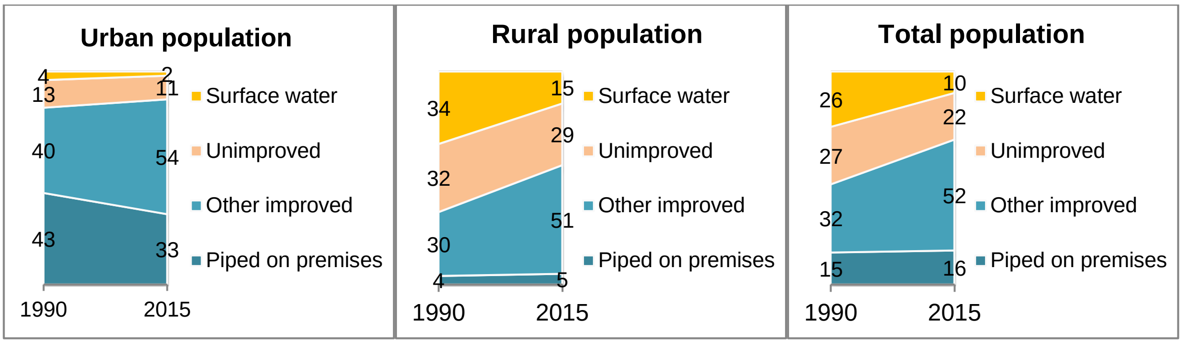
5.3 Trends in groundwater access

5.3.1 Groundwater for domestic use

Available data suggest most people in SSA source their drinking water from groundwater sources. Official estimates published by the WHO/UNICEF Joint Monitoring Programme (JMP) indicate "other improved" water sources have experienced the largest growth in access since 1990, rising from 32% to 52% of the population (Figure 2). However, this broad classification does not distinguish between improved sources supplied by groundwater and those supplied by surface water or rainwater. Over the same time period, there has been little change in the proportion of households with water piped onto the premises, and a major decline in surface water use. A World Bank study conducted by Banerjee & Morella (2011) suggested that by 2005 around 40% of the population in SSA sourced their drinking water from wells (seemingly both protected and unprotected) and boreholes, which represented a significant increase relative to levels in 1990-5. Aggregation of JMP Country Files reveals that by 2015, around half of the population in SSA used groundwater point sources (wells, boreholes, springs) for drinking, with 32% (~312m people) using protected groundwater point sources and 18% (~173m people) using unprotected groundwater point sources (Figure 3). This confirms not only the heavy dependence on groundwater for domestic purposes, but also signifies a continued growth in groundwater use in both urban and rural areas[vii].

Several studies provide further evidence of the increasing importance of groundwater, particularly in urban and peri-urban areas (Okotto et al, 2015; Grönwall, 2016; Thompson et al, 2000). Moreover, owing to its focus on 'main drinking water source', the JMP statistics may underestimate the true significance of wells in urban areas. Studies show households commonly use wells as a secondary water source – either as a back-up source for when utility supplies are disrupted or as a way to augment utility supplies for non-drinking purposes (Ejechi and Ejechi, 2007; Adekalu et al, 2002; Akple et al, 2011; Grönwall, 2016). For example, a large survey of households in informal settlements across Kenya found that 13.4% used groundwater point sources for drinking, but 22.6% used them for laundry[viii]. This serves to highlight the complicated water use patterns among low-income populations that commonly involve multiple sources (Howard et al, 2002; Okotto et al, 2015). The amount of water drawn from shallow wells in urban areas may be significant (Okotto et al, 2015), potentially undermining demand for urban utility services (Kulinkina et al, 2016) – see also chapter 8, this study.

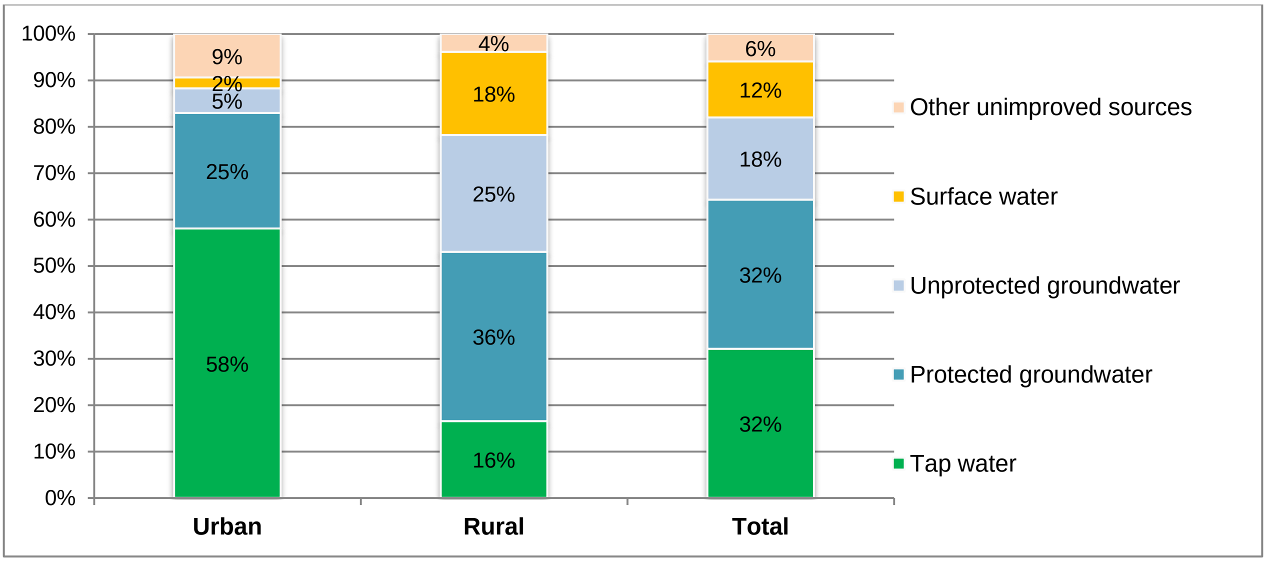
Figure 2 - Trends in access to water sources in sub-Saharan Africa 1990-2015 (JMP data)



Groundwater point source use is still skewed heavily towards rural areas, with around 6 in 10 households (~374m people) relying on wells, boreholes and springs (Figure 3), double the proportion seen in urban areas. Communal handpumps are the most common mode of lifting groundwater from protected sources in rural areas (MacArthur, 2015), with an estimated 60,000 imported into the continent every year (Sansom and Koestler, 2009). There is also growing interest in low-cost handpumps (MacCarthy et al, 2013; Harvey and Drouin, 2006; Baumann, 2011) and solar-powered pumps (Mudzingwa et al, 2016), although the continent-wide adoption rates are unknown.

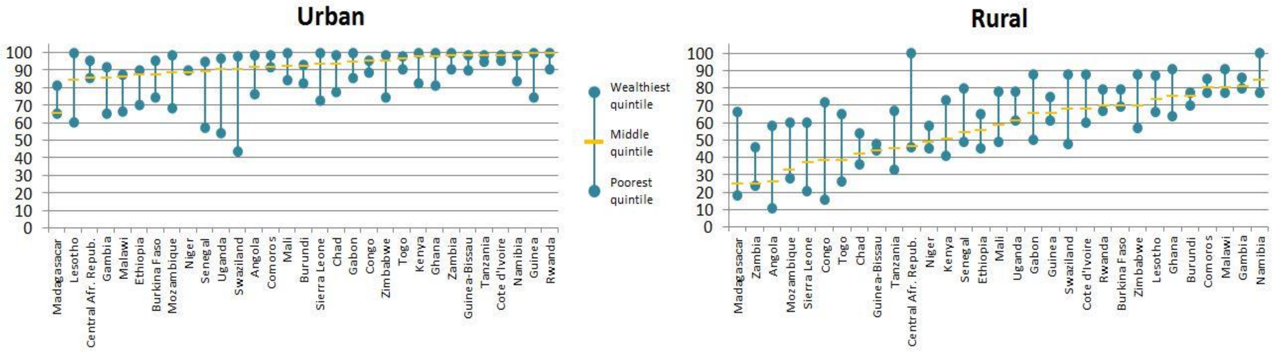
Figure 3 - Drinking water source access in SSA in 2015

[author's estimates based on most recent data in JMP Country files]



Aggregated water access figures mask significant disparities in improved water access between and within countries (Pullan et al, 2014; Yu et al, 2014). In terms of access to groundwater point sources, low-income countries range from greater than 80% (Liberia) to less than 25% (Senegal). Official JMP statistics highlight considerable inequalities by household wealth, and numerous other studies concur (Adams et al, 2016; Mahama et al, 2014; Kwaghe and Amaza, 2009; Schmidlin et al, 2013). In general, wealthier households (usually measured by a composite index) are much more likely to use improved drinking water sources, particularly piped connections (Figure 4)[ix]. Evidence from rural Ethiopia also illustrates how poorer households use less water than wealthier households, a disparity which is attributed to labour, water storage, and financial constraints (Tucker et al, 2014).

Figure 4 - Access to improved water sources in SSA by wealth quintile (2012)



Inequalities manifest themselves in other ways. Gender differences have been identified in an Ethiopian study, with female headed households less likely to access a safe water source than male-headed households (Adank et al, 2016). Benova et al (2014) expose inequities during childbirth, with women in the poorest wealth quintiles in Tanzania considerably less likely to give birth in a facility with adequate water supplies. Case studies from Mali and Zambia also highlight the groundwater accessibility challenges faced by persons with disabilities (Wilbur and Danquah, 2015; Tan et al, 2013).

While JMP estimates do not divulge inequities specifically from a groundwater perspective, there is evidence that the levels and nature of groundwater access are also strongly associated with household wealth (Banerjee and Morella, 2011). A study from rural Côte d'Ivoire suggests that wealthier households are more likely to access groundwater via a handpump than poorer households, who instead resort to surface water or open wells (Schmidlin et al, 2013). A similar pattern between household wealth and protected groundwater use is evident in some rural areas of Ethiopia, although there are significant variations by season, purpose of water use and livelihood zone (Tucker et al, 2014). Meanwhile, evidence from urban Kenya indicates that better-off groundwater users are more likely to own their well, whereas households in the middle wealth quintiles are more likely to purchase their groundwater from others (Okotto et al, 2015).

5.3.2 Groundwater for productive use

Despite the ubiquity of groundwater-based domestic supplies, use of groundwater for irrigation is the exception rather than the norm in SSA. Rainfed agriculture remains the chief source of livelihood for most households in rural areas across the continent. Recent estimate suggest only 1% of cultivated area in SSA is irrigated with groundwater (Siebert et al, 2010), and surface water irrigation is far more common. Giordano (2006) and Siebert et al (2010) have estimated that groundwater supplies 6-10% of irrigated agriculture in SSA, with Giordano estimating the benefits reach around 1.5-3% of the rural population. However, Villholth (2013) suggests these may be underestimates, with more granular studies pointing to a proportion of up to 20%.

There are few longitudinal data illustrating trends in small-scale groundwater irrigation in SSA. Fragments of evidence indicate that adoption of water lifting technologies is on the rise, though these may not always be used to access groundwater. According to Namara et al (2013), 800,000 motorized pumps were imported into Ethiopia between 2004-10, 60,000 treadle pumps had been distributed in Malawi by 2010, and in 2008-9 the number of small motorized pumps in Ghana was estimated to be around 170,000. Censuses of farming households in Ghana and Ethiopia shed additional light on the prevalence of small-scale groundwater irrigation. In 8 Ethiopian woredas (districts), 30.5% of farming households used a water lifting device of some sort (predominantly a rope and bucket) but only 4.3% of households utilised a motorized pump (Namara et al, 2013). A higher prevalence of groundwater irrigation was observed in several regions in Ghana, with 60%

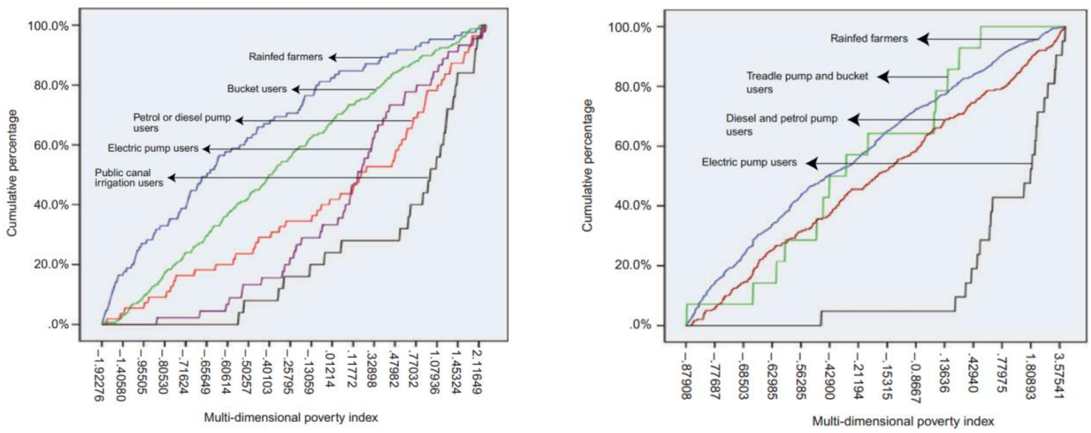
of households lifting groundwater by bucket and 15% using a motorized pump (Namara et al, 2014). Temporal shifts are also evident, with a discernible decline in treadle pumps and a corresponding rise in motorized pumps and bucket use.

Available evidence suggests that socio-economic characteristics are associated with access to groundwater for smallholder irrigation, as well as use of particular water-lifting technologies. Namara et al (2013) report that in both Ghana and Ethiopia, groundwater irrigators tend to be wealthier (as measured by a multi-dimensional poverty index) than rain-fed farmers, and wealth levels are correlated with lifting technologies: electrical pump users were the wealthiest, followed by petrol or diesel pump users, and then those using manual pumps or buckets (Figure 5). Groundwater irrigators in Ghana – especially those using electric pumps – also tended to have higher education levels than those relying on rainfed farming and disproportionately fell within the richest 20% of the farming population (Namara et al 2014). The same study revealed an under-representation of women among those adopting water-lifting technologies, a finding that concurs with observations from Zambia (Van Koppen et al 2013). Access to capital and land tenure issues are key barriers to poor households adopting groundwater lifting technologies (Kimmage, 1991; Villholth, 2013). Financial constraints have also been noted as a significant barrier preventing the poorest households from participating in productive uses of groundwater-fed domestic supplies (Van Houweling et al, 2012).

Household wealth and welfare are not the only determinants of groundwater irrigation and pump adoption. Hydrogeology may pose a constraint in some areas, but in others socio-economic and policy issues are more prominent obstacles (Villholth et al, 2013). Indeed, Xie et al (2014) estimate that areas suitable for treadle and motorized pump irrigation in Africa could directly benefit 185 million and 243 million respectively. Calculations by Pavelic et al (2013) also suggest significant potential for small-scale groundwater irrigation. Availability of pumps and energy sources, and access to markets present additional stumbling blocks (Villholth, 2013), and thus the more remote households are less likely to practice groundwater irrigation (Namara et al, 2014).

Figure 5 - Cumulative percentage of irrigation category by multi-dimensional poverty index

(Namara et al, 2013)



5.4 Poverty and wellbeing impacts of groundwater access

Literature pertaining to the pro-poor impacts of groundwater access traverses four domains of human development: health, education, livelihoods, and food security. Numerous studies examine and characterise these relationships, and despite their varying quality, indicate groundwater access confers benefits across all four areas. There is, however, a scarcity of studies from SSA that have rigorously examined longitudinal poverty and wellbeing pathways, and how these are shaped by access to groundwater for domestic and productive purposes.

5.4.1 Health

Hypothesis: By enabling more proximate, reliable and higher quality water for domestic purposes (MacDonald and Calow 2009), groundwater access can potentially reduce the burden of water-related diseases by lowering the risk of drinking contaminated water, increasing water use for hygiene purposes, and minimising exposure to other water-based diseases. This in turn could promote child growth and cognitive development, prevent premature deaths, reduce costs relating to healthcare, and result in wellbeing and productivity benefits in the long term.

Many of the health studies reviewed – including several systematic reviews and meta-analyses – provide evidence that improvements in water access are associated with a reduced burden of diarrhoea, intestinal parasites and protozoa, schistosomiasis, trachoma, stunting/wasting and malnutrition, and child and maternal mortality. Depending on the disease, both the level of water source protection and distance to the water source exhibit associations with health outcomes. While one would expect these relationships to hold specifically for improvements in groundwater access in SSA, the evidence base is weaker: only a small fraction of studies from SSA isolate effects pertaining to improved groundwater access.

The body of literature assessing the relationship between water and diarrhoea is vast. While methodological limitations abound and disagreements about the relative roles of water quality and quantity persist, there is evidence that water supply improvements reduce the burden of diarrhoeal diseases. Recent systematic reviews and meta-analyses concluded that water supply interventions are associated with lower rates of diarrhoea (Wolf et al, 2014; Cairncross et al, 2010). Although Wolf et al (2014) found no significant reduction in diarrhoea when comparing improved community sources with unimproved sources, they did find evidence of significant reductions when comparing basic piped water to an unimproved supply and higher quality piped water to an improved community supply. Findings from systematic reviews of on-plot water supplies and water usage levels also found significant associations with diarrhoea reductions (Overbo et al, 2016; Stelmach and Clasen, 2015), as did a multi-country analysis of DHS data (Fink et al, 2011). In contrast to Wolf et al (2014), Fink et al (2011) identified a significant relationship even when comparing communal waterpoints (i.e. wells, boreholes, standpipes) with surface water.

There is also evidence that distance to water source is associated with reduced risk of diarrhoea. Of the two African studies included in a systematic review by Wang & Hunter (2010), both identified significant relationships between distance to water and diarrhoea (Gascon et al, 2000; Tonglet et al, 1992). More recent studies have yielded consistent results (Diouf et al, 2014; Pickering and Davis, 2012). Based on analysis of almost 200,000 households in 26 African countries, Pickering and Davis (2012) concluded that a 15 minute decrease in one-way walk time was associated with a 41% reduction in diarrhoea prevalence.

Among the handful of papers that focus specifically on groundwater in SSA, there is some support for the proposition that improved groundwater access is associated with a lower risk of diarrhoea. A high quality investigation of spring protection measures in rural Kenya revealed reduced faecal contamination and lower rates of diarrhoea (Kremer et al, 2011). Likewise, Cha et al (2015) assessed a borehole rehabilitation and installation programme in Ghana and reported significantly lower diarrhoea rates among intervention communities compared with communities not receiving the intervention. Conversely, an evaluation of a similar borehole programme in Nigeria by Huttly et al (1990) found no significant reduction in diarrhoea following the intervention, though the authors observed that those living closer to the borehole had lower rates of diarrhoea than those living further away.

Numerous papers explore the link between water and mortality, though none expressly examine groundwater sources. The abovementioned study by Fink et al (2011) found both intermediate waterpoints (wells, boreholes and standpipes) and piped water were significantly associated with a lower risk of infant mortality. Similarly, Pickering and Davis (2012) found time to a water source to be a significant determinant of under-five mortality, with a 15 minute decrease in one-way walk time associated with a 11% reduction. A systematic review of maternal mortality by Benova et al (2014) identified four out of six ecological studies that suggested inadequate water was associated with higher maternal mortality rates. Of the ecological studies looking exclusively at SSA, one failed to find a significant relationship with water (Paul, 1993), while another did (albeit a univariate relationship, Alvarez et al, 2009). Studies by Urassa et al (1995) and Graham et al (2004) also found significant associations between access to water and maternal mortality in Tanzania, Ethiopia, Kenya, and Mali, although they were univariate in nature. A more recent ecological study focusing on SSA confirmed a significant multivariable relationship between access to improved water and maternal mortality (Sommer et al, 2016).

A number of studies support the proposition that access to water is related to child growth outcomes. Results from a systematic review and meta-analysis of cluster-randomised control trials suggest water quality improvements confer a small benefit on growth among children under five years of age (Dangour et al, 2013). Overbo et al (2016) also conclude that children with on-plot water supplies exhibit greater height than those without. Other studies from an African context concur with these verdicts. In rural Sudan, improved child growth was found to be associated with on-plot water supply (Merchant et al, 2003) The aforementioned assessment by Fink et al (2011) concluded that both intermediate waterpoints (wells, boreholes and standpipes) and piped water were significantly associated with lower risk of mild or severe stunting. Pickering and Davis (2012) also identified time to a water source as a significant determinant of anthropometric indicators of

child nutritional status. A recent study from Ethiopia found access to improved water sources at one year of age was associated with a lower risk of stunting at 5 years once adjusting for other variables (Dearden et al, 2017), while Altare et al (2016) identified similar relationships between water source type and stunting in Tanzania. In a separate Tanzanian study, Abubakar et al (2012) found water source distance was associated with underweight children.

A smaller number of studies examine the link between groundwater access and child growth in SSA, and their conclusions are generally aligned with the broader literature. Fenn et al (2012) reported that a WASH intervention group – which includes protection of springs and wells – resulted in a significant increase in mean height-for-age Z-score and a 12.1% decrease in the prevalence of stunting, compared with the baseline group (though the association may have resulted from other elements of the intervention). Results presented by Huttly et al (1990) suggest a borehole and handpump installation programme in Nigeria was associated with a decrease in wasting among children less than 3 years. Somewhat surprisingly, a Ugandan study found that children under 3 years using protected wells had significantly lower stunting status than those using piped supplies (Biondi et al, 2011), while in Ethiopia the odds of a child registering low body mass index were significantly lower for handpump supplies than for piped supplies (Mahmud et al 2013). An investigation in Niger also suggested that access to protected groundwater sources was associated with a lower a prevalence of secondary water-related infections and shorter lengths of stay for malnourished children in a therapeutic feeding programme (Dorion et al, 2012). Conversely, in Guinea Bissau unprotected well use (as compared with piped water) was significantly associated with severe malnourishment among paediatric outpatients (Colombatti et al, 2008), though the analysis did not control for potential confounders.

Water supply improvements have also been linked to reductions in other diseases, including Buruli ulcer, cholera, dracunculiasis, trachoma, schistosomiasis, soil-transmitted helminths, intestinal parasites and protozoa, and musculo-skeletal conditions (Mara and Feachem 1999; Strunz et al, 2014; Taylor et al, 2015;

Geere et al, 2010; Grimes et al, 2014; Stelmach and Clasen, 2015). Some of these relationships are evident in studies examining groundwater access in SSA. An investigation in Tanzania found those using handpumps had significantly lower (univariate) odds of cholera compared with those using tap water (Acosta et al, 2001). Installation of handpump-equipped boreholes in Imo State (Nigeria) resulted in a significant reduction of dracunculiasis (Huttly et al, 1990). Protected groundwater point sources have also been associated with a significantly lower likelihood of infection with intestinal parasites (Mason et al, 1986), campylobacter (Molbak et al, 1988), trachoma (Kalua et al, 2010), and schistosomiasis (Dawet et al, 2012; Nworie et al, 2012; Howarth et al, 1988). Not all associations are positive however - use of water from private wells in Cote d'Ivoire was found to be significantly associated with hookworm infection (Matthys et al, 2007).

5.4.2 Education

Hypothesis: By enabling more proximate, reliable and higher quality water for drinking and hygiene, groundwater improvements in the domestic or school environment have the potential to reduce the amount of time fetching water and improve health, thereby boosting enrolments, attendance and academic performance

Recent investigations from Mali, Ghana and Kenya have produced empirical evidence of a link between water access and educational outcomes. In particular, evaluations of school WASH interventions that included provision of groundwater point sources in both Kenya and Mali identified educational and health improvements. Trinies et al (2016) evaluated the impact of a school WASH intervention in Mali, which included provision of boreholes and protected wells. Although the results revealed significantly lower diarrhoea and respiratory infection symptoms and reduced absenteeism due to diarrhoea (but not overall absenteeism), it was not possible to isolate the impact of groundwater improvements from the effects of the sanitation and hygiene programme components. A Kenyan study by Garn et al (2013) found that schools subject to a WASH programme that included provision of safe water sources experienced improved school enrolment (equivalent to a 9% increase) and gender parity. The significant association for enrolment held when sub-analysis was conducted on those schools receiving a borehole and handpump specifically. Installation of these handpump-equipped boreholes was also associated with significantly lower odds of diarrhoea among younger siblings of the school pupils (Dreibelbis et al, 2014). Again, the positive outcomes may also have been attributable to other elements of the WASH programme.

Relationships between school attendance and water supply improvements at the household level have also been demonstrated, though the role of groundwater is unclear. Dreibelbis et al (2013) examined the effect of water supply characteristics in a domestic and school setting, and found school absenteeism for boys ($p<0.05$) and girls ($p<0.1$) was associated with water source proximity to the home. Water source protection at home or at school was not significantly associated with absenteeism, nor was involvement in school water collection. Econometric analysis of DHS datasets from Ghana by Nauges and Strand (2013) revealed a similar finding: water collection times at home were inversely associated with girls' attendance at school. A similar consequence for school attendance has been noted in Malawi (Robson et al, 2013).

5.4.3 Livelihoods and income

Hypothesis: Access to groundwater for irrigation and other productive purposes has the potential to improve livelihoods and bolster income, reduce vulnerability to rainfall shocks, and potentially cultivate higher value crops. By enabling more proximate water for domestic purposes, groundwater developments can also result in time savings – especially for women – thereby reducing the drudgery of water collection and freeing up time to carry out income-generating activities.

Numerous studies suggest a link between access to groundwater for small-scale irrigation and increased household incomes. The technology used to lift groundwater also has an important influence on livelihood outcomes. However, most evidence derives from Asian settings (Hussain and Hanjra, 2004), and many

African-based studies examine the impacts of irrigation using surface water rather than groundwater. Nonetheless, several studies from SSA have sought to evaluate the impacts of groundwater irrigation, particularly in relation to certain water lifting technologies. The studies indicate that compared with households relying on rain-fed agriculture, greater benefits accrue to groundwater irrigators in terms of food production and income. However, most studies suffer from various methodological limitations and potential sources of bias, and unpacking causal relationships is difficult because groundwater irrigators are generally wealthier than non-irrigators to begin with.

Dittoh et al (2013) conducted a study of farming households in Upper East Region of Ghana and concluded that those irrigating with groundwater using a bucket generated more revenue per acre than those simply relying on rainfed agriculture. Similarly, Owusu et al (2016) found that those lifting groundwater with manual pumps earn more income from crops than those using rainfed techniques; and those using a motor pump earn even more.

A study by Hagos (2014) from Eastern Ethiopia found small scale groundwater irrigation exhibited significant associations with lower poverty levels and higher household expenditure as compared with those practising rainfed farming. Likewise, in an earlier study, Hagos et al (2012) reported that irrigation using deep wells was associated with a 26% reduction in poverty compared with households practising rainfed agriculture, and households using motorized pumps had 44% lower incidence of poverty. Mangisoni (2008) evaluated the outcomes associated with treadle pump use in Malawi, and found adopters generated considerably higher incomes than non-adopters (i.e. those who irrigated with watering cans/buckets). When examining poverty transitions, the authors observed that non-adopters experienced higher poverty levels, and during the study period had a greater risk of becoming poor than adopters.

While a number of adopters moved out of poverty, there was no identified non-adopter who shifted from poor to non-poor. Adeoti et al (2009) examined treadle pump adoption in two regions of Ghana, and concluded that adopters of this manual water-lifting technology generate significantly more revenue per hectare, and significantly more income than non-adopters. Waughray et al (1998) examined the outcomes associated with the establishment of splash-irrigated community vegetable gardens around collector wells in Zimbabwe. They identified financial and economic benefits that accrue to women, with financial benefits reinvested into other income-generating activities. Research examining the impact of solar drip irrigation in northern Benin (partly supplied by groundwater) also suggest that such schemes result in an increase in household income (Burney et al, 2010; Alaofè et al, 2016).

The role of domestic groundwater supplies in promoting productive uses has also been highlighted in the literature, particularly in rural areas. This includes water for small-scale gardens, livestock, brick-making and brewing amongst other activities (Hall et al, 2014; Waughray et al, 1998; Makoni et al, 2004; Katsi et al, 2007; Wanke et al, 2014; Tucker et al, 2014).

A study by Hall et al (2014) illustrates the importance of groundwater for livelihoods and income generation in rural Senegal. Based on a survey of 1860 households across 47 rural piped schemes (supplied by electrically-powered pumped boreholes), the authors found an association between system performance and the proportion of households engaged in productive activities. They also found around one half of households earned an income from water-based activities (chiefly livestock-raising), and overall water-based income constituted one quarter of the total income across all households.

However, a related paper found that the poorest households faced significant barriers to participating in productive water use activities, and therefore were not the chief beneficiaries (Van Houweling et al, 2012). Crow et al (2012) also investigated the livelihood impacts of domestic water supply improvements in Kenya, observing that those households receiving spring-fed piped water were able to generate additional household income from fruit, vegetable and livestock production.

5.4.4 Food security

Hypothesis: Access to groundwater for irrigation has the potential to improve food security and nutritional outcomes by enabling consumption of a greater quantity and diversity of foods and bolstering income.

A systematic review of small-scale irrigation and food security by Domenech (2015) concluded that smallholder irrigation generally has a positive effect on food security, but called for more rigorous evaluations to strengthen the evidence base. Several individual studies indicate that groundwater access can enhance food security in SSA. In Benin, solar-drip irrigation (partly supplied by groundwater) of communal gardens resulted in an increase in vegetable intake during the dry months and beneficiaries were less likely to experience chronic food insecurity (Burney et al, 2010). Similarly, a study by Mangisoni (2008) observed treadle pump users were far less likely to experience maize deficits than non-users. In Ghana, Namara et al (2011) revealed that farmers practising groundwater irrigation enjoyed greater food security than those relying on rain-fed agriculture. Although designed for domestic water use, a programme involving spring protection and tap installation in rural Ethiopia was linked with a significant increase in food security among households (Stevenson et al, 2016).

5.5 Emerging groundwater issues and implications for the poor

The literature highlights a range of groundwater issues that may be of particular pertinence to the poor. These include threats to groundwater quality of both anthropogenic and geogenic origin, seasonal and secular changes in groundwater quantity, and financial and operational challenges to sustaining access. Some of these issues are becoming more prominent as a result of broader demographic and socio-economic trends, while others are unchanging albeit with a growing understanding of their extent. There are, however, few studies that present empirical evidence on how these issues impact the poor and their ramifications for long-term welfare trajectories.

5.5.1 Issues impacting groundwater quality

Hypothesis: The poor are more likely to be exposed to emerging groundwater quality risks due to poorer protection of sources, lower likelihood of treatment, and proximity to contamination sources.

ANTHROPOGENIC CONTAMINATION

Many studies reveal high levels of anthropogenic contamination – particularly faecal contamination – of wells, boreholes and springs in SSA. The problem is ubiquitous in both urban and rural areas, with contamination sources including on-site sanitation (Graham and Polizzotto, 2013); agricultural waste (Barnes et al, 1993; Akinbile et al, 2016); solid waste dumps (Kulabako et al, 2007); and surface runoff (Howard et al, 2003; Engstrom et al, 2015). Wells, boreholes and springs are generally more prone to contamination in rainy periods (Howard et al, 2003; Chippaux et al, 2002; Kostyla et al, 2015; Elisante and Muzuka, 2016; Akple et al, 2011; Butterworth et al, 2013; Dekker et al, 2015) and there is strong evidence that contamination levels increase during transport to and storage of water in the household (Bain et al, 2014; Shield et al, 2015).

A systematic review of water quality studies by Bain et al (2014) concluded that in low- and middle-income countries the microbiological water quality of borehole water is better than that supplied by shallow hand-dug wells; however piped supplies tend to provide the highest quality water. These findings are consistent with many studies from SSA (Verweij et al, 1991; Anim et al, 2010; Arnold et al, 2013; Elisante and Muzuka, 2016; Jimenez and Perez-Foguet, 2011). Meta-analysis indicates that protected groundwater sources are less likely to be contaminated with faecal indicator bacteria (FIB) than unprotected groundwater sources (Bain et al, 2014), a finding reinforced by a high quality study of a spring protection intervention in rural Kenya (Kremer et al, 2011). Studies in SSA looking beyond a dichotomous protected/improved definition also consistently show that incremental levels of groundwater source protection are associated with lower levels of

FIB (Sutton et al, 2015; Kumamaru et al, 2011; Rukure et al, 1993; Akple et al, 2011; Butterworth et al, 2013; Dekker et al, 2015). The way in which the well and its lifting technology are handled may also be important (Ejechi and Ejechi, 2007).

