Unlocking the Potential of Groundwater for the Poor

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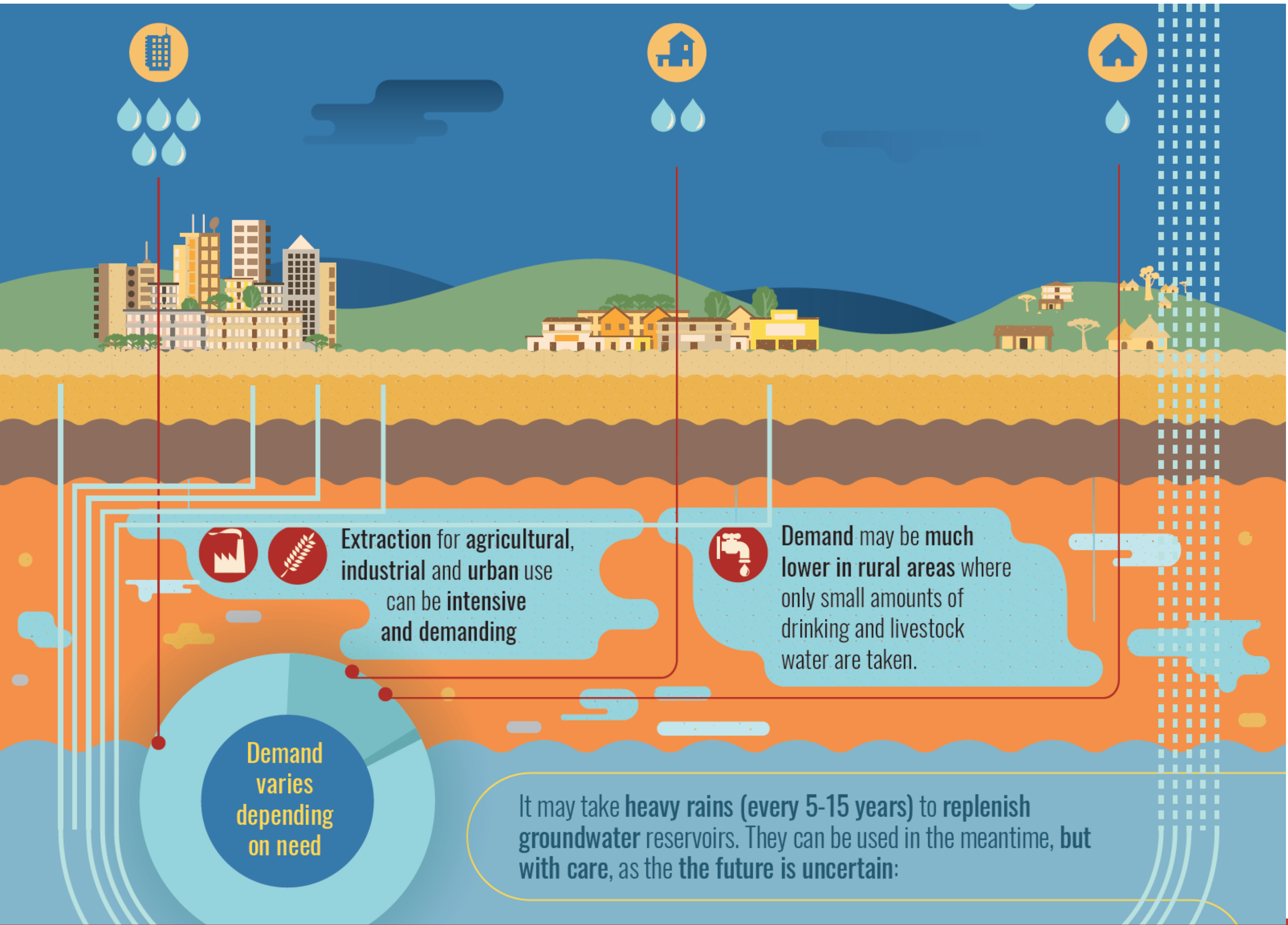

Groundwater's Contribution to Water Security in Africa

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on behalf of the UPGro Programme

UPGro Working Paper
January 2019

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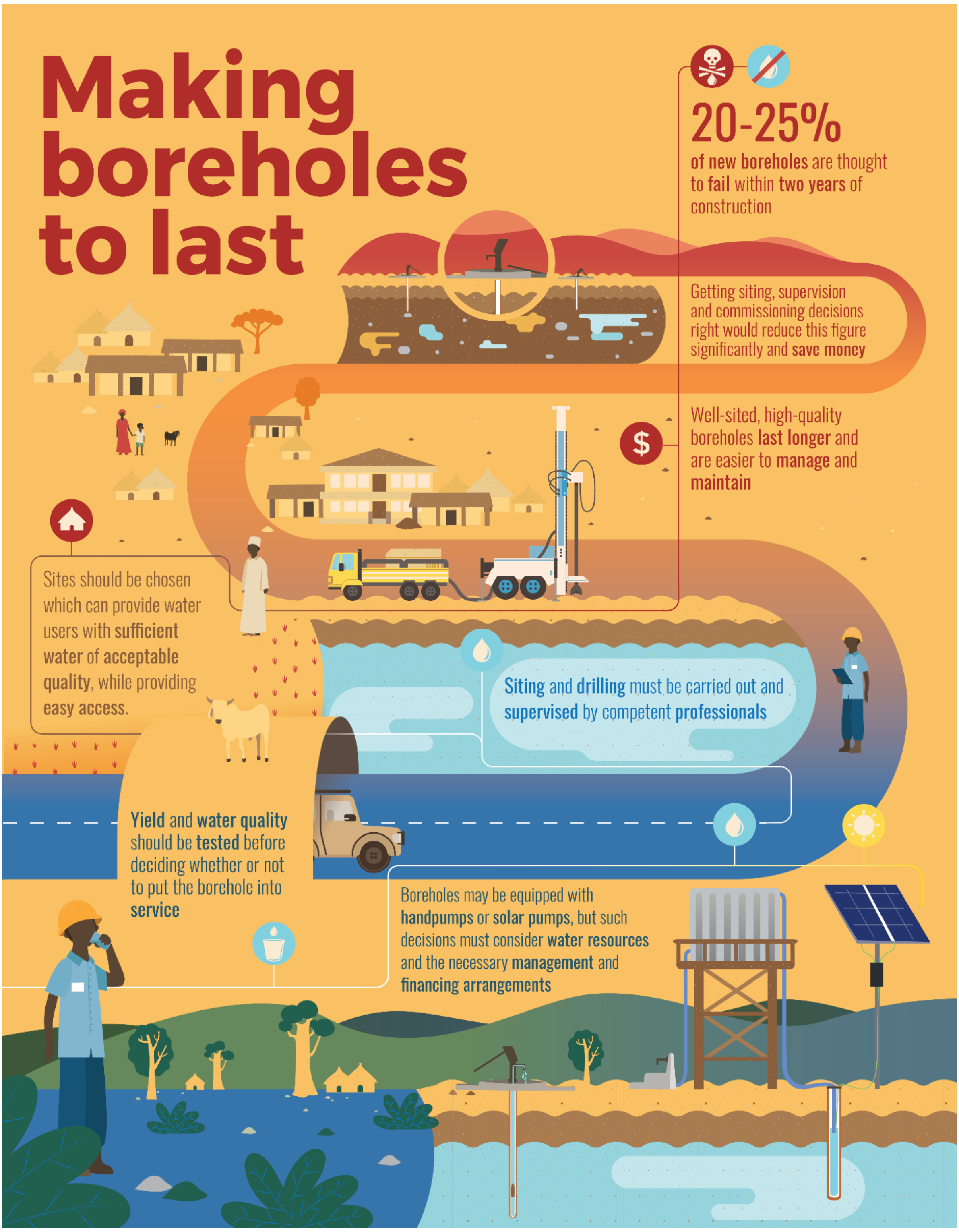


Above "Making boreholes to last"; Cover: extract from "Groundwater in Africa" – full version on back cover. UPGro infographic posters – available to download from https://upgro.org/about/upgro-posters/ (also in French). Designers: Dazzleship, Editor: Prof Richard Carter

Drilling Supervision Training, Sierra Leone (photo: Skat)

PREFACE

Achieving water security for Africa presents a challenge, particularly given the increasing pressures on water resources related to population growth, climate change, rising living standards and land use change. Water security can be defined as the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies (Grey & Sadoff, 2007).

Groundwater – the fresh water naturally stored in rocks beneath the ground surface – makes a significant contribution to the security of water supplies for both domestic and productive uses across the African continent. Its importance and use are increasing markedly.

Groundwater can help achieve universal and equitable access to resilient water services for both rural and urban populations in Africa. With the relevant methods and expertise, groundwater can be found across much of Africa, with even the least productive aquifers often capable of providing sufficient yields to supply communities with handpumps or low-intensity, small-scale irrigation schemes. The volume of water stored underground in Africa – estimated to be 20 times more than the freshwater stored in lakes and reservoirs – can also provide a critical buffer against short-term rainfall variability, making groundwater reserves less vulnerable than surface waters to drought. Groundwater is also less vulnerable to contamination.

The implications of resilient, safe, and sustainable water services for all, where groundwater forms a critical part of an integrated approach to water resource management, are significant and wide-reaching in terms of national growth, economic development and poverty reduction. Groundwater development is not, however, without risks. Securing equitable access to groundwater for both domestic and productive uses across rural and urban Africa requires a detailed understanding of groundwater resources coupled with adequate governance arrangements so that the potential gains of groundwater investment can be balanced against the associated risks for people, the environment, and the economy.

This paper has been prepared by researchers within the UPGro (Unlocking the Potential of Groundwater for the Poor) Programme, along with colleagues from the International Association of Hydrogeologists, Africa Groundwater Network, and GRIPP. It is intended as a working paper, presenting a summary of our current understanding of groundwater in Africa along four themes: (1) urban water security, (2) socially inclusive and sustainable rural water services, (3) groundwater for agricultural growth and transformation, and (4) groundwater resources and renewability.

CONTENTS

SUMMARY FOR DECISION-MAKERS

Urban water security

- Improve governance capacity and enforcement procedures to reduce damaging behaviour, such as uncontrolled drilling and abstraction and discharge of industrial or agricultural pollutants to groundwater, and/or incentivise good practice
- Improve collaboration between regulators, utilities, and private developers to integrate utility and private investments in piped and non-piped water supply within the urban planning process
- Establish low-income ('pro-poor') policy and technical units in water utilities or work with knowledge centres to support alternative water-supply provision (e.g. provide advisory services for private groundwater supplies)
- Improve collection of data on long-term groundwater use (including private groundwater sources), along with groundwater availability and quality
- Strengthen efforts to reduce non-revenue water losses in piped systems
- Introduce zoning and protection of municipal abstraction wells/well fields and improve sanitation systems and waste and waste water handling to reduce groundwater pollution

Socially inclusive and sustainable rural water services

- Maintenance of waterpoints needs a much higher priority and encourage scaling-up of innovative methods to deliver and sustain rapid maintenance.
- Be aware that universal drinking water services may not be compatible with financial sustainability and therefore look for novel models and partnerships to ensure system sustainability with a focus on 'service delivery for all'.
- Scale-up and develop on-going efforts to improve drilling professionalism to the level required through actions that strengthen capacity, improve groundwater data management, enhance project planning and design, and support the institutional framework. Foster dialogue between different stakeholders as well as awareness-raising about drilling professionalism, coupled with targeted investment.
- Investment in research to better understand the impact of groundwater access on poverty to address disparities in service levels and thus support efforts to develop groundwater for the benefit of all.

