Rural Water Supply Network

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Sustainable Groundwater Development

Manual Drilling Compendium 2015

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Summary

Manual drilling refers to several drilling methods that rely on human energy to construct a borehole and complete a water supply. Manual drilling is also referred to as hand drilling, or hand turning. The various techniques can be used in areas where formations are quite soft and groundwater is relatively shallow.

Manual drilling can provide safe drinking water. The equipment can easily be transported to remote, or difficult to serve populations which would otherwise be left behind. The lower costs compared to machine drilling are appreciated by households, businesses and governments: Manual drilling also provides local employment.

Manual drilling methods are being used to provide water for drinking and other domestic needs in at least 36 countries around the world. In some places, manual drilling methods are well established. In Bangladesh and India for example, millions of people in rural and urban areas use "tubewells" that were drilled manually.

In several African countries, manual drilling is also on the increase. Chad and Nigeria are two examples of countries where there has been a tremendous upsurge in manual drilling, with thousands of wells in use. In others countries, such as Malawi, manual drilling has been recently introduced. There is also considerable experience with manual drilling in Bolivia with an estimated 30,000 boreholes in use today.

There are examples of drilling techniques being adapted by private enterprises as well as development organisations to suit the local context within Africa. Experiences show that once manual drilling takes off, most boreholes are constructed for households and businesses as self-supply sources. Once established, manual drilling tends to operate in the informal and unregulated economy. Drilling supervision becomes virtually non-existent.

There is a wide spectrum of borehole designs in terms of diameter, casing and screen materials and sanitary seal. There are widespread concerns about the potential contamination of the shallow aquifers that have been tapped. Unfortunately, this is not backed up or refuted by synthesised information and analysis of water quality.

In many countries, lack of national guidelines and regulations (or poor enforcement) exacerbates concerns. Not all organisations that are promoting manual drilling consult or liaise with government, and there is a tendency (perhaps with the exception of Kenya) of promoting manual drilling in a vacuum rather than related to conventional drilling. Some organisations are promoting very low cost designs which may compromise the safety of a drinking water supply.

There is a growing popularity of manual drilling within certain countries, and also by several development agencies and philanthropists. For more than five years, UNICEF has been a key player in encouraging governments in Africa to consider manual drilling and support approaches that enable the work to be undertaken in a professional manner.

This compendium draws together experiences of manual drilling from 36 countries. It provides a synthesis of otherwise highly fragmented information, much of which has never been published in academic or even grey literature.

Take note – manual drilling is here to stay, and it is growing!

The compendium provides a useful overview for those wishing to further examine the impacts and challenges of manual drilling, and, more importantly, improve practices on the ground. It is hoped that the document will spur others to undertake further studies as well as research to document stories and analyse the promotion, uptake and use of manually drilled boreholes. In addition, the compendium should also enable those promoting manual drilling to realise that they are certainly not alone in their endeavours!

The profile of manual drilling among wider development and research communities should be higher than it currently is.

Abbreviations

ANEA	Agence Nationale de l'Eau et de l'Assainissement (Central African Republic)
ATPESFORC	L'association tchadienne pour la promotion des entreprises spécialisées en forage à faible coût (Chad)
ADPP	Ajuda de Desenvolvimento de Povo para Povo
AECID	Spanish Agency for International Development Cooperation
AMEC	Aerobombas de Mecate (Nicaragua)
DAPP	Development Aid from People to People
DGH	Direction Générale de l'Hydraulique (Central African Republic)
DGIS	Directorate-General for International Cooperation (Netherlands)
DPHE	Department of Public Health Engineering (Bangladesh)
EMAS	Escuela Móvil de Agua y Saneamiento (Bolivia)
EU	European Union
EW	EnterpriseWorks division of Relief International
EWV	EnterpriseWorks/VITA
FAMSI	El Fondo Andaluz de Municipios para la Solidaridad Internacional
GSB	Grupo de Saneamento de Bilibiza
GWASH	Ghana Water, Sanitation and Hygiene Programme
H2O	Hope 2 Others International
HEWASA	Health through Water and Sanitation (Uganda)
iDE	International Development Enterprises
IRC	International Rescue Committee
KEFINCO	Kenya Finland Corporation
LBDA	Lake Basin Development Authority (Kenya)
MSF	Médecins sans Frontières
ONEP	Office Nationale de l'Eau Potable de Côte d'Ivoire
PEPAM	Programme Eau Potable et Assainissement (Senegal)
PF	Practica Foundation

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RI	Relief International
SHIPO	Southern Highlands Participatory Organisation
TEECS	Tools for Enterprise & Education Consultants (Malawi)
USAID	United States Agency for International Development
UWASNET	Uganda Water and Sanitation NGO Network
VW	Village Water
WAI	Water for All International
WASH	Water, Sanitation and Hygiene

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1 Introduction

Groundwater sources comprise springs, hand dug wells or boreholes. In many countries, particularly in sub-Saharan Africa the use of groundwater as a source of drinking water has increased significantly over the last 20 years. A growing number of boreholes are being drilled manually. Manual drilling techniques use human energy, or a small pump to open a hole and construct a groundwater supply. Manual drilling can provide low-cost, but high quality water supplies. Recognising this, UNICEF and others have promoted the technology at global level as well as within several countries.

Not all formations can be drilled using manual methods. Sometimes the groundwater is too deep or the rock is too hard. However, where the formation comprises soft (unconsolidated) sediments or easy-to-break laterite and there is sufficient water at depths up to 35 meters, manual drilling may be a viable option.