Systematic reviews suggest that contamination levels in groundwater point sources are higher in rural areas (Kostyla et al, 2015; Bain et al, 2014). However, the problem in urban areas is widespread, as evidenced by a raft of studies assessing FIB and nitrate levels in groundwater from urban areas of Ghana (Akple et al, 2011), Nigeria (Salihu and Jimada, 2016), Guinea(Gelinas et al, 1996), Kenya (Opisa et al, 2012; Kimani-Murage and Ngindu, 2007), Malawi (Chidya et al, 2016; Msilimba and Wanda, 2013), Mozambique (Chairuca and Hassane, 1991), Cameroon (Dorice et al, 2010; Akoachere et al, 2013; Djaouda et al, 2014), Senegal (Diedhiou et al, 2012), Uganda (Kulabako et al, 2007), Benin (Degbey et al, 2008), Nigeria (Chippaux et al, 2002), Zimbabwe (Zingoni et al, 2005), DRC (Kapembo et al, 2016) and South Sudan (Engstrom et al, 2015). Yet, despite the ubiquity of microbiological contamination, evidence from informal settlements in Kenya suggests that users consider the quality of groundwater from protected sources to be on a par with piped water.

On-site sanitation is commonly considered the culprit for faecal contamination of shallow groundwater. In a systematic review, Sclar et al (2016) conclude that in general, studies show an inverse relationship between the distance of a water supply from a latrine and the risk of faecal contamination, although the association is mediated by a range of other factors such as soil conditions, topographic gradients, hydrology, rainfall, and latrine density (Graham and Polizzotto, 2013; Sclar et al, 2016). Several studies from Africa demonstrate the link between shallow groundwater contamination and on-site sanitation to varying degrees (Howard et al, 2003; Nwuba and Philips, 2015; Elisante and Muzuka, 2016; Opisa et al, 2012; Verheyen et al, 2009; Tandia et al, 1999). It is unclear to what extent open-defecation impacts water quality, though an evaluation of a CLTS programme in rural Mali found a reduction in open defecation did not lead to any significant improvement in groundwater quality (Pickering et al, 2015).

Studies have reported a range of other anthropogenic contaminants in African groundwaters. Elevated nitrate levels are common in both urban and rural areas of SSA, with a meta-analysis of 250 African studies finding a mean concentration of 55 mg/L, with higher levels significantly associated with shallow groundwater depth and population density (Ouedraogo and Vanclooster, 2016). Nitrate contamination is indicative of agricultural activities, waste and sewage, and is used as a proxy for groundwater vulnerability (Ouedraogo et al, 2016). Sorensen et al (2015) detected a number of organic contaminants in the aquifer underlying urban Kabwe (Zambia),with DEET being particularly prominent in the wet season. K'oreje et al (2016) also identified a range of pharmaceuticals in the groundwater underlying Nairobi and Kisumu, though the levels were generally lower than surface waters tested. Other studies have reported elevated levels of heavy metals in the groundwater associated with mining operations (Cobbina et al, 2015). More localised investigations in rural areas highlight the adverse water quality risks posed by certain handpump technologies. For example, aggressive groundwaters have led to corrosion of galvanised iron components of the India Mark II handpump, which in turn can culminate in users abandoning the waterpoint by virtue of the aesthetic impact of elevated iron levels (Ibe et al, 2002; Casey et al, 2016; Langenegger, 1989). There have also been reports from Madagascar of elevated lead concentrations caused by components of the pitcher pump (Akers et al, 2015).

Beyond seasonal changes, there is little empirical evidence of the longer-term trends of anthropogenic groundwater contaminants in SSA. In a longitudinal study from Kisumu, Okotto-Okotto et al (2015) reported a significant increase in density of latrines and shallow wells over a 15 year period, yet there was no commensurate uplift in faecal or nitrate contamination of groundwater, though the results may have been skewed by heavy rainfall levels around the time of baseline data collection. Nonetheless, a confluence of factors point to a growing risk – the urban population in SSA is increasing by 4% per year and with that comes a concomitant rise in industrial activities, solid waste disposal, and on-site sanitation.

While the evidence indicates lower-income households are substantially more vulnerable to anthropogenic impacts on water quality (Yang et al, 2013), few studies have specifically examined the extent to which groundwater quality trends impact the poor and their wellbeing. A greater vulnerability is likely for several reasons. First, the poor are less likely to have access to treated, piped water and hence more likely to rely on shallow groundwater for drinking. Second, the urban poor are more likely to live in densely populated areas, where sanitation and waste disposal are inadequate, and contamination risks are highest. This is evidenced by the study of Sorensen et al (2015), which notes that groundwater contamination was most extensive in areas of low cost housing. Third, low-income groundwater users are more likely to have poorly constructed wells, with inadequate or absent protection measures and rudimentary lifting devices. Fourth, the poor are less likely to undertake household water treatment.

GEOGENIC CONTAMINATION

Arsenic and fluoride are the two most commonly identified naturally-occurring geogenic water quality concerns in SSA. Excessive fluoride levels in water can lead to dental and skeletal fluorosis, while long-term exposure to arsenic can result in a variety of adverse health outcomes, including hyperkeratosis, circulatory disorders, diabetes and cancers.

Two reviews of fluoride in SSA by Ali et al (2016) and Kut et al (2016) identified studies reporting elevated fluoride concentrations in groundwater in a range of countries, including Ethiopia (Tekle-Haimanot et al, 2006; Ayenew, 2008; Rango et al, 2012), Ghana (Apambire et al, 1997; Craig et al, 2015), Cameroon (Fantong et al, 2010), Eritrea (Srikanth et al, 2002), Malawi (Msonda et al, 2007) and Zimbabwe (Mamuse and Watkins, 2016). The groundwater fluoride concentrations in certain parts of Ghana and Ethiopia have also been linked with a high rates of dental fluorosis (Craig et al, 2015; Rango et al, 2014). There are no reliable estimates for the number of people depending on groundwater with high fluoride levels, or their capacity to practice techniques for fluoride removal. Kut et al (2016) conclude that of the 18 countries known to have elevated fluoride levels in groundwater, only 12 are putting in place serious mitigation efforts. The authors also contend that sustaining use of fluoride removal technologies is most challenging in rural areas where illiteracy rates are high.

In their Africa-wide review, Ahoule et al (2015) found that studies report arsenic concentrations in groundwater that range between 0.02 and 1760 µg/L. In particular, elevated levels of arsenic have been reported in Ghana and Burkina Faso (Somé et al, 2012; Somé et al, 2014; Smedley, 1996). A recent assessment of the situation in Burkina Faso estimated that 560,000 people may be exposed to arsenic in excess of the WHO standard of 10 µg/L (Bretzler et al, 2017). There has been little documentation of adverse health impacts arising from arsenic exposure in SSA. One exception is an investigation in rural Burkina Faso by Somé et al (2012), which detected a substantial prevalence of melanosis (29%) and keratosis (46%) in 20 villages that relied on groundwater with high arsenic levels.

5.5.2 Issues impacting groundwater quantity

Hypothesis: The poor are more likely to be exposed to groundwater quantity changes due to greater reliance on shallow groundwater and lower ability to cope with seasonal or longer-term changes in groundwater levels.

CLIMATIC TRENDS AND SEASONALITY

The IPCC Fifth Assessment projects a continued warming of the climate across SSA in the coming decades, and a commensurate increase in the variability and intensity of rainfall. While the impact on groundwater resources will be dependent on land use changes, groundwater resources are expected to be relatively resilient in the face of long-term climatic changes, and will therefore play a pivotal role in adaptation strategies (MacDonald et al, 2011). Nonetheless, low-income users are likely to be most vulnerable to changes in groundwater recharge patterns, and fluctuations in the levels and quality of groundwater. This may be exacerbated by a broader reliance on groundwater for both domestic and agricultural purposes, as surface water sources become less reliable (Calow et al, 2011; MacDonald et al, 2009). According to MacDonald et al (2009), in rural areas the groundwater users who face the highest risk from climate change are those living in areas with less than 200-500 mm of annual rainfall.

Groundwater in SSA plays a critical role as a buffer against climate variability, particularly during prolonged dry spells (Calow et al, 2010). However, there is evidence that seasonal drying of shallow wells undermines the benefits of groundwater access in numerous areas, including Liberia (Rudge and Bosc, 2011), Tanzania (Jimenez and Perez-Foguet, 2011), Ethiopia (Garvey and Gebrehiwot, 1991), Sierra Leone (Ministry of Energy and Water Resources, 2012), Mali (Lutz et al, 2009), Burundi (Bakundukize et al, 2016), Zambia (Kumamaru et al, 2011) and Malawi (Chidya et al, 2016). The poverty implications of this issue have not been elucidated, though it is likely that the poor are most affected as a result of inadequate well construction (Bakundukize et al, 2016), and lower capacity to rectify the problem by deepening wells or lowering pump cylinders. There is evidence that changes in rainy periods can also have adverse ramifications for groundwater access. Demand for groundwater, particularly in rural areas, often declines during the wet season due to the preponderance of alternative sources (Huttly et al, 1990; Kendie, 1992; Pearson et al, 2016; Foster and Hope, 2016), though the opposite effect has also been noted (Tucker et al, 2014). The consequences of such seasonal shifts are likely to depend on whether users are switching to rainwater of reasonable quality or heavily contaminated surface water.

INCREASING DEMAND FOR GROUNDWATER RESOURCES

Demand for groundwater is increasing across SSA as a result of demographic changes (Carter and Parker, 2009), but there is little empirical evidence on the implications for poor households. Few studies present reliable information on groundwater abstraction trends, and their impacts on groundwater availability. Reports suggest groundwater levels in Lusaka, Dar es Salaam and Nairobi have experienced declines (Foster and Tuinhof, 2005; Mpamba et al, 2008; Sappa et al, 2015), though the effects appear to be localised. Excessive abstraction has also been identified as a driver of saline intrusion into some coastal aquifers (Ayolabi et al, 2013; Sappa et al, 2015; Tole, 1997). In contrast, land-use changes around Niamey have led to rises in groundwater levels (Leduc et al, 2001).

With rapid urbanisation, groundwater withdrawals are no doubt trending upwards in cities and towns (Carter and Parker, 2009). Although the proportion of urban dwellers in SSA with a piped water connection has declined substantially since 1990, the absolute number has been growing by about 2.5 million people per year. However, few urban utilities report their levels of groundwater abstraction. One exception is in Tanzania, where the national regulator EWURA reports that total borehole water production for all of the nation's utilities and water authorities has grown by around 4% per year since 2011[x].

There is little documented evidence of negative impacts for the rural poor as a result of increasing groundwater withdrawals. Population growth rates are slower than in urban areas and modelling suggests significant scope to scale up groundwater irrigation activities, even taking into account the uncertainty of environmental requirements (Altchenko and Villholth, 2015). In terms of domestic water use, handpumps - the most common form of water supply in rural areas - produce a modest output (0.01-0.3 l s-1) that requires less than 3mm of recharge per year (Calow et al, 2010; MacDonald et al, 2012).

Based on a continent-wide assessment of groundwater resources, MacDonald et al (2012) concluded that in many countries, properly constructed boreholes should be able to sustain handpump supplies through inter-annual recharge variations. Indeed, per capita water consumption from groundwater point sources (which are more common in rural areas) is substantially lower than those for piped connections (which are more common in urban areas) (Thompson et al, 2000), and populations are significantly sparser. Nevertheless, as groundwater irrigation becomes more prominent, cases of groundwater resource degradation in rural areas may well arise.

5.5.3 Issues impacting groundwater access

Hypothesis: The poor are more vulnerable to financial and operational barriers to accessing groundwater by virtue of a lower capacity or willingness to sustain systems and services, and to cope with non-functioning or intermittent services.

OPERATIONAL CHALLENGES TO SUSTAINING ACCESS

The challenges relating to the sustainable provision of groundwater services SSA have been well documented over several decades (Carter et al, 1999; McNeill, 1985; Harvey and Reed, 2006). Groundwater-fed piped schemes often provide an intermittent supply (Banerjee and Morella, 2011), while pumps for groundwater point sources suffer from lengthy breakdowns and high non-functionality rates (Whittington et al, 2009; Foster, 2013; Fisher et al, 2015; Carter and Ross, 2016).

According to Banerjee and Morella (2011), utilities in SSA provide an average of 19.5 hours supply per day and around 1 in 5 standpipes is non-operational. Likewise, around one in three handpumps is non-functional at any point in time (Rural Water Supply Network 2009), with reported breakdown durations often extending into weeks or months (Whittington et al, 2009; Koehler et al, 2015; McNicholl, 2011; Foster and Hope, 2017). The underlying root causes and risk factors are complex and multidimensional, with both hardware and software factors playing a role (Carter et al, 1999; Harvey and Reed, 2006; Bonsor et al, 2015; Foster, 2013; Fisher et al, 2015; Marks et al, 2014). High non-functionality rates have also been noted for pumps used for small-scale groundwater irrigation (Kimmage, 1991; Adeoti et al, 2009).

There has been little research into the welfare consequences of unreliable groundwater services. One would expect an effect that negates the full benefits that could be afforded by groundwater access, particularly for the poorest households which are less able to cope with intermittent or non-functioning services. But who bears the costs and the implications for poverty trajectories requires further elucidation.

Though the role of groundwater is unclear, a study from South Africa suggests unreliable water services can have a negative effect on health outcomes (Majuru et al, 2011). Similarly, the observations of Cairncross (1993) provide an illustrative example of regressive outcomes, when he attributed the recrudescence of dracunculiasis in Côte d'Ivoire to the high non-functionality rate of handpumps.

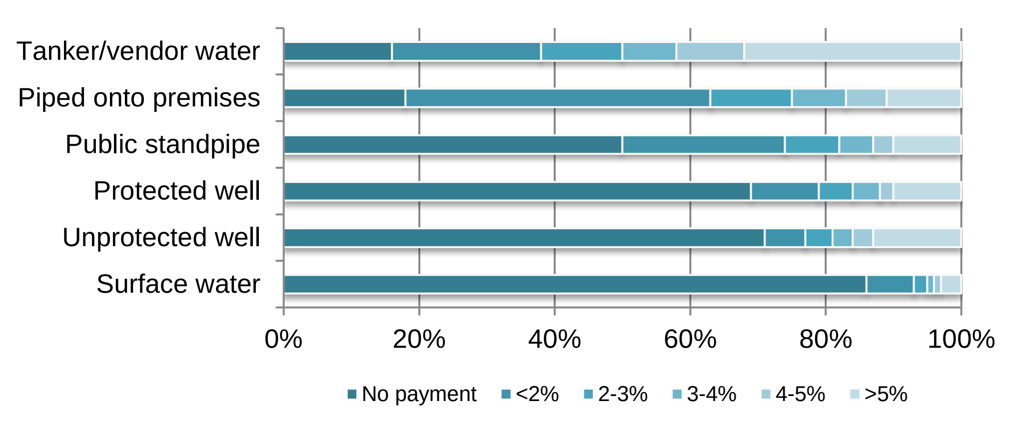
Poor operational performance also has implications for livelihoods, with Van Houweling et al (2012) observing the detrimental impact that unreliable services have on productive water use activities. The consequences largely depend on the alternatives to which users turn. In urban areas shallow wells appears to be a commonly deployed contingency for system disruptions. Less reported are the most common fall-backs used in rural areas.

FINANCIAL CHALLENGES TO SUSTAINING ACCESS

Sustaining access to groundwater, particularly when provided at a high service level, requires ongoing financing of operation and maintenance activities. Policies in SSA generally dictate that water users are responsible for covering these recurrent costs, and available data suggest payments depend on service levels. For example, survey results from Tanzania show that most people spend very little on surface water, a greater proportion of income on unprotected and protected groundwater, and even more on piped water (Figure 6). With the exception of vended water and piped water (where the ultimate source is unknown), around 10-15% of groundwater users spend in excess of 5% of their income on water.

Figure 6 - Proportion of population by % of total expenditure on water services, Tanzania

[Based on data from Tanzania HBS 2011-12, presented in WHO/UNICEF, 2017]



There is evidence that financial barriers thwart inclusive access to protected groundwater sources, with price being a key determinant of water source choice (Briscoe et al, 1993). Financing challenges also have major implications for the sustainable operation and maintenance of groundwater services (Carter et al, 1999; Foster and Hope, 2016). Whether it is willingness or ability to pay, evidence suggests the poor are most affected by the financial realities of groundwater services. Unsurprisingly, household wealth appears to be a determinant of stated willingness to pay for water services in SSA (Gebreegziabher and Tadesse, 2011). Van Houweling et al (2016) identified financial barriers that prevented poorer households using handpump water supplies in Mozambique, observing that protected groundwater supplies can reinforce social divisions. Foster and Hope (2017) found that handpumps requiring payment of fees on a 'pay-as-you-fetch' basis (which inherently involves a high unit price) are more likely to result in unimproved water source use, though surprisingly this dynamic was evident across all wealth strata. Willingness to pay for and use protected groundwater is also impacted by a range of other attributes and service levels, in particular taste and proximity (Mu et al, 1990; Naiga and Penker, 2014; Van Houweling et al, 2016; Foster and Hope, 2017; Boone et al, 2011).

5.6 Conclusion

The multiple linkages between groundwater access, poverty and well-being in SSA are bi-directional and mediated via people's health, education, livelihoods and food security. However, there is a dearth of high quality studies and firm evidence that details the long term poverty transitions associated with groundwater access. The pertinence of these evidence gaps differs for rural and urban areas. Understanding the longitudinal changes that access to groundwater for irrigation induces on the wealth and food security of poor households, as well as the wider economic and environmental ramifications, is perhaps most relevant to rural-dwellers. The effects arising from the growing dependence on shallow groundwater and the various risks and opportunities that entails is particularly salient for low-income households in urban areas. While the weight of evidence supports the notion that groundwater access improves human development outcomes, the degree to which it benefits the poorest households is less clear. Further investigations are warranted to critically and rigorously assess the ways in which groundwater access can reduce inequalities, rather than maintain or exacerbate them.

6 Review of the UPGro programme

6.1 Aim, questions and methods

The overall aim of this section of the study was to make explicit the nature of the analyses and narratives which are likely to emerge from each of the UPGro consortium projects, concerning their focus on "the Poor".

In this component we explored four main questions:

1. How are "poverty" and "the poor" conceptualised within each of the consortium projects?
    a. Are there explicit definitions and concepts?
    b. Is poverty perceived narrowly in income / consumption terms, or more broadly in relation to power, voice, vulnerability or other aspects of disadvantage?
    c. Or is it simply assumed that by working in low-income countries among low-income rural and urban communities, there is a poverty focus to the project?
2. Describe the field locations which have been to date the focus of studies of individuals, households and communities. Rural or urban? Types of livelihoods? Other contextual aspects?
3. In the field studies so far undertaken by the project, is poverty measured, and if so, how?
    a. Are the communities and households studied disaggregated in any way by wealth or other aspects of poverty, and if so, how?
    b. Is it possible to demonstrate that improving groundwater access/security has reduced poverty? Or have the poor been further marginalised by changes in groundwater resources, access and use?
4. In the remainder of the project, will poverty aspects of groundwater access (present and future) be explored in different ways than hitherto? If so, how?

To answer these questions, the consortium project "cases for support" (project proposals) were reviewed; the project websites and the shared Google drive[xi] were examined; and a number of key informant interviews with project PIs or their representatives[xii] were undertaken.

The limitations of this short review include: limited project documentation on the topic, lack of responses to email requests and limited time.

6.2 Findings

6.2.1 How are "poverty" and "the poor" conceptualised within each of the consortium projects?

No shared definition of poverty was developed for or by the consortia at the start of the project. However, UPGro refers in overarching terms to structural factors of poverty: gender, equality, access to resources and voice. So it is clear that poverty is understood to be more than household income or poverty line based definition. But what poverty means has been conceptualised quite differently across each of the five consortia (Table 1).

Table 1 Consortium definitions of poverty

Consortium	Definition
BRAVE	Attention to the poorest households that are vulnerable to climate-related shocks and least resilient. Referring to gender dimensions of poverty and seasonal fluctuations BRAVE aims to understand past, current and future vulnerability.
Gro for GooD	Using the term welfare rather than poverty, measured using a multi-dimensional welfare index and subjective welfare assessment. Attention to a wider set of indicators on deprivation, disadvantage, and social exclusion as well as assets, infrastructure, demography.
GroFutures	Initially aiming to produce a conventional wealth index based on asset data gathered from a survey. At a later date the project plans to use participatory diagramming to define the less tangible and wide ranging elements of poverty/ well-being. This part of the approach to poverty/defining who the poorest people are is more inductive. It is partly based on observations to date to infer a definition.
Hidden Crisis	Targeting based on project locations – working in places where communities are generically poor i.e. 50% of children are stunted and majority of community receive food aid.
T-GroUP	No theoretical definition. An empirical approach to defining poverty/who the poorest people are. Definition is based on findings concerning access to resources, control over resources and decision-making power as well as social networks in the community.

Thus, who 'the poor' are is being defined empirically, to various extents across the consortia, rather than based on *a priori* definitions of the dimensions of poverty or limiting attention to the groups that tend to be very poor (measured across multiple dimensions) such as women, older people or people with disabilities.

6.2.2 Describe the field locations that have been to date the focus of studies of individuals, households and communities.

All told, the UPGro projects are working in 11 countries, but with some activities which span the entire region. Four out of the five projects work mainly in rural locations (T-GroUP being the exception). A brief summary is set out in Table 2.

6.2.3 In the field studies so far undertaken by the project, is poverty measured, and if so, how?

Poverty is currently being measured in a number of different ways across the projects (Table 3). The consortia approaches to measuring poverty are differentiated, depending on the particular context. Using mixed, inter-disciplinary methods enables the consortia not only to measure poverty but also to explore poverty dynamics in relation to groundwater management. Notably, most consortia are measuring poverty in terms of a range of non-monetary indicators and are attempting to measure aspects of power and voice in relation to groundwater management. For instance by identifying who participates in water management discussions and who has the power to control or influence decisions. This might also tell researchers more about the trajectory of the relationship between poverty and groundwater management i.e. whether improving groundwater governance increases the possibility of escaping from poverty or whether asset accumulation is required first in order to drive improvement in groundwater management. Or how changes in groundwater governance affect the interlocking dimensions of people's experience of poverty.

Table 2 Study locations and contexts of the UPGro consortium projects

	BRAVE	Gro for GooD	GroFutures	Hidden Crisis	T-GroUP
Field location	Burkina Faso Ghana	Kwale County SE coast of Kenya	3 Basin Obs. in Ethiopia, Niger and Nigeria, and Tanzania + 4 Site Obs. in Benin, Burkina Faso, South Africa and Uganda	Ethiopia, Uganda and Malawi	Bwaise slum (Kampala, Uganda), Unga/Sombetini (Arusha, Tanzania), and in Dodowa (Accra Plains, Ghana)
Rural / urban	Rural	Rural	Rural	Rural	Peri-urban areas and slums
Types of livelihoods		Tourism, urban centres, sugarcane plantations, and mine	Farming, agricultural users, pastoralists (not all the users in basins)		Small scale farmers (Dodowa), small scale water vendors, people in different sections of the economy (Kampala) mixed (Arusha)
Other contextual factors	8 baseline sites within the Volta River Basin	Fragile and drought/famine affected areas Seventh highest poverty rate (75%) out of 47 Counties	Fragile and conflict affected areas		

Rather than counting people in poverty at one point in time, a snapshot, the Gro for GooD is measuring poverty to see whether this changes over time or whether poverty is long-lasting, long-term. For instance Gro for GooD is collecting yearly panel data (and more frequent mobile survey data) with multi-dimensional indicators to better understand poverty in the communities they are working in - why for some poverty is temporary, for others it is recurrent or persistent – as well as how this relates to groundwater access. Similarly, the Hidden Crisis project is performing longitudinal studies to see repeated observations over the course of the project.

A number of the consortia partner with others to reach disadvantaged communities and understand the needs of disadvantaged people and in some cases to speak for and on behalf of the poorest people. BRAVE is working with CARE International Ghana/Christian Aid Sahel. Hidden Crisis is working with WaterAid in Ethiopia, Malawi and Uganda. Gro for GooD partners with a mining company (BASE Titanium Ltd.) and KISCOL (a sugar company) as well as FundiFix, the pump maintenance company, to mitigate the socio-economic risks and the biophysical risks that affect poor people in Kwale. T-GroUP is working with chiefs of community and clan leaders to understand groundwater issues and facilitate access to disadvantaged communities.

Table 3 How poverty is currently measured across the consortia

Consortium	Approach to poverty measurement
BRAVE	WP1 attention to household demography (e.g. house ownership; larger households with more children), wealth and seasonal changes. Participatory community decision-making: people as researcher-advocates. Includes work to assess user vulnerability.
Gro for GooD	A multi-dimensional welfare index that includes indicators of education, dwelling, assets, drinking water, sanitation and health as well as groundwater quantity and quality (panel data collection) – completed round 3 of data collection, further data collected through targeted mobile phone surveys. Subjective welfare matrix to understand the individual welfare. Mapping poverty relationships. Modelling longitudinal data of distributional poverty impacts and outcomes. Secondary data analysis (of health data).
GroFutures	Household survey (2 rounds of data collection includes questions on assets) plus discussions about combining the participatory tools with household survey. The groundwater development pathways [WP2 & WP4] explicitly consider poverty alleviation and inclusion of poor people's voices in decision-making processes. Learning Platforms (multi-stakeholder forums) where ideas on pro-poor groundwater development can be integrated into the basic planning. Participatory decision-making (Kenya) and participatory research methods (set out in a Field Guide that has been developed by IDS and others). The partners in Ethiopia have been trained on the methods and they have been tested in Tanzania.
Hidden Crisis	Rapid political economy analysis studies to inform conceptualisation of poverty (generated some poverty statistics) and potentially also identify the safety nets for people in poverty A 'twin survey' (i.e. physical and social science surveys), first trialled in Uganda. Attention to the service delivery, survey of management arrangements (e.g. waterpoint committee), mechanisms for financing and the facilitating nature of local governance arrangements [functionality score for management] Includes assessment of the ability of the community to raise money to improve the functionality of water points (who can pay for services and/or raise money for maintenance/spare parts). Detailed community surveys based on 2 days per community to address local governance arrangements; 'bricolage' includes household surveys and community institution discussions. Training for national researchers on attention to community dynamics – who is participating, which could also be indicative of poverty.
T-GroUP	Secondary data/document analysis (debate in the media and articles). Key informant interviews using a snowball approach. Household surveys with a socio-economic questionnaire (not yet analysed). Poverty measured in terms of access (mediated through land ownership or tenancy). In Dodowa used science cafes to disseminate the research on ground water quality – more work on this is planned in Phase 2.

6.2.4 Are the communities and households studied disaggregated in any way by wealth or other aspects of poverty, and if so, how?

Individuals and households experience poverty in different ways and to different degrees over their lifecycle. Researchers need to disaggregate poverty and well-being in order to provide a differentiated policy or programme response. The ability to target pro-poor interventions also require the data to identify different groups and the particular barriers they face in accessing and managing groundwater as well as improved measures of the impact of governance interventions and to monitor this over time.

Inequalities in a number of dimensions not just incomes are important. Through the research methodologies, such as the use of participatory methods to enable citizens to define and measure poverty, the consortia can go some way to identify the traps or factors that drive people into poverty or that keep them poor. For example, the geographical concentrations of the poorest communities (in slums in the T-Group example) underline the fundamentally structural nature of poverty. GroFutures is working in fragile contexts: IDPs or migrants face particular challenges around rights and access to natural resources like groundwater. Other traps that underpin poverty, as identified by Chambers are shown in Figure 7.

A number of the consortia pay attention to assets, notably groundwater, land and livestock but also other assets. The Gro for GooD project focuses on health impact (morbidity) of intermittent water supply as well as real-time indicators of faecal contamination in drinking water supplies using tryptophan-like fluorescence. The consortia are also researching aspects of poverty related to power, vulnerability and isolation. The Hidden Crisis project claims to focus on the 'marginalized' and BRAVE focuses on vulnerable users of groundwater, identifying strategies to reduce vulnerability and increase resilience. T-Group includes reference to voice and access to resources. A number of the consortia intend to produce evidence on well-being i.e. self-esteem, life chances, security, inclusion in society and so forth.

Figure 7 Chambers' deprivation trap[xiii]

POVERTY: LACK OF ASSETS Small house, little land, few or no livestock. All family members work unless they are too young, old or sick.
PHYSICAL WEAKNESS Adults unable to work due to illness or disability, or migration of active adults.
ISOLATION Household is remote or on the edge of a community, and may lack access to markets or information.
VULNERABILITY Household becomes poorer through having to deal with unforeseen circumstances such as crop failure, accident, sickness, funerals or flooding.

POWERLESSNESS Weak negotiating position with those in control, ignorant of the law, competing for employment.

Alongside household surveys, use of sex disaggregated data and participatory methods can be used to focus attention to what goes on inside the household or over the life course to give a more complete picture of relevant issues (for instance whether women headed households and single elderly women may be more vulnerable). This would enable monitoring of impact on individuals and their trajectories over the life course, not just on the household. Projects can be expected to have an impact on gender through fairer access to resources/services for women and men over the life course as well as sharing of responsibilities for water and taking into account constraints imposed by gender roles and relationships. Hidden Crisis focus on the impact of poor performance of water services on gender dynamics; the project involves women from water point committees in each community/village in the process of mapping out the water points across the village and records the history of performance and management of each water point. BRAVE has generated evidence on the differences between men's and women's perceptions of the most risky times in the water-year. Others, including GroFutures, are still deciding whether to adopt random or purposive sampling strategies.

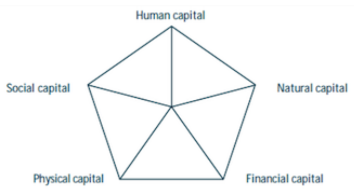
6.2.5 Is it possible to demonstrate that improving groundwater access/security has reduced poverty? Or have the poor been further marginalised by changes in groundwater resources, access and use?

The Business Case for UPGro states that the primary beneficiaries will be poor people in Sub-Saharan Africa whose lives should be improved through the application of the results of the research. The projects are pro-poor, in the sense that they aim to increase the net benefits for the poor (in terms of incomes, assets and decision making power) and that improved groundwater governance contributes to poverty reduction. But without an overarching Theory of Change it is difficult to understand the precise mechanisms for these improvements. One way to conceptualise this is through assets or capitals out of which people construct their lives and livelihoods and of the ways in which groundwater interventions support or undermine these efforts (Figure 8).

Financial capital: UPGro projects could potentially improve financial assets directly through provision of water to the household/community, growth in household income (water vending; improved farming on household plots; efficient cash crop farming; livestock) or decision making over access to resources.

Human capital: levels of human capital (health, knowledge and skills) of the household head/members are critical in determining poverty and affects personal resilience to cope with challenges. Gro for GooD is generating data on water use and health as key inputs to both the multi-dimensional poverty assessment and the Groundwater Risk Management Tool. Work Package 2d will generate a "water-health impact function" through determining health and poverty impacts specifically attributable to poor water supply that will be used to model the health impact of well failures.

Figure 8 Examination of assets / capitals in the UPGro projects



	BRAVE	Gro for GooD	GroFutures	Hidden Crisis	T-GroUP
Asset[xiv]					
Financial capital	x	x	x	x	x
Human capital	x	x	x	x	
Social capital	x	x	x	x	
Natural capital	x	x	x	x	x
Physical capital		x	x	x	

Social capital: strong social networks are important for providing financial, material and emotional in-kind support. Lack of social assets could make their experience of poverty worse or last longer. T-GroUP and Gro for GooD both recognize the importance to extend or diversify social networks. Gro for GooD are tracking poverty relationships to establish the density and types of social networks and the kinds of relationship/networks are more effective for reducing poverty. The political economy analyses performed in the Hidden Crisis project also have a role in identifying existing governance interventions.

Natural capital: a key asset in this context is groundwater, as well as land and livestock. UPGro aims to improve sustainable, long-term groundwater use by the poor in Africa. Gro for GooD is producing hydrogeological assessments; GroFutures is collecting data on the renewability, accessibility and management of groundwater resources. BRAVE is investigating water demands in a context of variable climate and changing land use. Hidden Crisis is focusing on groundwater availability and management. All are producing new evidence regarding the significance of ground water as a development challenge.

Physical capital: a number of consortia are improving the physical capital in communities, particularly through borehole/handpump maintenance. Gro for GooD are monitoring handpump and a professional maintenance company, Kwale Handpump Services Ltd, provides reliable and fast maintenance services whenever they break down. Hidden Crisis includes detailed borehole/handpump inspections as well as improving siting, construction supervision, construction and materials selection to ensure water security for rural people. The GroFutures is ranking the different groundwater technologies and asking stakeholders to explain the rank and the relevance for the context, which could also have a poverty dimension.