Groundwater for agricultural growth and transformation

- Plan groundwater irrigation in an integrated way to contribute to more socially and environmentally sustainable agri-food systems and to improve livelihoods across rural Africa. The success and sustainability of groundwater irrigation depends not only on the availability of groundwater, but on a combination of other policies, skills, investment and infrastructure factors. Groundwater irrigation has expanded most where enabling factors coincide – often in close proximity to urban areas or major transport corridors.
- Invest in developing a sound understanding of groundwater availability, across short and long time-scales, will be key for sustainable groundwater irrigation. Groundwater availability is dependent on a number of interacting factors which are often poorly understood at the local scale. In particular, while mechanised pumping has the potential (compared to handpumps or other water sources) to increase the resilience of farmers against weather related shocks, a good understanding and monitoring of local aquifers is critical, otherwise wells and boreholes could dry out without warning, leading to conflict between farmers (and other water users).
- Equitable access to technology and resources can create jobs in rural communities, improving household livelihoods and contributing to poverty reduction. However, further research is required to highlight and better understand issues of inequity regarding access to and control of finance and technology by smallholder farmers compared to larger, more intensive farmers.
- Make use of radio – it is one of the most important and cost-effective sources of information for the majority of rural farmers in Africa. Useful and entertaining radio programmes, combined with farmer listening groups, are an effective way of improving

farmer resilience in five key areas: groundwater access and water harvesting, crop yields, sustainable land management practices, health and nutrition, and prevention and treatment of water-related diseases.

Groundwater Renewability - Impacts of Climate and Land-use Change

Evidence is growing that rainfall patterns across West and East Africa are changing, with later rainy seasons, fewer rainfall days but higher rainfall intensity. Equally, our improved understanding of aquifer recharge suggests that groundwater levels respond to more intense rainfall. Therefore, aquifers will become an increasingly important buffer against a more challenging climate.

To respond to this, invest in and support monitoring land use changes, groundwater abstraction, and groundwater response to recharge and storage in order to:

- Better understand the localized and regional impacts of land use, and in particular different types of crop land, on groundwater recharge so as to inform adaptation strategies;
- Inform strategies for climate adaptation, particularly at the community or farm level;
- Reduce the uncertainty in quantifying potential future changes in groundwater recharge and storage.

Groundwater Resources of Africa

- Mapping and monitoring groundwater resources is expensive and time-consuming but are essential to revealing and understanding groundwater resources. Invest in some long-term monitoring in strategic locations to track trends and responses to weather events and pumping. Invest in targeted mapping and monitoring to support decision-making.
- Quality control and sharing of data, studies and mapping is essential and the Africa Groundwater Atlas provides an international sharing platform, but each country needs to have well resourced (hydro)geological agency for data management and publishing.

THE UPGRO PROGRAMME

UPGro (Unlocking the Potential of Groundwater for the Poor) is a seven-year interdisciplinary research programme (2012-2019), funded by the UK's Department for International Development, Natural Environment Research Council, and Economic and Social Research Council.

Within five research consortia (Box 1), 150 researchers from across sub-Saharan Africa and Europe are working with governments, civil society, NGOs and donors to tackle a range of issues surrounding sustainable groundwater use in the context of economic growth and poverty reduction. Issues include climate resilience, sustainability of urban and rural water supply systems, impacts of groundwater access on livelihoods and health, groundwater irrigation, and groundwater governance.

The five-year consortia phase was preceded by a two-year catalyst phase, consisting of 15 catalyst projects looking at a diverse range of issues including fluoride contamination, development of sensors for identifying micro-biological contamination, enhancing groundwater recharge from road run-off, and small-scale irrigation. In parallel to this research, the Africa Groundwater Atlas – an online resource providing country-level information about groundwater in Africa – has been developed in collaboration with over 50 African hydrogeologists.

Box 1 UPGro Consortia

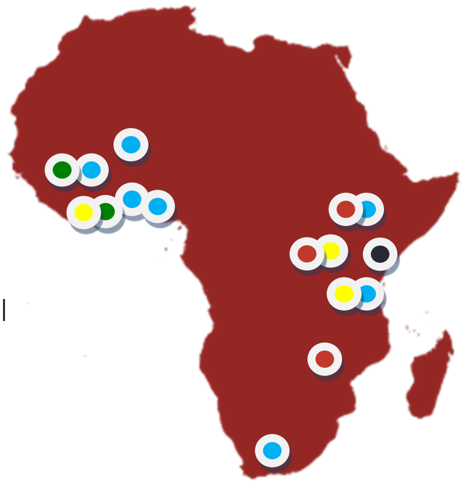
BRAVE
Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa

Gro For GooD
Groundwater Risk Management for Growth and Development

GroFutures
Groundwater Futures in Sub-Saharan Africa

Hidden Crisis
Unravelling current failures for future success in rural groundwater supply

T-GroUP
Experimenting with practical transition groundwater management strategies for the urban poor in Sub-Saharan Africa



WATER FOR NATIONAL GROWTH AND POVERTY REDUCTION

The crucial role of water in achieving socio-economic development on the African continent is widely recognized. The Africa Water Vision for 2025 is for:

An Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation, and the environment.

(United Nations Economic Commission for Africa *et al.*, 2003)

Groundwater often plays a critical, but unrecognised role in providing inexpensive distributed water supplies to both rural and urban populations in Africa. In the context of population growth, rising living standards, and climate and land use change the importance of groundwater, and its ability to provide drought-resilient water services, is increasing markedly. The potential impacts of over-abstraction and pollution could risk the long-term viability of groundwater exploitation with significant environmental, social and economic, as well as political implications.

Water plays a critical role in the national growth, development and poverty reduction strategies of many African nations (Tindimugaya *et al.*, 2018), contributing substantially to three key areas:

- Unlocking growth potential in the productive sectors through employment and revenue, where water forms a major component of agricultural development, and also contributes to improved access to electricity through hydropower and renewables, and to mining, industrial uses, and water transport.
- Social well-being, where improved Water, Sanitation and Hygiene (WASH) supports outcomes in health, education and housing in both urban and rural areas, and where focus is on equitable access and improved institutional accountability and service delivery.
- Governance and human capital, covering a broad range of measures including decentralisation, private sector engagement, and regional integration, where water is part of wider civil service reform, including environmental compliance, regulation and climate adaptation.

Water is the focus of Goal 6 of the Sustainable Development Goals – to ensure availability and sustainable management of water and sanitation for all. Critically, this moves beyond the goal for basic drinking water services to the much more ambitious goal of safely managed services, available on the premises when needed and of sufficient and reliable quality and quantity.

Achieving Goal 6 also underpins progress across the other 16 SDGs (Figure 1) particularly:

- End poverty in all its forms everywhere (Goal 1);
- Sustainable cities and communities (Goal 11) where all have access to basic services, including an adequate, safe and affordable water supply, where resources are used efficiently and environmental impact is minimised, and where communities are resilient to disasters and the impacts of climate change;
- Healthy lives and well-being (Goal 3), where epidemics of water-borne disease are eradicated and the number of deaths and illnesses related to contaminated water are substantially reduced;
- Industry, innovation and infrastructure (Goal 9), which is sustainable and resilient;
- Zero hunger (Goal 2), where water is used sustainably in agriculture to provide year-round food security, income for small-scale farmers, and food production systems that are resilient to climatic extremes and change;
- Responsible consumption and production (Goal 12), where natural resources are used efficiently and the impact of waste on human health and the environment is reduced through improved management;
- Life on land (Goal 15), where terrestrial ecosystems and land, often degraded by desertification, drought or flood, are protected, restored and managed sustainably.

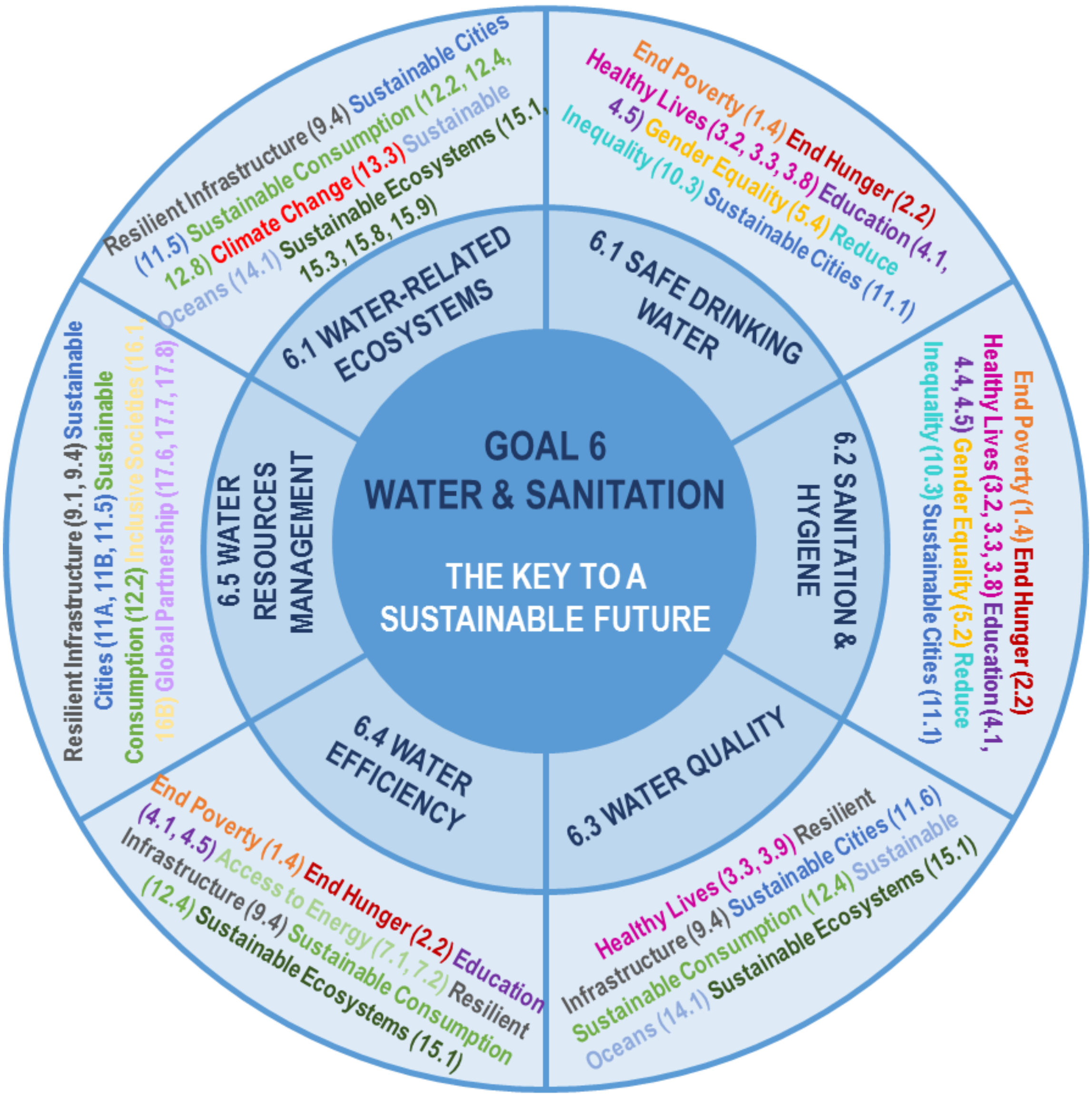
Achieving water security (Box 2) for Africa is a challenge, but is essential if the aims of the Africa Water Vision, national growth, development and poverty reduction strategies, and Sustainable Development Goals are to be met.

In fact, there is already a strong political will to do so through the Sharm El Sheikh commitments, which are backed by a national-level monitoring and evaluation process through the African Union. The strive for water security becomes more critical as we consider future pressures on water resources at both the supply and demand end, particularly related to population, climate, and land use change.

Africa is experiencing the highest rate of population growth of anywhere in the world. By 2050, an estimated 2.4 billion people will live on the African continent, compared to the current population of 1.1 billion (United Nations Department of Economic and Social Affairs Population Division, 2015). The proportion of people living in urban areas is also expected to increase from the current value of 40% to more than 55% in 2050 (United Nations Department of Economic and Social Affairs Population Division, 2018).