The main advantages of manual drilling techniques are:

- **Cost**: the cost of manual drilling is significantly lower than for machine drilled wells (at 10 to 25% of the cost). This also makes it economically feasible for some small communities or households to pay for the water supply themselves.
- **Accessibility**: manual drilling equipment is light and transportable and can reach places where conventional drilling equipment cannot (Box 1).
- **Local economic development**: local employment and income generation from borehole construction contributes to the local economy by enabling productive uses of water at the household or farm.
- **Time savings & safety**: manual drilling allows construction of shallow wells faster than hand digging and does not require labourers to work underground.

"[Manual drilling]equipment can be reported to the site by bus, small four wheel drive pickups and animal pull carts making it possible to access difficult to reach terrain"
Mgina (2014)

However, any borehole, whether drilled manually, or with a machine, poses a health risk if it is not properly sited or constructed. The borehole needs to be positioned at a sufficient distance from contaminants such as latrines, septic tanks and graveyards. As a drinking water supply, it should also be sealed with quality cement grout to ensure that surface pollution cannot flow into the borehole. Well screens needs to be positioned correctly and the borehole should be properly developed so that water is free of particles and does not silt up later.

In many places, manually drilled boreholes were originally introduced to provide water for irrigation by tapping very shallow groundwater. The siting requirements, materials used and completion methods for agricultural wells are often a lower standard than would be expected for boreholes to provide safe drinking water. It is not unusual for farmers to drink water from their agricultural boreholes. However, there is considerable unease among specialists of the water quality of boreholes designed for agricultural use.

Manually drilled boreholes provide a significant proportion of drinking water for Bangladesh's, India and Nepal's rural (and to a lesser extent urban) populations. A vibrant manual drilling industry has developed in Nigeria over the last 25 years. Chad and Bolivia are following suit. In Bangladesh, Chad, India, Madagascar and Nigeria, most of these manually drilled boreholes are bought by households themselves. In other words, self-supply.

In the countries where manual drilling has become widespread, most enterprises operate in the informal economy with minimum or no regulation. Over the last two decades, manual drilling techniques have been introduced, or become established in over 30 countries in sub-Saharan Africa. Technological know-how is being spread by development agencies as well as private enterprises as they cross national borders. Time will tell whether these initiatives will result in widespread use of the technology, and what construction standards will be followed.

Nevertheless, manual drilling is likely to take on an increasingly important role in drinking water supplies as its potential becomes more apparent and households decide to invest in their own water supplies. This publication synthesises experiences and challenges of manual drilling for drinking water from around the world. It documents a technology that operates mainly in the informal economy, and where recent introduction efforts are scattered between numerous small projects.

This compendium is an output of the collaboration between UNICEF and Skat Foundation within the Rural Water Supply Network (RWSN). The work is part of RWSN's theme on Sustainable Groundwater Development and UNICEF's initiative to professionalise manual drilling in Africa.

The compendium draws extensively on the findings of an online survey (Danert, 2013); interviews and email exchange with key informants; contributions to RWSN's online manual drilling community; grey and published literature; a series of five webinars in 2014 sharing experiences from 12 countries and field work by the author in Chad, Niger, Nigeria, Sierra Leone and Uganda. The compendium is structured as follows:

- Chapter 2: overview of the geological and hydrogeological conditions where manual drilling is feasible.
- Chapter 3: manual drilling methods.
- Chapter 4: the basics of good borehole design, key challenges and manual drilling specifications.
- Chapter 5: technology introduction and uptake,
- Chapter 6: context, history and extent of manual drilling uptake in 16 countries.
- Chapter 7: reflections of professionalisation of manual drilling, cost-effectiveness and recommendations.
- Annex 1 and 2 synthesise available information on manual drilling for drinking water supplies for 37 countries.

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Box 1: Examples of Manual Drilling in Remote Places

Manual drilling is providing water supplies in areas which cannot be reached by conventional drilling rigs. These are typically remote areas, with poor or seasonal road access, islands or areas with security concerns. Some examples are given below:

- In January 2013, manual rotary jetting was in used in Kwamekwaa village, Assin North Municipality, Central Region, **Ghana**, where there was no road. A conventional rig would have had to cross two streams and cut down portions of a cocoa plantation to reach the drilling site (Naugle, 2014a)
- "Water4, in collaboration with the University of Shalom in Bunia **Democratic Republic of Congo** is currently finishing the 4th well of 20 [planned] in remote regions of the Ituri Rainforest in recently resettled Mbuti Pygmy populations. Teams are often walking 8 miles on freshly cut foot-paths, over large downed trees, floating in dug-out canoes across rivers, to work in the rainforest there" Hangen (2014a)
- Manual drilling is providing a viable alternative in parts of Western **Zambia**, where off-road access is very difficult due the sandy conditions. Crossing the Zambezi river is another challenge. In Luapula Province in **Zambia**, people on the Lake Mweru Islands, Nchelenge district now have their first communal well. It is possible to transport manual drilling equipment on "banana boats", carved out of large tree trunks (Abuuru, 2014). A total of 33 wells have also been drilled on Mbabala and Chishi Islands, on Lake Bangweulu, reducing risks of crocodile attacks when collecting water (Carmen, 2014)
- Machine drillers refused to go to parts of **Chad** because of insecurity for their rigs in the region. Manual drilling was undertaken as an alternative (Gaya, 2015)
- Increasing access to safe drinking water on islands with manual drilling is what Wilammette International is doing in **Sierra Leone**

Figures clockwise from top right:

Manual rotary jetting in Kwamekwaa village, Central Region, Ghana (Source: Jon Naugle)

Handmade bridge to the Village of Omondjua, Togo where teams walked 5 miles to drill (Source: Matt Hangen)

Carrying Drilling tools into the Ituri Rainforest, DRC (Source: Matt Hangen)

With a Population of 14,000, the people on the Lake Mweru Islands, Luapala Province now have their first two productive boreholes thanks to manual drilling technology

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2 Where is manual drilling feasible?