Thus, all the research demonstrates the potential to be pro-poor but there are likely to be diverse outcomes for poor people. The researchers are alert to the possibility that the benefits for some might be at the cost of adverse and severe impacts on the poorest and most vulnerable or that there may be trade offs between what is good for groundwater management and pro-poor distribution of the benefits. However, the potential for the research uptake by the poorest is more problematic. There is an implicit assumption that (poor) people are always rational decision makers – once they are informed of the research findings they will weigh the costs, benefits and risks and act on the evidence. In fact those who take action may be more likely to be men, slightly better off, slightly better educated, or otherwise at an advantage. There are many intractable problems faced by people living in poverty, and the extent to which changes in groundwater access, governance and management will impact these is difficult to assess. For instance the first survey of the Hidden Crisis project found no immediate link between borehole functionality and improved functionality of governance arrangements (community management committee).

6.2.6 In the remainder of the project, will poverty aspects of groundwater access (present and future) be explored in different ways than hitherto? If so, how?

UPGro is intended to stimulate multidisciplinary research that focuses as much on socio-economic aspects as the natural science. To date, the projects appear to focus more on the physical/natural science rather than social science aspects, a conclusion that was also evident in the Catalyst Project phase. As the research progresses (Table 4), the majority of the consortia will be increasing attention to poverty. In some cases, they will be enabling communities to develop their own definitions of poverty and the transitions out of it.

Table 4 UPGro consortium projects' future poverty focus

Project	Future plans
BRAVE	Attention to integrated governance to reduce the vulnerability of poor people, improve the long term planning of groundwater supplies and provide early warnings of groundwater shortages so that the most vulnerable families and communities are more resilient to drought.
Gro for GooD	Continue the measurement of welfare (testing the number of indicators) over space and time; mobile surveys; assessing the interventions that would improve pathways out of poverty (the sequence and combination to raise and maintain welfare). Developing a Groundwater Risk Management Tool to balance the demands of human development and better health, economic growth and groundwater sustainability.
GroFutures	Plan for more qualitative approaches in Work Packages 2 and 4. WP2 uses diagramming and imagery as well as participatory wealth ranking and assessments of technology for pathways of different groups and different users. WP4 uses the mixed methods Multi Criteria Mapping software to allow participants to make scored and ranked evaluation of different groundwater development pathways. The activities in WP2 aim to achieve a better understanding of citizens' experience and own definition of well being - more holistic and involving relationships between households and individuals. And process of analysis led by the respondent using GW science to inform and constrain stakeholder-derived GW development pathways in Tanzania, Ethiopia & Niger. It will also focus on the power dynamic and assessment of potential conflicts at different scales and institutional levels.
Hidden Crisis	Will be undertaking targeted longitudinal social studies in Malawi and Uganda with attention to a more detailed understanding on access and who participates in water management and to some extent the impact of governance interventions. There will also be 'Reality Lite phase' [similar to Reality Check Approach?] for improving the connection between pro-poor research and people. This will pick up on dimensions of poverty (retrospective and longitudinal) includes community researchers – diaries, calendars, and observations by community. Efforts will be made to reduce vulnerability and increase resilience. Focus group discussions will be held in the communities based on the profile of the communities i.e. people who might be thought to be marginalised, 'fault lines of difference in communities.
T-GroUP	More attention to PRA/PLA type tools and Power analysis in the next phase (i.e. the political implications of involving the poorest in decision making). Considering the potential of Learning Alliances to find new and collaborative ways of using and managing urban groundwater along development pathways.

7 Groundwater in rural settings

In this chapter we present data and analysis at a regional and multi-country level (section 7.1), and we examine panel data from Rwanda and one county of Kenya.

7.1 Rural groundwater and poverty – evidence from JMP and DHS

7.1.1 Introduction and approach

This component addresses two questions:

1. How has access to different types of rural domestic water source, and especially those supplied by groundwater, changed over the period 1990-2015?

2. To what extent is rural poverty related to the type of water source used for domestic purposes?

The Joint Monitoring Programme for Water Supply and Sanitation (JMP) provides country level summaries of trends in access to improved water supply, collating data from national surveys, census data, and the Demographic and Health Surveys Program (DHS). The summary JMP files have standardised fields for water supply at different levels of resolution, from major categories (e.g. Piped water, groundwater, surface water) to more specific delivery systems (e.g. public standpipes, traditional wells, rivers and wells). However, the individual surveys summarised do not necessarily report against all these fields, limiting the potential for comparison. DHS data sets contain a large number of variables including sources of drinking water supply, household assets, education, and health status. However, the potential for comparison over time and between countries is limited as DHS surveys – particularly until the last decade – did not always code water sources consistently.

In this component we i) use information from the JMP country summaries to examine trends for different water delivery systems over the last 25 years, and ii) use the most recently available DHS data to examine how poverty correlates with groundwater access. Due to the complexity of the available data and the exploratory nature of the study, we chose to focus on just six countries - the Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Tanzania and Uganda. Although not selected to be represented in anyway, together they account for over 50 per cent of sub-Saharan Africa's population, and include both low and low-middle income economies and climates ranging from arid to tropical monsoon. Five of the 6 countries (the exception being DRC) are focus countries for the UPGro programme.

7.1.2 Trends in rural domestic drinking water for different sources, 1990 - 2015

The JMP summary files WHO/UNICEF (2015) for rural drinking water in each country were examined for consistency in coding and data robustness. Individual surveys were excluded where i) detailed information on water sources was not available, ii) results did not appear credibly representative (e.g., isolated instances reporting 80% rural access to Piped water), or iii) where JMP notes indicated caution. Data from missing recent DHS surveys (2014-16) was added from Kenya, Nigeria and Tanzania (Table 5). Resulting data were analysed in SPSS using linear regression with ANOVA to identify trends and determine significance.

Table 5 Surveys available in JMP country files used in the analysis

Country	Surveys available	N accepted	Period covered
DRC	8	6	1995 - 2014
Ethiopia	18	7	2000 - 2014
Kenya	17 (+1)	13	1992 - 2014
Nigeria	21 (+1)	14	1990 - 2015
Tanzania	21 (+1)	8	2000 - 2016
Uganda	21	10	1989 - 2012

Some clear country-level trends emerge in terms of access to different sources of water. The greatest consistency was in surface water access, with sharp and significant declines seen in Ethiopia ($p<0.001$) and Nigeria ($p<0.001$), and shallower but still significant declines in Kenya ($p<0.01$), DRC ($p<0.05$) and Uganda ($p<0.05$) (Figure 9).

There were strong, positive trends for improved groundwater in Uganda ($p<0.001$) and Nigeria ($p<0.001$), and a slower but significant upward trend in Kenya ($p<0.01$) (Figure 10).

Similarly, there were strong positive trends in tap water access in Ethiopia ($p<0.001$) – primarily due to expansion of public standpipes - Uganda ($p<0.01$), and to a lesser extent in DRC ($p=0.106$), while tap water access fell in Nigeria ($p<0.01$) (Figure 11).

Over the same period, unprotected groundwater access in Uganda more than halved ($p<0.001$) to less than 20%, and appears to have increased from less than 40% to over 50% in DRC ($p<0.1$).

Figure 9 Trends in surface water access for 6 countries in SSA

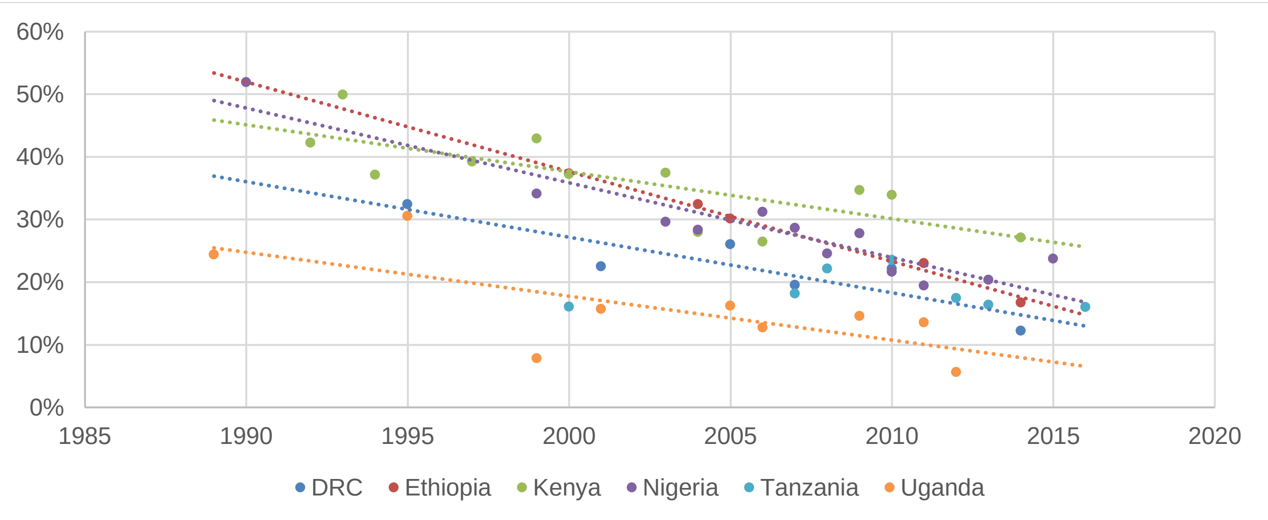


Figure 10 Trends in protected groundwater access for 6 countries in SSA

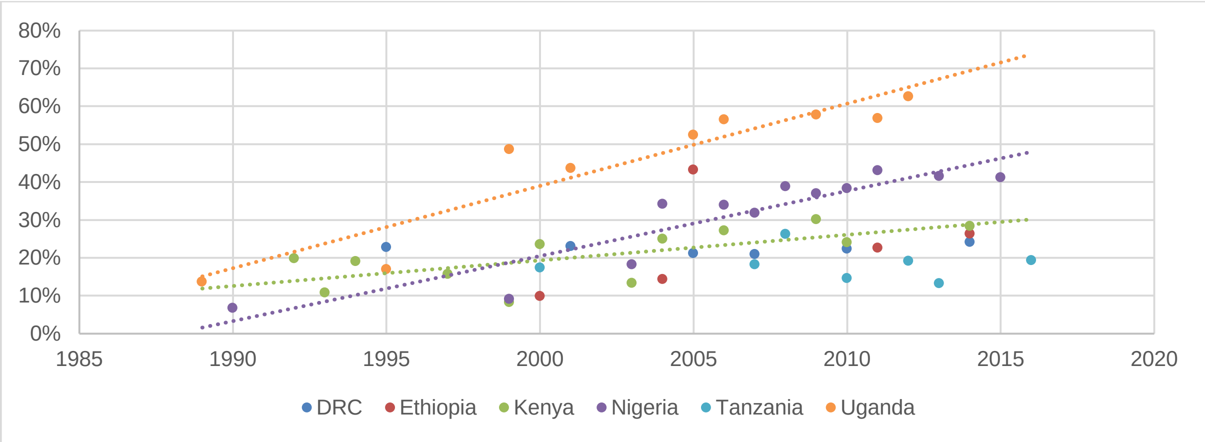
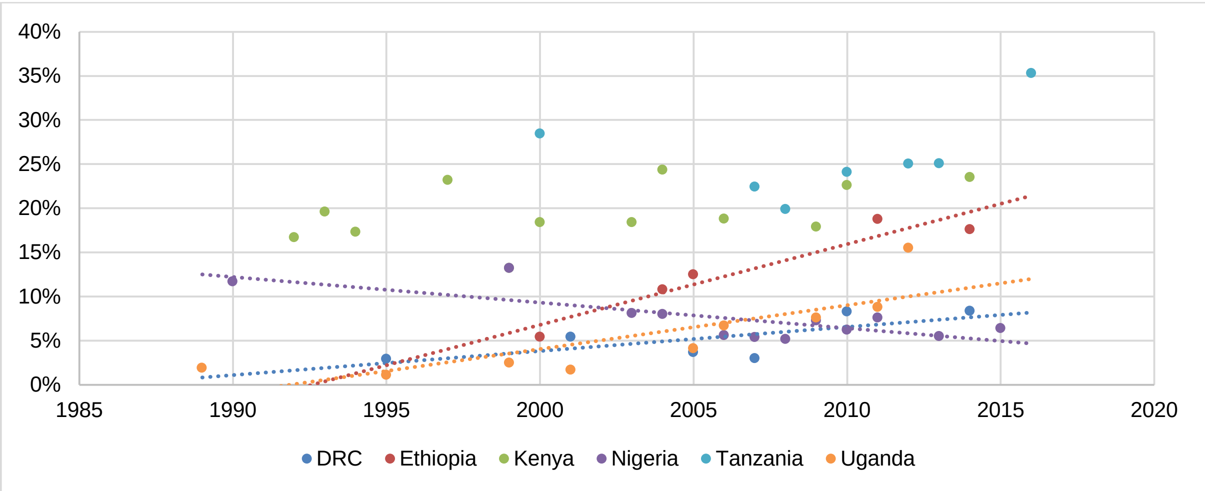
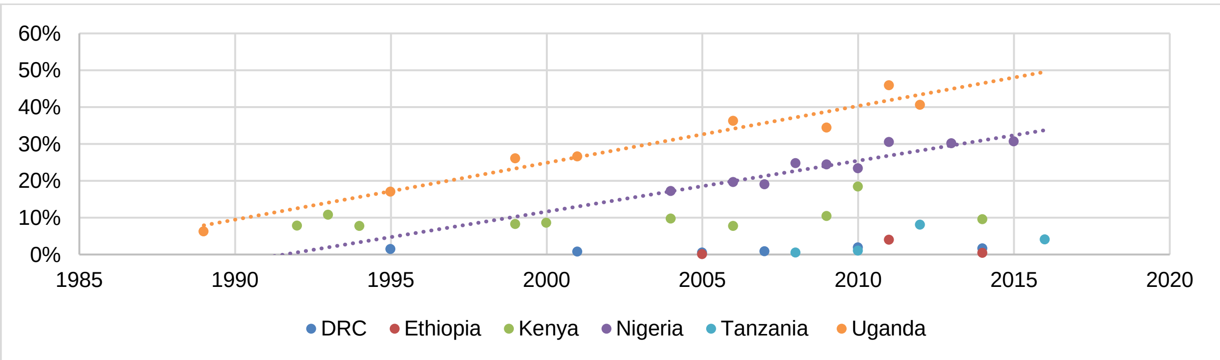


Figure 11 Trends in piped water access for 6 countries in SSA



When examining trends in improved groundwater delivery systems (boreholes, wells and springs), few clear trends were identified. The strongest and most significant trends were increased borehole access in Uganda ($p<0.001$) and Nigeria ($p<0.001$) (Figure 12). Access to protected springs also increased marginally in Kenya to around 10% ($p<0.05$).

Figure 12 Trends in borehole access for 6 countries in SSA



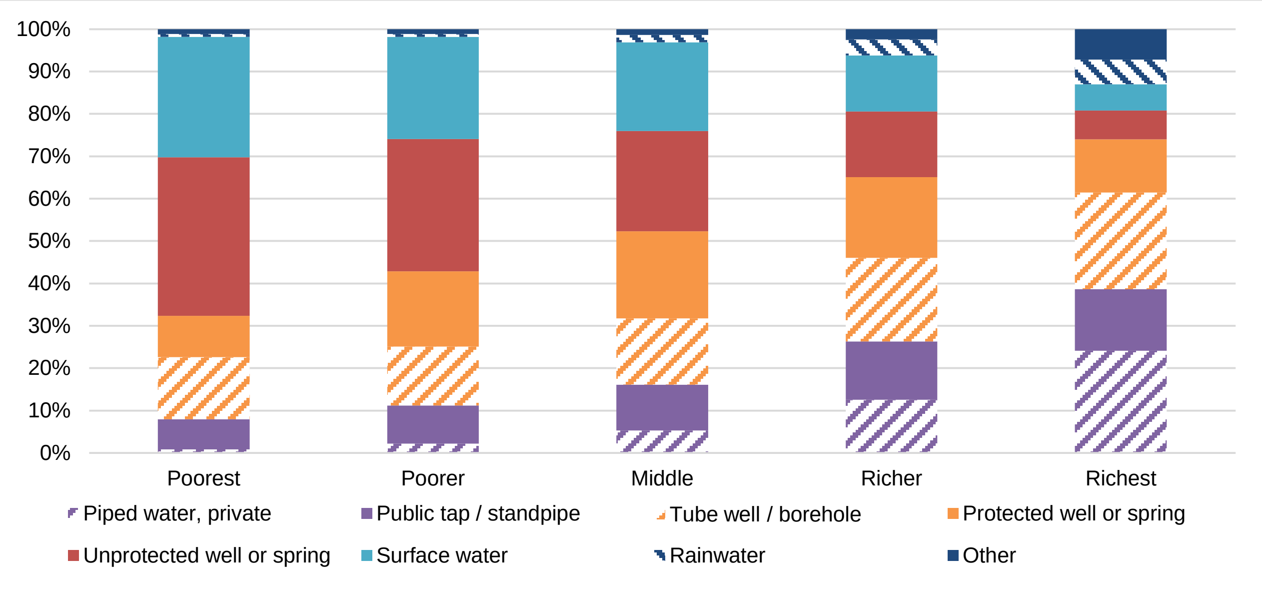
These results imply that while use of unimproved surface water fell in each country (except possibly Tanzania), and use of unimproved groundwater fell everywhere (except possibly DRC), the causes for these declines vary. Expansion of boreholes may be a major factor in Nigeria and Uganda, but in other countries declining reliance on unimproved drinking water sources is more likely to be a combination of factors.

7.1.3 Relationships between poverty and access to different water sources

To assess how rural poverty and different water sources are associated, we used data from the most recently available rounds of DHS surveys in the six countries. In addition to collecting information on drinking water sources, recent DHS surveys also assign households to national wealth quintiles assembled from data on household assets and utility services (Rutstein & Johnson, 2004).

We found significant (p<0.001) inequalities between wealth quintiles in accessing improved water sources (Figure 13). The poorest people were more likely to rely on surface water and unprotected groundwater, while the richest people were more likely to have access to piped water, boreholes, and alternative sources such as rainwater harvesting, bottled, and sold water. The middle and richer quintile were the most likely to access protected wells and springs.

Figure 13 Drinking water delivery by national wealth quintile, aggregate of 6 countries in SSA[xv]



However, these aggregated results disguise significant variations between countries. Nigeria follows the same general patterns for groundwater, but the greatest concentration of surface water use was in the poorer and middle quintiles (Figure 14). This is most likely due to the physical and economic geography of sub-national regions, as the greatest concentrations of poverty are in the arid North, where less surface water is available. The result may also be in part an artefact of using wealth quintiles calculated at the national level: relative to people in the North, poor people in the South may be in the middle quintile; but in the context of their own region they are relatively poor, and rely on unimproved water sources.

An entirely different pattern was observed in Uganda, where members of the poorest quintile were more likely to have access to tubewells / boreholes, while reliance on unimproved surface and groundwater was greatest in the middle quintile (Figure 15). Whether this is the result of targeted public investments, or an effect of physical geography similar to that in Nigeria is unclear.

Figure 14 Drinking water delivery by national wealth quintile, Nigeria

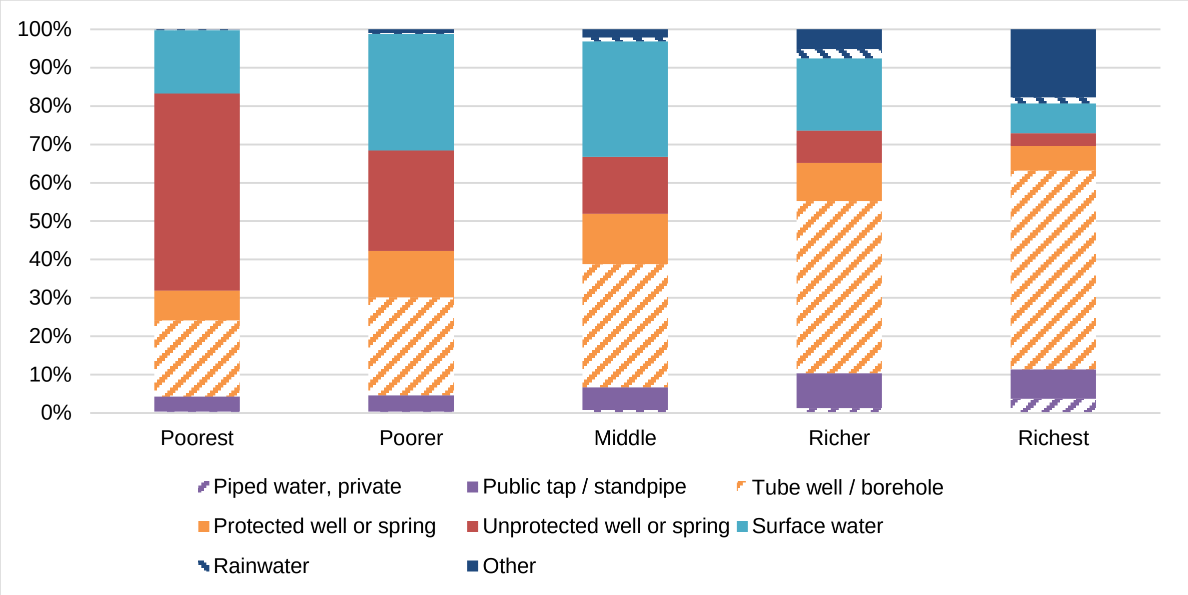
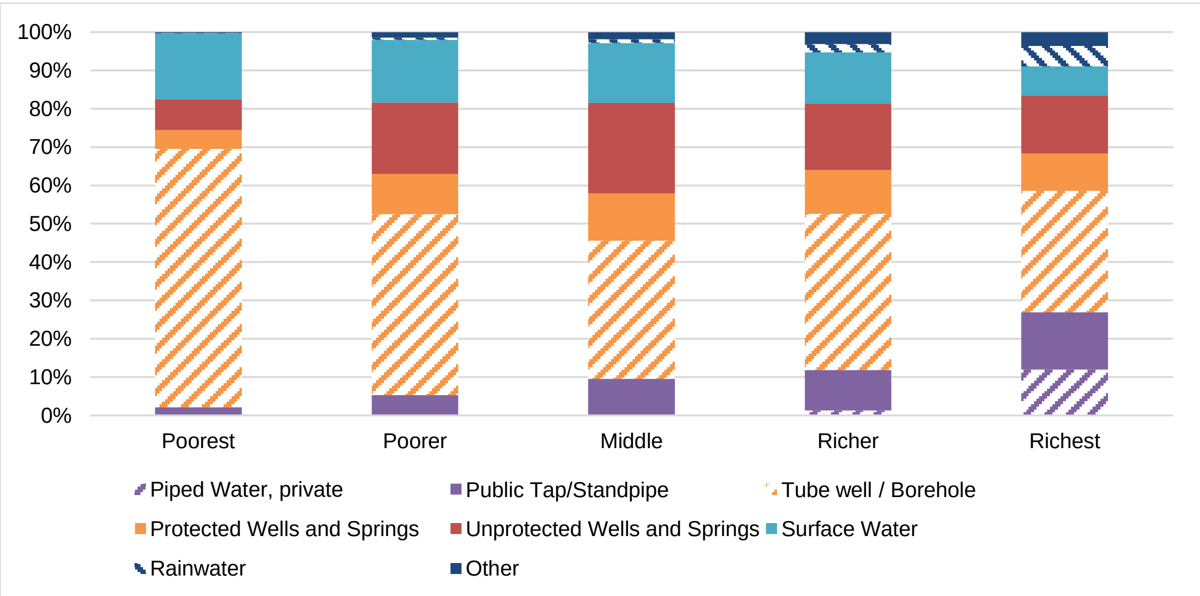
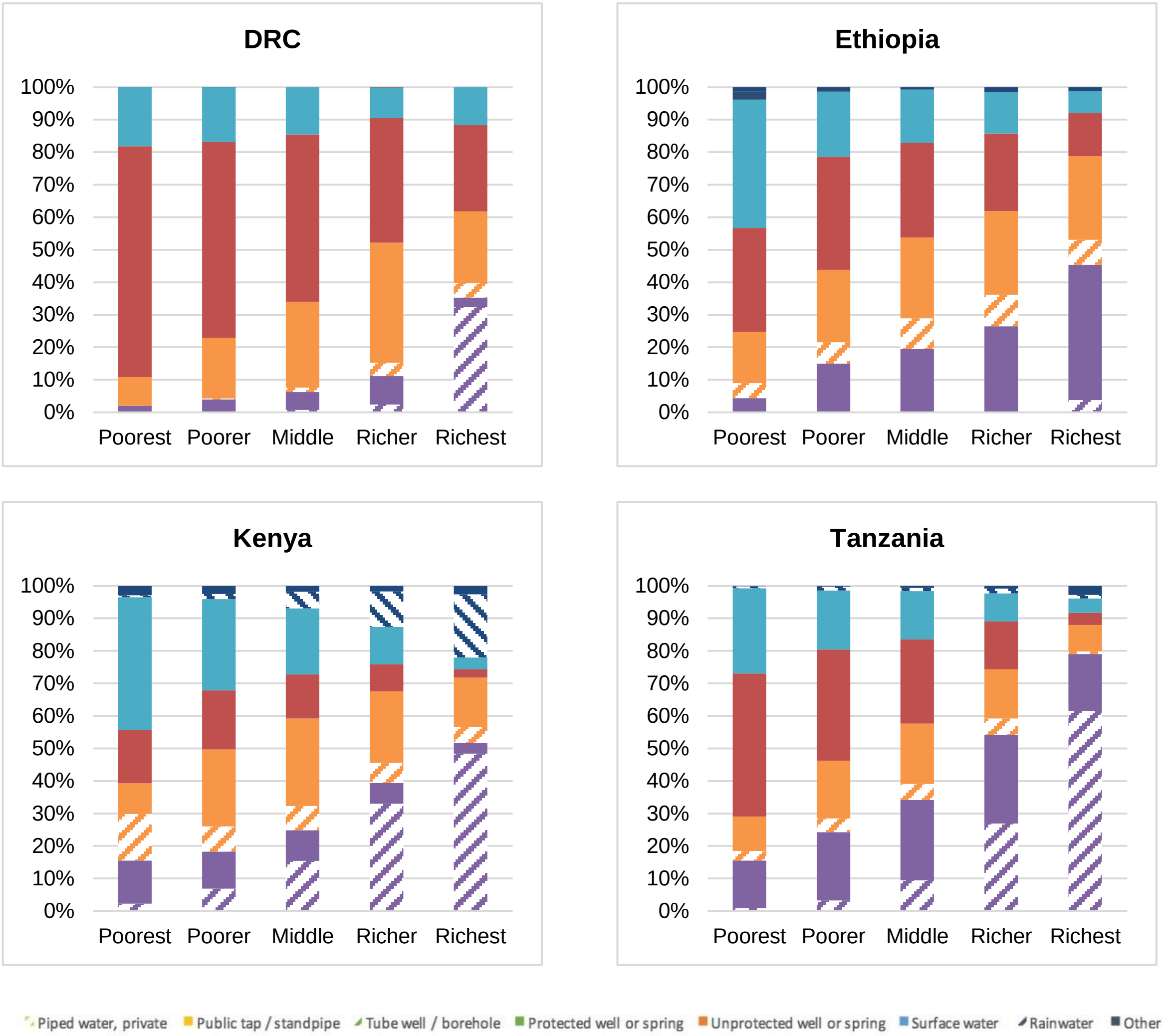


Figure 15 Drinking water delivery by national wealth quintile, Uganda



The equivalent country analyses for DRC, Ethiopia, Kenya and Tanzania follow the aggregate picture more closely, but they are included here for completeness (Figure 16).

Figure 16 Drinking water delivery by national wealth quintile in four countries of SSA



We also examined the implications of gender for access to different water sources, using sex of head of household as a proxy for gender effects. Chi-squared tests for aggregated multi-country data returned significant ($p<0.01$) results between male and female-headed households in all quintiles. Female-headed households were more likely to access piped water and alternative water sources, but also more likely to rely on surface water.

Findings at the country level varied and were less statistically significant. Female-headed households were more likely to access boreholes in Nigeria ($p<0.001$), Uganda and Ethiopia ($p<0.01$), Kenya and Tanzania ($p<0.05$), and DRC ($p<0.1$). For other water supply systems there was no consistent trend. For example, male-headed households were more likely to rely on unprotected wells and springs in all countries except for Kenya, and more likely to access protected groundwater in Nigeria ($p<0.001$) DRC, Ethiopia, and Kenya ($p<0.01$), but not in Tanzania or Uganda ($p<0.05$). Female-headed households were found to be more likely to rely on surface water in Nigeria ($p<0.001$), DRC, Ethiopia, Kenya, but not in Tanzania ($p<0.01$) or Uganda ($p<0.05$).

Nigeria provides a useful example of how sub-national geography may bias these types of findings. In the other five countries female-headed households were clustered in the bottom two quintiles. In Nigeria female-headed households were clustered in the middle-quintile and the south, being far less prevalent in the semi-arid, poorer, Muslim north. Despite several significant correlations at the national level between sex of head of household and access to water sources, few significant correlations remained after correcting for regional biases. Of the 240 possible relationships (5 wealth quintiles x 6 regions x 8 sources of water supply), just 10 were found to have significant gender differences ($p<0.01$) (Table 6).

Table 6 Gendered differences in rural drinking water in Nigeria, corrected for regional bias

Drinking water supply	N differences $p<0.01$	Details
Piped water, private	None	
Public tap / standpipe	2	Middle quintiles in North Central and South West, greater than expected use by FHH
Borehole	4	Poorest and Poorer quintiles in North West, Poorer and Middle quintiles in South South, greater than expected use by FHH
Protected well or spring	1	Poorer quintile in South West, greater than expected use by MHH
Unprotected well or spring	2	Middle quintile in North Central, Poorest quintile in North West, greater than expected use by MHH
Surface water	3	Poorest quintile in North Central, Richer quintile in South West greater than expected use by MHH
		Poorer quintile in North Central, greater than expected use by FHH
Rainwater	1	Poorer quintile in South West, greater than expected use by FHH (small N).
Other	None	

7.1.4 Conclusions and further questions

Some clear trends emerge from the last three decades of data, particularly at the country level. There appears to have been a general decline in the use of unprotected surface water. Piped water access has expanded in Ethiopia while remaining stagnant elsewhere, and increasing access to protected groundwater is most clearly visible in the expansion of boreholes in Nigeria and Uganda.

However, the demographics reached by different sources of water supply varies widely between countries, and the more detailed analysis of Nigeria implies there could be further significant subnational variation within each country. The results from the gender analysis highlight that an accurate assessment of trends on the ground requires contextual analysis, and a finer resolution of detail than is readily available from existing datasets.

This study has focused on proportional access, disregarding the fact that populations have almost doubled in these six countries since 1990. Stagnating piped water access therefore implies that twice as many people are now served than was the case 25 years ago, which is in itself an impressive achievement. This makes the rapid expansion of boreholes in Uganda and Nigeria of greater interest.

What combination of policies, institutions, politics and investments have enabled such growth? Enhanced access by the poorest quintile in Uganda implies public investment, while the demographics of access in Nigeria could imply private investment. Understanding and comparing the drivers in different contexts would be a useful area for future policy research.

7.1.5 Limits of the approach

These results demonstrate the hazards of using data aggregated from multiple sources; results significant at the aggregated level may be artefacts, and disguise contradictory trends on the ground. This is particularly the case given the biases present in the different surveys, the different sample sizes, frames, and the ranges of population and geographic diversity in the different countries. Opportunities for exploring subnational differences in gender access, for example, can be limited by small N samples for female-headed households in some quintiles for some regions.

Inconsistencies in coding water sources from different surveys, even from different rounds of the same survey (e.g. the DHS Programme), is a significant limitation in the publicly available data. Different surveys may code springs as groundwater or surface water, or not distinguish between boreholes and traditional wells. These challenges limit the number of survey points useable for comparison and developing trends. The use of wealth quintiles calculated at the national level produces other limitations. Because of urban/rural inequalities, using uncorrected quintiles introduces bias into our results; in each country the 'Richest' and 'Richer' quintiles have significantly smaller membership than the first three quintiles. The relative nature of national quintiles also limits their utility in making cross-country comparisons, Finally, the lack of panel data means that it is not possible to track how changing access to water sources affects livelihoods, wealth, education, health and other outcomes for individual households over time.

In the following sections we analyse panel data from Rwanda, and examine aspects of another set of panel data from Kwale County, Kenya, in order to generate insights which the cross-sectional household survey data cannot provide.