This will result in a significant increase in the demand for water and requires employment opportunities as well as resources to ensure continued economic growth, development and social well-being.

Figure 1 Water linkages across the SDGs



Source: Adapted from Unilever & UN Water (2015)

Box 2 Definition of water security

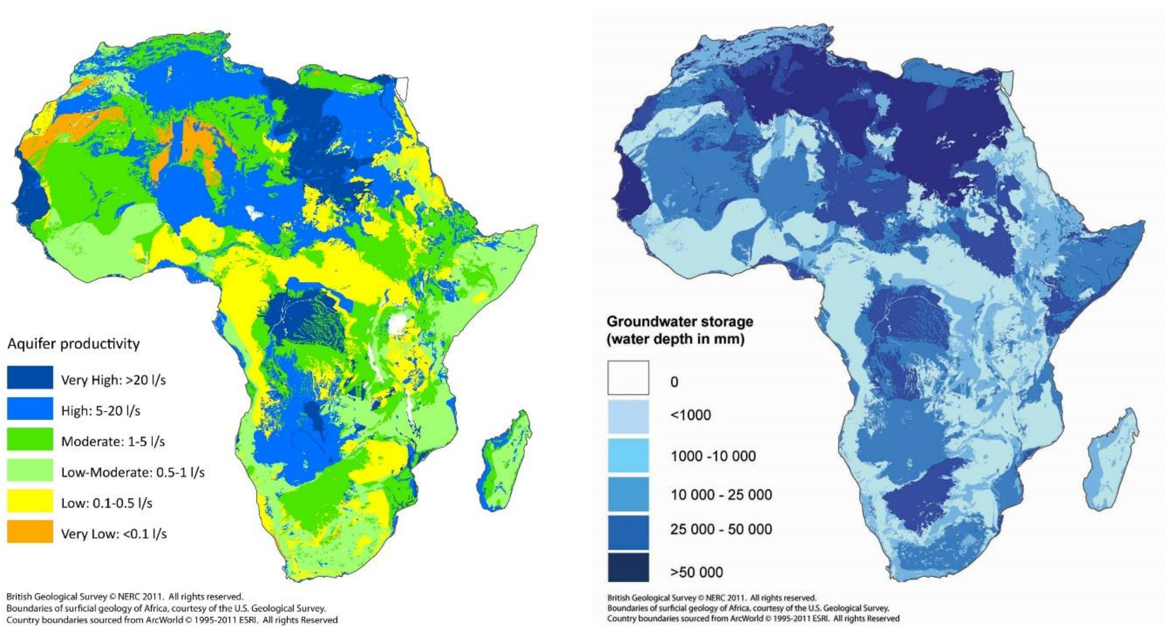
Many definitions for the term 'water security' have been suggested, but most are based on an interaction between the physical and societal aspects of water resources: physical in terms of availability, quality and stresses; societal in terms of the capacity of a population to access water and cope or adapt to change. A widely accepted and cited definition is:
"…the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies." (Grey & Sadoff, 2007)

Groundwater – the fresh water stored in rocks and sediments beneath the ground surface (Section 5: Groundwater Resources of Africa) – makes a significant contribution to the security of domestic, industrial and agricultural water supplies on the continent. However, if groundwater's contribution to economic growth, national development, and poverty reduction is to be realized, significant investment is required to understand groundwater resources at a local, national and transboundary level, to ensure they are developed, exploited and managed sustainably, and to the benefit of all.

Potential gains of groundwater investment for national growth and poverty reduction

Groundwater is widely distributed and can be found, in varying quantities and quality, across much of the African continent (Figure 2). Even the least productive aquifers in Africa, which tend to be where the geology consists of ancient basement rocks with relatively low groundwater availability, are often capable of providing sufficient yields to supply dispersed households or communities with handpumps or low-intensity small-scale irrigation schemes. With appropriately designed, installed and managed infrastructure, groundwater therefore has the potential to make a significant contribution to achieving universal and equitable access to water services for domestic and productive uses, for both rural and urban populations in Africa. Protected boreholes, stand pipes and wells for domestic supply or small-scale irrigation can support water security, helping to overcome the issue of *economic water scarcity (Seckler et al., 1998)* – the notion of water shortage caused by inadequate investment in its development and management – which is prevalent across sub-Saharan Africa.

Figure 2: Maps of aquifer productivity and groundwater storage in Africa (MacDonald *et al.*, 2012)



The volume of water stored underground in Africa is estimated to be more than 0.5 Million km^3 (Figure 2) – more than 20 times greater than the freshwater stored in lakes and reservoirs. Although only a small fraction of this groundwater can be used without environmental damage, this storage can provide a critical buffer against climate variability, making groundwater reserves less vulnerable than surface waters to short-term variability in rainfall.

Further, the shift towards more intensive rainfall events under climate change may actually amplify groundwater recharge (Jasechko & Taylor, 2015). An improved understanding of groundwater renewability allows sustainable abstraction scenarios to be developed as part of an integrated water management approach, increasing the resilience of water supply systems to climate extremes, including drought.

Through the provision of resilient urban and rural water services, groundwater can contribute to meeting Target 6.1 of the SDGs (Box 3) – to achieve universal and equitable access to safe and affordable drinking water for all – with potentially significant positive outcomes for social well-being. Direct causal links between groundwater access and well-being, including health, livelihoods, education and food security, are complex and often not fully understood or addressed.

However, evidence suggests that access to improved groundwater sources can have positive benefits for poor households in both urban and rural contexts. There is a vast body of literature outlining links between water and diarrhoea, with evidence to suggest that improved groundwater access is associated with a lower risk of diarrhoea (Hunter *et al*., 2010; Kremer *et al*., 2011; Cha *et al*., 2015). Similarly, recent studies have shown evidence of links between water access and educational benefits, although the role of groundwater in these outcomes is less clear (Garn *et al*., 2013).

Box 3 SDG water target and what it means for groundwater supplies

Goal 6: Ensure availability and sustainable management of water and sanitation for all

Target 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all

Criteria: Improved drinking water sources are those which by nature of their design and construction have the potential to deliver safe water. During the SDG period, the population using improved sources will be subdivided according to the level of service provided. In order to be considered as a safely managed drinking water service (SDG 6.1), people must use an improved source meeting all three of the following criteria:

- it should be accessible on premises,
- water should be available when needed, and
- the water supplied should be free from contamination.

The Joint Monitoring Programme (JMP) of WHO and UNICEF uses a service ladder to benchmark and compare progress across countries, providing continuity with Millennium Development Goal (MDG) monitoring, and introducing the additional criteria on the level of service as noted above. Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.

Drinking Water Service Ladder with Examples of Groundwater

Service Level	Definition (JMP, 2017)	Groundwater Examples
Safely managed	Drinking water from an improved water source that is located on premises, available when needed and free from faecal and priority chemical contamination.	Private borehole located on the household premises, available when needed and free from faecal and priority chemical contamination. Reticulated supply based on groundwater boreholes.
Basic	Drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing.	Community borehole or spring where close to the households, or private borehole not free from contamination.
Limited	Drinking water from an improved source for which collection time exceeds 30 minutes for a round trip, including queuing.	Community borehole where the collection time exceeds 30 minutes for a round trip, including queuing.
Unimproved	Drinking water from an unprotected dug well or unprotected spring.	Unprotected dug well or unprotected spring.
Surface water	Unsafe or unimproved drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal.	N/A

Groundwater irrigation has an important role to play in agricultural development in Africa. Currently, only 1% of cultivated land in Africa is irrigated, compared with 14% in Asia. With appropriate investment in groundwater and other related infrastructure this could be increased to 20-50% of all cropland based on the availability of surplus renewable groundwater resources, i.e. after satisfying environmental and other human and livestock requirements (Altchenko & Villholth, 2015), but not considering the socio-economic or political constraints to groundwater irrigation.

The socio-economic benefits of increased groundwater irrigation are multi-faceted, including increased agricultural production, increased income for farmers, and rural and peri-urban development. There are therefore different possible trajectories for groundwater-based agriculture. African governments have a wide range of different aspirations for what can be achieved through agricultural development, from securing household level food security through to employment opportunities and viable agricultural enterprises (both smallholder and large enterprises) and reducing national dependency on food imports.

Groundwater development combined with adequate waste and sanitation management, and watershed and water source protection can reduce risks to groundwater quality. Shallow aquifers in urban areas are particularly at risk from anthropogenic contamination. Safe groundwater sources, protected from contamination, increase water security for the continent and contribute to meeting UN SDG6 for water and sanitation, SDG3 for good health and well-being, as well as other SDGs as shown in Figure 1.

Potential risks of groundwater investment for national growth and poverty reduction

Groundwater has a significant role to play in achieving universal access to safe and resilient water supplies for domestic and agricultural use across Africa, with potential positive outcomes for economic development and social well-being. However, there is a risk that the benefits associated with groundwater development are disproportionately experienced by those in the upper wealth quintiles. Those with more significant resources, whether it be in terms of capacity, land ownership, financial means, or access to technology, may have the ability to access deeper groundwater, which may be less vulnerable to pollution and seasonal fluctuation, or utility-provided piped water.

Conversely, poorer people, both in rural areas and unplanned urban settlements, may not be able to access or afford piped water, and may be more reliant on low-cost shallow groundwater sources, which are highly vulnerable to pollution and more likely to fail in the dry season or during drought. Inequality in terms of access to safe and reliable groundwater may be exacerbated by climate change and population growth as well as weaknesses in governance or management, but a deeper understanding of the socio-economic and political factors influencing groundwater access and its implications for poverty reduction is required.

Increasing groundwater development presents the challenge of how to secure short-term socio-economic benefits without risk to the future sustainability of the resource. Risks to the long-term availability of groundwater exist where long-term average recharge does not cover groundwater removals from an aquifer, whether by abstraction for human use or discharge for ecosystem services. Sustainable groundwater development therefore requires a sound understanding of the local hydrogeological environment, along with the likely impacts of climate and land use change and increasing demand on local water resources. This understanding is heavily reliant on high quality data and the capacity to interpret and use that data for effective groundwater governance.