Favourable conditions for manual drilling in terms of geology and hydrogeology are usually found in:

- Low lying areas of loose unconsolidated sediments (e.g. Ganges Plain, Coastal Plain Sands of Nigeria and the Chad formation).
- Highly weathered crystalline rocks (also referred to as rego-lith, or the overburden) above the bedrock.

Studies by UNICEF et al (nd) and others indicate zones within 14 countries where manual drilling is highly feasible (Table 1).

Table 1: Manual Drilling Potential for Select Countries[i]

County	Areas of High Potential for Manual Drilling
Benin	Sediments of the coastal basin in the south. Sedi-ments in the north-west and north east. Alluvium river deposits (UNICEF et al, nd-a).
Central African Republic	Sediments and alluvium in the north of the country (UNICEF et al, nd-b).
Chad	Large parts of western and south-western Chad. Parts of the east on the sediments surrounding seasonal water courses (MEERH, nd & Danert, 2014).
Guinea	West coast and eastern and southern regions (GRAIA, 2012).
Ivory Coast	Sediments of the south –eastern coastal fringe and pockets within central and western Ivory Coast. However, there are concerns about groundwater pollution by nitrates and phosphates in the Abijan Basin. (UNICEF et al, 2009a).
Liberia	Sediments within the north and central Liberia and along the coastline near Monrovia (UNICEF et al, nd-c).
Madagascar	Along the east coast and within the western sedi-mentary areas (Abric, 2014b; MINEAU, nd).
Mali	Sediments and alluvium of the Inner Niger Delta and along the Niger, and Bani rivers (UNICEF et al, nd-d).
Mauritania	Within the: west (oasis zone in the Taoudeni basin), south-west (alluvium along the Senegal River), south (Aioun, Tintane, Kankossa) and east (Aouker) (UNICEF et al, nd-e).
Niger	Alluvial deposits close to major rivers in Maradi, Tahoua and Tillabéry; sediments around Lake Chad; sediments towards the north-east of Zinder; sedi-ments in north and north-east Niger (MEELCD, nd).
Senegal	Mid to north west coast (UNICEF et al, nd-f), Kane et al (2013).
Sierra Leone	Unconsolidated sediments along the coast (the Bullom Series) and the inland valley swamps that overly the crystalline basement (Adekile, 2014)
Togo	Parts of the weathered material within the north of the country are classified as favourable (not not highly favourable (Ministre de L'Eau, 2009).
Zambia	Primarily in the sediments of Western Province (MLGHEEEP, 2011).

3 Technology

Basic Principles

All drilling techniques must be able to penetrate the formation, remove loose material and support the hole from collapse (Box 2). Human energy limits what manually-powered drilling can achieve. Unconsolidated materials such as sands and silts re-quire relatively little energy to penetrate. Materials such as clays, laterite, sandstone and limestone require considerably more energy to break and remove.

Box 2: Basic principles of water well drilling (Carter, 2005)

The formation can be broken by:

- Percussion (repeated striking of the formation with a pick, chisel, end of pipe or a drill bit).
- Rotary action (grinding or tearing at the surface of the for-mation). This can be combined with percussion.
- Loosening by a water jet directed at the bottom of the hole.
- High energy percussion with rotation (known as down the hole hammer – used for machine drilling only).

Removal of the loose material from the hole can be done by:

- Alternate removal with breaking (ie break, clean, break again, clean and so on).
- Continuously remove material as the drilling proceeds by using a medium to flush the hole (eg water, drilling mud, compressed air). Mud-rotary drilling uses mud; well-jetting, wash-boring and sludging use water and down-the-hole hammer uses compressed air.

Supporting the hole to prevent collapse during, or immedi-ately after drilling is achieved by:

- Lining the hole as the drilling progresses with temporary casing, or permanent lining.
- Maintaining a sufficient pressure (hydraulic head) of fluid in the hole at all times.

Minimising drilled diameters and limiting depth reduces energy requirements. A tripod (or derrick), equipped with a pulley or lever can enable manual drilling techniques to penetrate deeper than relying on the direct human energy to lift and drop a drill pipe and remove drill cuttings.

In cases where the formation is too hard, or the water-bearing formation too deep, conventional drilling may be preferable to manual drilling.

The depths of formation that manual drillers are prepared to drill vary. Extremes include 100 meters in Bolivia and 250 meter depths in Bangladesh. However drilling depths of up to 40m are common in other countries. Depths are also limited by the ca-pability of the pump that is subsequently installed for the water supply.

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Methods

Manual drilling comprises four methods, or techniques which are often used in combination:

- **Augering & Bailing**- penetrating the ground with a cylindrical or helical soil auger. Either the auger itself or a bailer is used to remove the loose materials. Augering can penetrate certain sands and silts and some clay formations. Very little water is required to remove the drilling spoil.

Figure 1: Auger bit for a Vonder Rig (Source: Kerstin Danert)

- **Jetting** – injection of fluid (water, sometimes mixed with thickeners known as drill mud) down and out of the bottom of a drilling pipe to wash the spoil up to the surface via the annulus (i.e. the gap between the drill pipe and drilled hole). Considerable amounts of water are used. Jetting (also known as washboring) equipment uses a small petrol pump or manual pump to inject the fluid down the drill pipe. There have been a number of improvements of the original "rapid well jetting technique" including:
  - Self-jetted well-screens
  - Additives to the water to stabilise the hole
  - Improved drilling bit and rotary arm to grind compact materials

Figure 2: Drill Crew undertaking well jetting in Nigeria

- **Percussion & Bailing** - lifting and dropping a cutting tool suspended at the end of a rope. The cuttings are usually removed with a bailer. Only a little water is added to remove the spoil. Cable tool rigs use a motor and winch to help lift and drop the cutting tool. In Nepal, this technique is referred to as "stonehammer" drilling. A driven well is a variation of percussion and involves driving a well point and well screen directly into the ground using a hammering tool. The material is forced aside rather than excavated by this technique. Driven wells are sometimes used in conjunction with hand augering.