7.2 Analysis of panel data from Rwanda

7.2.1 Introduction

In its revised Vision 2020, the main document leading the country, the Republic of Rwanda states that "74.2% of Rwandans have access to clean water. The country is endowed with reserves that could provide enough water for both consumption and agricultural purposes. These include substantial rainfall [...] and the abundance of lakes, streams and watercourses [...]. Rwanda will continue to invest in protection and efficient management of water resources, as well as water infrastructure development to ensure that by 2020 all Rwandans have access to clean water"[xvi]. In line with this general objective and as mentioned by the other main documents leading the policy of the country[xvii], access to improved water source must be seen as a cross cutting issue, which support other investments including those in education, health, agriculture and SMEs. To illustrate its importance in terms of public investment, water and sanitation was the fifth most important thematic sector of projected investment for the Economic Development and Reduction Strategy II which has been leading the orientation of the Rwandan policy from 2013 until 2018[xviii].

The Water and Forest Authority from the Ministry of Natural resources (MINIRENA) is in charge of the management of groundwater in Rwanda. The integrated water resources management plan[xix] gives the main orientation of the policies. The overarching water management tool is the Natural Capital Accounting which monitors water supply and water demand, that is the water asset, how much water is abstracted and how much water comes back in treated or untreated form, including groundwater. This helps the ministry monitoring water resources in the country. A new program also aims at monitoring and identifying who are the water users in Rwanda and what uses they make of the water. This mainly consists of a centralized database which will be a major source of information for future research, once established.

If we look at the top-down management of groundwater in Rwanda, we have the water and forest Authority, the line ministry of MINIRENA, who is in charge of the policy implementation. WASAC[xx] is the water utility company in charge of the technical and logistics management of groundwater in the urban areas, that is in the capital Kigali and in the six secondary cities of the country[xxi]. In the rural area, WASAC has the mandate to monitor groundwater. However, groundwater is managed at the district level, conditional on the approval of the line ministry. That is, the district has the upper hand regarding what to do with its groundwater.

From a bottom-up perspective, each manager of a water source in Rwanda has to be registered as such and needs a water permit. One can suggest to improve an existing water source or use a new water source[xxii]. The district can then choose to proceed conditional on the approval of the line ministry. The district can also ask for water testing by experts and for technical and engineering support by WASAC to improve the water source. The line ministry then assesses whether the request accords with the water resource management policy at the national level and assesses whether the new use will produce negative externalities.

In terms of consumption in Rwanda, households use 78 billion cubic meters of groundwater while other services use 87 billion cubic meters. That is, households consume about 47% of groundwater. The use of protected springs, the main source of groundwater, accounts for 38% of groundwater used by households. Households in rural areas consume almost 10 times more water from protected springs than urban households[xxiii].

While the goal pursued by Vision 2020 lies at the national level, we are also interested in what is hiding behind access to clean water. In particular, we would like to be better informed about how direct or indirect access to improved or unimproved groundwater affects poverty in Rwanda. That is, we are interested in how access to improved (or unimproved) groundwater sources affect poverty dynamics such as health, time saving for education or other activities and economic investment. The analysis here aims to provide general preliminary results on the link between direct and indirect access to improved and unimproved groundwater and poverty status in Rwanda. It also examines differences between rural and urban areas. The rest of the analysis proceeds as follows: the next section presents descriptive statistics before the quantitative analysis which follows. The section concludes with the identification of further research needs.

7.2.2 The panel dataset

We use a panel dataset made available from the National Institute of Statistics Rwanda (NISR)[xxiv]. This panel dataset is a subset of the cross section dataset derived from the Enquête Intégrale sur les Conditions de Vie des ménages (EICV)[xxv] conducted periodically. The last two waves of the cross section survey, EICV3 and EICV4, were undertaken respectively in 2010/11 and 2013/14. From the 14308 households surveyed in 2010/2011 in EICV3, 2423 households were resurveyed in 2013/14 to constitute our panel households.

The identifiers of the households surveyed in EICV3 and again in EICV4 have been made available by NISR to allow us constructing a panel dataset. From identical questions asked in both questionnaires, we are able to get information on the poverty status at the household level. We can hence categorize households in extreme poverty, 'moderate' poverty[xxvi] and non-poverty and how they have evolved along the two waves.

We also have information on the type of water source that each household is using. The source of water is divided into the following 12 categories: Piped into dwelling, Piped to yard/plot, Public Tap/Standpipe, Tubewell/Borehole, Protected well, Unprotected Well, Protected Spring, Unprotected Spring, Rainwater, Tanker Truck and Surface Water (River/ Lake/ Pond/ Stream/ Irrigation Channel) and other. According to the classification of the Joint Monitoring Program (JMP) of UNICEF and WHO, we can regroup these categories into improved and unimproved water source.[xxvii]

In addition to data on the main water source, the panel data contains information on the distance between the household dwelling and the water source, the expenditures on water bought from non-professional water services[xxviii] as well as the financial contribution toward the maintenance of the water source[xxix].

7.2.3 Descriptive statistics

According to our panel dataset, the share of households living in poverty and extreme poverty has dropped from respectively 38.84% and 19.77% of the population in 2010/11 to 29.42% and 10.81% in 2013/14[xxx]. The poverty transition matrix gives more details about the dynamics of poverty. As we can see in Table 7, among the households who were poor in EICV3, around half of them managed to make the transition out of poverty. In contrast, among the non poor in EICV3, around one household out of six fell into poverty.

Table 7 Poverty transition matrix, Rwanda

	EICV4			
EICV3	**Extremely poor**	**'Moderately' poor**	**Non-poor**	**Total**
Extremely poor	5.57	6.03	8.17	19.77
'Moderately' poor	2.68	5.24	11.14	19.07
Non-poor	2.56	7.35	51.26	61.16
Total	10.81	18.61	70.57	100.00

When we examine the evolution of access to water sources, quite surprisingly, we observe that 75.11% of the surveyed households of our panel have access to improved water in both waves. This means that there was no aggregate improvement between 2010/11 and 2013/14. However, at a more disaggregated level we can see in Figure 17 the evolution of household access to each category of water source. It is worth noting that there are two primary types of water source in Rwanda, which are protected spring and public standpipe. Together they account for around 60% of the total source of water. We then have three secondary types of water source. These are piped to yard, unprotected spring and surface water. They account for about 30% of the source of water for households in Rwanda. The remaining types of water source are much less used.

Focusing on the poor, we now observe that between the two waves, the share of the poor having access to improved water has significantly increased from 64% in EICV3 to 68% in EICV4. However, running a t-test comparing the share of poor having access to an improved water source with the share of non-poor having access to an improved water source[xxxi] reveals that the non-poor have a significantly higher access to improved water sources[xxxii]. With respect to each water source category, the poor use significantly more unprotected wells[xxxiii],protected springs[xxxiv], unprotected springs[xxxv] and surface water[xxxvi]. In contrast, poor households have less piped water to dwelling[xxxvii] and less piped to yard[xxxviii] as their main source of drinking water.

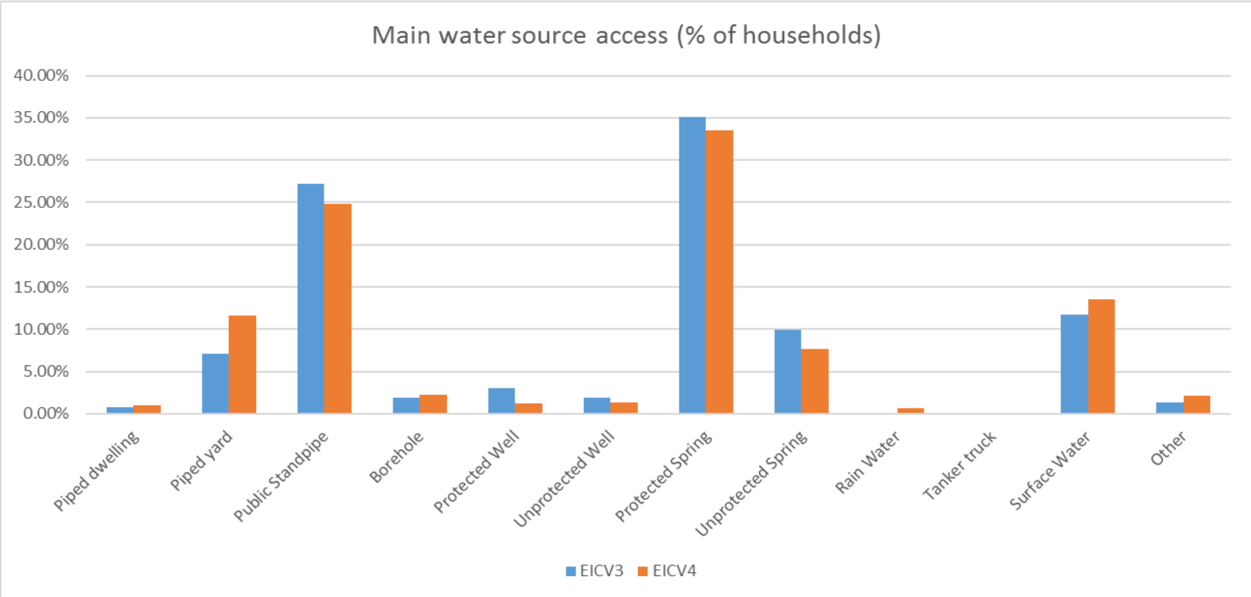
Poor households are located significantly[xxxix] further away from the water source than the non-poor. They also make less private water expenditure than non-poor[xl]. Moreover, people living in urban areas have a significantly higher access to improved water than people living in rural areas: 87% for urban dwellers and 70% for rural. This is not surprising since there is a significantly higher level of poverty in the rural areas in Rwanda.

It is also worth noting that we do not observe any significant difference between poor and extremely poor households in direct or indirect access to improved or unimproved water sources. That is, extremely poor households are not located significantly further away from water sources; neither do they use significantly less improved water. This holds for each of the above-mentioned variables except for borehole water sources, which extremely poor households tend to use more. Results suggest that monetary poverty reduction can be achieved without improved access to water. However, our preliminary analysis shows that improved access to water contributes to poverty reduction. In addition, improved access could contribute to other deprivation reductions.

Extremely poor households have not significantly increased their access to improved water between 2010/11 and 2013/14. The improved access is therefore only among the 'moderately' poor. This result calls for further research.

Figure 17 Source of water in two panel surveys, 2010/11 and 2013/14, Rwanda[xli]

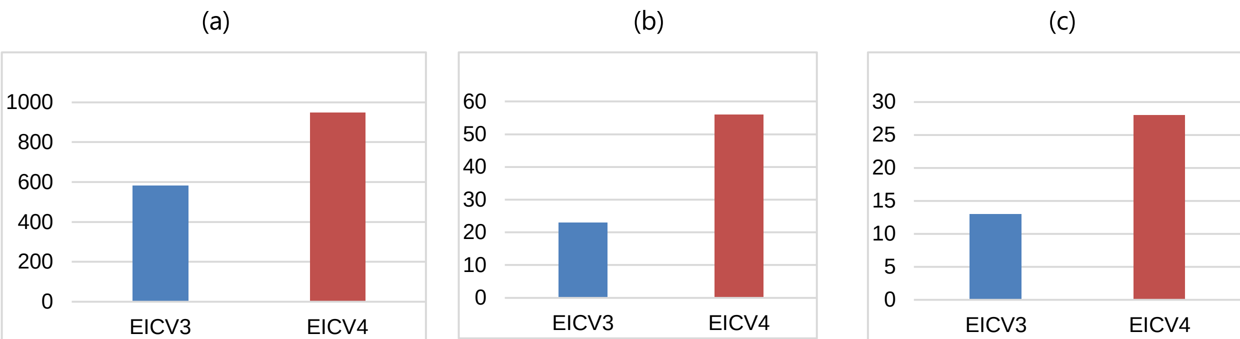
[EICV3 n=13321; EICV4 n=13464]



Further summary data regarding access and expenditure by the poor is provided in Figure 18.

Figure 18 Changes in access and expenditure by the poor between EICV3 and EICV4

(a) one-way distance (m) to main drinking water source; (b) expenditure (RWF) in last 7 days on private water vendors; (c) expenditure (RWF) in last month on maintenance of water source



7.2.4 Quantitative analysis

We now move to the core of our research question, i.e. how groundwater factors might affect the poverty status of households in Rwanda. The groundwater factors which are available in our panel dataset are provided in Annex C1 and the summary statistics in Annex C2.

We estimate the following equation[xlii]:

$$POV = f(\,DIST, WATER\_EXP, MAINT, IMPROVED, PROTECT\_SPRING)$$

We examine the probability of being poor (in non-statistical terms, the strength of association between poverty and the variable in question) for a household with the mentioned characteristics in the specified model. We then analyze the effect of a marginal change of a variable on this probability of being poor.

We run the regression using three different types of models (i) ordinary least square (OLS) as the linear probability model; (ii) the random effects probit (RE) and (iii) the fixed effects logit (FE)[xliii]. The results of the regression are shown in Annex C3.

Analyzing the results, surprisingly, we observe that being located further away from a water source lowers the probability of being poor. Actually, the longer the distance to the water source, the lower the probability of being poor. Note the coefficient is always strongly significant but very low. The low level is not surprising since (i) we do expect other factors to influence more the probability of being in poverty than the distance to the main water source and (ii) the unit of distance is in meters, hence the marginal effect is very low. However, we expected the opposite sign of distance to water on poverty.

The amount paid to buy water from a private water vendor or a neighbour during the last 7 days significantly increases the probability of being non-poor. Again, the low level of the coefficient is not surprising for the main reasons as just mentioned above: other explanatory factors and the unit is the Rwandan Franc so we do not expect a high reactivity to a small increase in the spending. Regarding the negative sign of the coefficient, that is the more you spend the more you are likely to be non poor. We would like to go deeper and understand to what extent poor people tend to rely more or less than the rich on private water sellers. This could help explain our results. Alternatively, it would also be of interest in future research to look at the role of expenditure in impoverishment. When it comes to the participation in the maintenance of the water source, it does not affect the probability of being poor.

Finally, with respect to access to improved water, we observe that it increases the probability of being non-poor which is in line with what we would expect. That is, access to better water reduces common risks directly linked to poverty. The channel could be through health status of people or other factors. More research is needed to identify these factors. However, it is worth noting that it is not significant for the FE model, probably because of the drop in the number of observations due to the modeling features of FE. When we go deeper and look at the source of water used, we see that using a protected spring significantly increases the probability of being poor while using the other sources has no significant impact. Why we observe this relation only for this kind of water source needs to be studied further.

7.2.5 Conclusion and further research

This preliminary analysis has shed light on a research question that has so far received almost no attention in the academic or the grey literature in Rwanda. That is, the effects of direct access to improved groundwater on poverty transitions in Rwanda. The dataset used is rich and we can exploit it further to derive policy recommendations from more advanced analysis. Further research should focus on the effects of access to improved groundwater on poverty and extreme poverty, through health, education, gender and economic investment and activities.

However, it is worth noting that there are some limitations, especially the fact that our information does not allow for multiple water sources and does not provide information about the uses of water by households. If we want to understand how access to different types of groundwater is linked to poverty we need to have this kind of information, both quantitative and qualitative. In Rwanda, this information is being collected. We will soon know how much water is consumed by each household as well as by other services, from which type of source and to which use. This will open the door to further research.

7.3 Findings from Kwale County, Kenya

7.3.1 Introduction

We explore associations between groundwater and welfare in Kwale County, Kenya, where poverty is widespread with around seven out of ten households estimated to live below the poverty line. Communities partly depend on groundwater from 300 functional Afridev handpumps across the study area.

7.3.2 Methodology

We draw from a longitudinal household socio-economic survey data of 3,500 households and volumetric water usage data estimated from novel water data transmitters in 300 'smart' handpumps. We examine groundwater and welfare in three dimensions: (1) productive uses, (2) groundwater depth, and (3) level of drinking water services. A multidimensional welfare index was constructed using 29 indicators drawn from household composition, dwelling characteristics, asset ownership, sanitation and health, and drinking water variables (Katuva and Hope, forthcoming). Households were grouped into welfare quintiles. Monthly data on volumetric usage of groundwater from each handpump was obtained from the water data transmitters.

7.3.3 Results and Discussion

DESCRIPTIVE STATISTICS

Results show (Table 8) that over 80% of the households rely on groundwater sources while only one in ten households depend on piped water sources. The piped water sources were largely found in Ukunda/Diani and Tiwi (North of Ukunda) areas which are supplied by a water service provider- the Kwale Water Supply Company (Foster and Hope, 2016).

Table 8 Descriptive statistics for all households in panel survey, Kwale County Kenya (n=3349)

Variable	Mean	Std. Err.	95% Conf. Interval
Groundwater Source	0.81	0.007	(0.81 - 0.83)
Piped /Surface Source	0.10	0.005	(0.09 - 0.11)
Use GW for Irrigation*	0.06	0.004	(0.05 – 0.07)
Use GW for Livestock*	0.18	0.007	(0.16 – 0.19)
Own Livestock*	0.21	0.008	(0.19 - 0.22)
Water Table depth (<8m)*	0.13	0.006	(0.12 – 0.15)
Fresh water (E.C<1,500 $\mu S/cm$)*	0.84	0.007	(0.83 - 0.86)
Affordable*	0.13	0.006	(0.12 - 0.14)
Reliable*	0.33	0.009	(0.31 - 0.34)
Safe*	0.39	0.009	(0.37 - 0.41)
Taste*	0.40	0.009	(0.38 – 0.42)
Only Source*	0.22	0.008	(0.20 - 0.23)
Close (distance water source)*	0.63	0.009	(0.61 - 0.65)

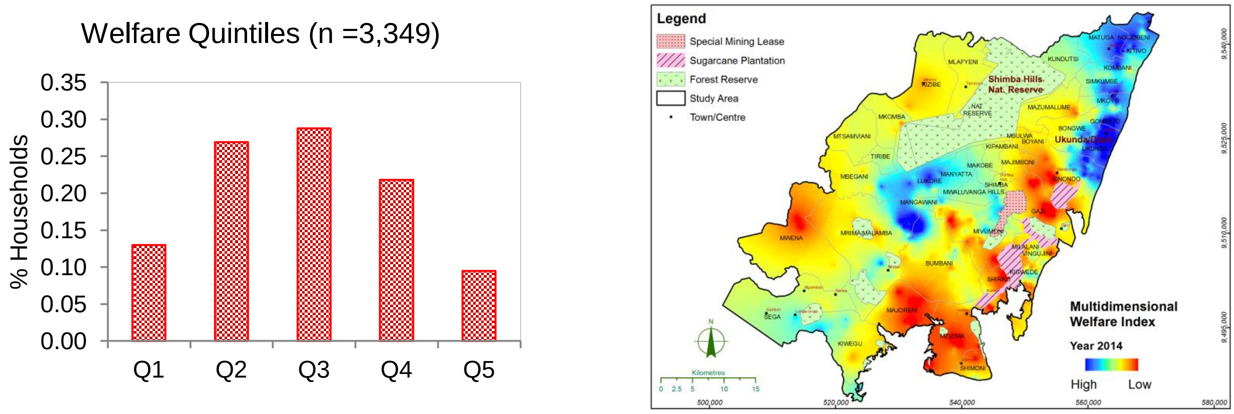
*statistics only computed for groundwater sources. GW refers to groundwater.

Households were three times more likely to use groundwater for watering livestock than irrigation. A small fraction of households (6%) were engaging in productive use of groundwater for irrigation. We also observed that slightly more than one in ten handpumps had water rest level less than 8m while five out of six handpumps had water with electrical conductivity within the recommended threshold of 1,500 $\mu S/cm$. One in every eight households perceived the groundwater sources to be affordable while a third found them reliable. Two out of five households found the groundwater sources to be safe and had good taste. Only a fifth of the households exclusively relied on the groundwater sources with the rest having alternative sources. As expected, two thirds of the households found the groundwater sources to be relatively close to their homesteads.

7.3.4 Welfare Distribution

The spatial welfare map (Figure 19) illustrates that geographical distribution of welfare in the study area which is discussed more widely (Katuva et al, 2017; Katuva and Hope, forthcoming). The incidence and intensity of welfare also varies and in this report we plot the distribution of key variables of interest by welfare quintiles by ‘within quintile’ and ‘within variable’ metrics. The former plots the fraction of households by each variable as a % of all households within each quintile; the latter restricts the sample to only households measured by the variable and represents these households as % of each quintile. In other words, ‘within quintile’ is a measure of incidence and ‘within variable’ a measure of intensity.

Figure 19 Kwale County: (a) welfare quintiles; (b) spatial representation of welfare in 2014



(a)

(b)

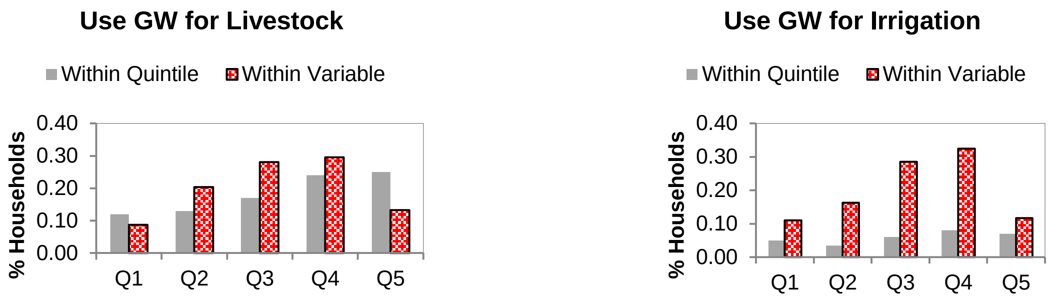
7.3.5 Groundwater Productive Uses

Livestock watering increases steadily in the within quintile measure, as expected (Figure 20a). The within variable measure shows a similar pattern, though the top quintile has a similar intensity to the bottom quintile. This may suggest that groundwater for livestock supports welfare transitions up to a threshold (Q4) when it becomes less significant to households’ welfare. For irrigation using groundwater (Figure 20b), the within quintile graph shows limited (<8%) incidence across all quintiles but a similar trend of increasing intensity for the within variable up to the fourth quintile when it declines.

7.3.6 Groundwater Level

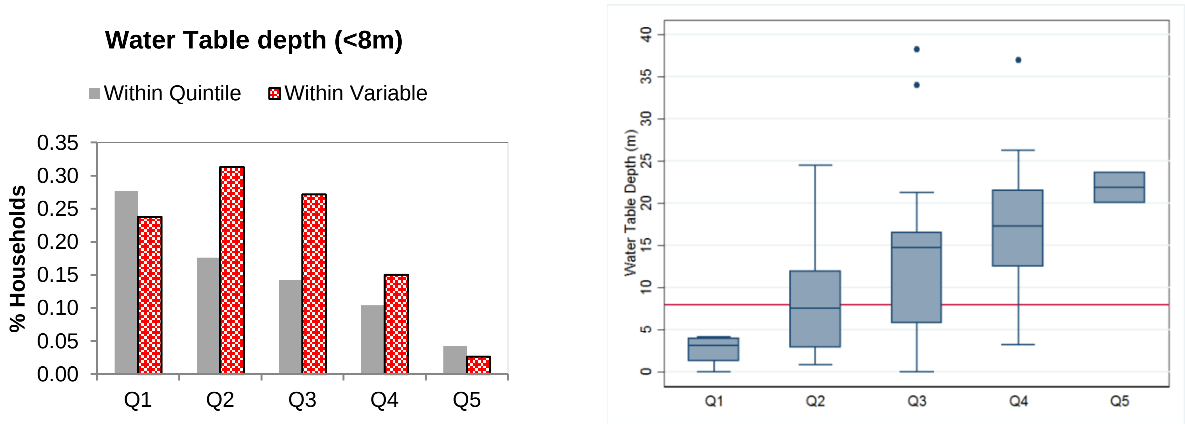
The within quintile graph shows a progressive decline (from Q2 to Q5) in the fraction of people that relied on boreholes with a water table of less than 8m deep (Figure 21a). The within variable graph showed that households in the first welfare quintile were eight times more likely to rely on shallow groundwater compared to those in the top welfare quintile. Figure 21b shows a boxplot of water table depth and welfare quintiles, the red line marks the 8m threshold. The first welfare quintile showed almost all households in this welfare quintile relied on boreholes with water table depth of less than 4 metres. Groundwater table depths in the second to fifth welfare quintiles were higher indicating increased welfare led to increased use of deeper groundwater.

Figure 20 Kwale County: households using groundwater for (a) livestock and (b) irrigation



(a) (b)

Figure 21 Kwale County: water table depth v. welfare quintiles



(a) (b)

7.3.7 Drinking Water Services

We examine drinking water services across the SDG 6.1 categories of affordable, reliable, safe (perceived, taste and EC), and physical accessible (close). While affordability predictably favours the wealthy (within quintile), this is muted by less than one in five of households agreeing drinking water is affordable even in the top quintile (Figure 22a). The within variable results show an unexpected dip in affordability for Q4 and Q5 which needs further investigation. Reliability (Figure 22b) reflects a similar trend to affordability by both measures though slightly higher percentage values though all below 50%. Alternatively, perceived 'safety' of drinking water (Figure 22c) rises by quintile to just exceed 50% of households by the 'within quintile' measure. Again, the 'within variable' exhibits a similar pattern to 'affordability' and 'reliability' for within quintile measures with the concern that more than 70% of first welfare group consider water 'unsafe' to drink.

The above results are tempered by a relatively low percentage of households using groundwater as their only source across all quintiles (Figure 23a). Groundwater supplies are 'close' to around three in five households, again across all quintiles, though this falls for the 'within variable' group though no welfare effect emerges (Figure 23b). The water quality (EC) threshold is exceeded by one in five households with no discernible welfare effects which are stable though lower for the 'within variable' measure (Figure 23c). Acceptable taste is identified by roughly a third of all households with no major welfare effect, though this indicates most households are not satisfied (Figure 23d). The 'within variable' measure identifies an increasing welfare effect, though still low (<30%), for households up to Q4 when it falls sharply. The latter requires further investigation.

7.3.8 Groundwater Dependency

Groundwater dependency was assessed using estimated volumetric data from the water data transmitters from 300 handpumps. We plotted usage against welfare quintiles which were estimated from the resampled spatial welfare maps at 1km grid. Figure 24 shows a box plot of monthly total volume of groundwater abstracted from the handpumps and welfare quintiles for years 2014 and 2015. These do not show a clear association between dependency on groundwater and welfare. However, high water usage from handpumps by households in the second and third welfare quintiles was observed where the maximum volume was high as 190,000 litres in 2014 (second welfare quintile) and 148,000 in 2015 (third welfare quintile).

Figure 22 Kwale County: drinking water services which are (a) affordable, (b) reliable, (c) safe

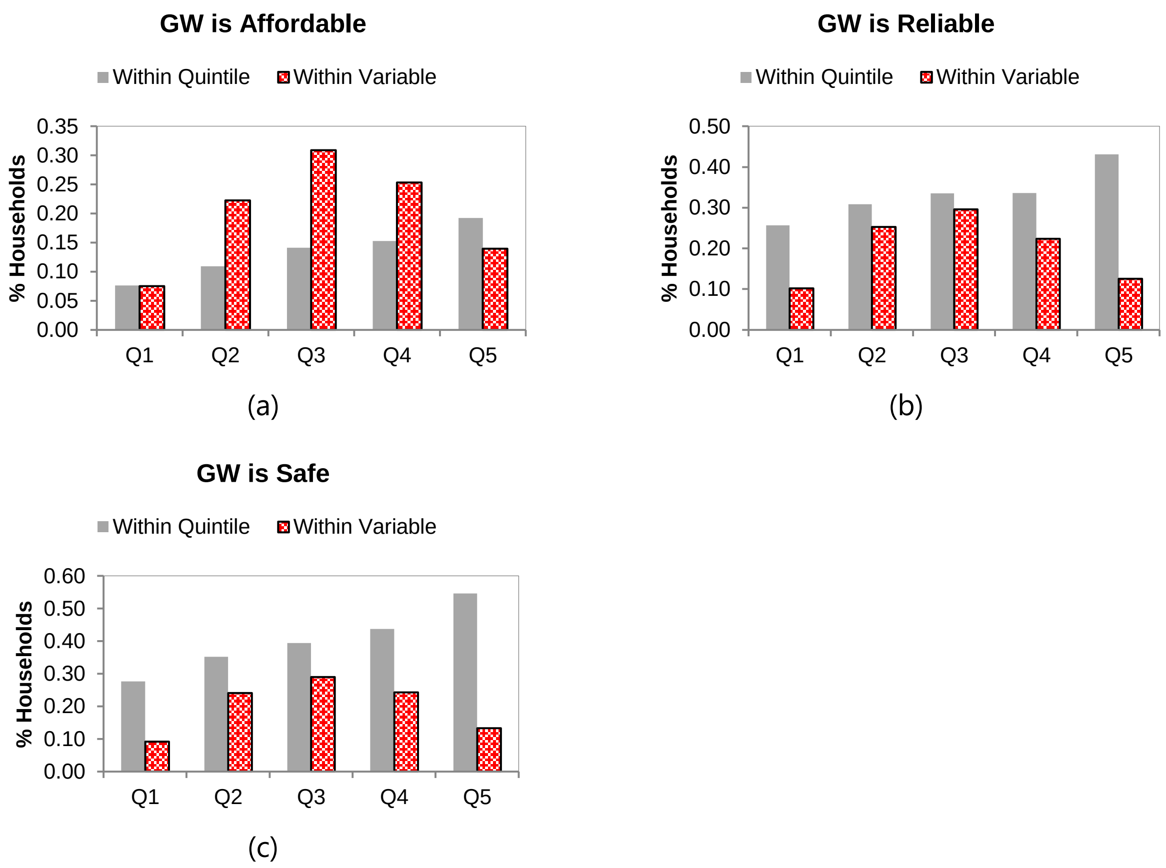
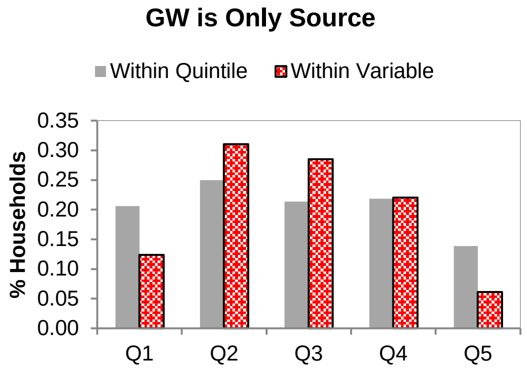
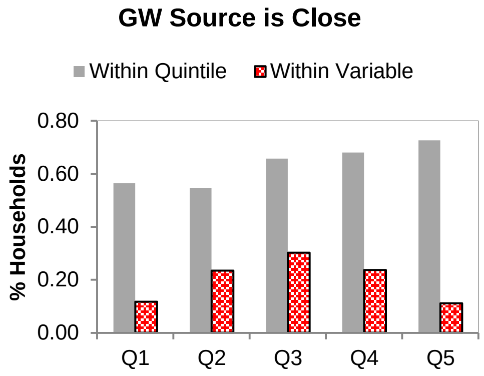


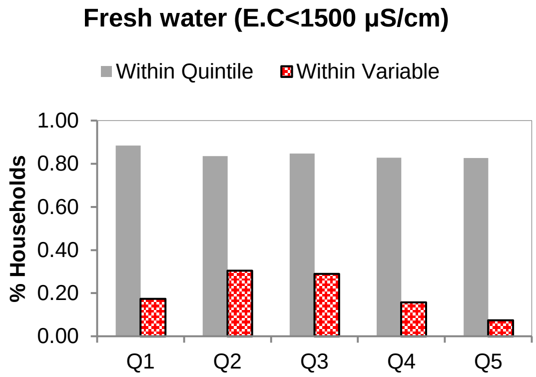
Figure 23 Kwale County: drinking groundwater: (a) only source, (b) close, (c) EC, (d) taste



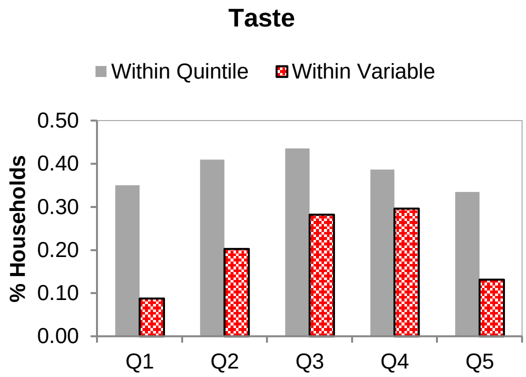
(a)



(b)

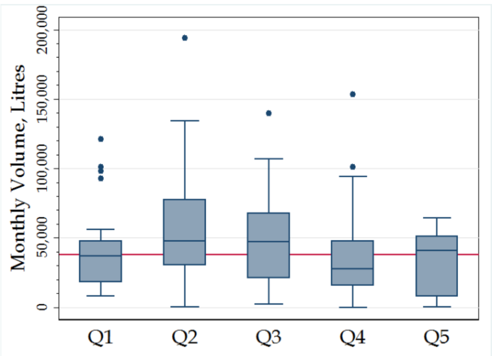


(c)

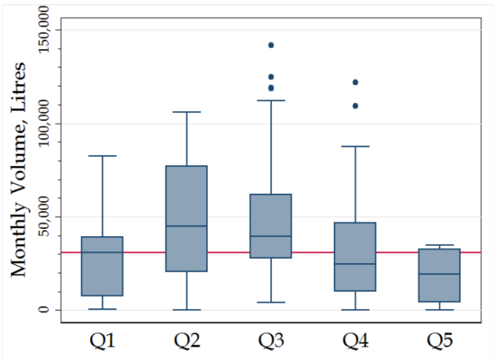


(d)

Figure 24 Kwale County: groundwater dependency and welfare (a) 2014, (b) 2015



(a)



(b)

8 Urban study

[Please note this is a shortened version of a longer report which is also available on upgro.org]

8.1 Background

The urban population of Tropical Africa get their water-supply from a variety of sources – but overall failed to achieve the corresponding UN-MDG (Millennium Development Goal). In this context the objectives of this rapid scoping study were:

- to assess from existing databases the proportion of the urban population obtaining their water from different sources;
- to discuss the implications of these water-supply realities and to assess the groundwater dependence of low-income communities within the urban environment;
- to provide the outline of further research to address the issue in a more comprehensive manner, identifying key partners and modes of working.