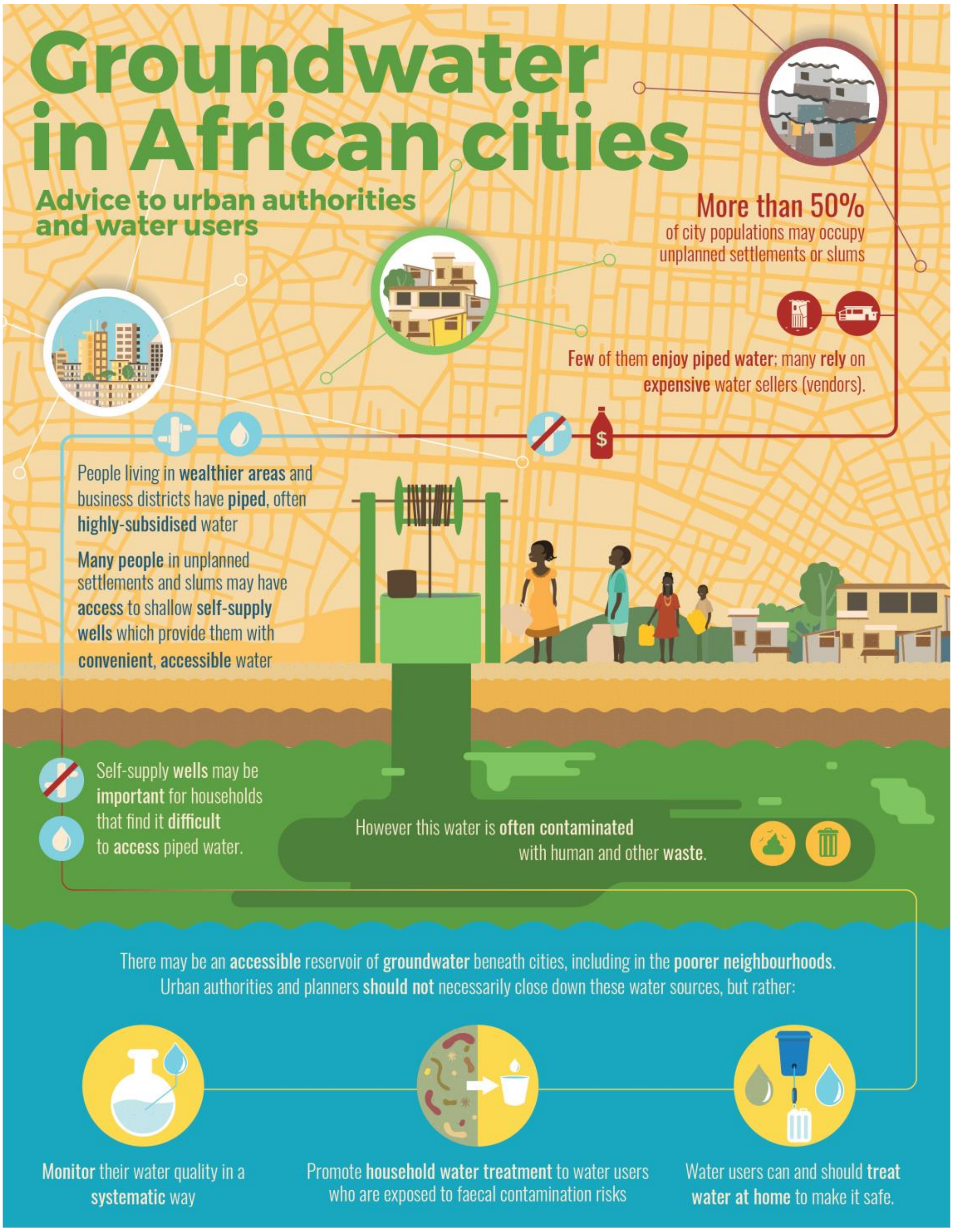
Data and capacity are limited in many parts of Africa and significant investment is required to increase our knowledge and understanding of groundwater and to ensure there is a political commitment to develop or enforce legislation for groundwater management at local, national and regional levels. In many hydrogeological environments, the long-term availability of the resource is at risk due to siting, constructing, and use of groundwater sources without sufficient local knowledge. Similarly, long-term risks to groundwater quality exist where groundwater, land-use and waste are not adequately managed.

Groundwater is often perceived as a local resource, satisfying the needs of dispersed communities. While this is correct, the demand for groundwater is increasing rapidly across the continent for various purposes: urban water supply; industry and other commercial activities like mining and intensive agriculture; and use as part of groundwater-based natural infrastructure, where the subsurface and its water resources are used to support the environment, increased water storage, water retention, and improved water quality. Larger-scale developments may have transboundary implications so that adequate governance arrangements are required to provide national benefits without risking regional resources.

SECTION 1: URBAN GROUNDWATER SECURITY

Key message

Groundwater, through public and private supplies, provides an essential source of water for urban populations in many parts of sub-Saharan Africa. However, urban growth and increasing demand, climate change, and poor sanitation and land use practices pose a threat to groundwater quality and availability. Declining groundwater quality poses a significant challenge to urban water security.



Setting the scene

Urban dwellers in Africa obtain water from multiple sources, according to their availability and affordability (Figure 3). Those with more income are more likely to have a piped water supply in the home than poorer households (Thompson *et al.*, 2000; Tucker *et al.*, 2014). Among the more affluent, who often own the land on which they reside, private groundwater supplies (boreholes and hand dug wells) are increasingly used to improve the availability of water in the home (Foster *et al.*, 2018), particularly in places where governments and utility companies are unable to ensure a reliable service or cover all parts of the city.

Figure 3 Types of water sources used by urban and peri-urban populations

Piped water

Community stand-posts

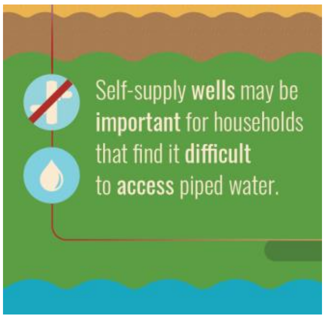
Improved/unimproved wells

Photo credits: Adrian Healy

The urban population in the lower-income quintiles, often living in informal settlements in urban and peri-urban areas meet their basic water requirements using a range of sources according to availability and cost: utility stand-posts and kiosks, private or community boreholes, private water vendors, unimproved shallow wells and potentially-polluted surface water (Foster, 2017). Unless the water table is very shallow, private sources are beyond the financial reach of the urban poor using their own means.

Trends in urban water-supply coverage for sub-Saharan Africa show that the proportion of the population served by mains water-supply piped to their dwelling decreased significantly (from 50% to 38%) between 1990 and 2010 (Foster, 2017). National statistics of groundwater use, both as part of the public water supply system and for private use, are lacking in terms of reliability, spatial coverage, and representativeness. However, urban groundwater use for private on-site supply (often referred to as self-supply) is a major and growing phenomenon. It is estimated that private supply from groundwater through hand dug wells and boreholes may account for between 20 and 60% of total water supply in some cities across sub-Saharan Africa (Foster, 2017; Healy *et al.*, 2018).

The decline in piped water supplies has been attributed to population growth, rapidly-growing cities and the inability of public water-supply utilities to keep up with increasing demand; it is underscored by challenges relating to the political economy[1] and land tenure. Meanwhile the proliferation of private groundwater supplies for individuals, households and developers is a major and growing phenomenon. These supplies are increasing access to a viable water supply, at least in the short term and mainly for wealthier households. However, these private, on-site supplies may be inadvertently contributing to a reduction in water-utility revenue collection, thereby reducing the ability of water utilities to expand infrastructure and provide subsidized tariffs to those on lower incomes.



While households facing unreliable piped supplies invest in their own groundwater supplies, this does not benefit from 'economies of scale', and such sources may lack protection in the face of potential pollution from on-site sanitation and wastewater discharge to the environment. The reliance of poorer urban groundwater users on shallower sources increases their risk to exposure from contamination even more (Foster *et al.*, 2018).

In urban areas, groundwater is used for both domestic and industrial uses. Cities are increasingly developing groundwater to expand and stabilize their piped water supplies, either from aquifers under the cities, or from areas outside the cities, depending on resource context and costs. While there is no comprehensive data on the use of groundwater for urban piped-supply in Africa, a study of groundwater use for six African cities[2] found indications that where the water utility has been able to develop groundwater rationally, the public water-supply usually provided a better service at lower cost (as a result of enabling phased investment and avoiding advanced treatment) and offered greater water-supply security in drought and from pollution (Foster *et al.*, 2018). Cape Town, South Africa, which almost ran out of water in 2017/18 because of sole reliance on surface water, had to develop an emergency programme to rapidly provide groundwater sources for key services.

Urban growth, increasing demand, inadequate sanitation and land use practices all pose serious threats to urban groundwater quality and availability. Continued unregulated private groundwater development and abstraction has the potential to cause localized aquifer depletion, which risks the long-term availability of groundwater from an aquifer. This problem of competitive abstraction has already happened in Nairobi, Kenya, where boreholes typically have to be drilled to depths of 200 m to achieve yields of 1-2 l/s (Foster, 2017). Looking ahead, in Arusha, Tanzania, under most urban growth and climate change scenarios groundwater levels are predicted to drop by several tens of metres by 2050 (Olarinoye, submitted). Falling groundwater levels significantly increases the cost of groundwater development, which in terms of private borehole development, disproportionately impacts the urban poor. Over-abstraction can also cause land subsidence and saline intrusion – a

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[1] **Political economy** is the study of production and trade and their relations with law, custom and government; and with the distribution of national income and wealth.
[2] Lusaka & Kabwe, Zambia; Dar-es-Salaam & Arusha, Tanzania; Accra & Kumasi, Ghana.

groundwater quality issue that is well documented in urban coastal aquifers across Africa (Steyl & Dennis, 2010; Comte *et al.*, 2016).

Box 4 Urban groundwater pollution from on-site sanitation in Lusaka, Zambia (adapted from Africa Groundwater Atlas (2018a))

Lusaka, Zambia is underlain by limestone, which means that the groundwater flows in conduits and channels and can typically provide high yielding boreholes. The permeable superficial deposits on the surface are connected to the aquifer beneath with a very shallow water table. This means that contaminants that enter the aquifer can be quickly and easily transmitted through it. Prior to the 2011 Water Resources Management Act, followed by subsequent lack of implementation of the act, households in Lusaka have been able to sink wells and boreholes where they choose. Consequently, boreholes and potential pollution sources from neighbouring properties can be very close.

Studies examined water quality in a low-density, high-income area with boreholes and septic tanks, and high-density, low-income areas where pit latrines and shallow wells were used (Nkhuwa, 2006; Nkhuwa *et al.*, 2015). It was concluded that contamination from waste water disposal was a risk not only in low-income, high density areas without sewage infrastructure, but also in high-income low density areas. Installation of septic tanks alone appears insufficient to protect against groundwater contamination, and an adequate distance between septic tanks and boreholes, maintenance of boreholes, and regular emptying and management of septic tanks also has to be implemented.

In many urban areas, inadequate waste management and source protection risks contamination of groundwater supplies. This is a particular problem where private groundwater supplies and on-site sanitation facilities, developed in response to a lack of public provision, are co-located (Box 4). Increased extreme, heavy rainfall as expected with climate change heightens the risk of groundwater contamination and may even damage water supply infrastructure. Contamination of shallow groundwater from pit latrines, but also deeper groundwater from inappropriately maintained septic tanks, has been well documented in Lusaka, Zambia, where groundwater contamination has been linked with widespread cholera outbreaks.

In practice, investment in existing technologies (i.e. more wells by public suppliers and households), will certainly lead to increased degradation of ecosystems, limiting economic opportunities, and accentuating social inequalities. The lack of reliable data on groundwater use, availability and quality in urban areas renders it difficult to understand such risks until they become felt. Clearly there are major challenges to effectively governing groundwater in many parts of urban Africa.

What is needed?

To ensure water security for urban and peri-urban populations across Africa the groundwater resources in and around urban areas need to be better managed. Only then can the entire urban population, irrespective of wealth, be served. Specific actions that could be undertaken include:

- Improve governance capacity and enforcement procedures to reduce damaging behaviour, such as uncontrolled drilling and abstraction and discharge of industrial or agricultural pollutants to groundwater, and/or incentivise good practice
- Improve collaboration between regulators, utilities, and private developers to integrate utility and private investments in piped and non-piped water supply within the urban planning process
- Establish low-income ('pro-poor') policy and technical units in water utilities or work with knowledge centres to support alternative water-supply provision (e.g. provide advisory services for private groundwater supplies)
- Improve collection of data on long-term groundwater use (including private groundwater sources), along with groundwater availability and quality
- Strengthen efforts to reduce non-revenue water losses in piped systems
- Introduce zoning and protection of municipal abstraction wells/well fields and improve sanitation systems and waste and waste water handling to reduce groundwater pollution

The numerous challenges need to be addressed in context-specific and collaborative ways. Current research suggests that change-models, whereby the urban population is the change agent, or driver of change, and is engaged in a constructive dialogue with policy-level stakeholders supportive of change, may be an effective way of developing socially inclusive groundwater management policies and practices for urban water supply provision (Box 5).

Box 5 Experimenting with practical transition groundwater management

Transition management – a participatory, iterative and reflexive approach to governance – is being tested within the UPGro T-GroUP project to address groundwater issues in urban and peri-urban areas in Dodowa (Ghana), Arusha (Tanzania), and Kampala (Uganda). The aim of the project is to identify, and where possible put in motion, the social, technical and political changes required to transition towards sustainable urban groundwater use and management in the case study areas in sub-Saharan Africa.