Figure 3: Percussion Drilling in Niger (Source: Richard Carter)

- **Sludging** – is a continuous drilling method. The drill stem, fitted with a cutting shoe is lifted and dropped into the hole to loosen the formation. Drilling fluid (water, mixed with thickeners known as drill mud) flows down the annulus (i.e. the gap between the drill pipe and the drilled hole) and carries the cuttings up through the drill pipe. A hand placed at the top of the drill pipe acts as a flap valve to release the drilling fluid and cuttings. Alternatively a check valve is sometimes used at the bottom of the drill pipe to achieve the same result. As with jetting, sludging requires considerable volumes of water.

In the case of the jetting and sludging techniques, the hole is generally kept open by the hydraulic pressure and wall-coating ability of the drilling fluid (i.e. water which may be mixed with additives to thicken it). Temporary casing is needed in cases where there is a loss of circulation (i.e. the drilling fluid is lost in the hole). With augering and percussion drilling, temporary casing is required once the drilling is below the water table.

Figure 4: Sludging in Chad (Source: Sylvia Gaya)

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Toolkits

The above methods may be used alone, or in combination with others:

- "... a simple 2-4m auger set....to remove the 'soft' top soil and to set a guide/support for any drill bit. It is very quick and helps with the circulation of water once starting to jet or sludge. ... There is also a combination of jetting ... in soft layers of clay and sand... When formations become more consolidated, a more percussive action is used .... In such a system the drill pipes and bit are of the same system, but a weighted pipe is added and a lever is used for the up and down motion (Vuik, 2014a).
- "If [a well drilling businesses] drills locally, they gravitate to a small set of tools that work best under their prevailing drilling conditions and abandon the rest. However, where the drillers work over a broader range of geological conditions they may use a wider variety of tools overall, but still specific sub-sets of the tools for each location... it is not uncommon in Senegal to drill a starting hole using augers and then use a combination of rotary jetting and percussion depending on the strata encountered" (Naugle, 2014a).

The last 40 years have witnessed considerable innovation with respect to manual drilling. Today there are several manual drilling kits or brands that can either be bought "off the shelf", or manufactured by following manuals, drawings or videos (Table 2).

Table 2: Methods used in Select Manual Drilling Kits

Method / Toolkit/Brand	Augering & Bailing	Percussion & Bailing	Jetting	Sludging
Baptist Kit		X		X
Driven Well		X*		
Donkey drilling			X	
EMAS Kit		X	X	X
Flo- Flo		X		
MaDrill Kit		X	X	
Rota-sludge		X		X
Rotary jetting		X	X	
SHIPO Kit		X	X	X
Vonder Rig	X			
Water4 Kit	X	X	X	
Water Requirement	Very little		Considerable volumes	

* There is no bailing for a driven well.

New kits for manual drilling have recently been developed and brought into use, but it is too early to comment on their uptake. The Village Drill is an example, which uses jetting and rotary principles, i.e. injection of water to flush out the cuttings combined with a turning action (WHOlives, 2014).

In Lagos, Nigeria, some manual drillers have improved their jetting equipment to incorporate aspects of percussion (Danert et al, 2014) The rota-sludge uses the sludging technique combined with a rotating action to grind compacted materials. EMAS uses jetting with a rotary action.

More details on manual drilling techniques are available from:

- Blankwaardt (1984)
- RWSN (2014)
- Akvopedia (2014a)
- Practica Foundation (2010a; 2010b; 2010c; 2010d)

Some of the American and European-based organisations as well as private enterprises that have been recently promoting, or learning about manual drilling have little knowledge of practices elsewhere or of machine drilling. They thus end up facing technical problems that have already been faced and solved elsewhere (Box 3).

RWSN's online manual drilling community (available from https://dgroups.org/rwsn) enables experiences and ideas to be shared. However, this is no substitute for on-the-job technical training and mentoring by experienced professionals.

Box 3: Solutions to Common Technical Problems

Poor Siting

A basic understanding of hydrogeology, coupled with the collection of drill samples will enable drillers to improve their siting skills. Drilling a test well with a small diameter test auger can also help the identification of suitable areas – particularly in relation to hard layers.

Formation Collapse

Wells can be stabilised with polymers, including those which are used in the mines in Zambia. Drillers in Nigeria use light cement-slurry. Temporary casing can also be used to stabilise the hole although it can be difficult to remove manually depending on the depth of installation and equipment. Cow dung is also used in some places, but is controversial due to concerns about water quality in the short term.

Drilling Vertically

A guide can be used that is part of a tripod or a drilling table. This is a standard aspect of the Vonder Rig design. For other equipment some redesign may be required.

Clogging of the screen in very fine sands

Polyester, or other synthetic filter cloths have been used to cover the screens and prevent the ingress of fine sands in Niger. Notably the formations do not contain clay or silt which would otherwise plug the cloth.

Lack of Factory-slotted screens

Obtaining factory-slotted screens has proven to be a challenge in many countries. A slotting machine that can be used in-situ (developed in Senegal) allows screen slots to be more uniform than handmade slots.

Borehole pumps muddy water

Correct borehole design is essential to ensure a productive well. This includes the correct placement of screen next to the aquifer, hole verticality (see above), a gravel pack that is course enough to allow the finer particles through when the well is developed, fine enough to retain the rest of the aquifer material and homogeneous to allow water to pass through freely. The borehole also needs to be properly developed.