The World Bank-Africa Infrastructure Country Diagnostic (AICD) provides an excellent overview of trends in urban water-supply in Africa during 2010-16, and addresses in general terms the issues of accessibility and affordability. Its latest compilations reveal that on average urban water-services have declined with respect to proportion served during 1990-2005 (Table 9), with alternative sources including direct collection from water wells figuring prominently. The main reason for this appears to be the rapid growth of urban population (averaging 3.6% pa) compounded by decreasing household size, resulting in a 5.2% pa growth rate in the dwellings requiring water-supply services.

Table 9 Trends in water supply access, Africa, 1990-2005

[Source: Foster and Briceño-Garmendia, 2010. Note row sums are not 100% in the original references]

Period	Piped supply (Utility-provided)	Water wells (boreholes / hand-dug wells) (private)	Standposts (utility or private)	Surface water
1990-1995	50%	20%	29%	6%
1995-2000	43%	21%	25%	5%
2000-2005	39%	24%	24%	7%

Urban households obtain their domestic water-supply from multiple sources, which vary with income-group, physical location, financial cost and time of year according to availability. A very important question in relation to urban private domestic self-supply from water wells is – whether it is essentially a pro-poor phenomenon or favours wealthier households? The answer to this question is far from straightforward – and it involves consideration of physical accessibility, financial affordability, resource sustainability and quality vulnerability, compared to other available sources of basic water-supply.

8.2 Groundwater Use in Selected Cities

This scoping study found (within the above picture) that reliable data on urban groundwater use and dependency, both by water-service utilities and private users, are for the most part very patchy and poorly collated. To obtain more reliable information it was found necessary to take a city-by-city approach, where possible establishing links with local groundwater specialists and water utility contacts. Although time-consuming this approach was attempted on a pilot scale for 6 selected cities (chosen on the basis of existing contacts) – Lusaka and Kabwe in Zambia, Dar-es-Salaam and Arusha in Tanzania and Accra and Kumasi in Ghana, and a summary of the best available data on groundwater use and dependency in these cities is given in Table 10. The appraisal of whether open access to groundwater favours or impedes water-supply provision for poorer households was also usefully informed by specific, relatively recent, research in parts of Lusaka (2009) and Accra (2015).

Table 10 Groundwater use and dependency in 6 cities of three countries in SSA

City (population)	Lusaka (1.94m)	Kabwe (0.22m)	Dar-es-Salaam (3.80m)	Arusha (0.42m)	Accra (3.90m)	Kumasi (2.50m)
Year	2011	2015	2013	2012	2015	2007
Water Utility	LWSC	LGWSC	DAWASA(CO)	AUWSA	GWCL	GWCL
Utility Water Supply	270 Ml/d	~ 50 Ml/d	290 Ml/d	175 Ml/d	360 Ml/d	90 Ml/d
Utility GW Proportion	45%	100%	10%	80%	<5%	0%
Private Supply	100-300 Ml/d	? 10 Ml/d	110 Ml/d	?? Ml/d	? 15Ml/d	? 25 Ml/d
Overall GW Proportion	60-75%	100%	35%	? 85+%	? <5%	? >20%
Comments		LGWSC water-production includes other smaller towns	major new ground-water prospect under development		Greater Accra MA much larger population	

8.3 Water Utilities & Groundwater Resources

Wherever high-yielding aquifers exist say within 30km of an urban demand centre their managed and staged development by the water utility can significantly increase water-supply security (during extended drought or river-water pollution incidents). Moreover, the modest and phased capital cost of groundwater development (avoiding expensive advanced water treatment) will make it more feasible to meet rising water-demand, to reduce mains connection charges, to provide better service continuity, and to allow social (pro-poor) tariffs. This should be to the benefit of all water users, and especially to poorer households, providing tariff structures and water charging can be appropriately structured.

Given current rapid urban growth, water-service systems in peri-urban areas will need to be decentralised, and planned as closed-loops in new suburbs with populations of 10,000–50,000. Such systems can be operated to minimise infrastructure costs, energy use, and water losses, and can also promote energy and nutrient recovery by converting current liabilities (energy for wastewater treatment) into assets (energy recovery from wastewater carbon) and facilitate local water reuse. The natural drought resilience and quality protection of many aquifers means that deep water wells are well suited to be the water-supply source for such systems. And since these systems will treat wastewater nutrient content as a resource (by separating urine from faeces and recovering it for sale as fertiliser) their installation should substantially reduce subsurface contaminant loading from in-situ sanitation. Nevertheless, it will also be necessary to put a special effort into control of other forms of urban groundwater contamination (such as gasoline stations, small-scale motor shops, dry-cleaning laundries) to prevent the loss of important water well sources.

However, to make best use of such opportunities will require more water-resource awareness in water utilities, and closer partnership with groundwater resource regulator and knowledge centres. Some major African cities (eg. Dar-es-Salaam and Addis Ababa) have embarked on this course in recent years to explore the development of major new groundwater resources. Elsewhere, even if only lower-yielding aquifers are available, there are strong operational arguments for water-utility expertise to be guiding the construction of individual water wells (even if not connected to the mains distribution system) for communal use by low income households.

In general, water utilities have struggled to expand water-mains coverage, in response to extremely rapid rates of peri-urban growth. In the absence of NGO finance the drilling of water-supply boreholes is widely beyond the financial reach of the urban poor. But in peri-urban areas where no other service is available, and hydrogeological conditions allow, there has been major growth in the construction of low-cost hand-dug wells for basic water-supply (often with only poor sanitary protection), together with a spectacular growth in the activities of water vendors (in many cases unregulated and whose product often derives from private water wells).

It will be necessary to integrate utility and private investments in urban water-supply expansion more effectively, and use both piped and non-piped solutions for safe water-supply provision. This can be facilitated by the establishment of low-income (pro-poor) policy and technical units in water utilities tasked with pursuing appropriate alternative routes to water-supply provision in poorer neighbourhoods such as efficient construction, operation and maintenance of community boreholes, including the possibility of using appropriately protected water wells to supply local distribution networks in fast-growing peri-urban areas,

There are also strong arguments for national governments to utilize the organizational and logistic capacity of water utilities by commissioning them to collaborate in the regulation of private urban groundwater use in view of its many potential side-effects on utility operation and finance. This includes effects on the distribution and trends in water-demand, the opportunities and impediments to revenue collection and influence of sewer flows and treatment plant. There is also considerable scope for utilizing water utility laboratory capacity to provide a water-quality monitoring and advisory service to private water well users and water vendors.

8.4 Self-Supply from Groundwater

The high-cost of private water well drilling (compared to South Asia) has been identified as a critical factor constraining domestic groundwater use in African cities. In more recent years there have been some significant reductions in some cities and increases in others.

For example in Lusaka there are now about 150 water well drilling companies, operated by experienced Indian personnel using mainly relatively old equipment. This has lowered water well costs to between US$1,500 for a 50m borehole installed with a low-cost electric pump to US$3,500 for a deeper borehole with a more reliable electric submersible pump. Shallow hand-dug wells equipped with a hand-pump usually around cost about US$500.

By way of contrast in Nairobi, where groundwater levels fell notably between 1970 and 2010, much deeper water boreholes are required. A typical borehole yielding 1-2 l/s would now be some 200m in depth and cost US$12-14,000 with submersible pump installed. Nevertheless, large numbers of water boreholes are being drilled by apartment blocks, commercial premises and medium-sized industries because of the inadequate service levels of the water utility (which is faced with a lack of major capital investment to cope with rapid urban expansion and escalating demand).

In West African cities a high level of private water-borehole drilling is also reported. Despite unfavourable hydrogeological conditions in Accra, with saline groundwater in the southern part of the city, costs for an equipped system are said to be mainly in the range US$7-12,000. Nigeria has a very large and rapidly growing urban population, and by 2010 was reporting that more than 40 million urban dwellers were dependent upon unreticulated water wells, although no systematic data is available on more recent trends and current costs.

At first sight one might imagine that the poor would be major beneficiaries, at least where usable shallow aquifers provide easy access to groundwater. This is to some degree the case, but in the majority of hydrogeological settings the cost of water borehole construction is still usually beyond the reach of individual poor household, and they are thus totally dependent on communal NGO action and/or neighbour agreement to gain access to the resource.

Moreover, detailed surveys reveal that :

- large numbers of households in affluent urban areas are resorting to in-situ self-supply from groundwater by drilling deep water-supply boreholes to overcome the poor service-levels offered by many water utilities and later to avoid paying the higher tariffs levied on high consumption
- in those low-income districts where the groundwater table is shallow enough, most households are dependent upon less safe hand-dug water wells, which are far more prone to faecal pollution from on-site sanitation systems and surface drainage.

When large numbers of more affluent dwellers opt for in-situ self-supply the knock-on effects are complex. On the one hand it frees-up utility water-production capacity to meet the needs of more marginal low-income neighbourhoods – but on the other hand the same phenomena reduces utility revenue collection and makes it more difficult for them to make new infrastructure investments and to maintain highly-subsidised social tariffs for minimal use.

8.5 Urban Pro-Poor Access to Safe Water-Supplies

A regional trend of decreased rates of improved urban water-supply provision has been observed by the AICD in Tropical Africa during 1990 to 2015. The urban population that remain unserved with improved water-supply can be usefully divided into those people that :

- live physically-close to the existing infrastructure (70-80%), but who are not willing to meet the connectio

n cost, because of either prohibitive connection costs and/or the insecurity of tenure at their dwelling place;

- live outside existing infrastructure (20-30%), where the capital cost for the water utility of extending coverage is too high given the poor prospect of capital cost recovery

and a third (less well defined) category whose continuity and reliability of utility water-supply is so poor that they have to make regular recourse to alternative solutions.

The traditional inverted tariff for water-supply services – with in effect a cross-subsidy between the social tariff and standard high-use tariffs – has not been a major help as regards water-supply affordability for poor households , since it is poorly targeted and has the effect of providing an element of subsidy over a wide range of income quintiles. Access to utility piped water-supply to dwelling is entirely confined to the upper income quintiles – given that for example the current limits on household water-service expenditure in Tanzania, Ghana and Zambia are US$1, 2 and 3/month respectively. All other households have to depend on alternative water-supply sources, such as utility stand-posts or water-kiosks, community boreholes and water vendors. In reality most urban consumers depend on combinations of all these sources according to availability, season and price.

8.6 Consequences of open access to groundwater

It would appear that in most situations the main beneficiaries of open access to groundwater are high-income water-users, who benefit from being able to invest in private boreholes to increase supply reliability and reduce cost for large-volume use compared to standard utility tariff. A loss of high-tariff revenue by the water utility and thus no economy of scale in urban water-services investments is an inevitable consequence, and private self-supply can generate large additional flows to the sewage system and sewage treatment works (where these exist or are in project), for which no revenue has been generated (unless regulatory provision is made for private water wells to be licensed and charged). However, large-scale private self-supply from groundwater can have the indirect effect of relieving demand pressures on the water utility, especially in critical districts and where large point demands exist from industrial, commercial and recreational users.

There is also a public-health hazard where groundwater quality is seriously compromised, which impacts more on poorer households because of their dependence on shallow hand-dug wells. This needs to be carefully managed, with recommendations that water well supplies only be used for non-sensitive purposes.

9 Conceptual framework revisited

9.1 Introduction

The quality and quantity of groundwater as a natural resource is dynamic and subject to many local, regional and global influences. Those influences range from the impacts of abstractions and return flows, through the actions of mandated public sector organisations to govern and manage the resource, to the wider pressures imposed by demographic and land use change, and the wider consequences of global political and economic choices (including anthropogenic climate change).

Access to groundwater may be direct (through local use of natural discharges), indirect (through enjoyment of groundwater-fed ecosystem services such as lowland grazing), or more commonly mediated by investments in engineering and water service management (supplying water from wells and boreholes).

Groundwater resources and groundwater-supplied services are developed, governed and managed by organisations and institutions in the public and private sectors, and also by citizens themselves (in the case of self-supply).

The interactions between these three primary components – groundwater as a resource, groundwater as a service, and groundwater institutions – may contribute to poverty outcomes and trajectories.

Access to groundwater (especially if that access is sufficient in quantity and quality, close to the point of use, affordable, manageable and reliable) may help to support subsistence livelihoods, contribute to incomes and consumption, save time and energy, and so contribute to wider impacts on health, education, livelihoods and well-being. Alternatively, the benefits of groundwater access may be disproportionately captured by the relatively well-off. And if groundwater access is deficient in regard to quantity, quality, affordability, manageability or reliability, the impacts on the poor may be curtailed or even negative.

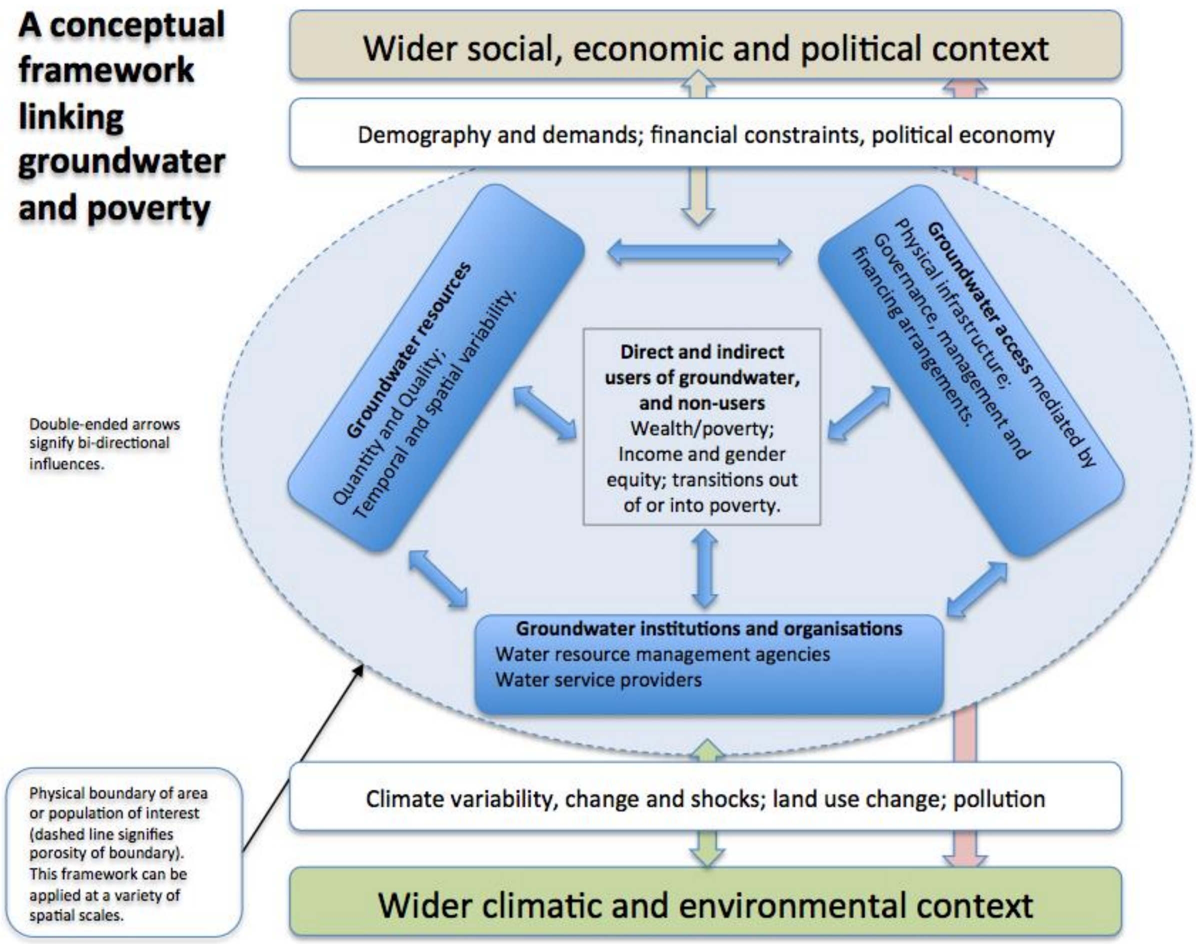
These links and relationships are brought together in a simple diagrammatic summary as Figure 25. This is offered as (a) an outcome of this study, and (b) a representation and summary of the system, in its social, political, economic, technical, managerial and natural resource dimensions. Its purpose is to aid understanding of the system, but it can also permit the situating of individual research studies within a wider framework.

More work is needed to adequately capture the important elements of the system without over-complicating the resulting framework(s). In particular, the interactions and implications for the poor of groundwater as a resource, groundwater as a service, and the institutions and organisations involved in groundwater governance and management need to be unpacked. Furthermore, the social and cultural relationships between poverty, gender and exclusion need to be highlighted.

9.2 Links to wider thinking on poverty dynamics

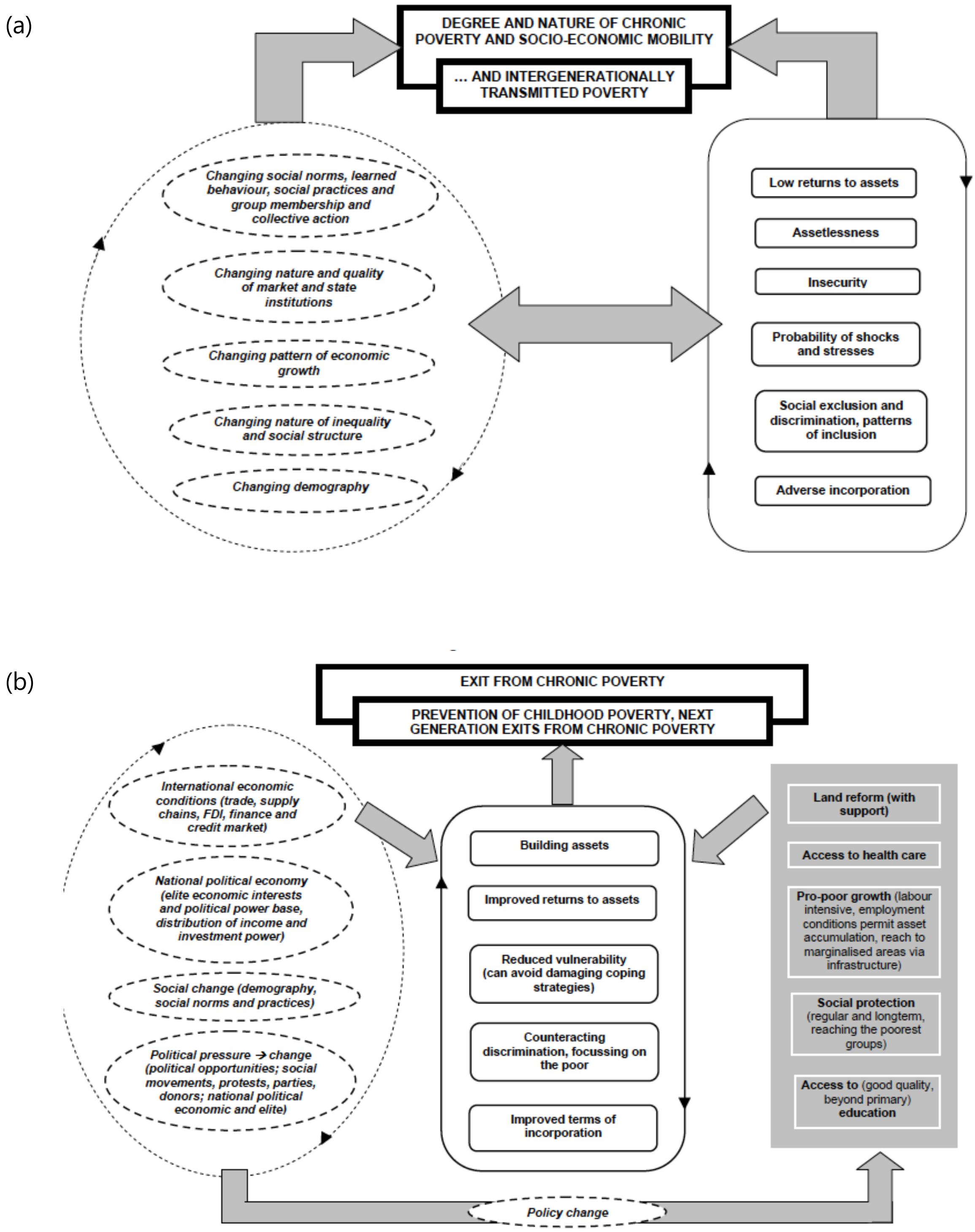
In a working paper of the Chronic Poverty Research Centre (Shepherd, 2007) a matrix (op. cit. Table 1) is presented setting out examples of measures to prevent descent into poverty, addressing the factors which maintain people in poverty, and facilitating escape from poverty. These are mapped against policies which can stimulate growth, enhance human development, improve security, and address matters of rights, culture and empowerment. Water related examples can readily be fitted within most of the cells of this matrix.

Figure 25 A conceptual framework linking groundwater and poverty



Shepherd (2007) goes on to set out two conceptual frameworks, one explaining chronic poverty, and the second explaining exits from chronic poverty. These are shown below as Figure 26. Perhaps a useful next step for the UPGro community and others interested in the place of (ground)water in addressing poverty is to examine the links between Figure 25 and Figure 26b. In particular to take Figure 25 – which focuses on poverty reduction through a groundwater lens — and ask "how may improved access to groundwater and the services it provides contribute to elements of the more generic framework set out in Figure 26b?"

Figure 26 Poverty: (a) explaining chronic poverty, (b) explaining exits from chronic poverty



10 Knowledge gaps

This study has highlighted a number of key knowledge gaps.

10.1 A paucity of high quality research

Despite the numerous studies considering the wellbeing implications of groundwater access, the vast majority suffer from methodological limitations, and there is a dearth of high quality research unravelling causal linkages and assessing the longer term impacts on poverty trajectories. The assumption is made that improved groundwater access brings benefits to all, while inequalities in those benefits and unintended consequences for the poor tend to be ignored.

10.2 Few studies of risks and threats

Changes and emerging threats to the quality and quantity of groundwater resources and to access, are documented in the literature, including geogenic and anthropogenic contamination, climatic change, growing demand, and financial and operational challenges associated with sustaining access. While it is likely that these issues disproportionately impact the poor, few studies have sought to empirically assess their impact on welfare outcomes, and their implications for longer term poverty pathways.

10.3 Weaknesses in the publicly available data

The publicly available household survey datasets (including DHS, MICS, and national censuses) tend to use the same or similar categories of water sources. However, the categories themselves are flawed – at least in terms of the type of analysis attempted in this study. In particular, "piped supply" gives no information about the origin of the water (groundwater or surface water or a mix of the two). In contrast, "springs", "wells", "boreholes", "rain water" and "surface water" permit analysis not only by delivery system but also by the component of water resources.

Furthermore, the household surveys ask about the household's main source of drinking water, and so fail to fully address the reality of people's use of multiple sources of water for multiple uses.

10.4 Limited availability of panel datasets

Cross-sectional household survey datasets provide useful information, to the extent that sampling is undertaken rigorously and that pertinent questions are asked. Multiple household surveys, across a significant time period, provide indications of temporal change. But neither single nor multiple household surveys can tell us how changes in access to groundwater affect individual households and their transitions out of, or into, poverty.

In this short study, we have analysed panel data for one country (Rwanda) and used longitudinal data from surveys in another (Kenya). In future work it will be important to identify, generate and analyse more such datasets in order to develop a more complete understanding of such poverty dynamics.

10.5 Limited understanding of country-specific causative factors

Analysis of quantitative data in isolation from understanding of the political economy, social and cultural context, and within-country differences of the countr(y/ies) involved is of limited value. The questions raised for example over the analyses for Nigeria and Uganda (section 7.1) highlight this.

10.6 The urban picture

Underlying causes of the reductions in utility-derived piped water supply services certainly include those related to demographic change and a rate of increase in demand which cannot keep up with investments. However, many aspects of the political economy of specific countries are also strong contributory causes of the difficulties faced by utilities. The details are the subject of continuing diagnostic studies by the World Bank at the present time.

In attempting to analyse the situation in specific cities, the weaknesses in data availability become even more pronounced. In particular, the proportions of the water supplied by utilities which are groundwater-derived; and the proportions of groundwater consumed which are self-supplied (as opposed to utility-supplied) are not easy to quantify. The implications of self-supply, both for the financial viability of utilities, and for the health of the poor (and to a lesser extent the well-off), are probably highly context-specific, and little known.

10.7 Concepts, frameworks and inter-disciplinarity

In developing conceptual frameworks which can enhance understanding and guide further research, there needs to be some consensus around their scope (for example ecosystem services, water services, or specifically groundwater services), complexity, and relationships to other frameworks (eg livelihoods). Differing approaches to inter-disciplinarity (already subjected to investigation in the UPGro programme, Dobson, 2016) need to be brought into future dialogue over such conceptual frameworks.

11 Next steps

The following steps are either planned or under consideration.

11.1 Reporting

Because of the tight deadline for completion of this report, it has only been subject to limited review by the team responsible for its production, and a very small number of other reviewers. Synthesis and cross-checking between the various components of the study has similarly been time-constrained. This draft report will therefore be reviewed at greater length by the project manager, the research team and the UPGro project Principal Investigators or their nominees during the month of April. A final version will be issued in May 2017.

11.2 Further research

Assuming there is appetite within and beyond UPGro to further develop the research ideas indicated in this report, a face-to-face meeting will be held, probably in London, before August 2017. Building on the findings of this report, such a meeting will represent an opportunity to continue the process of developing a more substantive research proposal

Discussions will continue in the coming weeks, both within the UPGro programme and beyond (including about 50 individuals and related applied research programmes) as to the leadership and membership of a core team to take forward the development of a full research project.

11.3 Follow-up from the urban study

Two specific recommendations were made as a consequence of undertaking the urban component of this project.

11.3.1 Dialogue on Water-Utility Pro-Poor Operations and Groundwater

The first recommendation is to promote and facilitate a structured dialogue on approaches to the expansion of water-utility operations to include a range of 'pro-poor' technical and policy interventions, together with a more integrated focus on groundwater development and management.

This could comprise a focused workshop to explore water-utility training needs in relation to a range of potential pro-poor facets of their operations including all or some of the following :

- reviewing mandates to evaluate the constraints and potential of current governance to allow utilities to assume a broader vision of urban water-supply and water resources
- approaches to structuring connection charges and consumption tariffs to favour supply of low-income households
- assessing 'unaccounted for' water, and especially physical system leakage, and approaches to recovery
- assessment of groundwater pollution vulnerability and protection of drinking- water quality
- rational development and management of groundwater resources for utility water-supply (so as to improve drought security and minimise quality hazard)
- fostering an integrated approach to urban water-services including prioritisation and zoning of sanitation/sewerage and urban drainage
- potential utility services to monitor and manage direct self-supply from groundwater (including use metrics, sewer discharges, quality hazards/use suitability).

The following are identified as lead collaborating organisations with UPGro for the promotion of the workshop and design of the emerging training programme : Global Water Operators Partnership Alliance (GWOPA of UN-Habitat), African Water Association (AFWA via GWOPA), Water Aid-UK, Skat, AfGW-Net (African Groundwater Network), International Association of Hydrogeologists (IAH) and International Water Association (IWA). The workshop should also be on interest to various International Development Banks. Resource persons with close familiarity with these topics are Jenny Grőnwall, Anne Bousquet and Stephen Foster. It would be sensible to limit participation to those water utilities considered in the current project.

11.3.2 Technical and Economic Field Appraisal of Urban Water Sources

The second recommendation is to undertake a systematic technical assessment of the sources of domestic water-supply in (say) two of the 6 selected cities, including consideration of drought security and quality hazards, coupled with an economic appraisal of the trends in public and private investment on domestic water-supply provision in those cities. This should be undertaken by a consortium of local and international consultants, be sequential and have a total duration of about 6 months.

11.4 Further research by CPAN

The Chronic Poverty Advisory Network (CPAN) is currently (2017) carrying out quantitative and qualitative poverty dynamics studies, identifying people's trajectories, the causal processes, and key policy factors in the following countries: Bangladesh, Cambodia, Ethiopia, Kenya, Malawi, Nepal, Niger, Philippines, Rwanda Tanzania, and have recently also worked on Uganda. CPAN also has analysis of panel data only going on in Mexico, Uganda, Vietnam, India, Pakistan and Nigeria. In most cases this work is with partners. CPAN is willing to explore the availability of data on water in the datasets they are using, and help design a multi-country study to investigate the relationships between poverty trajectories and the various less researched aspects of ground water access, use and threats identified in this report.

References

Abou-Zeid AHA, Abkar TA, Mohamed RO. Schistosomiasis and soil-transmitted helminths among an adult population in a war affected area, Southern Kordofan state, Sudan. Parasit Vectors. 2012;5. doi:10.1186/1756-3305-5-133.

Abubakar, A. et al, 2012. Prevalence and Risk Factors for Poor Nutritional Status among Children in the Kilimanjaro Region of Tanzania. International Journal of Environmental Research and Public Health, 9(10), pp.3506–3518.

Acosta, C.J. et al, 2001. Cholera outbreak in southern Tanzania: Risk factors and patterns of transmission. Emerging Infectious Diseases, 7(3, S), pp.583–587.

Adams, E.A., Boateng, G.O. & Amoyaw, J.A., 2016. Socioeconomic and Demographic Predictors of Potable Water and Sanitation Access in Ghana. Social Indicators Research, 126(2), pp.673–687.

Adank, M. et al, 2016. Looking beyond headline indicators: water and sanitation services in small towns in Ethiopia. Journal of Water, Sanitation and Hygiene for Development, 6(3), pp.435–446.

Adekalu, K.O., Osunbitan, J.A. & Ojo, O.E., 2002. Water sources and demand in South Western Nigeria: implications for water development planners and scientists. Technovation, 22(12), pp.799–805.

Adeoti, A. et al, 2009. The Impact of Treadle Pump Irrigation Technology Adoption on Poverty in Ghana. The Journal of Agricultural Education and Extension, 15(4), pp.357–369.

Ahoule, D.G. et al, 2015. Arsenic in African Waters: A Review. Water Air and Soil Pollution, 226(9).

Akers, D.B. et al, 2015. Lead (Pb) Contamination of Self-Supply Groundwater Systems in Coastal Madagascar and Predictions of Blood Lead Levels in Exposed Children. Environmental Science & Technology, 49(5), pp.2685–2693.

Akinbile, C.O. et al, 2016. Environmental implications of animal wastes pollution on agricultural soil and water quality. Soil and Water Research, 11(3), pp.172–180.

Akoachere, J.-F.T.K., Omam, L.-A. & Massalla, T.N., 2013. Assessment of the relationship between bacteriological quality of dug-wells, hygiene behaviour and well characteristics in two cholera endemic localities in Douala, Cameroon. BMC Public Health, 13.