The transition management approach is based on a set of principles and methods that are applied to trigger and accelerate change to address complex and persistent governance problems. This is done by engaging with actors across all societal levels, bringing together front-runners, or agents of change, to identify problems (Foppen, 2018b; Silvestri, 2018b), create a vision of change (Foppen, 2018a), and experiment with different pathways towards achieving (transitioning to) that vision.



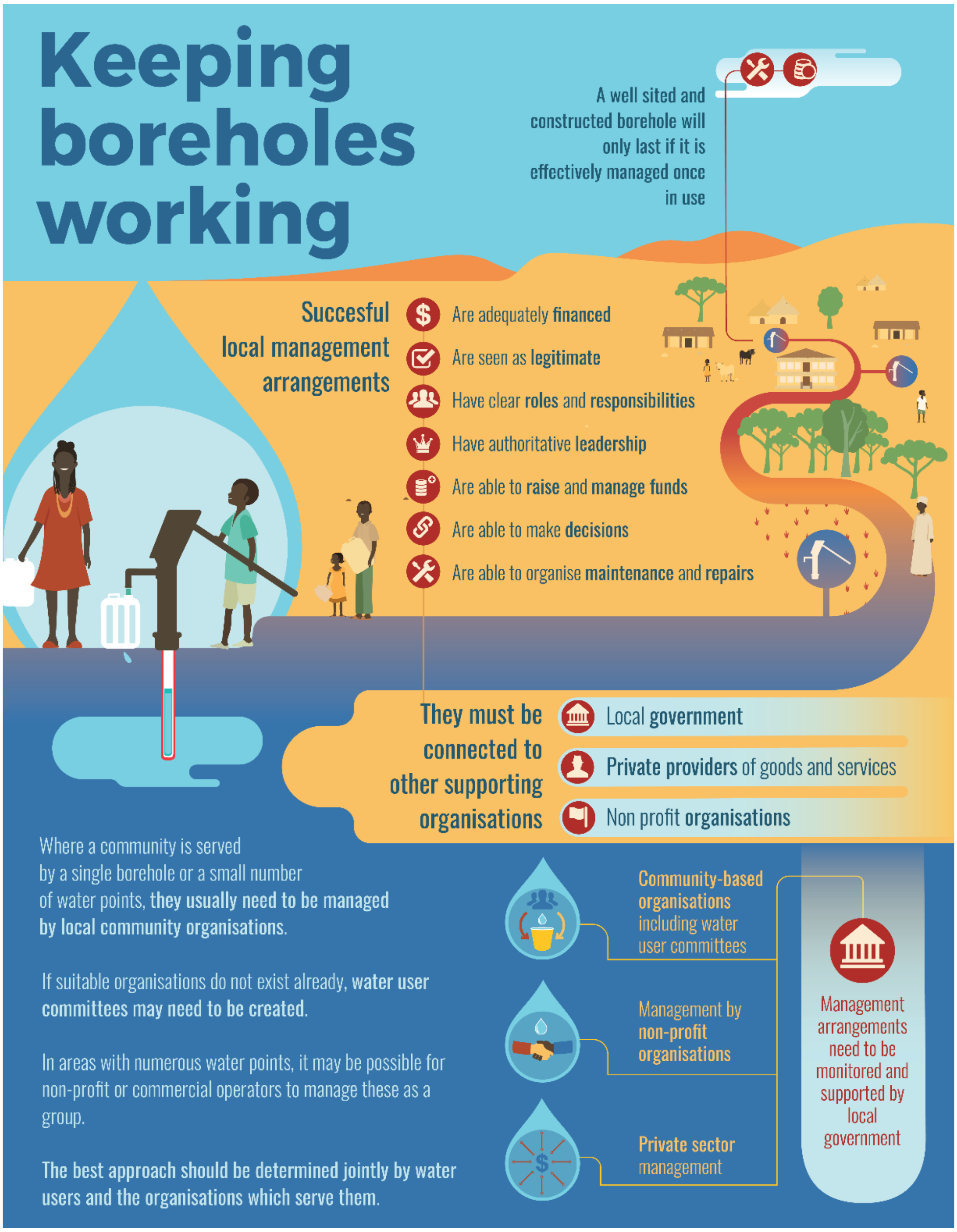
Participatory approaches to problem structuring, visioning, and agenda setting as part of the transition management process.

In the three case study areas, the local transition teams have been working with a range of stakeholders, including local communities, to identify problems (such as groundwater contamination, poor sanitation, and lack of waste management), facilitate front-runners, and build local capacity, to mobilise communities to take actions (Silvestri, 2018a; Silvestri, 2019) that will enable them to transition towards their envisioned futures.

SECTION 2: SOCIALLY INCLUSIVE AND SUSTAINABLE RURAL WATER SERVICES

Key message

Groundwater is the main source of drinking water for over half the rural population of sub-Saharan Africa and also has an important role for economic activities. Boreholes fitted with handpumps serving communities are particularly important but functionality rates are often lower than 50%, effectively lowering service levels and placing an unnecessary burden on users. Among the many reasons for borehole failure are poor siting and construction practices, a problem which some organisations are trying to address. Promising ways of monitoring and maintaining handpumps are emerging in a number of countries.



Setting the scene

Notably, either a private borehole or a piped water supply can provide a safely managed service, as long as they are located on the premises, available when needed and free from faecal and priority contamination (Box 3).

In sub-Saharan Africa, the majority of the rural population source their drinking water from groundwater, with around half the population using wells, boreholes and springs and an additional but unknown number served by groundwater-fed piped supplies (UPGro, 2017). Much of Africa's rural population will be reliant on community water points, mainly boreholes equipped with handpumps, for decades to come. Given that such sources are not located on premises, but serve a community, community boreholes would generally be classified as providing a basic or limited, rather than improved, level of service, depending on the collection time (Box 3).

Groundwater sources within a community often have multiple uses, both domestic and productive. Where water is used for economic activities such as livestock watering, small-scale gardens, brick making or brewing, groundwater positively impacts peoples' livelihoods (Waughray *et al.*, 1998; Makoni *et al.*, 2004; Hall *et al.*, 2014). There are numerous studies demonstrating the livelihood benefits of groundwater irrigation, particularly in comparison to rain-fed agriculture (Adeoti *et al.*, 2009; Dittoh *et al.*, 2013; Villholth, 2013b; Hagos & Mamo, 2014; Owusu, 2016). These impacts are felt in terms of income and food security and tend to disproportionately benefit women. However, household wealth is a key factor in determining the level and nature of groundwater access for both domestic and productive uses (UPGro, 2017). Variations in access to service levels means that the poorest households do not necessarily capture an equitable share of the potential benefits associated with improved groundwater access.

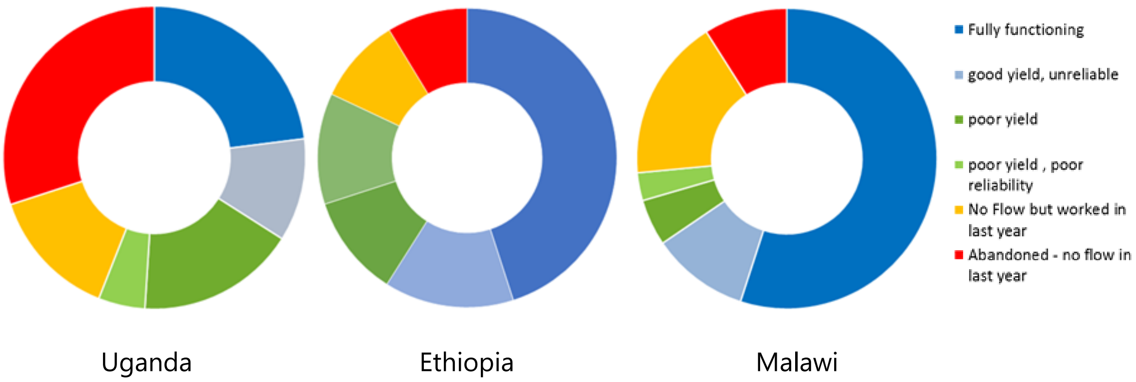
UPGro research has demonstrated that the actual functionality rates of community boreholes are generally <50% (Kebede *et al.*, 2017; Mwathunga *et al.*, 2017; Owor M *et al.*, 2017) (Box 6). This implies that although the infrastructure to access groundwater is in place, service levels are falling short as drinking water is not available when needed. Emerging evidence from UPGro research highlights the impact on people when water points fail. The effects are felt most strongly along lines of gender, health, and wealth: women typically travel further and/or visit less safe sources, those who are older and/or with health issues are less able to travel to alternative sources, and those with a means of transport can cope with increased distance or may be able to pay for water delivery from vendors. In many instances, broken down water points result in a community using the water point in a neighbouring village, often greatly increasing pressure on that point resulting in congestion, delays, conflict, and increased risk of breakdown.

Box 6 Defining and measuring borehole functionality

National statistics on water point functionality may hide as much as they reveal. Detailed assessments of the functionality of handpump boreholes (HPBs) in Uganda found:

- 55% of HPBs were working on the day of the survey (compared to the nationally reported figure of 86% for rural water supply)
- 34% of HPBs passed the design yield of 10 litres per minute
- 23% passed the design yield and also experienced < 1 month downtime within a year
- 18% passed the design yield, reliability criteria and water quality criteria

The figures below show the results of the Uganda survey (Owor M *et al.*, 2017), and for comparable research in Ethiopia (Kebede *et al.*, 2017) and Malawi (Mwathunga *et al.*, 2017).



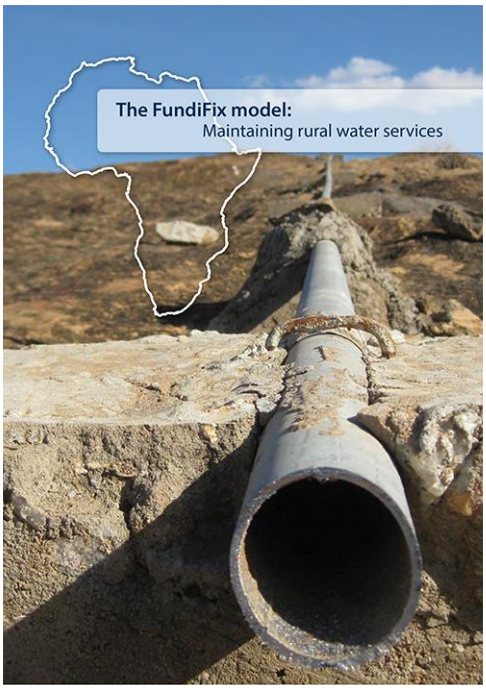
The reasons for water point failure are complex, multifarious, and related to power dynamics between a range of actors (locally, regionally and nationally). Poor siting of the borehole, inferior construction, and unrealistic demands put on communities to operate and maintain their supplies affects community management structures and arrangements. There is growing recognition of weaknesses in siting, drilling and supervision practices, as well as challenges of human capacity and the wider enabling environment in several countries in sub-Saharan Africa (Danert, 2018; Liddle & Fenner, 2018; Wanangwa, 2018). Poorly constructed boreholes not only pose a problem for maintenance but also risk contamination of the source and the aquifer.

Efforts to improve the professionalism of borehole drilling through advocacy, face-to-face and online training, as well as improvements to programme/project planning and design are being spearheaded by UNICEF and Skat Foundation in several countries in sub-Saharan Africa under the umbrella of the Rural Water Supply Network (RWSN) (Danert & Gesti Canuto, 2016; RWSN, 2016; Danert & Theis, 2018; RWSN, 2018b; RWSN, 2018a; Serele, 2018), with other organisations also taking up this agenda (e.g. Malawi (Mannix, 2018), Zimbabwe (SADC-GMI, 2018), Zambia (RWSN, 2018a) and beyond).