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Table 3: Suitable Formations for Manual Drilling Methods

	Unconsolidated			Consolidated
	Silt, sand & gravel	Clay	Soft weathered rock	Basement rock
Augering & Bailing	Yes	Limited	No	No
Jetting	Yes	Yes	No	No
Percussion & Bailing	Yes	Yes	Yes	No
Sludging	Yes	Yes	No	No

4 Borehole Design and Installation

Designs of manually drilled boreholes vary between and within countries. Table 4 sets out the key official parameters where standards have been set. There is scope for improvement, particularly with respect to design and borehole development.

Even if governments have published official technical specifications for manually drilled wells, there is very little monitoring or reporting on adherence.

Table 5 summarises the implications of poor quality borehole construction. These apply to both machine and manually drilled boreholes.

Supervision of the borehole construction by qualified and experienced personnel is arguably the only way to ensure that construction standards are maintained by the driller.

However, in the countries where manual drilling is widespread, most boreholes are constructed for private households who are not familiar with construction standards or do not know about the importance of drilling supervision or what it entails. What the household wants is an accessible and affordable water supply.

In Chad and Nigeria, supervision, of private boreholes, if carried out at all, is undertaken by building construction supervisors, who have no training on how to supervise drilling. Anecdotal evidence from Nigeria (Danert et al, 2014) suggests that the construction quality of manually drilled wells depends on what the drillers know as good practice, what they are prepared to do, and what their clients are prepared to pay for.

Table 4: Excerpts from Specifications for Manually Drilled Wells

County	Specifications
Chad (MPHVP et al, 2009)	Specifications for manually drilled wells: ■ 6 inch diameter ■ <5% deviation from the vertical ■ uPVC casing (certified to international standards) of 100 mm inside diameter, min wall thickness 5 mm ■ Factory fabricated screens (0.5 to 1.0 mm depending on sand particle size) ■ Surface seal – grout mix to to 5m depth
Guinea (SNAPE et al, nd)	Specifications for manually drilled wells: ■ 6 to 8 inch diameter ■ <5% deviation from the vertical ■ Depth: 8 meters below static water level in dry season; or specified for west, east and south. ■ Screen placement to align line with aquifer. 3 to 6 m length depending on aquifer properties ■ Development time specified (2 hours) at 1m^3/h for first hour followed by 2 m^3/h rather than clearness of water.
Nigeria	■ No specifications for manually drilled wells – but national Code of Practice for water well drilling in general
Kenya (Adenya, 2014)	Specifications for manually drilled wells: ■ 8 inch drilled diameter ■ 6 inch casing (pVC or steel) ■ Pre-slotted or manually cut screen ■ 5mm course sand for gravel pack ■ 6m grouting/sanitary seal
Sierra Leone (Moijue and Goba, 2014)	■ No official national standards exist ■ NGOs promoting manual drilling use very different standards: ▪ Willamette: 7" hole, installed with 4" PVC ▪ Welthungerhilfe: 2" diameter drilled hole installed with Canzee Pump

Table 5: Key quality issues for drilling construction (manual and machine drilling)

	Good Quality	Poor Quality	Implications of poor quality
Siting	At least 30 meters from contamination source	Close to latrine, septic tank or soakaway	Borehole contamination; aquifer contamination. Risk of cholera!
Depth	No inflow of surface water	Tapping very shallow water levels	Borehole contamination; aquifer contamination. Risk of cholera!
Casing	Grade 3 uPVC pipe	Waste disposal pipes	Borehole collapse & slots cannot be properly cut.
Screen	Factory slotted screen	Poor hand slotting on site	Lower yield due to clogging
Gravel Pack	Sieved and washed sand of appropriate particle size	Unwashed, un-sieved river or beach sand	Fine materials flow into well and water is turbid and takes long to develop
Sanitary Seal	Cement grout to 5 or 6 meters below ground level	No grout, or less than 5 meters of grout	Borehole contamination; aquifer contamination. Risk of cholera!
Borehole Development	Develop until water is clear and sand free	None or inadequate	Turbid water, sandy water, reduced lifespan of pump.

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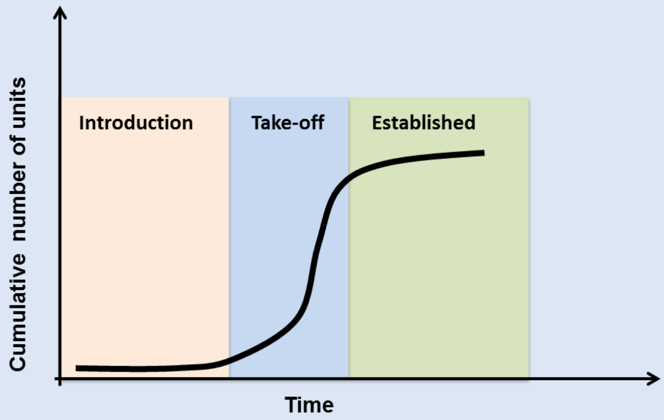
5 From Innovation to Widespread Use

Diffusion of Innovation is an entire discipline that looks at how new ideas or technologies are taken up and spread. In order to better understand the uptake of manual drilling in different contexts, the three main stages of innovation diffusion provide a useful starting point (Box 4).

Box 4: Three Stages of Innovation Diffusion

Innovations, whether Bronze Age tools, paper, or mobile phones take time to be taken up on a large scale. The time taken varies from years to decades and even centuries. However, there is consensus that technology uptake, if it is successful at all, generally passes through three stages:

- Invention or introduction – when a technology is developed and tested or introduced into a new context. At this stage, the uptake is quite low.
- Take-off (or tipping point) - when there is a sharp increase in the number of people adopting the technology, often copying others.
- Established – when the technology is common, generally accepted and widely used.