Akple, M. et al, 2011. Microbiological quality of water from hand-dug wells used for domestic purposes in urban communities in Kumasi, Ghana. Urban Water Journal, 8(1), pp.57–64.

Alaofè, H. et al, 2016. Solar-Powered Drip Irrigation Impacts on Crops Production Diversity and Dietary Diversity in Northern Benin. Food and Nutrition Bulletin, 37(2), pp.164–175.

Ali, S. et al, 2016. Worldwide contamination of water by fluoride. Environmental Chemistry Letters, 14(3), pp.291–315.

Altare, C. et al, 2016. Factors Associated with Stunting among Pre-school Children in Southern Highlands of Tanzania. Journal of Tropical Pediatrics, 62(5), pp.390–408.

Altchenko, Y. & Villholth, K.G., 2015. Mapping irrigation potential from renewable groundwater in Africa-A quantitative hydrological approach. Hydrology and Earth System Sciences, 19(2), pp.1055–1067.

Alvarez, J.L. et al, 2009. Factors associated with maternal mortality in Sub-Saharan Africa: an ecological study. BMC Public Health, 9, p.462.

Anim, F., Nyame, F.K. & Armah, T.K., 2010. Coliform status of water bodies from two districts in Ghana, west Africa: implica`tions for rural water resources management. Water Policy, 12(5), pp.734–745.

Apambire, W.B., Boyle, D.R. & Michel, F.A., 1997. Geochemistry, genesis, and health implications of fluoriferous groundwaters in the upper regions of Ghana. Environmental Geology, 33(1), pp.13–24.

Arnold, M. et al, 2013. Drinking water quality and source reliability in rural Ashanti region, Ghana. Journal of Water and Health, 11(1), pp.161–172.

Awoke W, Bedimo M, Tarekegn M. Prevalence of schistosomiasis and associated factors among students attending at elementary schools in Amibera District, Ethiopia. Open J Prev Med. 2013;03(02):199-204. doi:10.4236/ojpm.2013.32027.

Ayenew, T., 2008. The distribution and hydrogeological controls of fluoride in the groundwater of central Ethiopian rift and adjacent highlands. Environmental Geology, 54(6), pp.1313–1324.

Ayolabi, E.A. et al, 2013. Mapping saline water intrusion into the coastal aquifer with geophysical and geochemical techniques: the University of Lagos campus case (Nigeria). Springerplus, 2(433).

Bacha, D. et al, 2011. Impact of small-scale irrigation on household poverty: Empirical Evidence from the Ambo District in Ethiopia. Irrigation and Drainage, 60(1), pp.1–10.

Bain, R. et al, 2014. Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. PLoS Medicine, 11(5).

Bakundukize, C. et al, 2016. Poor understanding of the hydrogeological structure is a main cause of hand-dug wells failure in developing countries: A case study of a Precambrian basement aquifer in Bugesera region (Burundi). Journal of African Earth Sciences, 121, pp.180–199.

Banerjee, S.G. & Morella, E., 2011. Africa's water and sanitation infrastructure: access, affordability and alternatives, Washington DC: World Bank.

Barnes, E., Bosque-Hamilton, E. & Osafo, R., 1993. Monitoring bacteriological quality of groundwater. In 19th WEDC Conference: Water, Sanitation, Environment and Development. Accra: WEDC, pp. 293–294.

Baumann, E., 2011. Low Cost Hand Pumps, St. Gallen.

Benova, L., Cumming, O. & Campbell, O.M.R., 2014. Systematic review and meta-analysis: Association between water and sanitation environment and maternal mortality. Tropical Medicine and International Health, 19(4), pp.368–387.

Benova, L., Cumming, O., Gordon, B.A., et al, 2014. Where There Is No Toilet: Water and Sanitation Environments of Domestic and Facility Births in Tanzania K. Sestak, ed. PLoS ONE, 9(9), p.e106738.

Biondi, D. et al, 2011. Risk Factors and Trends in Childhood Stunting in a District in Western Uganda. Journal of Tropical Pediatrics, 57(1), pp.24–33.

Bonsor, H.C. et al, 2015. A hidden crisis : strengthening the evidence base on the current failures of rural groundwater supplies. In 38th WEDC International Conference - Water, Sanitation and Hygiene Services Beyond 2015: Improving Access and Sustainability. Loughborough: WEDC.

Boone, C., Glick, P. & Sahn, D., 2011. Household Water Supply Choice and Time Allocated to Water Collection: Evidence from Madagascar. The Journal of Development Studies. 41(12), pp.1826-1850.

Bretzler, A. et al, 2017. Groundwater arsenic contamination in Burkina Faso, West Africa: Predicting and verifying regions at risk. Science of The Total Environment, 584-585, pp.958–970.

Briscoe, J. et al, 1993. The demand for water in rural areas - determinants and policy implications. World Bank Research Observer, 8(1), pp.47–70.

Burney, J. et al, 2010. Solar-powered drip irrigation enhances food security in the Sudano–Sahel. Proceedings of the National Academy of Sciences of the United States of America, 107(5), pp.1848–1853.

Butterworth, J., Sutton, S. & Mekonta, L., 2013. Self-Supply as a Complementary Water Services Delivery Model in Ethiopia. Water Alternatives, 6(3, SI), pp.405–423.

Cairncross, S. et al, 2010. Water, sanitation and hygiene for the prevention of diarrhoea. International Journal of Epidemiology, 39(Supplement 1), pp.i193–i205.

Cairncross, S., 1993. Guinea worm eradication - Is the target attainable? In 19th WEDC Conference - Water, Sanitation, Environment and Development. Accra: WEDC.

Calow, R. et al, 2011. Climate change, water resources and WASH: A scoping study. , p.69.

Calow, R.C. et al, 2010. Ground Water Security and Drought in Africa: Linking Availability, Access, and Demand. Ground Water, 48(2), pp.246–256.

Carter, R.C. & Parker, A., 2009. Climate change, population trends and groundwater in Africa. Hydrological Sciences Journal, 54(4), pp.676–689.

Carter, R.C. & Ross, I., 2016. Beyond "functionality" of handpump-supplied rural water services in developing countries. Waterlines, 35(1), pp.94–110.

Carter, R.C., Tyrrel, S.F. & Howsam, P., 1999. The impact and sustainability of community water supply and sanitation programmes in developing countries. Water and Environment Journal, 13(4), pp.292–296.

Casey, V. et al, 2016. The role of handpump corrosion in the contamination and failure of rural water supplies. Waterlines, 35(1), pp.59–77.

CGIAR Research Program on Water, Land and Ecosystems (WLE) (2015). Groundwater and ecosystem services: a framework for managing smallholder groundwater-dependent agrarian socio-ecologies - applying an ecosystem services and resilience approach. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 25p. http://dx.doi.org/10.5337/2015.208

Cha, S. et al, 2015. The Effect of Improved Water Supply on Diarrhea Prevalence of Children under Five in the Volta Region of Ghana: A Cluster-Randomized Controlled Trial International Journal of Environmental Research and Public Health, 12(10), pp.12127–43.

Chairuca, L. & Hassane, I., 1991. Nitrate contamination in peri-urban Maputo (Mozambique). In 17th WEDC Conference: Infrastructure, environment and people. Nairobi: WEDC.

Chidya, R.C.G., Mulwafu, W.O. & Banda, S.C.T., 2016. Water supply dynamics and quality of alternative water sources in low-income areas of Lilongwe City, Malawi. Physics and Chemistry of the Earth, 93, pp.63–75.

Chippaux, J.P. et al, 2002. Groundwater pollution in Niamey, Niger. Bulletin de la Societe de Pathologie Exotique, 95(2), pp.119–123.

Cobbina, S.J. et al, 2015. Comparative Assessment of Heavy Metals in Drinking Water Sources in Two Small-Scale Mining Communities in Northern Ghana. International journal of environmental research and public health, 12(9), pp.10620–34.

Colombatti, R. et al, 2008. A short-term intervention for the treatment of severe malnutrition in a post-conflict country: results of a survey in Guinea Bissau. Public Health Nutrition, 11(12), pp.1357–1364.

Craig, L. et al, 2015. Recommendations for fluoride limits in drinking water based on estimated daily fluoride intake in the Upper East Region, Ghana. Science of The Total Environment, 532, pp.127–137.

Crow, B., Swallow, B. & Asamba, I., 2012. Community Organized Household Water Increases Not Only Rural incomes, but Also Men’s Work. World Development, 40(3), pp.528–541.

Dangour, A.D. et al, 2013. Interventions to improve water quality and supply, sanitation and hygiene practices, and their effects on the nutritional status of children. Cochrane Database of Systematic Reviews, 8.

Dawet A, Yakubu DP, Longmut R, Benjamin CB, Daburum YH, Nannim N. Prevalence and intensity of Schistosoma haematobium among residents of Gwong and Kabong in Jos North Local Government Area, Plateau State, Nigeria. Int J Biol Chem Sci. 2012;6(4):1557-1565. doi:10.4314/ijbcs.v6i4.15.

Dearden, K.A. et al, 2017. Children with access to improved sanitation but not improved water are at lower risk of stunting compared to children without access: a cohort study in Ethiopia, India, Peru, and Vietnam. BMC Public Health, 17(1), p.110.

Degbey, C. et al, 2008. The quality of well water in the municipality of Abomey-Calavi in Benin. Environnement Risques & Sante, 7(4), pp.279–283.

Dekker, D.M. et al, 2015. Drinking Water from Dug Wells in Rural Ghana - Salmonella Contamination, Environmental Factors, and Genotypes. International Journal of Environmental Research and Public Health, 12(4), pp.3535–3546.

Descroix L, Mahé G, Lebel T, Favreau G, Galle S, Gautier E, Olivry J-C, Albergel J, Amogu O, Cappelaere B, Dessouassi R, Diedhiou A, Le Breton E, Mamadou I, Sighomnou D (2009) Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: a synthesis. Journal of Hydrology 375 (2009) 90–102 http://dx.doi.org/10.1016/j.jhydrol.2008.12.012

DHS Program (1990 - 2016) Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Tanzania, Uganda [Datasets]. Calverton, Maryland: ICF International Available online: http://www.dhsprogram.com/Data/

Diedhiou, M. et al, 2012. Tracing groundwater nitrate sources in the Dakar suburban area: an isotopic multi-tracer approach. Hydrological Processes, 26(5), pp.760–770.

Diouf, K. et al, 2014. Diarrhoea prevalence in children under five years of age in rural Burundi: an assessment of social and behavioural factors at the household level. Global Health Action, 7, pp.1–9.

Dittoh, S., Awuni, J.A. & Akuriba, M.A., 2013. Small pumps and the poor: a field survey in the Upper East Region of Ghana. Water International, 38(4, SI), pp.449–464.

Djaouda, M. et al, 2014. Bacteriological Quality of Well Waters in Garoua, North Cameroon. Water Quality Exposure and Health, 6(4), pp.161–176.

Dobson C (2016) How are natural and social science disciplines being integrated in interdisciplinary research on groundwater sustainability? A comparative study of the five UPGro consortium projects. Unpublished MSc thesis, University of Sussex, School of Business, Management and Economics.

Domènech, L., 2015. Improving irrigation access to combat food insecurity and undernutrition: A review. Global Food Security, 6, pp.24–33.

Dorice, K. et al, 2010. Bacterial contamination of water points of the upper Mfoundi watershed, Yaounde, Cameroon. African Journal of Microbiology Research, 4(7), pp.568–574.

Dorion, C. et al, 2012. Does Village Water Supply Affect Children's Length of Stay in a Therapeutic Feeding Program in Niger? Lessons from a Medecins Sans Frontieres Program. PLoS ONE, 7(12).

Dreibelbis, R. et al, 2013. Water , sanitation , and primary school attendance : A multi-level assessment of determinants of household-reported absence in Kenya. International Journal of Educational Development, 33, pp.457–465.

Dreibelbis, R. et al, 2014. The Impact of School Water, Sanitation, and Hygiene Interventions on the Health of Younger Siblings of Pupils: a Cluster-Randomized Trial in Kenya. American Journal of Public Health, 104(1), pp.E91–E97.

Edwards T, Smith J, Sturrock HJW, et al. Prevalence of Trachoma in Unity State , South Sudan : Results from a Large-Scale Population-Based Survey and Potential Implications for Further Surveys. PLoS Negl Trop Dis. 2012;6(4). doi:10.1371/journal.pntd.0001585.

Ejechi, E.O. & Ejechi, B.O., 2007. Sociological dimension in the handling habit and sanitary quality of hand-dug well water from oil-producing area of Nigeria. Environmental Monitoring and Assessment, 134(1-3), pp.255–261.

Elisante, E. & Muzuka, A.N.N., 2016. Sources and seasonal variation of coliform bacteria abundance in groundwater around the slopes of Mount Meru, Arusha, Tanzania. Environmental Monitoring and Assessment, 188(7), p.395.

Engstrom, E. et al, 2015. Prevalence of microbiological contaminants in groundwater sources and risk factor assessment in Juba, South Sudan. Science of the Total Environment, 515, pp.181–187.

Fantong, W.Y. et al, 2010. Geochemical provenance and spatial distribution of fluoride in groundwater of Mayo Tsanaga River Basin, Far North Region, Cameroon: implications for incidence of fluorosis and optimal consumption dose. Environmental Geochemistry and Health, 32(2), pp.147–163.

Fenn, B. et al, 2012. An evaluation of an operations research project to reduce childhood stunting in a food-insecure area in Ethiopia. Public Health Nutrition, 15(9), pp.1746–54.

Fentie T, Erqou S, Gedefaw M, Desta A. Epidemiology of human fascioliasis and intestinal parasitosis among schoolchildren in Lake Tana Basin, northwest Ethiopia. Trans R Soc Trop Med Hyg. 2013;107(8):480-486. doi:10.1093/trstmh/trt056.

Fetter C W (1994) Applied hydrogeology. Third edition. MacMillan Publishing Company.

Fink, G., Günther, I. & Hill, K., 2011. The effect of water and sanitation on child health: Evidence from the demographic and health surveys 1986-2007. International Journal of Epidemiology, 40(5), pp.1196–1204.

Fisher J A, Patenaude G, Giri K, Lewis K, Meir P, Pinho P, Rounsevell M D A, Williams M (2014) Understanding the relationships between ecosystem services and poverty alleviation: a conceptual framework. Ecosystem services 7, 34-45 http://dx.doi.org/10.1016/j.ecoser.2013.08.002

Fisher, M.B. et al, 2015. Understanding handpump sustainability: Determinants of rural water source functionality in the Greater Afram Plains region of Ghana. Water Resources Research, 51(10), pp.8431–8449.

Foster V, Briceño-Garmendia C (2010) Africa's infrastructure – a time for transformation. Chapter 16. Water supply – hitting the target? pp299-322. African Development Forum. http://documents.worldbank.org/curated/en/246961468003355256/pdf/521020PUB0EPI1101Official0Use0Only1.pdf

Foster, S. & Tuinhof, A., 2005. The Role of Groundwater in the Water-Supply of Greater Nairobi- Kenya, Washington DC.

Foster, T. & Hope, R., 2016. A multi-decadal and social-ecological systems analysis of community waterpoint payment behaviours in rural Kenya. Journal of Rural Studies, 47, pp.85–96.

Foster, T. & Hope, R., 2017. Evaluating waterpoint sustainability and access implications of revenue collection approaches in rural Kenya. Water Resources Research, 53(2), pp.1473–1490.

Foster, T., 2013. Predictors of Sustainability for Community-Managed Handpumps in Sub-Saharan Africa: Evidence from Liberia, Sierra Leone, and Uganda. Environmental Science & Technology, 47(21), pp.12037–12046.

Garn, J. V et al, 2013. A cluster-randomized trial assessing the impact of school water, sanitation and hygiene improvements on pupil enrolment and gender parity in enrolment. Journal of Water Sanitation and Hygiene for Development, 3(4), pp.592–601.

Garvey G, Kiros Gebrehiwot, A.Y., 1991. Hand dug wells : field experience from Ethiopia. In 17th WEDC Conference: Infrasutrcture, environment and people. Nairobi.

Gascon, J. et al, 2000. Diarrhea in children under 5 years of age from Ifakara, Tanzania: a case-control study. Journal of Clinical Microbiology, 38(12), pp.4459–4462.

Gebreegziabher, K. & Tadesse, T., 2011. Household demand for improved water supply services in Mekelle City, Northern Ethiopia. Water Policy, 13(1), pp.125–142.

Geere, J.L. et al, 2010. How do children perceive health to be affected by domestic water carrying? Qualitative findings from a mixed methods study in rural South Africa. Child Care Health and Development, 36(6), pp.818–826.

Gelinas, Y. et al, 1996. Well water survey in two districts of Conakry (Republic of Guinea), and comparison with the piped city water. Water Research, 30(9), pp.2017–2026.

Giordano, M., 2006. Agricultural groundwater use and rural livelihoods in sub-Saharan Africa: A first-cut assessment. Hydrogeology Journal, 14(3), pp.310–318.

Golovaty I, Jones L, Gelaye B, et al. Access to Water Source, Latrine Facilities and Other Risk Factors of Active Trachoma in Ankober, Ethiopia. PLoS One. 2009;4(8). doi:10.1371/journal.pone.0006702.

Graham, J. & Polizzotto, M.L., 2013. Pit latrines and their impacts on groundwater quality: A systematic review. Environmental Health Perspectives, 121(5), pp.521–530.

Graham, W.J. et al, 2004. The familial technique for linking maternal death with poverty. Lancet, 363(9402), pp.23–27.

Grimes JET, Croll D, Harrison WE, Utzinger J, Freeman MC, Templeton MR. The Relationship between Water, Sanitation and Schistosomiasis: A Systematic Review and Meta-analysis. PLoS Negl Trop Dis. 2014;8(12). doi:10.1371/journal.pntd.0003296.

Grönwall J T, Mulenga M, McGranahan G (2010) Groundwater, self-supply and poor urban dwellers A review with case studies of Bangalore and Lusaka. IIED Human Settlements Working Paper Series, Water and Sanitation, 26, November 2010 http://pubs.iied.org/pdfs/10584IIED.pdf

Grönwall, J., 2016. Self-supply and accountability: to govern or not to govern groundwater for the (peri-) urban poor in Accra, Ghana. Environmental Earth Sciences, 75(16), p.1163.

Hagos, F. & Mamo, K., 2014. Financial viability of groundwater irrigation and its impact on livelihoods of smallholder farmers: The case of eastern Ethiopia. Water Resources and Economics, 7, pp.55–65.

Hagos, F. et al, 2012. Agricultural water management and poverty in Ethiopia. Agricultural Economics, 43, pp.99–111.

Hall, R.P., Vance, E.A. & van Houweling, E., 2014. The Productive Use of Rural Piped Water in Senegal Water Alternatives, 7(3), pp.480–498.

Harvey, P.A. & Drouin, T., 2006. The case for the rope-pump in Africa: a comparative performance analysis. Journal of Water and Health, 4(4), pp.499–510.

Harvey, P.A. & Reed, R.A., 2006. Community-managed water supplies in Africa: sustainable or dispensable? Community Development Journal, 42(3), pp.365–378.

Hope R (2017) Conceptual framework based on Ostrom (2009). Pers. comm.

Howard, G. et al, 2002. Water usage patterns in low-income urban communities in Uganda: implications for water supply surveillance. International Journal of Environmental Health Research, 12(1), pp.63–73.

Howard, G. et al, 2003. Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. Water Research, 37(14), pp.3421–3429.

Howarth SE, Wilson JM, Ranaivoson E, Crook SE, Denning AM, Hutchings MS. Worms, wells and water in western Madagascar. J Trop Med Hyg. 1988;91(5):255-264.

Hussain, I. & Hanjra, M., 2004. Irrigation and poverty alleviation: Review of the empirical evidence. Irrigation and Drainage, 53(1), pp.1–15.

Huttly, S.R.A. et al, 1990. The Imo State (Nigeria) Drinking Water Supply and Sanitation Project, 2. Impact on dracunculiasis, diarrhoea and nutritional status. Transactions of the Royal Society of Tropical Medicine and Hygiene, 84(2), pp.316–321.

Ibe, K.M., Egereonu, U.U. & Sowa, A.H.O., 2002. The impact of handpump corrosion on water quality in rural areas of West African sub-region. Environmental Monitoring and Assessment, 78(1), pp.31–43.

Jimenez, A. & Perez-Foguet, A., 2011. The relationship between technology and functionality of rural water points: evidence from Tanzania. Water Science and Technology, 63(5), pp.948–955.

K'oreje, K.O. et al, 2016. Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya. Chemosphere, 149, pp.238–244.

Kabatereine NB, Standley CJ, Sousa-Figueiredo JC, et al. Integrated prevalence mapping of schistosomiasis, soil-transmitted helminthiasis and malaria in lakeside and island communities in Lake Victoria, Uganda. Parasit Vectors. 2011;4(1):232. doi:10.1186/1756-3305-4-232.

Kalua K, Chirwa T, Kalilani L, Abbenyi S, Mukaka M, Bailey R. Prevalence and Risk Factors for Trachoma in Central and Southern Malawi. PLoS One. 2010;5(2):e9067. doi:10.1371/journal.pone.0009067.

Kapembo, M.L. et al, 2016. Evaluation of Water Quality from Suburban Shallow Wells Under Tropical Conditions According to the Seasonal Variation, Bumbu, Kinshasa, Democratic Republic of the Congo. Exposure and Health, 8(4), pp.487–496.

Katsi, L. et al, 2007. Assessment of factors which affect multiple uses of water sources at household level in rural Zimbabwe - A case study of Marondera, Murehwa and Uzumba Maramba Pfungwe districts. Physics and Chemistry of the Earth, 32(15-18), pp.1157–1166.

Keane A (2016) A review of conceptual frameworks arising from the ESPA programme. ESPA Working Paper Series No 002, January 2016, ISSN 2058-9875 http://www.espa.ac.uk/files/espa/Review-Of-Conceptual-Frameworks_0.pdf

Kendie, S.B., 1992. Survey of water-use behaviour in rural north Ghana. Natural Resources Forum, 16(2), pp.126–131.

Kimani-Murage, E.W. & Ngindu, A.M., 2007. Quality of water the slum dwellers use: The case of a Kenyan slum. Journal of Urban Health, 84(6), pp.829–838.

Kimmage, K., 1991. Small-scale irrigation initiatives in Nigeria - the problems of equity and sustainability. Applied Geography, 11(1), pp.5–20.

Knopp S, Stothard JR, Rollinson D, et al. From morbidity control to transmission control: time to change tactics against helminths on Unguja Island, Zanzibar. Acta Trop. 2013;128(2):412-422. doi:10.1016/j.actatropica.2011.04.010.

Koehler, J., Thomson, P. & Hope, R., 2015. Pump-Priming Payments for Sustainable Water Services in Rural Africa. World Development, 74, pp.397–411.

Kostyla, C. et al, 2015. Seasonal variation of fecal contamination in drinking water sources in developing countries: A systematic review. Science of the Total Environment, 514, pp.333–343.

Kremer, M. et al, 2011. Spring Cleaning: Rural impacts, valuation,, and property rights institutions. Quarterly Journal of Economics, 126(1), pp.145–205.

Kubasta M. Schistosomiasis mansoni in the Harar Province. Ethiop Med J. 1964. https://www.cabdirect.org/cabdirect/abstract/19652900659. Accessed March 17, 2017.

Kulabako, N.R., Nalubega, M. & Thunvik, R., 2007. Study of the impact of land use and hydrogeological settings on the shallow groundwater quality in a peri-urban area of Kampala, Uganda. Science of the Total Environment, 381, pp.180–199.

Kulinkina, A. V. et al, 2016. Piped water consumption in Ghana: A case study of temporal and spatial patterns of clean water demand relative to alternative water sources in rural small towns. Science of The Total Environment, 559, pp.291–301.

Kumamaru, K., Smout, I. & Odhiambo, F., 2011. Self-supply : bridging the gap between household demand and community water supply ? In 35th WEDC International Conference, Loughborough. WEDC.

Kut, K.M.K. et al, 2016. A review of fluoride in african groundwater and local remediation methods. Groundwater for Sustainable Development, 2-3, pp.190–212.

Kwaghe, P. V & Amaza, P.S., 2009. Poverty status and its relationship with environmental, health-related and living condition factors among farming households in Borno State, Nigeria. Journal of Food Agriculture and Environment, 7(2), pp.823–828.

Langenegger, O., 1989. Groundwater Quality - An Important Factor for Selecting Handpumps. Developments in Water Science, (39), pp.531–541.

Leduc, C., Favreau, G. & Schroeter, P., 2001. Long-term rise in a sahelian water-table: the Continental Terminal in South-West Niger. Journal of Hydrology, 243(1-2), pp.43–54.

Lutz, A. et al, 2009. Sustainability of groundwater in Mali, West Africa. Environmental Geology, 58(7), pp.1441–1450.

MacArthur, J., 2015. Handpump Standardisation in Sub-Saharan Africa, St. Gallen.

MacCarthy, M.F., Annis, J.E. & Mihelcic, J.R., 2013. Unsubsidised Self-Supply in Eastern Madagascar. Water Alternatives, 6(3), pp.424–438.

MacDonald, A. & Calow, R.C., 2009. Developing groundwater for secure rural water supplies in Africa. Desalination, 248(1-3), pp.546–556.

MacDonald, A. et al, 2011. Groundwater Resilience to Climate Change in Africa, Keyworth.

MacDonald, A.M. et al, 2009. What impact will climate change have on rural groundwater supplies in Africa? Hydrological Sciences Journal, 54(4), pp.690–703.

MacDonald, A.M. et al, 2012. Quantitative maps of groundwater resources in Africa. Environmental Research Letters, 7(2).

Mahama, A.M., Anaman, K.A. & Osei-Akoto, I., 2014. Factors influencing householders' access to improved water in low-income urban areas of Accra, Ghana. Journal of Water and Health, 12(2), pp.318–331.

Mahmud MA, Spigt M, Mulugeta Bezabih A, López Pavon I, Dinant G-J, Blanco Velasco R. Risk factors for intestinal parasitosis, anaemia, and malnutrition among school children in Ethiopia. Pathog Glob Health. 2013;107(2):58-65. doi:10.1179/2047773213Y.0000000074.

Majuru, B. et al, 2011. Health impact of small-community water supply reliability. International Journal of Hygiene and Environmental Health, 214(2), pp.162–166.

Makoni, F.S., Manase, G. & Ndamba, J., 2004. Patterns of domestic water use in rural areas of Zimbabwe, gender roles and realities. Physics and Chemistry of the Earth, 29(15-18), pp.1291–1294.

Mamuse, A. & Watkins, R., 2016. High fluoride drinking water in Gokwe, northwest Zimbabwe. Journal of Water, Sanitation and Hygiene for Development, 6(1), pp.55–64.

Mangisoni, J.H., 2008. Impact of treadle pump irrigation technology on smallholder poverty and food security in Malawi: a case study of Blantyre and Mchinji districts. International Journal of Agricultural Sustainability, 6(4), pp.248–266.

Mara, D.D. & Feachem, R.G.A., 1999. Water- and Excreta-Related Diseases: Unitary Environmental Classification. Journal of Environmental Engineering, 125(4), pp.334–339.

Marks, S.J., Komives, K. & Davis, J., 2014. Community Participation and Water Supply Sustainability: Evidence from Handpump Projects in Rural Ghana. Journal of Planning Education and Research, 34(3), pp.276–286.

Mason, P.R., Patterson, B.A. & Loewenson, R., 1986. Piped water supply and intestinal parasitism in Zimbabwean schoolchildren. Transactions of the Royal Society of Tropical Medicine and Hygiene, 80(1), pp.88–93.

Matthys, B. et al, 2007. Risk factors for Schistosoma mansoni and hookworm in urban farming communities in western Cote d'Ivoire. Tropical Medicine and International Health, 12(6), pp.709–723.

McNeill, D., 1985. The appraisal of rural water supplies. World Development, 13(10-11), pp.1175–1178.

McNicholl, D., 2011. Accessing handpump spare parts : a study of Northern Malawi. In 35th WEDC International Conference - The Future of Water, Sanitation and Hygiene: Innovation, Adaptation and Engagement in a Changing World. Loughborough: WEDC.

Merchant, A.T. et al, 2003. Water and sanitation associated with improved child growth. European Journal of Clinical Nutrition, 57(12), pp.1562–1568.

Ministry of Energy and Water Resources, 2012. Sierra Leone Waterpoint Report: Review Version,

Moench M (2002) Groundwater and poverty: exploring the connections. Chapter 21 in Llamas M.R and Custodio, E (Eds) Intensive Use of Groundwater: Challenges and Opportunities CRC Press.

Molbak, K., H0jlyng, N. & Gaarslev, K., 1988. High prevalence of campylobacter excretors among Liberian children related to environmental conditions. Epidemiology and Infection, 100(2), pp.227–237.

Mpamba, N.H. et al, 2008. Evidence and implications of groundwater mining in the Lusaka urban aquifers. Physics and Chemistry of the Earth, 33(8-13), pp.648–654.

Msilimba, G. & Wanda, E.M.M., 2013. Microbial and geochemical quality of shallow well water in high-density areas in Mzuzu City in Malawi. Physics and Chemistry of the Earth, 66, pp.173–180.

Msonda, K.W.M., Masamba, W.R.L. & Fabiano, E., 2007. A study of fluoride groundwater occurrence in Nathenje, Lilongwe, Malawi. Physics and Chemistry of the Earth, 32(15-18), pp.1178–1184.

Mu, X., Whittington, D. & Briscoe, J., 1990. Modeling village water demand behavior: A discrete choice approach. Water Resources Research, 26(4), pp.521–529.

Mudzingwa, A.R., Nyakutsikwa, B.F. & Ngogodo, K.C., 2016. Replacing Type " B " Bush Pumps With Solar Powered Pumps For Rural Water Supply. In 7th Forum of the Rural Water Supply Network. Rural Water Supply Network.

Naiga, R. & Penker, M., 2014. Determinants of Users' Willingness to Contribute to Safe Water Provision in Rural Uganda. Lex Localis - Journal of Local Self-Government, 12(3), pp.695–714.

Namara, R. et al, 2011. Smallholder Shallow Groundwater Irrigation Development in the Upper East Region of Ghana. IWMI, Colombo.

Namara, R.E. et al, 2013. Small pumps and poor farmers in Sub-Saharan Africa: an assessment of current extent of use and poverty outreach. Water International, 38(6), pp.827–839.

Namara, R.E. et al, 2014. Adoption patterns and constraints pertaining to small-scale water lifting technologies in Ghana. Agricultural Water Management, 131, pp.194–203.

Nauges, C. & Strand, J., 2013. Water hauling and girls' school attendance: Some new evidence from Ghana. Environmental and Resource Economics, 66(1), pp.65–88.

Nworie O, Nya O, Anyim C, Okoli C, Okonkwo E. Prevalence of urinary schistosomiasis among primary school children in Afikpo North Local government area of Ebonyi State. Ann Biol Res. 2012;3(8):3894-3897.

Nwuba, R. & Philips, A., 2015. Assessment of Hydrological Properties and Proximate Impact of Septic Tank Leachate on Well-water Quality in Two Residential Areas in Ibadan, South-western Nigera. British Journal of Applied Science & Technology, 10(6), pp.1–18.

Okotto-Okotto, J. et al, 2015. A Longitudinal Study of Long-Term Change in Contamination Hazards and Shallow Well Quality in Two Neighbourhoods of Kisumu, Kenya. International Journal of Environmental Research and Public Health, 12(4), pp.4275–4291.

Okotto, L. et al, 2015. Socio-economic aspects of domestic groundwater consumption, vending and use in Kisumu, Kenya. Applied Geography, 58, pp.189–197.

Opisa, S. et al, 2012. Faecal contamination of public water sources in informal settlements of Kisumu City, western Kenya. Water Science and Technology, 66(12), pp.2674–2681.

Ostrom E (2009) A general framework for analysing sustainability of social-ecological systems. Science, 325, 419-422 http://dx.doi.org/10.1126/science.1172133

Ouedraogo, I. & Vanclooster, M., 2016. A meta-analysis and statistical modelling of nitrates in groundwater at the African scale. Hydrology and Earth System Sciences, 20(6), pp.2353–2381.

Ouedraogo, I., Defourny, P. & Vanclooster, M., 2016. Mapping the groundwater vulnerability for pollution at the pan African scale. Science of The Total Environment, 544, pp.939–953.

Overbo, A. et al, 2016. On-plot drinking water supplies and health: A systematic review. International Journal of Hygiene and Environmental Health, 219(4-5), pp.317–330.

Owusu, V. et al, 2016. The economics of small-scale private pump irrigation and agricultural productivity in Ghana. The Journal of Developing Areas, 50(1), pp.289–304.