In addition to the few, but promising initiatives to raise drilling professionalism, there is also encouraging news about different approaches to operation and maintenance that increase the operational and financial sustainability of rural water services. These include the FundiFix model (Box 7), as well as other initiatives, whereby multiple sources are maintained by trained and equipped mechanics (Allen & Lane, 2016; Harvey *et al.*, 2016; Lockwood *et al.*, 2016; USAID Water Team, 2018), often using smart monitoring of handpumps, for example in Rwanda, Kenya, Ethiopia and beyond (Cohen, 2016; Weaver *et al.*, 2016; Murray, 2018; CAYA, 2019). Of note, is community, school and clinic demand for reliable maintenance services with over 70,000 women, men and children paying for performance-based contracts in Kenya for both handpumps and small piped systems. This is not an isolated case with other African entrepreneurs providing similar social enterprise models in Benin, Central African Republic, Mali and Uganda serving over one million rural people.

Box 7 The FundiFix model with smart handpump monitoring

The FundiFix model (UNICEF *et al.*, 2016) is based on the business rationale of scale reducing risk. Professional service providers take responsibility for the maintenance of a network of rural water points so that economies of scale lower costs and improve service delivery. In the study sites in Kenya, average downtime was reduced from 30 days to less than 3 days. Finance for the maintenance service providers is performance-based, coming from communities, schools and clinics with support from local investors, and government. This co-investment spreads the financial risk, increasing the financial sustainability and ensuring no-one is left behind in terms of water service provision. Smart monitoring (SSEE Water Programme, 2015), whereby handpumps are equipped with simple transmitters, is currently being developed, so usage and groundwater levels can be monitored remotely by maintenance service providers. This technology allows failures to be reported and addressed very quickly, or even before they occur.



An available and functional groundwater supply is not only important for drinking water and livelihoods for rural populations in sub-Saharan Africa; there are also other advantages that include:

- Equitable groundwater access has a very important role for welfare (Foster & Hope, 2016; Foster & Hope, 2017)
- Emerging work is identifying that rapid handpump repair times are a priority for water users (Hope, 2015; Koehler *et al.*, 2015)
- Successful community-based management of groundwater sources can have widespread social benefits for communities where funds collected for waterpoint maintenance are used for other socially inclusive projects, such as the construction of a mill or repair work in a village

- Recent studies also show evidence of links between water access and educational benefits, although the role of groundwater in these outcomes is less clear (Garn *et al.*, 2013).

Emerging threats to groundwater access include contamination, both from natural (geogenic) and anthropogenic sources, environmental change, and increasing demand.

What is needed?

It is important to deepen the understanding of the underlying causes of borehole failure and widen this research to more countries with a view to addressing the root causes of failure and thus improve the sustainability of rural water services for all. Maintenance of waterpoints needs to be given a much higher priority and innovative methods developed to deliver and sustain rapid maintenance.

Furthermore, it is critical to support and enhance on-going efforts to improve drilling professionalism to the level required through actions that strengthen capacity, improve groundwater data management, enhance project planning and design, and support the institutional framework. Dialogue between different stakeholders as well as awareness-raising about drilling professionalism, coupled with targeted investment is essential.

Given the challenge of ensuring equitable rural water services there is a need to better understand the impact of groundwater access on poverty, address disparities in service levels and thus support efforts to develop groundwater for the benefit of all. Universal drinking water services may not be compatible with financial sustainability requiring novel models and partnerships to ensure system sustainability with a focus on 'service delivery for all'.

SECTION 3: GROUNDWATER FOR AGRICULTURAL GROWTH AND TRANSFORMATION

Key Message

Levels of irrigation are relatively low in Africa compared to Asia, however evidence suggests that groundwater irrigation is expanding, with the potential for a much higher proportion of cropland to be irrigated by renewable groundwater resources. An integrated approach to expanding groundwater-fed irrigation, adapted to the environmental, socio-economic, and political context, can contribute to agricultural growth, food security, and poverty reduction for rural communities in Africa.

Setting the scene

Evidence suggests that groundwater irrigation, driven largely by smallholder farmers, is expanding in Africa in response to improved access to low-cost pumps and drilling technologies, and to market opportunities (Villholth, 2013a). Irrigation is developed solely from groundwater, or through conjunctive use of groundwater, dams and existing canal irrigation systems (Villholth *et al.*, 2013). Groundwater is also used for livestock farming in semi-arid and arid areas, for intensive irrigation, for example in Ethiopian greenhouse horticulture (Moges, 2012), and for centre-pivot irrigation systems for maize and potato production in Zambia and South Africa, respectively (Conrad & Carstens, 2014).

Groundwater irrigation plays a significant role in agricultural growth and transformation, food security, and household livelihoods across rural Africa by providing a nutritional source in the dry season and a source of income and local employment. Evidence suggests that smallholder farmers using motorized pumps for groundwater irrigation experience greater agricultural productivity than those relying on manual pumps or rain-fed agriculture, except where rainfall is particularly abundant (Shah *et al.*, 2013). Due to the reliable water source, farmers are incentivized to invest in improved seeds, higher-value crops, and agricultural inputs such as fertilizers and pesticides, enabling intensive and relatively income-secure production.

Diesel and petrol-powered pumps have emerged as a key irrigation technology that smallholder farmers are using to draw water from groundwater sources, as well as lakes and rivers, for intensive, high-value, horticultural production and to provide supplemental irrigation during dry periods in rainfed areas. The use of these low-cost pumps appears to be a widespread phenomenon across sub-Saharan Africa (Giordano *et al.*, 2012).

In some places, notably valley bottoms with high groundwater tables, access to water is created by hand-drilling or digging shallow wells. Petrol pump irrigation by smallholder farmers has, for instance, been well documented for Ethiopia (Dessalegn & Merrey, 2015), Ghana (Laube *et al.*, 2012; Namara *et al.*, 2014) and Zambia (de Fraiture & Giordano, 2014). The development of irrigation using small motorised pumps in Africa is primarily driven by farmers' own initiatives and their ability to tap into a supporting network of local retailers and agricultural merchants. In some countries, such as

Malawi, it has also been facilitated by national trade policies, such as duty-free imports of irrigation equipment (Woodhouse *et al*., 2017).

There is growing interest in the use of solar pumps to increase groundwater abstraction for irrigation. Solar-powered irrigation can offer a cost-effective and sustainable energy source to help improve food production and water access, and sustain livelihoods while reducing fuel-based carbon emissions. For example, affordable solar pumps for small-scale agriculture (e.g. US$400 pumps operating on 80 Wp solar modules) have been developed through market and technical advances and are already supporting smallholder irrigation, for example in Kenya (Kunen *et al*., 2015). New multi-criteria suitability mapping methods have shown that solar pump-based groundwater irrigation in Ethiopia could cover 9% of irrigated land and 18% of rain-fed land, replacing 11% of motorized fuel pumps (Schmitter *et al*., 2018).

Although groundwater-fed irrigation appears to be expanding in Africa, the levels of development remain relatively small compared to Asia. It is estimated that only 1% of cultivated land is currently irrigated by groundwater in Africa, compared to 14% in Asia. At a continental scale, research suggests that the proportion of cropland irrigated by renewable groundwater could be increased to more than 20% (Altchenko & Villholth, 2015). The irrigation potential of Africa has been estimated to have much greater returns from investing in small-scale irrigation than in large-scale, dam-based systems. The internal rate of return (IRR) for large irrigation projects was found to be 7%, but 28% for small-scale irrigation because there is still so much unirrigated arable land located away from any large irrigation infrastructure (You *et al*., 2011). With small-scale irrigation the initial cost is lower as are the costs of operation and maintenance.

If sub-Saharan Africa is to achieve the Sustainable Development Goals, particularly those related to eradicating poverty (SDG 1) and enhancing food security (SDG 2), the expansion of both small and large-scale groundwater irrigation will play a central role. However, to ensure that groundwater resources are managed sustainably and equitably for both current and future generations, attention needs to be paid to addressing the social and institutional, as well as the technical dimensions of their abstraction, access and use.

What is needed?

While various development models have been implemented across Africa, ranging from state or community-driven deep groundwater schemes to individual shallow groundwater promotion, there is a limited understanding of the relative impacts of these interventions on poverty and food security. An integrated approach to expanding groundwater irrigation, which takes account of the impacts of irrigation on water resources and the wider environment, the whole agricultural value chain, and on vulnerable communities, can contribute to more socially and environmentally sustainable agri-food systems and to improved livelihoods across rural Africa.

Groundwater availability is dependent on a number of interacting factors which are often poorly understood at the local scale. Developing a sound understanding of groundwater availability, across short and long time-scales, will be key for sustainable groundwater irrigation. This will be particularly important for petrol or solar-powered motorized pumping technologies, which allow potentially higher rates of groundwater abstraction than manually-operated pumps, and in drought-affected regions where the resilience of small-holder farmers is impacted by weather-related shocks and lack of access to water (Box 8).

The success and sustainability of groundwater irrigation depends not only on the availability of groundwater, but on the provision of policy, finance, and institutional arrangements to provide equitable access to groundwater development technologies, crop storage facilities, financing, markets, and land. Groundwater irrigation has expanded most where enabling factors coincide – often in close proximity to urban areas or major transport corridors. Analysis of different business model scenarios for solar-pump based irrigation in Ethiopia shows that models adapted to the policy and regulatory framework of a country, can provide investment opportunities for smallholder solar pump-based irrigation, which ultimately contributes to sustainable intensification for food and nutrition security (Otoo *et al*., 2018).

Equitable access to technology and resources can create jobs in rural communities, improving household livelihoods and contributing to poverty reduction. However, further research is required to highlight and better understand issues of inequity regarding access to and control of finance and technology by smallholder farmers compared to larger, more intensive farmers.

Furthermore, while the potential for rapid and widespread adoption of groundwater irrigation exists, especially among smallholder farmers, there is a need for an integrated and interdisciplinary approach to improve the analysis and understanding of the technical and socio-economic challenges and opportunities they face. Findings from this work will generate context-sensitive insights into the critical internal and external factors that lead to more sustainable and socially just outcomes and produce evidence-based recommendations to support groundwater irrigation development across the region.

Box 8 Radio outreach programmes (UPGro BRAVE Project, 2018)

Radio is one of the most important and cost-effective sources of information for the majority of rural farmers in Africa. In partnership with the Lorna Young Foundation, the UPGro BRAVE project are running a radio extension program to help improve the resilience of farming communities in drought-affected areas by providing up to date information and farmer training in five key areas: groundwater access and water harvesting, crop yields, sustainable land management practices, health and nutrition, and prevention and treatment of water-related diseases.

The radio outreach approach uses farmer listening groups to steer the content of the programs, empowering farmers and ensuring their concerns are adequately addressed. Every month, groups meet with radio presenters and local agricultural extension staff to select key subjects in line with a seasonal and agricultural calendar. The aim is to help the local communities prepare for the challenges related to climate and water in the coming months.
In Ghana (March 2018), the farmer field listening groups selected water harvesting, livestock health, storage of foods and prevention of illness. The programmes that were recorded addressed issues that are faced by the community in their respective areas:

- In Jawani, charcoal production is rife and deforestation is a major issue. The group sung a song about deforestation and protecting the trees, with their radio shows for March focusing on land preparation (avoiding burning, ploughing techniques, proper use of agrochemicals, mulching and encouraging planting of shade trees to provide crop cover).
- In Tariganga, the community asked about techniques for building water harvesting facilities, and to prevent contamination of rainwater and harvested water. A community water specialist provided advice on the selection of materials, cleaning of recipients and treatment of water.