The take-off stage is also referred to as the "valley of death" as the transition from testing and introducing a technology to its widespread establishment is extremely difficult, and, within the context of products for the poor, tends to be under-resourced.

Understanding these three stages can help those that are promoting manual drilling to be better prepared for the different opportunities and problems encountered over time:

- In the early years of introduction, influential leaders may need to be convinced that manual drilling is a viable technology. Selecting suitable sites can be a challenge (failure rates can be high) and there may be difficulties in obtaining the necessary equipment and materials. Targeted and carefully applied subsidies may be useful at the introduction stage.
- At the stage at which the technology takes off, demand can outstrip supply, and entrepreneurs with little technical expertise jump onto the bandwagon to try and make money. This can lead to poor quality workmanship which can damage the reputation of manual drilling. Alternatively, the trained and equipped drillers are not able to generate enough work, lose motivation and turn to other activities (i.e. the "valley of death" scenario in Box 4). Knowledge by the enterprises of marketing, business development, financial management, record keeping and business ethics, as well as the formation and nurturing of associations to self-regulate is vital.
- Once manual drilling methods have become established and are widespread, quality assurance can continue to be a problem. Problems of over-abstraction of groundwater may also emerge depending on the level of abstraction and rates of recharge. Groundwater resources monitoring as well as regulation of abstraction is recommended.

Generally, policies and regulation are not able to keep up with the expansion of manual drilling. In the meantime, populations benefit from more accessible water supply sources. Overly strict regulation can prevent the spread of manual drilling before it gets started.

Countries (as well as parts of countries) can be categorised according to the extent of manual drilling diffusion (Figure 5) and the examples below:

- In **Bangladesh, India** and **Nepal** manual drilling techniques are well established. Over 130 and 500 million people respectively depend on tubewells in Bangladesh and India for their drinking water supply. In Bangladesh, most of these were drilled manually. In some parts of **Nigeria** and **Niger** jetting is fully established.
- In parts of **Chad** well jetting has become established. Over the last 10 years, there has been a rapid expansion in the number of enterprises offering manual drilling services, particularly in the growing capital, N'Djamena. The uptake is being driven by private users and the private sector. Manual drilling seems to be taking off in **Kenya**, where techniques have been introduced in different parts of the country by various agencies.
- In **South Sudan and Uganda** hand augering was undertaken in the 1990's within drinking water supply projects. In **Uganda**, other manual drilling techniques are currently being introduced by development agencies. In South Sudan there are efforts to use old equipment.
- Over the last 10 years, manual drilling has been introduced into over 15 countries in Africa (Annex 1 and 2 and Figure 5). Techniques are mainly being introduced through relatively small-scale projects. Not all initiatives are well documented or have been followed up after the project leaves. Technology introduction is being undertaken by private drillers from within Africa as well as by American and European organisations.
- In countries where manual drilling has been introduced in the past 5 to 10 years, a suite of techniques rather than one specific method is being promoted. This is different from India where manual drilling is synonymous with sludging, or Nigeria where it is synonymous with jetting.

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6 Country Overview

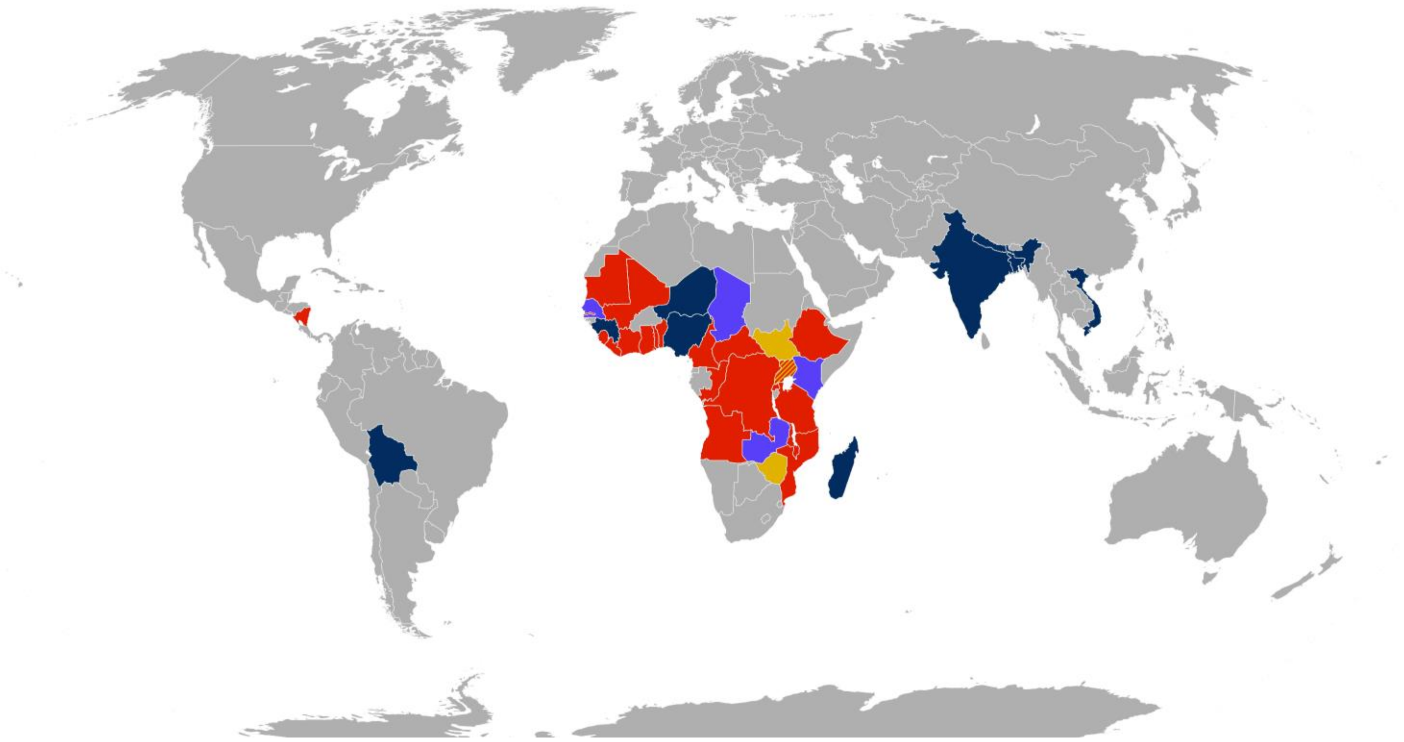
Manual drilling is a subject which has received very limited research. Most data and case studies are found in the grey literature such as project documents or in people's heads. In cases where NGOs are promoting manual drilling techniques, the information in the public domain is intended for fundraising. It does not include detailed documentation or analysis. In cases where manual drilling is an established technology, this is firmly in the hands of local private enterprises, and the householders who pay for the boreholes construction.