Paul, B.K., 1993. Maternal mortality in Africa. Social Science & Medicine, 37, pp.745–752.

Pavelic, P. et al, 2013. Smallholder groundwater irrigation in Sub-Saharan Africa: country-level estimates of development potential Water International, 38(4), pp.392–407.

Pearson, A.L. et al, 2016. Seasonal Shifts in Primary Water Source Type: A Comparison of Largely Pastoral Communities in Uganda and Tanzania. International Journal of Environmental Research and Public Health, 13(2), p.169.

Pickering, A.J. & Davis, J., 2012. Freshwater Availability and Water Fetching Distance Affect Child Health in Sub-Saharan Africa. Environmental Science & Technology, 46(4), pp.2391–2397.

Pickering, A.J. et al, 2015. Effect of a community-led sanitation intervention on child diarrhoea and child growth in rural Mali: A cluster-randomised controlled trial The Lancet Global Health, 3(11), pp.e701–e711.

Pullan, R.L. et al, 2014. Geographical Inequalities in Use of Improved Drinking Water Supply and Sanitation across Sub-Saharan Africa: Mapping and Spatial Analysis of Cross-sectional Survey Data. PLOS MEDICINE, 11(4).

Quicke E, Sillah A, Last A, et al. Follicular trachoma and trichiasis prevalence in an urban community in The Gambia , West Africa : is there a need to include urban areas in national trachoma surveillance ? Trop Med Int Heal. 2013;18(11):1344-1352. doi:10.1111/tmi.12182.

Rango, T. et al, 2012. Groundwater quality and its health impact: An assessment of dental fluorosis in rural inhabitants of the Main Ethiopian Rift. Environment International, 43, pp.37–47.

Rango, T. et al, 2014. Fluoride exposure from groundwater as reflected by urinary fluoride and children's dental fluorosis in the Main Ethiopian Rift Valley. Science of the Total Environment, 496, pp.188–197.

Reuben RC, Tanimu H, Musa JA. Epidemiology of Urinary Schistosomiasis Among Secondary School Students in Lafia, Nasarawa State, Nigeria. J Biol Agric Healthc. 2011;3(2):73-82.

Rieger K, Holm R H, Sheridan H (2016) Access to groundwater and link to the impact on quality of life: A look at the past, present and future public health needs in Mzimba District, Malawi. Groundwater for Sustainable Development 2-3 (2016) 117–129 http://dx.doi.org/10.1016/j.gsd.2016.07.002

Robson, E. et al, 2013. Heavy loads: children's burdens of water carrying in Malawi. Waterlines, 32(1), pp.23–35.

Rudge, L. & Bosc, E., 2011. Sustainability factors for water points in Liberia. In 34th WEDC International Conference, Water, Sanitation and Hygiene: Sustainable Development and Multisectoral Approaches. Addis Ababa: WEDC.

Rukure, G; Mtepo, S. Mukandi, C., 1993. Water quality in family wells. In 19th WEDC Conference: Water, Sanitation, Environment and Development. Accra: WEDC.

Rural Water Supply Network, 2009. Handpump Data, Selected Countries in Sub-Saharan Africa, St. Gallen.

Rutstein S O, Johnson K (2004). The DHS Wealth Index. DHS Comparative Reports No. 6. Calverton, Maryland: Orco Macro. Available online: http://dhsprogram.com/pubs/pdf/CR6/CR6.pdf

Salihu, H.D. & Jimada, A.M., 2016. Groundwater quality in shallow unconfined sedimentary aquifers in Bida, Nigeria. In 39th WEDC International Conference, Kumasi. WEDC, pp. 1–6.

Sansom, K. & Koestler, L., 2009. African Handpump Market Mapping Study: Summary Report for UNICEF WASH Section and Supply Division., New York.

Sappa, G. et al, 2015. Effects of seasonal change and seawater intrusion on water quality for drinking and irrigation purposes, in coastal aquifers of Dar es Salaam, Tanzania. Journal of African Earth Sciences, 105, pp.64–84.

Schémann J, Guinot C, Traore L, et al. Longitudinal evaluation of three azithromycin distribution strategies for treatment of trachoma in a sub-Saharan African country , Mali. 2007;101:40-53. doi:10.1016/j.actatropica.2006.12.003.

Schmidlin, T. et al, 2013. Effects of hygiene and defecation behavior on helminths and intestinal protozoa infections in Taabo, Côte d'Ivoire. PloS ONE, 8(6), p.e65722.

Sclar, G.D. et al, 2016. Assessing the impact of sanitation on indicators of fecal exposure along principal transmission pathways: A systematic review. International Journal of Hygiene and Environmental Health, 219(8), pp.709–723.

Shepherd A (2007) Understanding and explaining chronic poverty: an evolving framework for Phase III of CPRC's research. CPRC working Paper 80, Chronic Poverty Research Centre, Overseas Development Institute, London. ISBN: 1-904049-79-6.

Shield et al, 2015. Association of Supply Type with Fecal Contamination of Source Water and Household Stored Drinking Water in Developing Countries: A Bivariate Meta-analysis. Environmental Health Perspectives, 123(12), pp. 1222-1231.

Siebert, S. et al, 2010. Groundwater use for irrigation - A global inventory. Hydrology and Earth System Sciences, 14(10), pp.1863–1880.

Smedley, P.L., 1996. Arsenic in rural groundwater in Ghana. Journal of African Earth Sciences, 22(4), pp.459–470.

Somé, I. et al, 2012. Arsenic levels in tube-wells water, food, residents' urine and the prevalence of skin lesions in Yatenga province, Burkina Faso. Interdisciplinary Toxicology, 5(1), pp.38–41.

Somé, T.I. et al, 2014. A Survey of Arsenic Level in Tube-Wells in Bam Province (Burkina Faso). Journal of Environmental Protection, 05(14), pp.1406–1410.

Sommer, J., Shandra, J. & Restivo, M., 2016. Water, Sanitation, and Health in Sub-Saharan Africa: A Cross-national Analysis of Maternal and Neo-natal Mortality. Human Ecology.

Sorensen, J.P.R. et al, 2015. Emerging contaminants in urban groundwater sources in Africa. Water Research, 72, pp.51–63.

Srikanth, R. et al, 2002. Fluoride in Groundwater in Selected Villages in Eritrea (North East Africa). Environmental Monitoring and Assessment, 75(2), pp.169–177.

Stelmach RD, Clasen T. Household Water Quantity and Health: A Systematic Review. Int J Environ Res Public Health. 2015;12(6):5954-5974. doi:10.3390/ijerph120605954.

Stevenson, E.G.J. et al, 2016. Community Water Improvement, Household Water Insecurity, and Women's Psychological Distress: An Intervention and Control Study in Ethiopia. PloS ONE, 11(4), p.e0153432.

Stocks ME, Ogden S, Haddad D, Addiss DG, McGuire C, Freeman MC. Effect of Water, Sanitation, and Hygiene on the Prevention of Trachoma: A Systematic Review and MetaAnalysis. PLOS Med. 2014;11(2). doi:10.1371/journal.pmed.1001605.

Strunz, E.C. et al, 2014. Water, Sanitation, Hygiene, and Soil-Transmitted Helminth Infection: A Systematic Review and Meta-Analysis. PLoS Medicine, 11(3).

Suich H (2012) Conceptual framework: poverty. Ecosystem services for poverty alleviation (ESPA). Version 1.0, 27th February 2012 http://www.espa.ac.uk/files/espa/ESPA-Poverty-Framework.pdf

Suich H, Howe C, Mace G (2015) Ecosystem services and poverty alleviation: a review of the empirical links. Ecosystem services, 12, 137-147 http://dx.doi.org/10.1016/j.ecoser.2015.02.005

Sutton, S. et al, 2015. Exploring the bottom end of the water ladder. In WEDC, ed. 35th WEDC International Conference, Loughborough.

Tan, K.S. et al, 2013. Access to water, santiation and hygiene: a survey assessment of persons with disabilities in rural Mali. In 36th WEDC International Conference - Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment. Nakuru: WEDC.

Tandia, A.A., Diop, E.S. & Gaye, C.B., 1999. Nitrate groundwater pollution in suburban areas: example of groundwater from Yeumbeul, Senegal Journal of African Earth Sciences, 29(4), pp.809–822.

Taylor, D.L. et al, 2015. The Impact of Water, Sanitation and Hygiene Interventions to Control Cholera: A Systematic Review. PLoS ONE, 10(8).

Tekle-Haimanot, R. et al, 2006. The geographic distribution of fluoride in surface and groundwater in Ethiopia with an emphasis on the Rift Valley. Science of the Total Environment, 367(1), pp.182–190.

Thompson, J. et al, 2000. Waiting at the tap: changes in urban water use in East Africa over three decades. Environment and Urbanization, 12(2), pp.37–52.

Todd D K (1959) Ground water hydrology. John Wiley and Sons Inc.

Tole, M., 1997. Pollution of groundwater in the coastal Kwale District, Kenya. In Sustainability of Water Resources under Increasing Uncertainty: Proceedings of the Rabat Symposium. Rabat: IAHS.

Tonglet, R. et al, 1992. Can improvements in water-supply reduce childhood diarrhoea. Health Policy and Planning, 7(3), pp.260–268.

Trinies, V. et al, 2016. The Impact of a School-Based Water, Sanitation, and Hygiene Program on Absenteeism, Diarrhea, and Respiratory Infection: A Matched-Control Trial in Mali. American Journal of Tropical Medicine and Hygiene, 94(6), pp.1418–1425.

Tucker, J. et al, 2014. Household water use , poverty and seasonality : Wealth effects , labour constraints , and minimal consumption in Ethiopia. Water Resources and Rural Development, 3, pp.27–47.

Urassa, E., Lindmark, G. & Nystrom, L., 1995. Maternal mortality in Dar es Salaam, Tanzania: Socio-economic, obstetric history and accessibility of health care factors. African Journal of Health Sciences, 2(1), pp.242–249.

Van Houweling, E. et al, 2012. The role of productive water use in women's livelihoods: Evidence from rural Senegal Water Alternatives, 5(3), pp.658–677.

Van Houweling, E. et al, 2016. "My Neighbour Drinks Clean Water, While I Continue To Suffer": An Analysis of the Intra-Community Impacts of a Rural Water Supply Project in Mozambique. The Journal of Development Studies, pp.1–16.

Van Koppen, B., Hope, L. & Colenbrander, W., 2013. Gender aspects of smallholder private groundwater irrigation in Ghana and Zambia. Water International, 38(6), pp.840–851.

Verheyen, J. et al, 2009. Detection of Adenoviruses and Rotaviruses in Drinking Water Sources Used In Rural Areas of Benin, West Africa. Applied and Environmental Microbiology, 75(9), pp.2798–2801.

Verweij, P.E. et al, 1991. Hygiene, Skin Infections and Types of Water Supply in Venda, South Africa. Transactions of the Royal Society of Tropical Medicine and Hygiene, 85(5), pp.681–684.

Villholth, K.G. et al, 2013. Smallholder groundwater irrigation in sub-Saharan Africa: an interdisciplinary framework applied to the Usangu plains, Tanzania. Hydrogeology Journal, 21(7), pp.1481–1495.

Villholth, K.G., 2013. Groundwater irrigation for smallholders in Sub-Saharan Africa - a synthesis of current knowledge to guide sustainable outcomes. Water International, 38(4), pp.369–391.

Wang, X. & Hunter, P.R., 2010. Short report: A systematic review and meta-analysis of the association between self-reported diarrheal disease and distance from home to water source. American Journal of Tropical Medicine and Hygiene, 83(3), pp.582–584.

Wanke, H. et al, 2014. Hand dug wells in Namibia: An underestimated water source or a threat to human health? Physics and Chemistry of the Earth, 76-78, pp.104–113.

Waughray, D.K., Lovell, C.J. & Mazhangara, E., 1998. Developing basement aquifers to generate economic benefits: A case study from southeast Zimbabwe. World Development, 26(10), pp.1903–1912.

Whittington, D. et al, 2009. How well is the demand-driven, community management model for rural water supply systems doing? Evidence from Bolivia, Peru and Ghana. Water Policy, 11(6), pp.696–718.

WHO / UNICEF (2015a). Estimates on the use of water sources and sanitation facilities: Country Files. Joint Monitoring Programme for Water Supply and Sanitation. June 2015. WHO/UNICEF. Available online: https://www.wssinfo.org/documents?tx_displaycontroller[type]=country_files

WHO / UNICEF, 2017. JMP Water Supply & Sanitation Data Tables. Available at: https://www.wssinfo.org/data-estimates/tables/ [Accessed March 14, 2017].

WHO / UNICEF, 2017. Safely managed drinking water, Geneva. Available at: https://data.unicef.org/resources/safely-managed-drinking-water/.

Wilbur, J. & Danquah, L., 2015. Undoing inequity: water, sanitation and hygiene programmes that deliver for all in Uganda and Zambia - an early indication of trends. In WEDC, ed. 38th WEDC International Conference - Water, Sanitation and Hygiene Services Beyond 2015: Improving Access and Sustainability. Loughborough: WEDC.

Wolf, J. et al, 2014. Systematic review: Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. Tropical Medicine & International Health, 19(8), pp.928–942.

Xie, H. et al, 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. Agicultural Water Management, 131, pp.183–193.

Yang, H. et al, 2013. Water Safety and Inequality in Access to Drinking-water between Rich and Poor Households. Environmental Science & Technology, 47(3), pp.1222–1230.

Yu, W. et al, 2014. A cross-sectional ecological study of spatial scale and geographic inequality in access to drinkingwater and sanitation. International Journal for Equity in Health, 13.

Zingoni, E. et al, 2005. Effects of a semi-formal urban settlement on groundwater quality Epworth (Zimbabwe): Case study and groundwater quality zoning. Physics and Chemistry of the Earth, 30(11-16), pp.680–688.

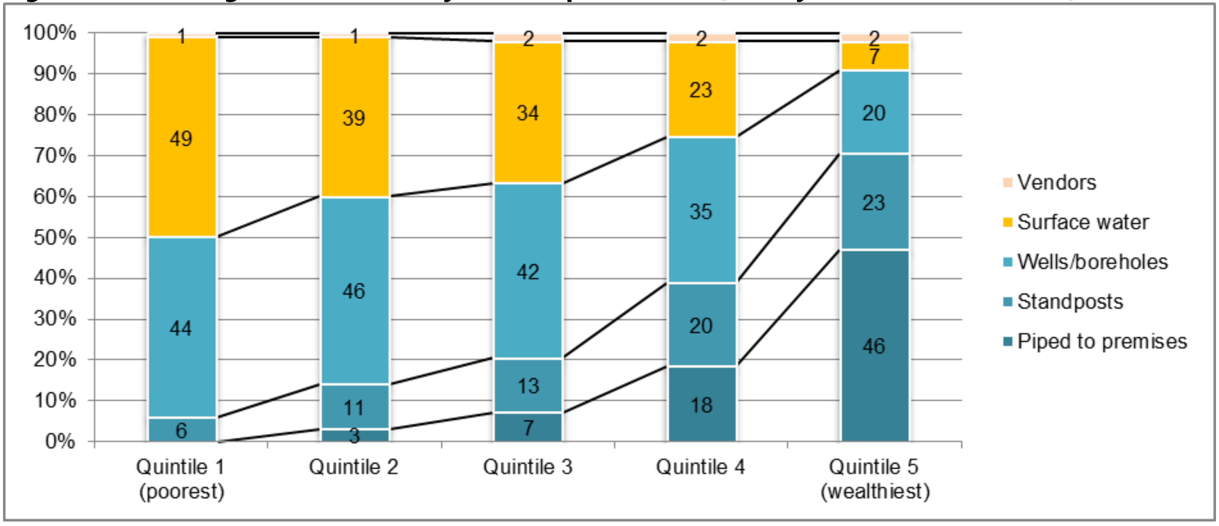
Annex A Literature review: search strategy and supplementary material

A1 SEARCH STRATEGY

Database	Search strategy	Docs found	Docs rev
Web of science	TOPIC: (development* OR poverty OR income OR health OR welfare OR wealth OR poor OR wellbeing OR economic OR livelihood OR "time savings" OR "collection time*" OR "time to collect water" OR "food security" OR education* OR enterprise OR employment OR diarrhoea* OR disease OR infection OR access OR quantity OR availability OR quality OR benefit OR impact OR outcome OR implication OR outcome OR effect OR "water us*" OR demand OR "willingness to pay" OR affordab* OR "ability to pay" OR "population growth" OR urbanisation OR change OR trend) AND TOPIC: (Groundwater OR "Ground water" OR waterpoint OR "water point*" or "hand pump*" OR handpump OR "water supply" OR "water supplies" OR "drinking water" OR "water service*" OR "water source" OR borehole OR "shallow well*" OR "*dug well*" OR "dug well*" OR irrigation OR (spring* AND *water) OR aquifer OR hydrogeolog* OR "submersible pump*" OR "solar pump*" OR "water pump*" OR "bore water" OR "bore well*" OR borewell OR tubewell OR "tube well*" OR "protected well*" OR "unprotected well*" OR "covered well*" OR "uncovered well*" OR "Open well*" OR "Motori?ed pump*" OR "mechani?ed pump*") ANDTOPIC: (Africa* OR "South Africa" OR Nigeria OR Ethiopia OR Kenya OR Mauritius OR DRC OR Congo OR Zaire OR "Cape Verde" OR Madagascar OR Tanzania OR Ghana OR Cameroon OR Seychelles OR Gambia OR Mali OR Zimbabwe OR Senegal OR "Cote d'Ivoire" OR "Ivory Coast" OR Uganda OR Sudan OR Namibia OR Gabon OR Somali OR Mozambique OR Angola OR Eritrea OR Rwanda OR "Burkina Faso" OR "Upper Volta" OR Guinea OR Zambia OR "Guinea Bissau" OR Zambia OR Botswana OR Chad OR "South Sudan" Or Malawi OR Niger OR Mauritania OR Benin OR Djibouti OR Liberia OR Togo OR "Sierra Leone" OR Burundi OR "Central African Republic" OR Swaziland OR Lesotho OR "Equatorial Guinea")	8959	1582
WEDC Conf Papers	Reviewed all titles	2909	175
IWMI Online Library	As per Web of Science search string above	6549	65
World Bank Water online library	Filtered documents by: Africa	1022	61
UNICEF/WHO JMP documents	Browsed all documents in following sections: (i) Update reports, (ii) Snapshots, (iii) Thematic reports, (iv) Water quality docs, (v) Annual reports	87	7
British Geological Survey	Browsed all documents in Africa Groundwater Literature Archive	1527	39
Rural Water Supply Network online library	Filtered documents by: • Sub-Saharan African, AND • Reports/papers OR RWSN publications	183	59

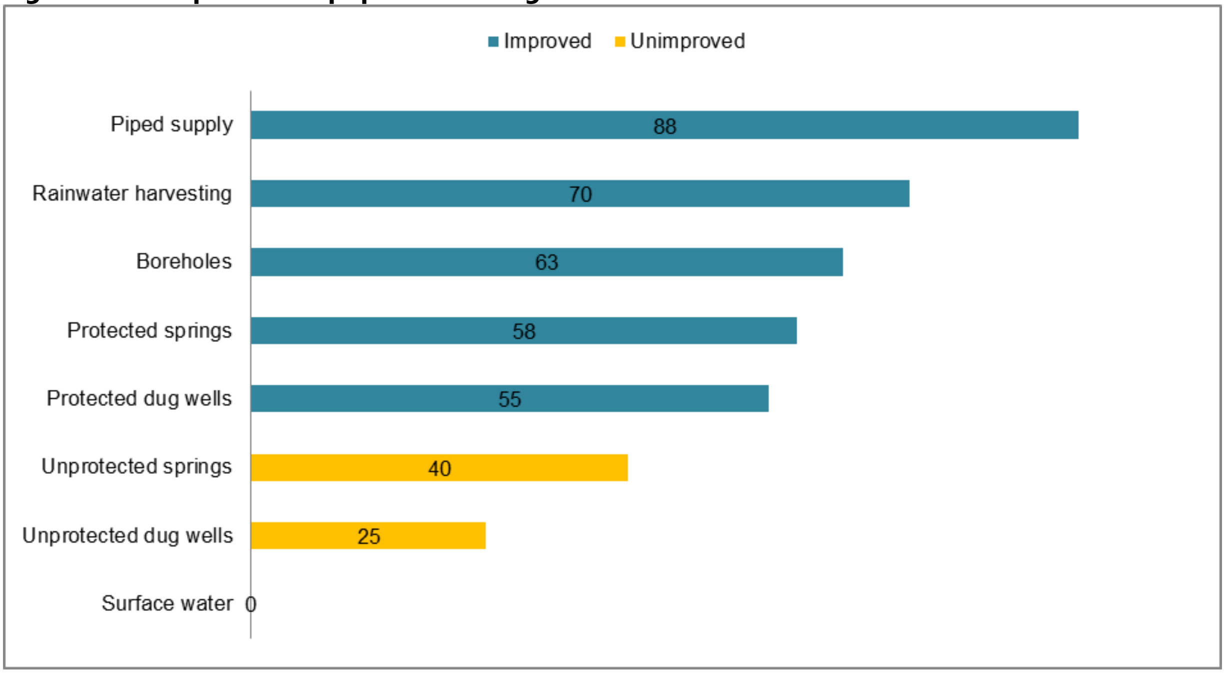
A2 SUPPLEMENTARY CHARTS AND TABLES

Figure A1 Drinking water sources by wealth quintile SSA (Banerjee and Morella, 2011)



Data source: Banerjee & Morella (2011) *Africa's Water and Sanitation Infrastructure: access, affordability and alternatives.* World Bank, Washington DC.

Figure A2 - Proportion of population using water sources free of faecal contamination



Data source: WHO/UNICEF (2017) *Safely managed drinking water*, WHO/UNICEF, Geneva. **(**based on analysis of information in Bain et al. 2014))

Figure A3 GW point sources in SSA (estimated from most recent JMP country data)

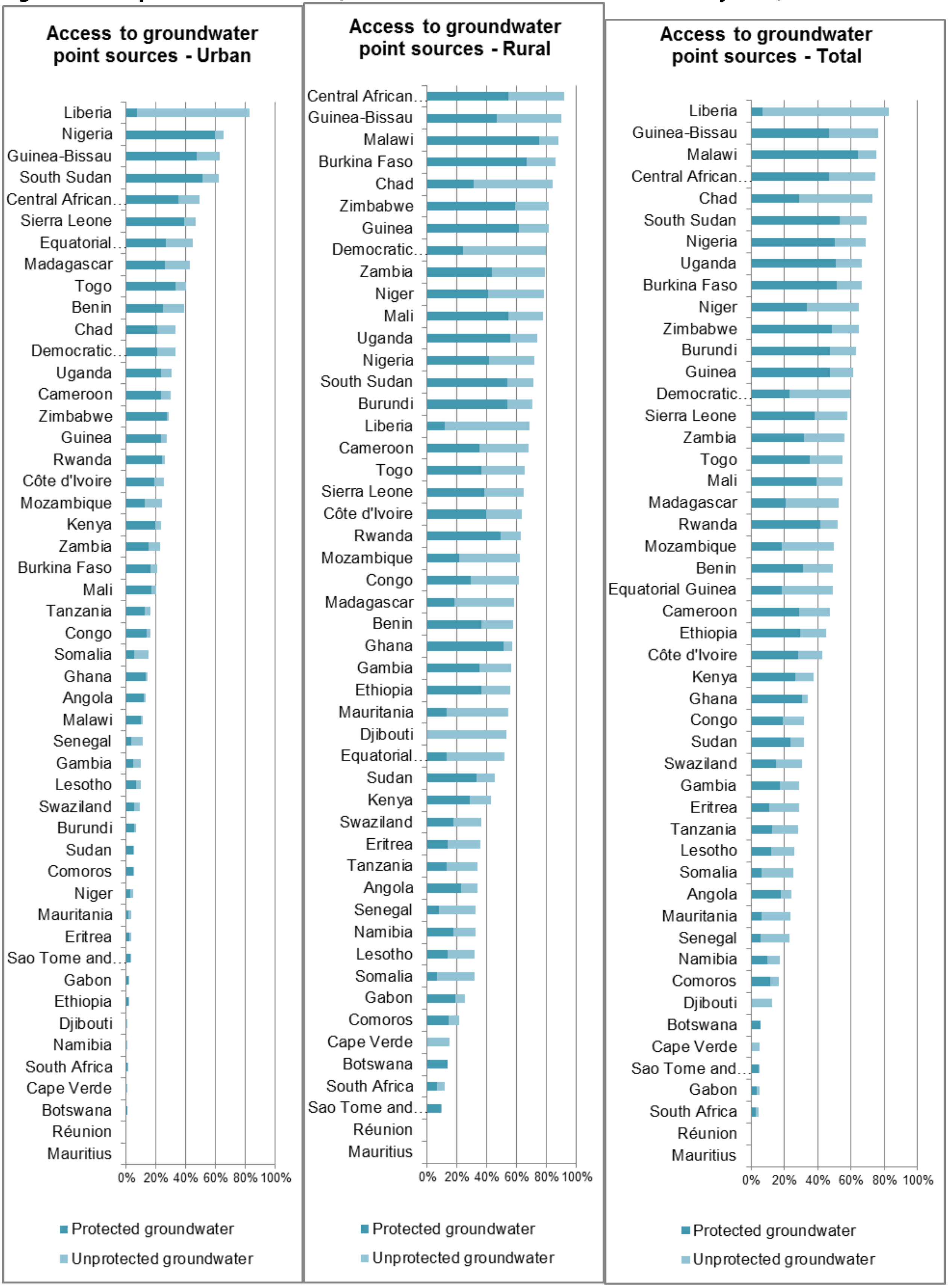
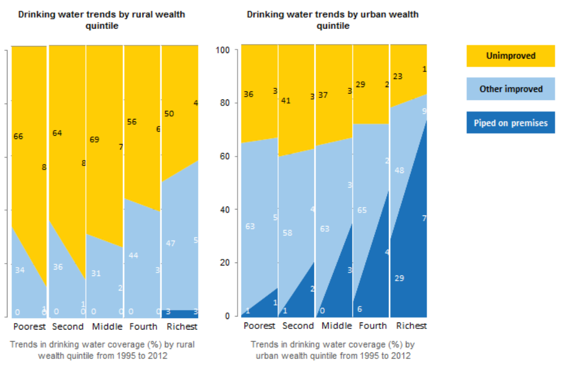


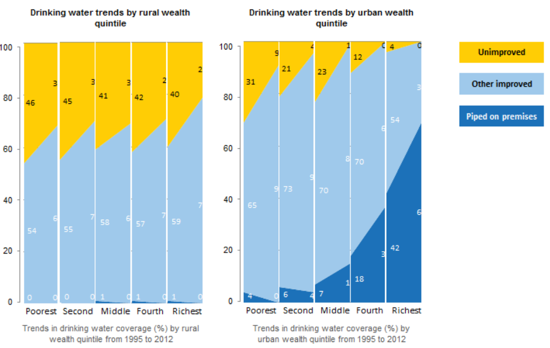
Figure A4 – Improved water access by wealth quintile in urban and rural areas in SSA

[Data available from https://www.wssinfo.org/documents/?tx_displaycontroller[type]=wealth_quintiles