Radio frequency for URA FM: 89.7, 93.7

SECTION 4: GROUNDWATER RENEWABILITY - IMPACTS OF CLIMATE AND LAND-USE CHANGE

Key message

Groundwater recharge is heavily dependent on patterns of rainfall distribution and changes in land use. Significant recharge occurs episodically – often once or twice a decade – related to global climate phenomena such as El Niño Southern Oscillation (ENSO) which affect the volume and intensity of rainfall. Monitoring and managing recharge can help secure the buffer role of groundwater in the face of cycles of excess and scarcity of surface water. While heavy rainfall can have a positive effect on groundwater recharge, it has been shown to increase the risk of groundwater contamination.

Setting the scene

Groundwater storage provides a vital buffer against the impacts of climate variability on freshwater availability between seasons and years. Generally, groundwater withdrawals during dry periods or drought lower groundwater levels when recharge is low or absent. Groundwater levels then rise during wet periods when groundwater can be replenished. Understanding cycles of groundwater withdrawals and replenishment is critical to the sustainable management of groundwater, alone or in conjunction with seasonal withdrawals of surface water (Box 9).

Box 9 Main determinants of the local water balance

When rain falls on to the land surface, a proportion may run off to lower points in the landscape, while the remainder infiltrates into the soil or remains held in surface depressions.
Of these last two components, part may evaporate, part be taken up by plant roots and transpired, while the rest may percolate to greater depths as potential recharge.

The proportions of the rainfall which result in runoff, evapotranspiration and recharge are determined by the interplay of land cover (crops and/or natural vegetation with their varying root depths), soil properties (in particular the infiltration capacity and hydraulic conductivity) and weather (notably sunshine, temperature, humidity and wind speed).

The local water balance is consequently rather complex, and changes or trends in one component do not always result in readily predictable changes in the component of particular interest. Land use changes have often been shown to have greater impacts than those resulting from the variability of or trends in weather and climate.

Substantial uncertainty remains in climate change projections of rainfall from Global Climate Models yet one widespread and observable impact of climate change is the intensification of rainfall in which the number of light and medium rainfall events reduces and the number of heavy rainfall events rises (Allan & Soden, 2008). UPGro research interrogating long-term records of groundwater levels across sub-Saharan Africa shows that groundwater recharge is heavily dependent on the occurrence of intense rainfall events. Consequently, the amplification of heavy rainfall under climate change may serve to promote replenishment of groundwater storage (Box 10). In more arid environments, such events occur less frequently (Taylor *et al*., 2013; Jasechko & Taylor, 2015) and replenishment of groundwater occurs via leakage from often ephemeral floodwater flows.

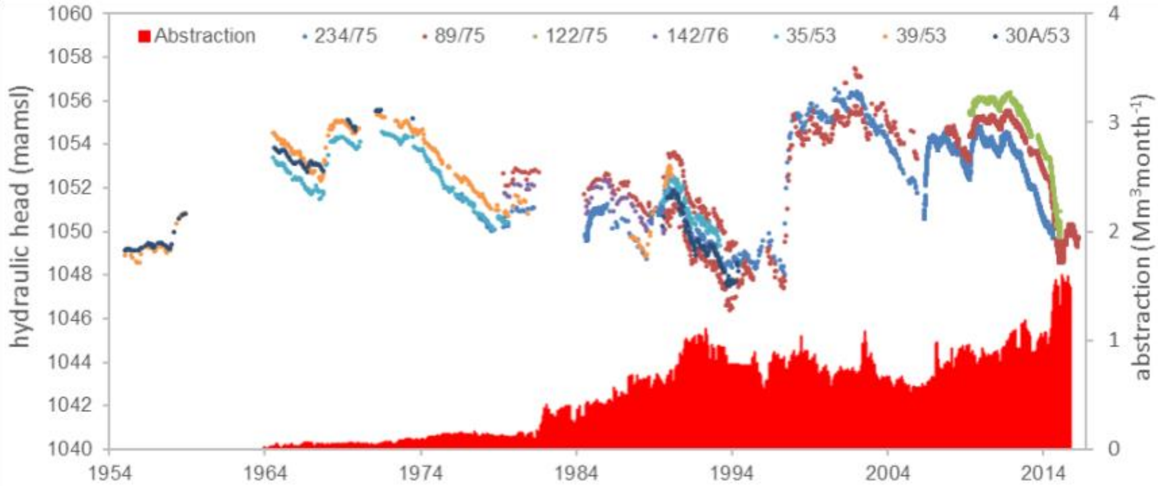
An improved understanding of these cycles and their impact on precipitation and groundwater recharge at regional and local scales in sub-Saharan Africa is being developed under UPGro and is expected to aid long-term planning and management of groundwater resources, particularly during droughts. This will become increasingly important as population rises and the demand for groundwater increases. In Windhoek, Namibia, the sustainability of intensive groundwater abstraction has been improved through use of Managed Aquifer Recharge (MAR) whereby seasonally available, treated surface water is injected into the pumped aquifer (Murray *et al*., 2018).

Managing recharge, e.g. through dedicated managed aquifer recharge (MAR) schemes is increasingly being explored, and will likely increase in importance in order to secure the buffer role of groundwater under the extreme climate variability that characterises much of sub-Saharan Africa. Such MAR schemes would exploit inter-annual cycles of excess of surface water flows by harvesting and storing them underground in the wet season for subsequent abstraction and use in dry periods. Examples include MAR schemes like in Windhoek, Namibia (Murray, R., *et al*. (2018))and the smaller, dispersed sand dams in Kenya (Benedicto van Dalen *et al*., 2018).

Box 10 Episodic groundwater recharge from heavy rainfall in central, semi-arid Tanzania

The Makutapora Wellfield in central Tanzania is the primary source of water for the nation's capital, Dodoma. It features one of the longest, near-continuous records of groundwater levels in Sub-Saharan Africa. This record reveals that recharge in this semi-arid environment occurs episodically in response to extreme seasonal rainfall associated with the El Niño Southern Oscillation (ENSO) in the early 1960s, 1997-98, 2007-07, and 2015-16.

Record of groundwater levels from multiple monitoring wells and wellfield pumpage from 1954 to present.



Episodic recharge which derives from leakage from ephemeral floodwater flows entering the wellfield, has, to date, sustained groundwater storage despite significant increases in the rate of groundwater abstraction (~ 50 000 m^3 per day). On-going research under UPGro is examining the sustainability of projected increases in pumpage and potential opportunities for Managed Aquifer Recharge (MAR) amplifying the storage of floodwaters associated heavy rainfall associated with ENSO.

Replenishment of groundwater via leakage from ephemeral floodwater flows

A potential negative impact of increased heavy rainfall across Africa is that although studies of impacts on groundwater quality are limited, most reports from urban and peri-urban areas indicate elevated concentrations of faecal coliforms during the rainy season or after extreme rain events with varying response times (Taylor *et al.*, 2009; Seidu *et al.*, 2013; Sorensen *et al.*, 2015). This has implications for drinking water supplies that rely on groundwater.

At the regional or basin scale, recent studies indicate that land cover has a significant impact on the response of groundwater recharge to precipitation:

- The seasonal response of groundwater to similar rainfall patterns is markedly different in southern African sedimentary basins compared to Sahelian basins (Bonsor *et al.*, 2018). Basins in the Sahel, which have largely been cleared of native deep-rooted vegetation, show a more pronounced recharge response than similar basins in southern Africa, which are more densely vegetated, indicating that infiltrated water preferentially goes into evapotranspiration processes as vegetation density increases, rather than going into recharge.
- Similarly, relative changes in groundwater recharge are also observed where forest is cleared for crop land, resulting in increased recharge; whereas restoring bare land to (non-irrigated) dryland cropping results in decreased recharge (Owuor *et al.*, 2016).
- On-going research in the Sahel region of West Africa (MacDonald, 2017), building on research undertaken in southern Africa (Butterworth *et al.*, 1999), is showing that land use practices at the local scale have a significant impact on diffuse groundwater recharge, with ploughing appearing to be important for promoting recharge.
- Urbanization, which is increasing significantly in Africa, also changes recharge patterns, with recharge often reduced, due to less permeable surfaces.

A key challenge for climate resilient water supply planning is uncertainty. Uncertainty in predicted changes to precipitation patterns under climate change, particularly at the regional scale, and uncertainty in the impacts of climate and land use change on groundwater recharge present significant challenges to those responsible for developing and managing resilient groundwater supplies.

What is needed?

There is need to monitor land use changes, groundwater abstraction, and groundwater response to recharge and storage in order to:

- Better understand the localized and regional impacts of land use, and in particular different types of crop land, on groundwater recharge so as to inform adaptation strategies;
- Inform strategies for climate adaptation, particularly at the community or farm level;
- Reduce the uncertainty in quantifying potential future changes in groundwater recharge and storage.

SECTION 5: GROUNDWATER RESOURCES OF AFRICA

Setting the scene

Groundwater can be found in many places in Africa, but its usefulness as a resource largely depends on:

- Availability – how much groundwater is present at a given location?
- Accessibility – how easy is it to access and extract the water for its intended use?
- Cost – how expensive is it to develop and abstract the groundwater?
- Quality – is the water of sufficient quality to provide a safe supply for its intended use?
- Sustainability – can the resource provide enough water of sufficient quality across the seasons and during significantly wet or dry years without affecting groundwater-dependent ecosystems?
- Manageability – what management arrangements are needed to govern resource use and stewardship? What roles for communities, local and national Government and environmental regulatory authorities?
- Equity – can a groundwater resource be developed and used by poorer, remote or marginalised communities/segments of the population?

These factors are influenced by complex interactions between the environmental and socio-economic context.

Environmental Context

The main hydrogeological environments in Africa are summarised below and in Figure 4.

Basement aquifers

Crystalline basement rocks of Precambrian age underlie much of Africa, forming low productivity aquifers capable of supporting small rural water supplies. Over 30% of the total population of Africa live in areas overlying basement aquifers (Africa Groundwater Atlas, 2018b).

Volcanic aquifers

Volcanic rocks underlie a small but significant area, particularly in East Africa. Borehole yields can be high and springs are important water sources in highland areas. Approximately 10% of the population live in areas overlying volcanic aquifers (Africa Groundwater Atlas, 2018b).

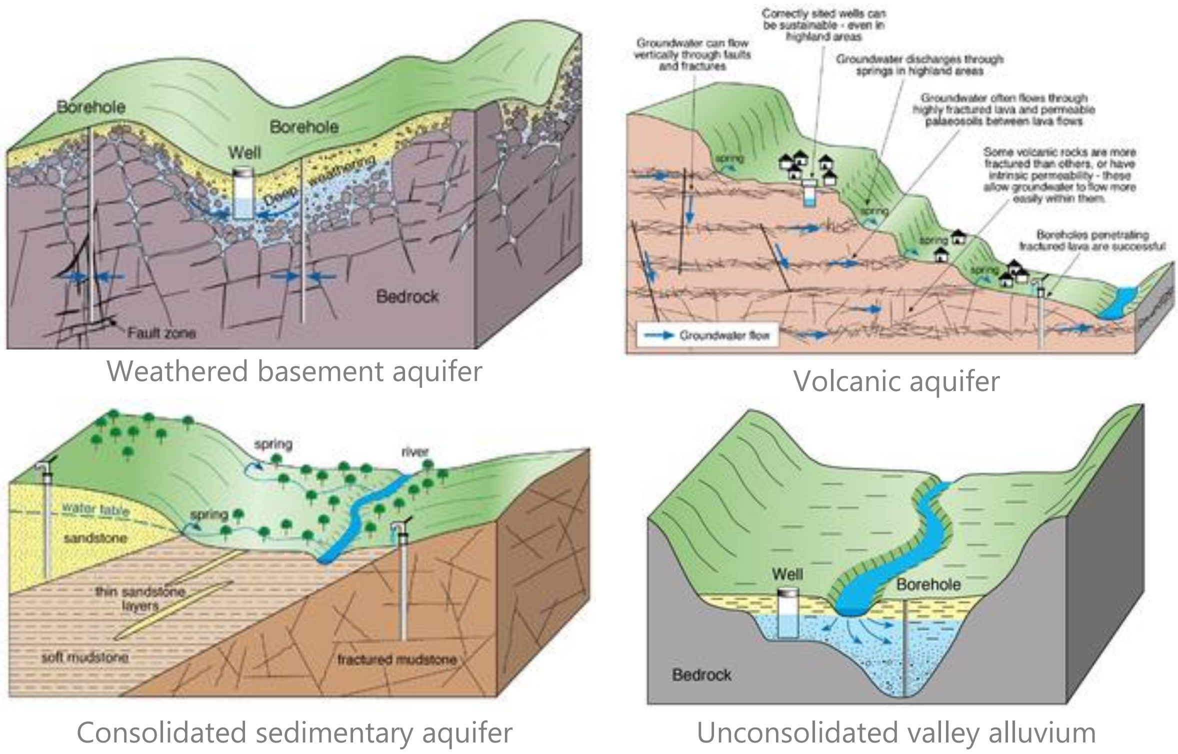
Consolidated sedimentary aquifers

Consolidated sedimentary rocks underlie around one third of Africa's land area. Sandstones and limestones can form thick, highly productive aquifers; mudstones, which comprise around 65% of sedimentary rocks in Africa, contain little groundwater but can be developed for small water supplies based on detailed investigation. Around 35% of the total population live in areas overlying consolidated sedimentary aquifers (Africa Groundwater Atlas, 2018b).