This compendium pulls together information on the extent and status of manual drilling from around the world. Figure 5 shows the countries where manual drilling is, or has been undertaken. The countries have been colour coded according to whether manual drilling methods are established, taking off, have been introduced, or were introduced in the past, but are not longer used extensively. This chapter summarises what is known about manual drilling, including its history and how it fits within the wider national context.

The countries are grouped according to the different stages of innovation (Box 4) as well as past use. A summary of the manual drilling story and key information is provided for 16 countries. Annex 1 and 2 set out key data, where available for 36 countries.

The compendium provides a useful overview for those wishing to further examine the impacts and challenges of manual drilling, and, more importantly, improve practices on the ground. It is hoped that the document will spur others to undertake further studies as well as research to document stories and analyse the promotion, uptake and use of manually drilled boreholes.

Figure 5: Extent of Manual Drilling for Domestic Water Supplies Today



Key

- Manual drilling is established
- Manual drilling is take-off or tipping point
- Manual drilling introduced (by development agencies or private enterprises from neighbouring countries)
- Manual drilling was used in the past
- Not covered by compendium

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A. Countries where manual drilling is established

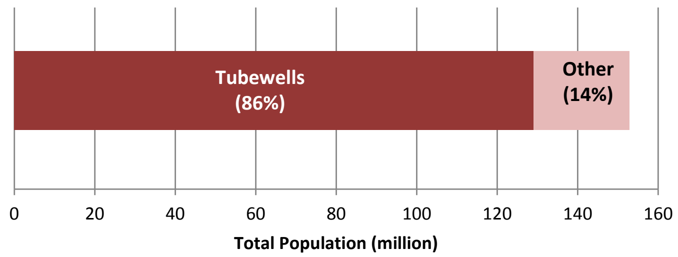
Manual drilling technology is established in Bangladesh, Bolivia, India, Kenya, Niger, Nigeria and Madagascar as summarised in the text below as well as in Annex 1 and 2.

Bangladesh

Groundwater dependency

In Bangladesh, almost 130 million people depend on tubewells for their drinking water (NIPORT et al, 2013), most of which were drilled manually. In rural areas, 96% of the population drinks tubewell water. It is estimated that there are about 10 million private and 1 million public tubewells (BBS 2011). 72% of the population has drinking water on their premises and 24% take less than 30 minutes to obtain it (BBS, 2011). Household tubewells relieve the burden of fetching water from long distances and can be used for productive purposes. On the other hand there are concerns about the safety of some sources.

Figure 6: Sources of Drinking Water in Bangladesh (NIPORT et al, 2011)



Groundwater Resources and Water Quality

Bangladesh is positioned across the delta of the Ganges, Brahmaputra and Meghna rivers. The hydrogeology of the delta area is complex and many layers of sand, silt and clay create more than one aquifer in any given vertical column of, say, 100m depth. This creates opportunities to tap uncontaminated aquifers at depth. However, careful placement of well screens is required to avoid mixing these aquifers.

Studies of water balance indicate that there is sufficient groundwater availability for water supply, apart from constraints along the north-western and north-central parts, especially beneath the Pleistocene clay deposits. The lowering of groundwater, due to over-abstraction, in and around Dhaka city is a specific problem (MLG, 2011). When the level drops below 7m, water can no longer be lifted by cheap, easy to maintain suction pumps.

Despite the widespread availability of shallow groundwater, many of these aquifers are unsafe due to naturally high levels of arsenic (Table 6). It is estimated that about 12.6% of tube wells have high arsenic concentrations, exposing approximately 20 million people to excessive quantities (UNICEF, 2010a). Contamination from human discharge and high levels of manganese and iron are also problematic in some parts of Bangladesh. Saline groundwater can be found along the coastal fringe, and in inland deep aquifers containing fossil seawater.

Table 6: Arsenic level in household drinking water (BBS 2011)

Classification	%
Population using an improved drinking water supply	97.8%
Population using an improved drinking water supply (following Bangladesh national standard of < 50 micrograms of arsenic per litre)	85.5%

Manual Drilling Industry

Tubewells have been drilled using the sludging method since at least the 1960s in Bangladesh. UNICEF worked with the Department of Public Health Engineering to install them in the 1970s. The 1980s saw widespread uptake by the private sector, who installed millions of tubewells. By 2000, an estimated 80% of the population used tube wells for drinking water (Smith et *al*, 2000). By 2011 it was 86% of the population (NIPORT et al 2011).

There has been an explosion of self-supply in Bangladesh since the mid-1970s which has gone largely unregulated (WSP, 2000). It is estimated that there are eight times as many private shallow wells in rural areas compared to public ones (MLG, 2011).