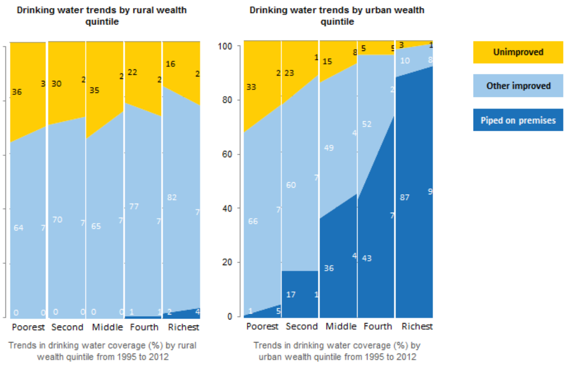
ANGOLA



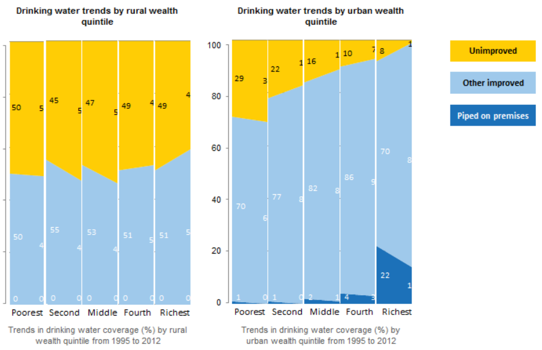
BURKINA FASO



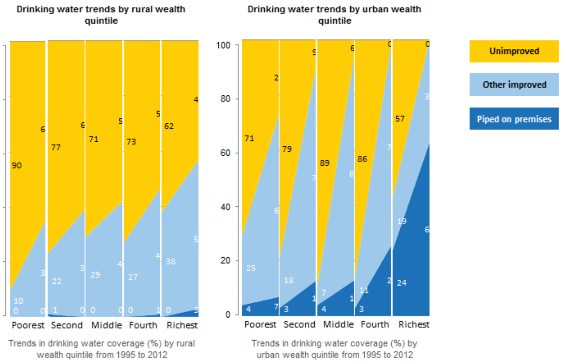
BURUNDI



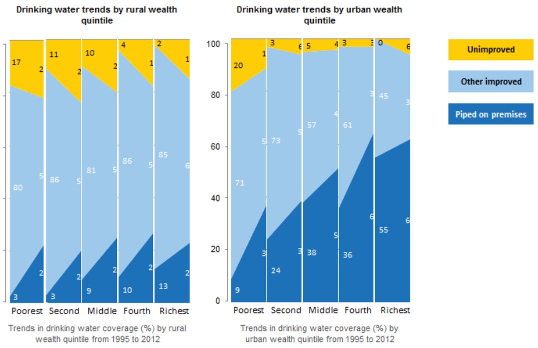
CENTRAL AFRICAN REPUBLIC



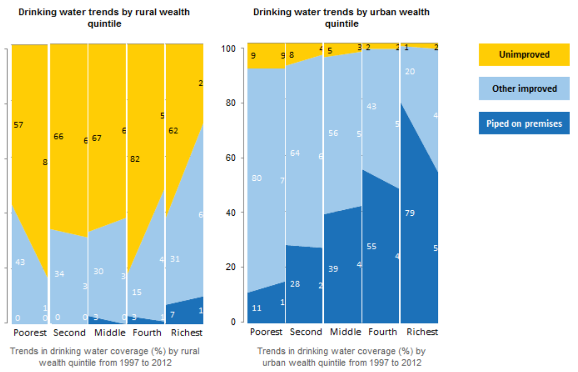
CHAD



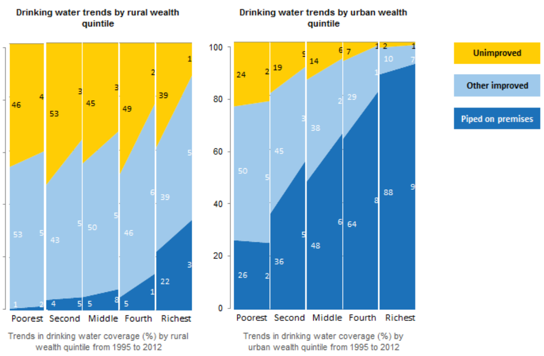
COMOROS



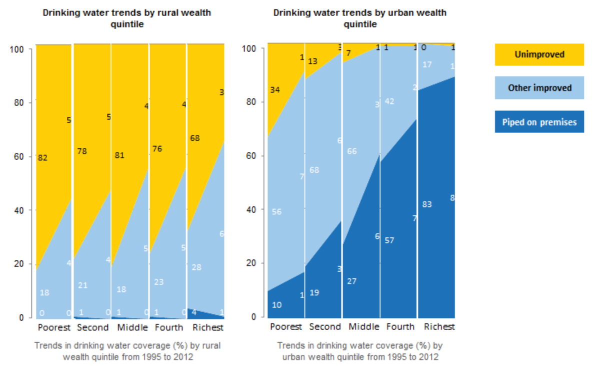
CONGO



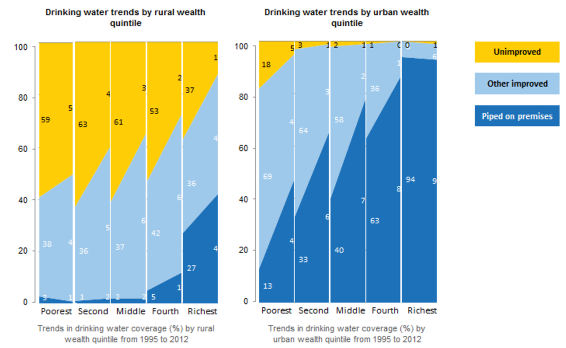
COTE D'IVOIRE



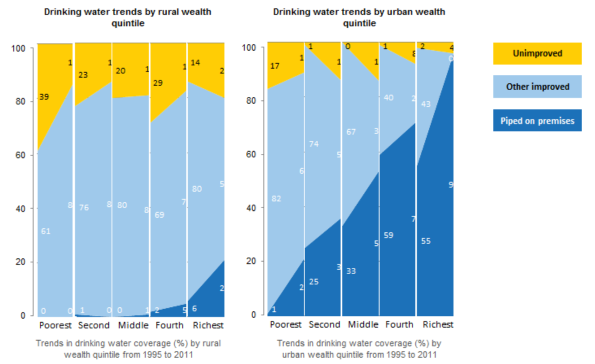
ETHIOPIA



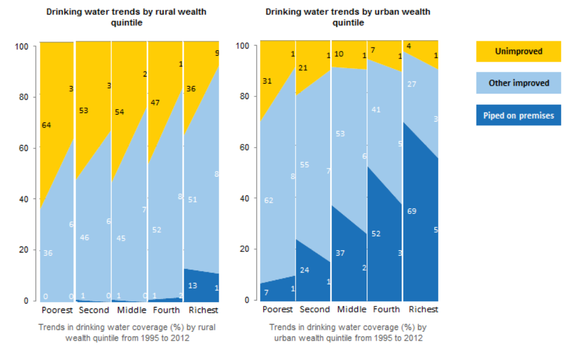
GABON



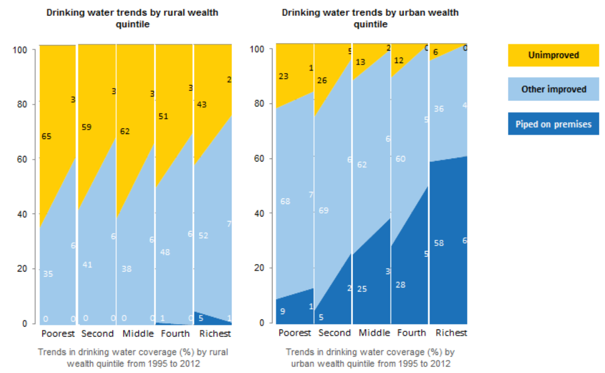
GAMBIA



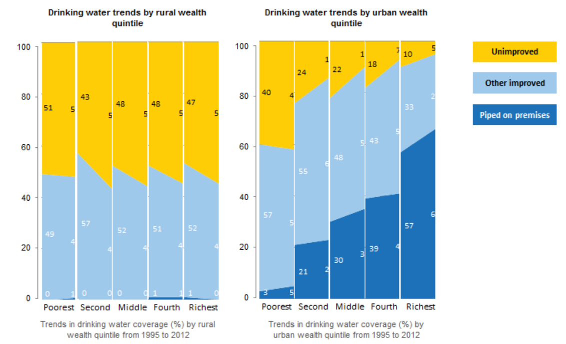
GHANA



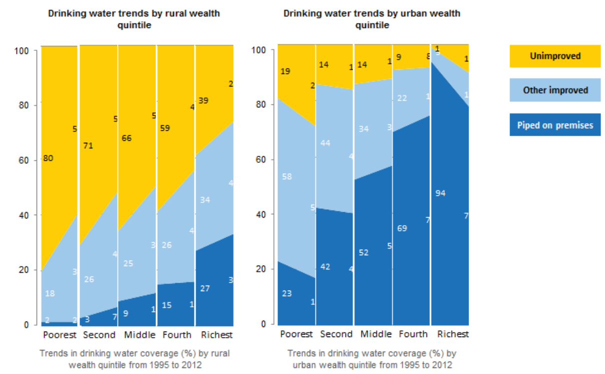
GUINEA



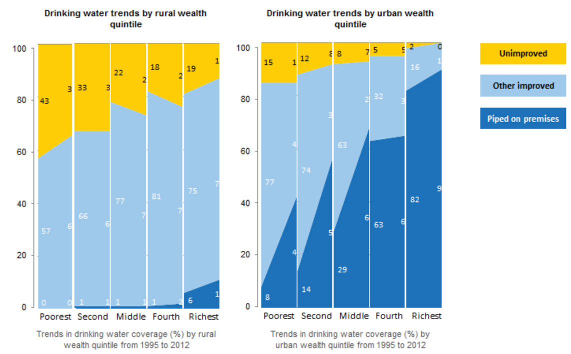
GUINEA-BISSAU



KENYA

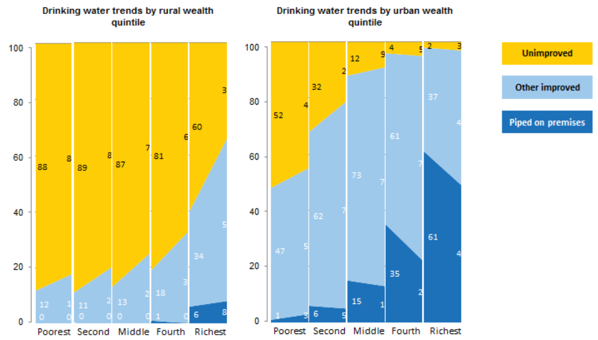


LESOTHO



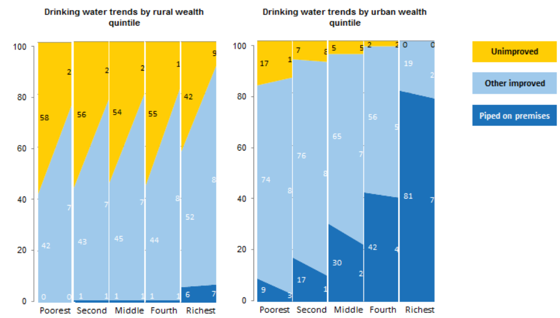
MADAGASCAR

MALAWI



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

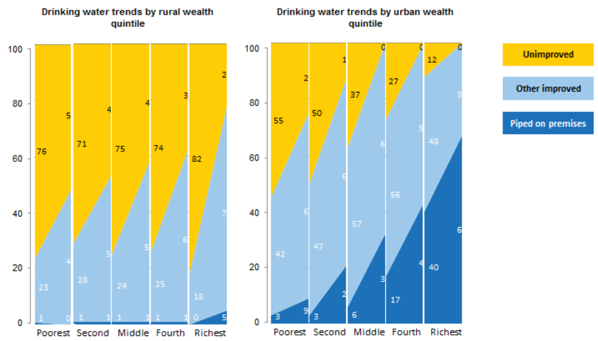
Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

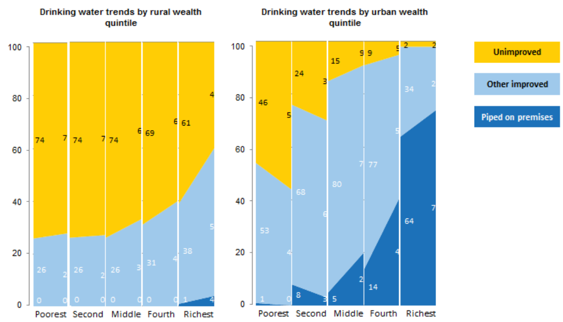
MALI



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

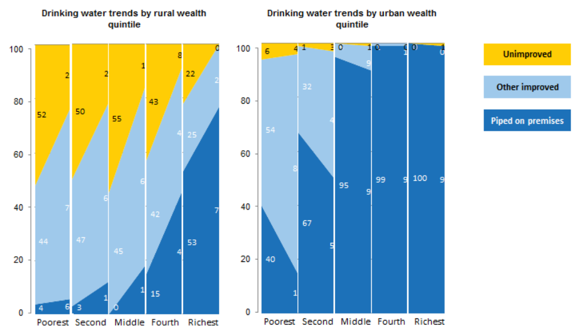
MOZAMBIQUE



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

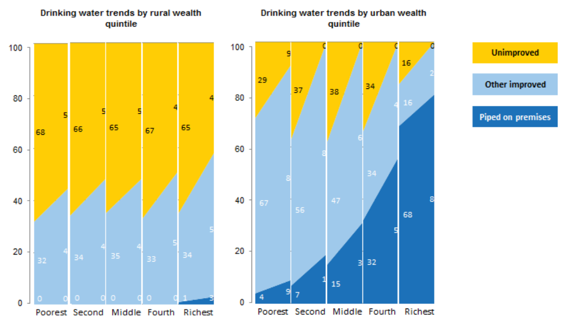
NAMIBIA



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

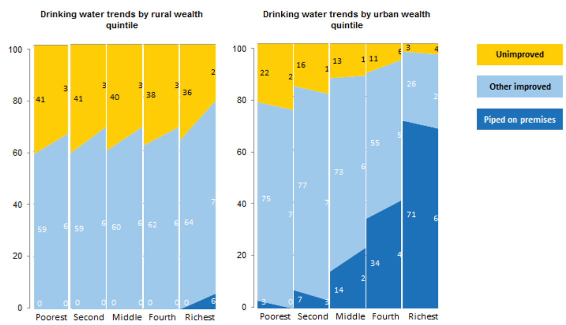
NIGER



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

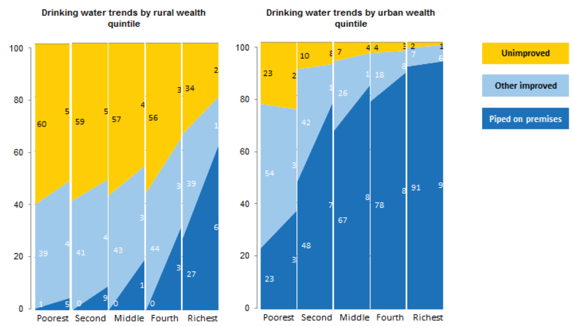
RWANDA



Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

SENEGAL

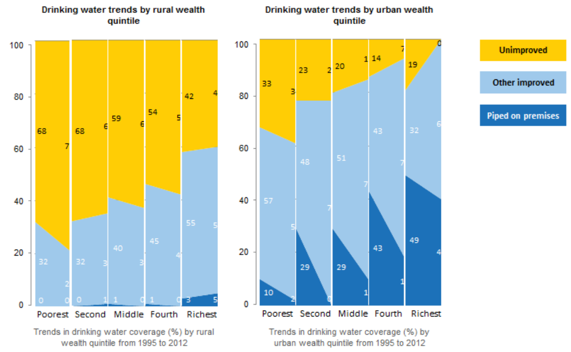


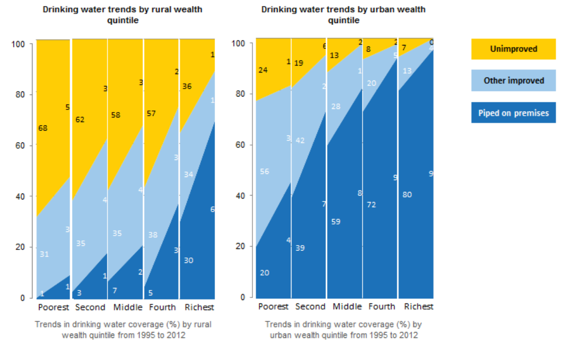
Trends in drinking water coverage (%) by rural wealth quintile from 1995 to 2012

Trends in drinking water coverage (%) by urban wealth quintile from 1995 to 2012

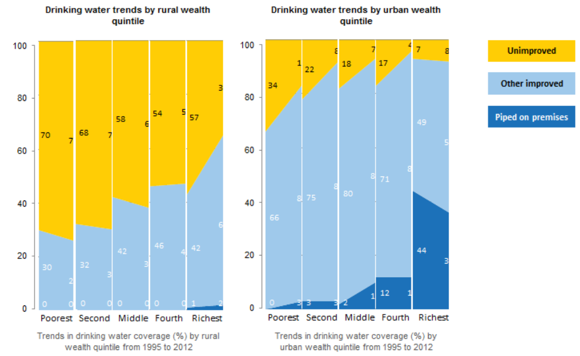
SIERRA LEONE

SWAZILAND

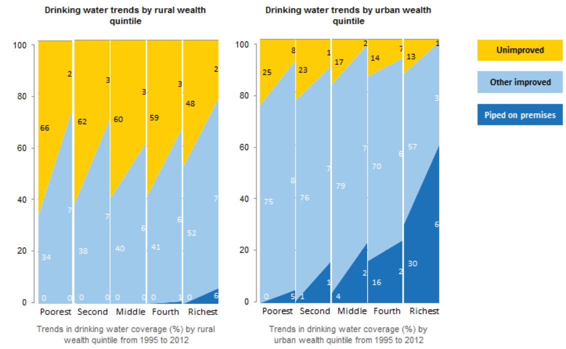




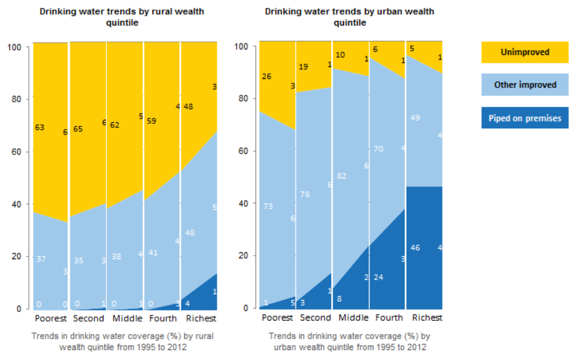
TOGO



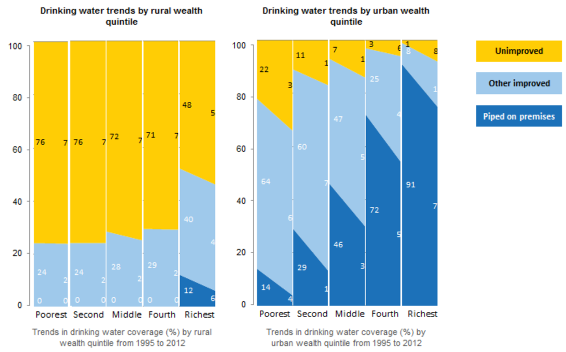
UGANDA



TANZANIA



ZAMBIA



ZIMBABWE

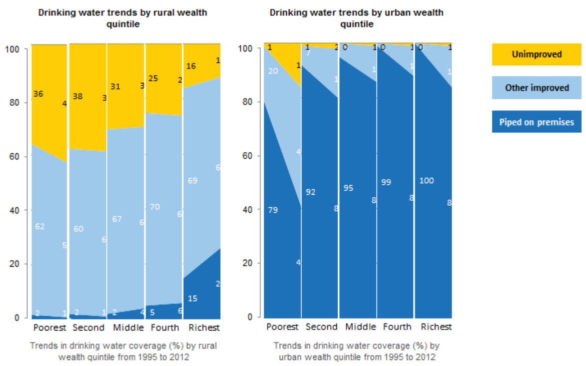


Figure A5 – Access to wells and boreholes by region and wealth quintile in SSA in 2001-5 (Banerjee & Morella, 2011).

(Note – cell colours indicate well/borehole access levels, with greener colours indicating higher levels of access and redder colours indicating lower levels of access)

Country	**Rural**	**Urban**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**
Benin	54	28	50	60	62	44	8
Burkina	79	13	65	83	84	77	19
Cameroon	48	15	47	56	34	20	5
CAR	41	35	31	35	53	43	30
Chad	74	34	52	76	77	85	40
Comoros	55	24	19	50	57	62	46
DRC	8	11	4	13	15	11	4
Congo	25	6	18	27	21	8	2
Ivory Coast	54	20	56	55	64	30	2
Ethiopia	11	2	5	14	12	11	8
Gabon	24	3	22	15	3	1	0
Ghana	57	21	51	56	49	46	8
Guinea	59	30	30	71	67	72	13
Kenya	24	14	12	25	30	26	16
Lesotho	38	10	44	43	32	33	15
Madagascar	22	19	19	18	19	28	25
Malawi	78	24	84	83	77	69	33
Mali	75	37	95	80	62	62	27
Mauritania	68	15	96	45	53	24	6
Mozambique	73	33	68	78	77	60	13
Namibia	47	0	67	52	35	4	0
Niger	87	8	99	95	92	52	20
Nigeria	57	48	59	58	52	48	51
Rwanda	21	18	6	37	18	25	15
Senegal	56	10	77	56	36	8	0
South Africa	9	0	9	7	3	1	0
Sudan	51	36	74	58	41	27	12
Tanzania	48	19	57	54	45	34	15
Togo	45	23	40	51	49	38	15
Uganda	73	35	66	69	72	82	52
Zambia	64	16	69	63	60	36	6
Zimbabwe	76	1	80	68	76	34	1
Resource-rich	57	39	60	58	49	42	37
Middle-income	13	0	13	11	6	2	1
Fragile, low income	42	14	28	35	39	26	6
Non-fragile, low income	43	18	43	47	43	38	17
Overall	**45**	**24**	**44**	**46**	**42**	**35**	**20**

A3 ADDITIONAL HEALTH IMPACTS OF (GROUND)WATER ACCESS

Trachoma. A systematic review by Stelmach and Clasen (2015) concluded that increased water usage for personal hygiene can improve trachoma outcomes. However, a systematic review and meta-analysis by Stocks et al (2014) did not find a significant association between trachoma and whether a water source was within 1 km. Equally, no clear relationship with water source type emerged, though the authors concluded that improved water sources were protective against trachoma. While acknowledging the major methodological limitations, studies specific to SSA provide equivocal support for an association between groundwater access and reduced burden of trachoma. Kalua et al (2010) reported that those using borehole water had significantly lower odds of trachoma, albeit applying univariate analysis. Schemann et al (2007) also found a significant univariate association between trachoma and borehole use in Mali, though the relationship was not significant in the multivariate model. Edwards et al (2012) found no significant association between trachoma and protected groundwater usage (compared with surface water). Golovaty et al (2009) found piped water was significantly associated with piped water (compared with surface water), but no significant difference between piped and spring water. Similarly, in an urban setting Quicke et al (2013) found no significant difference in odds of trachoma for those using open wells and those using tap water. There is mixed evidence of a relationship between distance to a water source and trachoma. Some studies in Africa (which do not stratify by water source) find no significant relationship between distance to water source and trachoma, (Schemann et al, 2007; Quicke et al, 2013) while others do.

Schistosomiasis. A systematic review and meta-analysis by Grimes et al(2014) found a significant relationship between safe water supplies and lower levels of schistosomiasis, with this association evidence for both household-level and communal sources, and for African studies. Among those studies focussing on African settings, several applied a distinction of safe/unsafe or piped/unpiped water sources, and so did not analyse the role of groundwater sources (Abou-Zeid et al, 2012; Fentie et al, 2013; Kabatereine et al, 2011; Knopp et al, 2011; Kubasta, 1964). Another study combined protected groundwater and piped water into one category reported significantly lower odds of schistosomiasis relative to surface water sources (Awoke et al, 2013). Three studies found those using groundwater point sources had significantly lower odds of schistosomiasis than those using surface water (Dawet et al, 2012; Nworie et al, 2012; Howarth et al, 1988), while another study calculated lower but non-significant odds (Reuben et al, 2011). A study by Mahmud et al (2013) found no significant difference in schistosomiasis between those with piped and handpump water.

Annex B Six country regression analyses using DHS data (section 7.1)

	n	m	R^2	Sig (p)
Tapwater				
DRC	6	0.003	0.524	0.104
Ethiopia	7	0.01	0.928	0.000
Kenya	13	0.002	0.137	0.214
Nigeria	14	-0.003	0.547	0.003
Tanzania	8	0.003	0.089	0.473
Uganda	10	0.005	0.681	0.003
Surface water				
DRC	6	-0.009	0.784	0.19
Ethiopia	7	-0.014	0.957	0.000
Kenya	13	-0.007	0.546	0.004
Nigeria	14	-0.012	0.833	0.000
Tanzania	8	0.000	0.005	0.866
Uganda	10	-0.007	0.470	0.029
Unimproved Groundwater				
DRC	6	0.006	0.535	0.098
Ethiopia	7	-0.007	0.099	0.491
Kenya	13	-0.004	0.220	0.106
Nigeria	14	-0.003	0.099	0.272
Tanzania	8	-0.007	0.263	0.194
Uganda	10	-0.015	0.892	0.000
Improved Groundwater				
DRC	6	0.000	0.027	0.758
Ethiopia	7	0.010	0.214	0.296
Kenya	13	0.007	0.491	0.007
Nigeria	14	0.017	0.818	0.000
Tanzania	8	-0.001	0.008	0.838
Uganda	10	0.021	0.862	0.000
Boreholes				
DRC	6	0.000	0.090	0.564
Ethiopia	3	0.001	0.275	0.835
Kenya	10	0.002	0.188	0.211
Nigeria	9	0.014	0.856	0.000
Tanzania	4	0.006	0.288	0.463
Uganda	8	0.015	0.951	0.000
Protected Traditional Wells				
DRC	5	0.001	0.695	0.079
Ethiopia	4	0.008	0.816	0.097
Kenya	10	0.000	0.010	0.780
Nigeria	12	0.001	0.022	0.649
Tanzania	8	-0.003	0.228	0.232
Uganda	6	-0.001	0.002	0.926
Protected Springs				
DRC	5	-0.001	0.290	0.349
Ethiopia	5	0.005	0.037	0.756
Kenya	7	0.002	0.676	0.023
Nigeria	8	0.000	0.241	0.216
Tanzania	6	-0.001	0.019	0.796
Uganda	4	0.004	0.617	0.215

n = number of data points in analysis

m = regression slope, i.e. predicted annual change in access, 0.01=1%

R^2 = variation in access explained by regression slope
Sig (p) = statistical significance of regression

Annex C Rwanda panel survey statistical analysis (section 7.2)

C1 VARIABLES USED IN THE ANALYSIS

POV: Dummy variable, with value 0 if the household is living in poverty and 1 if the household is not living in poverty. The poverty line used is the Rwandan national poverty line at 159 375 RWF per adult equivalent per year in January 2014 prices[xliv].
DIST: The distance in meters between the household dwelling and the main source of water used for the household.
WATER_EXP: The amount paid to buy water from a private water vendor or a neighbor during the last 7 days.
MAINT: The amount of money spent by the household to contribute to water source maintenance during the last month.
IMPROVED_WAT: Dummy variable with value 1 if the main source of water used for the households comes from an improved water source and with value 0 if is not the main source of water.
PROTECT_SPRING: Dummy variable with value 1 if the main source of water used for the households comes from a protected spring and with value 0 if is not the main source of water.
UNPROTECT_SPRING: Dummy variable with value 1 if the main source of water used for the households comes from an unprotected spring and with value 0 if is not the main source of water.
PUBLIC_STANDPIPE: Dummy variable with value 1 if the main source of water used for the households comes from a public standpipe and with value 0 if is not the main source of water.
SURFACE_WATER: Dummy variable with value 1 if the main source of water used for the households comes from a surface water and with value 0 if is not the main source of water.
Note that the dummy variables PROTECT_SPRING, UNPROTECT_SPRING, PUBLIC_STANDPIPE and SURFACE_WATER are all mutually exclusive subcategories of IMPROVED_WAT, and are hence collinear.

C2 SUMMARY STATISTICS

Variable	Mean	Std. Dev.	Min	Max
POV (EICV3)	0.3883615	0.4874781	0	1
POV (EICV4)	0.2942633	0.455805	0	1
MAINT (EICV3)	28.27757	312.7688	0	10000
MAINT (EICV4)	33.34889	217.6591	0	5000
IMPROVED (EICV3)	0.751135	0.4324447	0	1
IMPROVED (EICV4)	0.751135	0.4324447	0	1
DIST (EICV3)	546.161	623.5435	0	9999
DIST (EICV4)	756.331	1039.903	0	9000
WATER_EXP (EICV3)	96.17623	287.9975	0	3500
WATER_EXP (EICV4)	120.097	458.9393	0	14000
PROTECT_SPRING (EICV3)	0.3508048	0.4773205	0	1
PROTECT_SPRING (EICV4)	0.334709	0.4719861	0	1

C3 RESULTS OF THE REGRESSION ANALYSIS

Dependent variable: Poverty (Non-poor = 0; Poor = 1)				**Note**
	OLS	**RE**	**FE**[xlv]	
Intercept	0.51 ***	0.51***		The coefficient reveals the impact of a variable (or characteristic), that is how the probability of being poor increases when we change that variable (or characteristic). The sign of the coefficient describe how the variables evolves along with poverty: a positive [negative] sign is associated with a higher [lower] probability of being poor. The level of the coefficient shows the magnitude of the impact of the variable: the higher the level, the stronger the impact.
	(0.02)	(0.02)		
DIST	-0.00003***	-0.00003**	0.999***	
	(0.00001)	(0.00001)	(0.0002)	
WATER_EXP	-0.0002***	-0.0002***	0.998***	
	(0.00002)	(0.00002)	(0.0006)	
MAINT	0.00	0.00	1	
IMPROVED	-0.15***	-0.14***	1.02	
	(0.02)	(0.02)	(0.36)	
PROTECT_SPRING	0.13***	0.13***	2.97***	
	(0.22)	(0.22)	(1.15)	
R-square	0.07	0.07		
Root MSE	0.47			
Observations	2807	2807	328	

Level of significance : 1% ***, 5%**, 10%*

Endnotes

[i] Groundwater is water which is stored, and which moves, in the saturated zone of the sub-surface. In terms of volume it constitutes more than 9.8% of available fresh water (Fetter, 1994).

[ii] See for example Todd (1959) p5.

[iii] Recharge refers to the periodic replenishment of groundwater, either directly from vertical percolation of rainwater or indirectly from surface water features such as rivers, lakes and wetlands.

[iv] Land use changes may often have greater impacts on the natural water balance than changes in weather and climate – see for example Descroix et al (2009).

[v] This paragraph is a very short summary of Suich (2012).

[vi] The latter is highlighted in particular by Suich et al (2015).

[vii] The extent to which piped water (both private connections and public taps) is supplied by groundwater is unclear

[viii] See http://www.majidata.go.ke/

[ix] Though the relationship may not hold in areas where wealthier households purchase drinking water from vendors (Adank et al, 2016).

[x] By 2015-6, boreholes supplied only 10% of total water abstracted by Tanzanian utilities and authorities.

[xi] https://upgro.org/ ; https://drive.google.com/open?id=0B84D-J6lRlPTc1M1ajJtaWt4QnM; https://braveupgro.org/about/; http://grofutures.org/project/; http://gtr.rcuk.ac.uk/projects?ref=NE%2FL002116%2F1; https://upgro-hidden-crisis.org/

[xii] Hidden Crisis: Frances Cleaver; T-GroUP: Jan Willem Foppen and Maryam Nastar; Gro for GooD: Rob Hope ; BRAVE: - ; GroFutures: Imogen Bellwood-Howard

[xiii] Chambers R. 1983. *Rural Development: putting the last first*. Essex, England: Longmans Scientific and Technical Publishers; New York: John Wiley

[xiv] Financial capital denotes the financial resources that people use to achieve their livelihood objectives. Human capital represents the skills, knowledge, ability to labour and good health that together enable people to pursue different livelihood strategies and achieve their livelihood objective. Social capital represents the social resources upon which people draw in pursuit of their livelihood objectives. Natural capital is the term used for the natural resource stocks from which resource flows and services (e.g. nutrient cycling, erosion protection) useful for livelihoods are derived Physical capital comprises the basic infrastructure and producer goods needed to support livelihoods. http://www.eldis.org/vfile/upload/1/document/0901/section2.pdf

[xv] 'Other' refers to water from bottles, vendors with small tanks, tanker trucks, and unnamed sources.

[xvi] Rwanda Vision 2020, Revised 2012, Republic of Rwanda

[xvii] Economic Development and Poverty Reduction Strategy II, 7 Year Government Programme.

[xviii] Water and Sanitation accounts for 10% or 823,215 million RwF. The first four sectors of projected investment were Education (20%), Agriculture (19%), Health (13%) and Transport (11%).

[xix] Water Resources Management sub-sector strategic plan (2011-2015), Ministry of Natural Resources, Republic of Rwanda.

[xx] Water and Sanitation Corporation.

[xxi] The price of water is fixed by the Rwanda Utilities Regulatory Authority (RURA).

[xxii] Who and how to formally request in practice for an improvement of an existing water source or for using a new source is still unclear and needs further research.

[xxiii] Data comes from Department of Civil and Environmental Engineering, College of Science and Technology, University of Rwanda.

[xxiv] We are grateful to NISR for their contribution in sharing the panel dataset.

[xxv] Integrated Household Living Conditions Survey

[xxvi] The Rwandan national poverty and extreme poverty lines lie respectively at RWF159375 and RWF105064 per adult equivalent per year in January 2014 prices. The 2014 average Purchase Power Parity conversion factor for private consumption was RWF264431 per International dollar. In Rwanda, the extreme poverty line is the RWF equivalent of 2500kcal per day. The poverty line is derived from this food poverty line (called extreme poverty line). The median household in terms of food to non-food spending, whose consumption lies in a range of ten percent of the extreme poverty line, allocates 65.9225% of its expenditure on food items. The poverty line is the total expenditure (100%) of this median household.

[xxvii] An "improved" drinking-water source is one that, by the nature of its construction and when properly used, adequately protects the source from outside contamination, particularly faecal matter. Piped water into dwelling, piped water into yard/plot, public tap or standpipe, tubewell or borehole, protected well, protected spring and rainwater are improved sources of drinking water. Unprotected spring, unprotected well, tanker-truck and surface water are unimproved sources of drinking water.

[xxviii] That is, the water purchased from other individuals which are not official water sellers.

[xxix] Note that 1796 households are missing data for water purchased from non-professional water services and 495 households are missing data for distance to the water source.

[xxx] Note that these numbers overestimate the drop in poverty and extreme poverty when we compare it to the full cross section dataset. This comes from the absence of household weights in the panel dataset.

[xxxi] We run the t-test diff=mean(non-poor)–mean(poor). Ho: diff=0 Ha: diff<0 ha:diff>0.

[xxxii] The results are t= 4.1954, Pr(T>t)=0.0000, degrees of freedom=2421

[xxxiii] t= -1.5142, Pr(T<t)=0.0651, degrees of freedom=2421

[xxxiv] t= -4.8730, Pr(T<t)=0.0000, degrees of freedom=2421

[xxxv] t= -2.7270, Pr(T<t)=0.0032, degrees of freedom=2421

[xxxvi] t= -3.5458, Pr(T<t)=0.0002, degrees of freedom=2421

[xxxvii] t= 3.1845, Pr(T>t)=0.0007, degrees of freedom=2421

[xxxviii] t= 10.9329, Pr(T>t)=0.0000, degrees of freedom=2421

[xxxix] t= -2.8068, Pr(T<t)=0.0025, degrees of freedom=2116

[xl] t = 3.5492, Pr(T>t)=0.0002, degrees of freedom=625

[xli] Among the different categories of water sources, piped water, public standpipe, water truck and 'other' may not be fully supplied by groundwater in Rwanda. Surface water and rain water are not groundwater. The remaining categories (borehole, protected well, unprotected well, protected and unprotected spring) are groundwater sources.

[xlii] We estimate the following equation, for household i at time t (t=EICV3, EICV4):

$$POV_{it} = Intercept + \alpha_1\ DIST_{it} + \alpha_2\ WATER\ EXP_{it} + \alpha_3 MAINT_{it} + \alpha_4 IMPROVED_{it} + \alpha_5 PROTECT\ SPRING_{it} + u_{it}$$

Where u is the residual term (RE probit and FE logit are estimated accordingly to their functional form). These equations have also been estimated with the other dummy variables: UNPROTECT_SPRING, PUBLIC_STANDPIPE and SURFACE_WATER. However, these variables were always insignificant and do not significantly, alter the results of the other variables. We hence do not present the results here.

[xliii] As we are interested in individual (household) effects, FE is preferred to RE. In addition, we run the Hausman test to choose between fixed effects versus random effects. We strongly reject the null of a non-systematic difference in coefficients, which clearly suggest a preference for the fixed effects model. We also run a Breusch-Pagan Lagrange Multiplier test to choose between OLS and RE. We reject the null of a zero variance of unobserved fixed effects, which suggests using the RE.

[xliv] Further research should also look extreme poverty as the dependent variable but this is beyond the scope of this study.

[xlv] For the sake of clarity and interpretations coefficients are expressed in odds ratio i.e the odds that the dependent variable occurs, when the independent variables occurs (dummy) or increases (continuous).

Note also that the FE regression model uses only observations changing within households over time. As a result, a significant number of observations is dropped.