Unconsolidated sedimentary aquifers

Unconsolidated rocks are widespread, with sands and gravels – the most productive of these rocks – occurring in most river valleys and in many coastal areas. These rocks can be highly productive and easy to exploit at shallow depths, but are also vulnerable to contamination. Around 20% of the total population live in areas overlying unconsolidated sedimentary aquifers.

Figure 4 Hydrogeological environments of Africa (MacDonald *et al.*, 2005)



As discussed in Section 4: Groundwater Renewability - Impacts of Climate and Land-use Change, a major limiting factor for sustainable groundwater use is the renewability of the resource, i.e. how much of the groundwater storage is actively recharged over annual or decadal timescales. Broad relationships exist between average rainfall and recharge, but other factors such as rainfall intensity and land cover also exert a significant influence.

Socio-Economic and Political Context

Socio-economic and political context influences the accessibility, cost, and equity of groundwater resource development. This relates to the capacity of individuals', communities' and governments' to pay for, design, implement and maintain different types of technology and water supply infrastructure. In certain hydrogeological environments groundwater can be accessed at relatively shallow depths, with simple technology, and at relatively low cost. In this context, groundwater may be accessible to the majority of the population through hand-dug wells or manually drilled shallow boreholes. There may, however, be risks associated with its quality and availability as shallow resources are more vulnerable to contamination and drought. Where groundwater is only found at greater depths, or where shallow resources are unsafe or unreliable, access may be limited to those who are able to pay for appropriate technology to drill deeper boreholes. Other factors, such as land ownership, also influence the accessibility of groundwater through privately developed wells or boreholes. Groundwater access is also dependent on appropriate governance arrangements to maintain groundwater supplies, whether through privately, community, donor, or state-owned infrastructure.

Transboundary Aquifers

Africa counts on more than 70 mapped and named transboundary aquifers (International Groundwater Resources Assessment Centre (IGRAC) & UNESCO International Hydrological Programme, 2015). They are typically large and prolific and span across borders between two and seven countries. They underlie 40% of the continent, where 33% of the population lives, often in arid or semi-arid regions.

Transboundary aquifers do not normally coincide with international borders or river basins, and hence call for special attention in order to set up appropriate transboundary institutional frameworks for their joint development and management. Knowledge of the aquifers is often limited and variable, with limited exchange of information between states sharing the aquifer, either informally or through formal agreements. Significant work is required to upgrade and harmonize existing knowledge and develop joint visions and management frameworks for these aquifers. This is already happening in Northern Africa and progressively so in Southern Africa, driven by traditional or increasing reliance on groundwater in these regions. A few transboundary aquifers in these regions now count on formalized agreements and coordinating mechanisms (Nijsten *et al*., 2018).

Groundwater Monitoring

The key to understanding groundwater resources for effective, equitable, and sustainable management, is groundwater data. This refers to measured parameters – groundwater levels from wells or boreholes, rainfall, pumping test data, borehole yields, groundwater chemistry and microbiology, and geological borehole logs – all of which provide vital information about the quantity and quality of groundwater available from an aquifer.

Collecting and managing groundwater data so the resource can be used effectively presents a challenge, but is essential for sustainable groundwater management. Many countries have a national borehole inventory and strategic groundwater level monitoring networks, and some have a strategic groundwater quality monitoring network, with data held in databases at a national level. However, databases and monitoring networks are often not fully functional and investment and capacity building is required to operationalise these so they can be used effectively for groundwater management at a local, national or regional level (International Groundwater Resources Assessment Centre (IGRAC), 2013).

The economics of groundwater data are difficult to quantify, but the benefits of collecting, analysing, and using monitoring data can far outweigh the cost, particularly for strategic resources, or those that are vulnerable to over-abstraction or contamination. Long-term monitoring data that feeds into an integrated water resources management process can enable planners at the local, national or regional level to provide water security both now and into the future.

Further Information

There is a vast body of information available about groundwater in Africa – at a continental and country scale. The Africa Groundwater Atlas[3] is an online resource that provides an introduction to the groundwater resources of 51 African countries. It improves the availability and accessibility of high quality information on groundwater in Africa, to support the safe and sustainable development and use of groundwater resources. The Atlas includes a summary of the hydrogeology, groundwater status and groundwater management of individual countries, with links to further information through the Africa Groundwater Literature Archive[4]. It also provides a summary of the main sources of groundwater data for each country, where available.

Case studies of groundwater use and management in Africa are also provided through the Africa Groundwater Atlas. These case studies, along with a collation of groundwater syntheses for 15 countries in sub-Saharan Africa (Pavelic *et al*., 2012), illustrate the importance of an interdisciplinary approach to groundwater development, use, and management, given the complex set of interacting factors influencing groundwater availability, accessibility and sustainability.

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[3] https://www.bgs.ac.uk/africagroundwateratlas/index.cfm
[4] https://www.bgs.ac.uk/africagroundwateratlas/archive.cfm

CONCLUSIONS AND RECOMMENDATIONS

Groundwater can make a significant contribution to secure and sustainable rural and urban water services and to irrigation demand in Africa, with potentially significant benefits for economic growth and poverty reduction. However, several key risks require further understanding, quantification, and consideration to ensure that groundwater is developed sustainably and for the benefit of all. These risks include:

1. Unequal access, where the potential benefits of groundwater development are disproportionately felt by those who are wealthier and have the resources to access groundwater, particularly deeper resources which are less vulnerable to contamination and seasonal shortages;
2. Lack of local-scale information and data to fully understand groundwater availability to prevent over-abstraction and long-term depletion of resources;
3. Groundwater pollution, related to seawater intrusion in coastal areas, and inadequate waste disposal, particularly in densely populated urban areas.

Mitigation of these risks requires technical- and governance-based solutions alongside political commitment. Human and financial resources, data, capacity, and networks are needed to address knowledge gaps. These include, but are by no means limited to:

- Aquifer characterisation and understanding of groundwater availability at the aquifer scale
- The local-scale impacts of climate change and land use practice on seasonal and long-term groundwater availability
- Groundwater data, and the economic case for increased investment in groundwater monitoring and management by government agencies
- Groundwater-based solutions for climate-resilient water services which serve the poor and protect them from the hardship of many drought events
- The socio-economic and political factors impacting groundwater access and implications for pro-poor governance arrangements
- The direct links between groundwater access and poverty reduction
- Current and future dependence on groundwater for economic growth under increasing rainfall variability with unpredictable drought events
- Approaches to allocating groundwater and surface water in strategic locations such as major urban or industrial centres
- Effective institutional models to identify and mitigate pollution risks to groundwater as a primary source of drinking water for urban and rural populations

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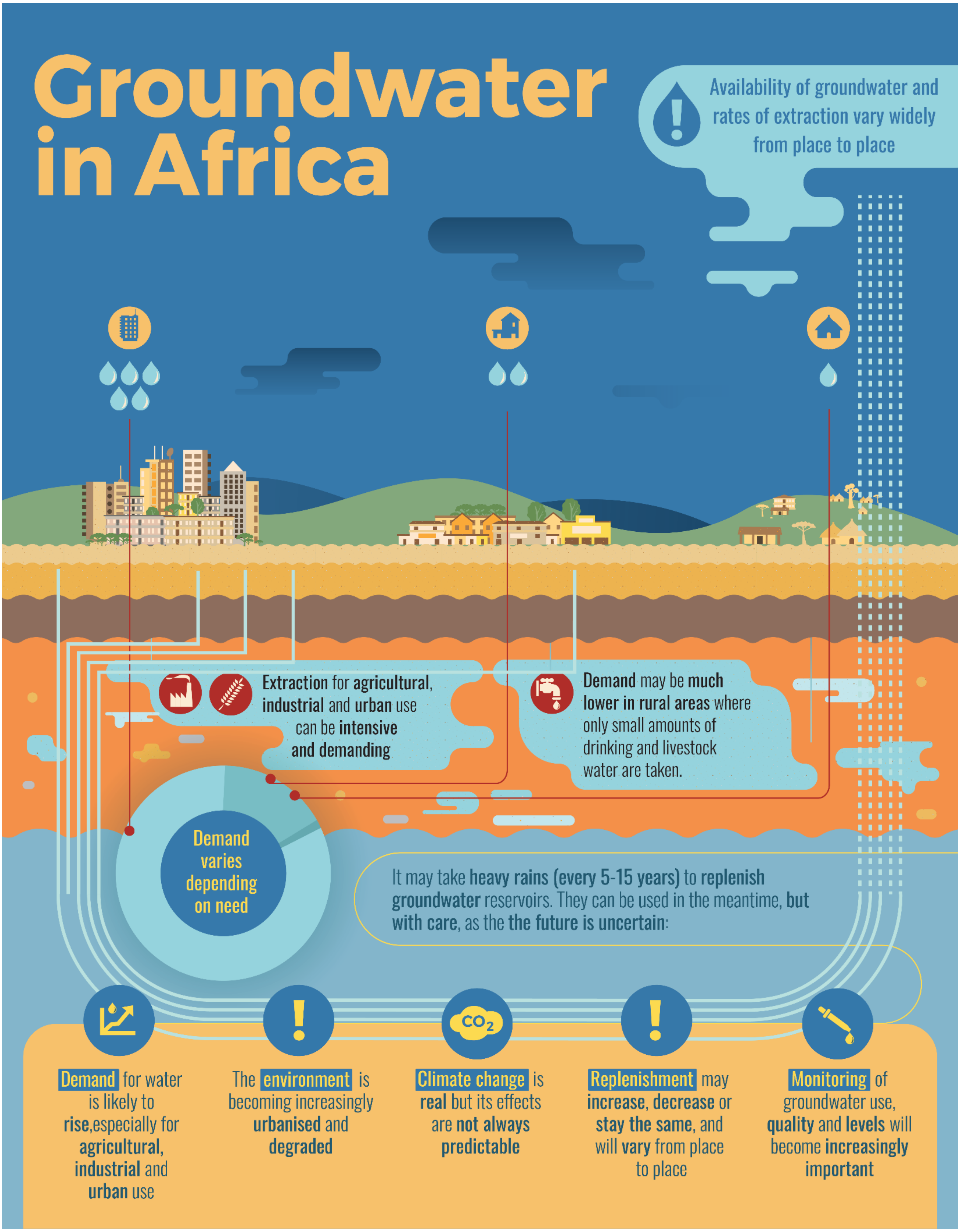

UPGro is funded by:
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