Early hypotheses suggested that groundwater development was in part responsible for the widespread arsenic contamination of the shallow aquifer; later research has convincingly shown that arsenic occurrence is natural and pre-dates the large-scale installation of both irrigation and drinking water tubewells in Bangladesh (Johnston, 2014).

While manual drilling in Bangladesh has traditionally tapped shallow aquifers, deep tubewells (>150m) are becoming more prevalent. These are constructed using what is locally called "donkey pump drilling". Traditionally drilling mud was circulated by a mechanical piston pump but now most drillers use diesel-operated pump for mud circulation. The Bangladesh Sector Development Plan (MLG, 2011) points to over 230,000 public deep tubewells plus another third that are private. Water quality test results show that only 60% of deep tube wells meet Bangladesh standards for arsenic, manganese and iron (MLG, 2011).

Manual drilling in Bangladesh is primarily in the informal sector. One concern raised by public health experts is the use of cow dung (gobar) as a drilling thickener for both shallow and deep installations.

Box 5: Manual Drilling to greater depths in Bangladesh

Deep tubewells are commonly drilled to between 250-320 meters using manual methods for a cost of less than US $1,000 (including drilling, well components, and pump installation).

Workers balance on 8-10 meter high bamboo scaffolding (Figure right) to hoist a hose that injects water from a circulation pump into the hollow stem connected to a drill bit that is rotated continuously by men. A team of ten men can reach 300 meters in two to three days (Annis, 2013).

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Bolivia

Groundwater Dependence

The incredible height of the Andes Mountains is the dominant image of Bolivia and its geology. What is less known is that an estimated 71% of the population relies on groundwater for potable water (University of Calgary, 2005).

According to the University of Calgary (nd) Bolivia's groundwater is under-utilized, poorly mapped and poorly protected. Most of the country sits on sedimentary formation (Cortez 2012), of which a large proportion is unconsolidated. In areas with relatively shallow water tables, this soft material provides ideal conditions for manual drilling.

Manual Drilling History & Industry

Low-cost water supply technologies date back to the mid-1970s, when manual drilling and pump techniques were introduced by a Mennonite missionary organisation. In 1983 EMAS (a Spanish acronym for Mobile Water & Sanitation School) started to develop manual drilling techniques and low cost hand pumps and train local enterprises (Box 6). Additionally, Terry Waller of "Water for All International" developed the "Baptist" drilling technique in 1993.

Box 6: EMAS Strategies for Promoting Manual Drilling

EMAS trains local independent technicians from across Bolivia. The training, which takes a month, is subsidised by EMAS and is carried out 1-2 times per year (often co-sponsored by the Bolivian Government). There are also extensive training materials available on the internet (see http://vimeo.com/emas), and videos are broadcast on Bolivian television.

Figure (above) EMAS Percussion-Jetting-Rotation manual drilling, Trinidad, Beni region (Source Mike MacCarthy)

MacCarthy (2013) estimate that 30,000 to 35,000 manually drilled wells have been installed in households throughout Bolivia using EMAS methods. About 75% of these wells have been completely financed by small private farmers and ranchers. The remaining 25% have been financed by public institutions and are used for drinking water. A few thousand "Baptist" manually drilled wells have also been installed, primarily in eastern Bolivia.

There are an estimated 50 to 100 small enterprises currently constructing EMAS systems (Buchner and MacCarthy 2013). Usually family members provide unskilled labour to help keep the costs down. Drillers are not regulated, with most clients paying for the work themselves. According to Buchner and MacCarthy (2013), word travels fast if standards are high.

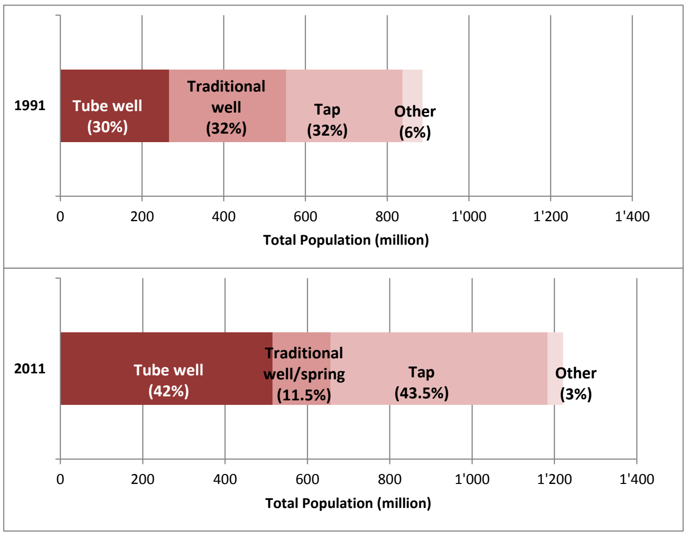
Since 2005, the Government has been working on a presidential decree that would require all water wells drilled in Bolivia be registered with the government. According to the draft decree, water well drillers are to be properly trained and drilling information would be collected according to a standardized format and entered into a water well database. If the decree is to be effective, considerable support will be required for its implementation.

India

Tube well dependency

In India, the proportion of the total population relying on tube wells for their drinking water rose from 30% to 42% between 1991 and 2011 (JMP, 2013). Today, tubewells supply over half a billion people with their drinking water.

Figure 7: Sources of Drinking Water in India (JMP, 2013)



The sheer numbers of private manually drilled wells for drinking water in India dwarfs current efforts in Africa. There are no state wide inventories of the number of privately owned hand drilled tube wells, only estimates:

- Sinharoy (2014) estimates that today there are over two million tube wells for drinking water supply and 600,000 irrigation wells in West Bengal alone.
- Daw (2013) takes the northern State of Uttar Pradesh with a population of 200 million and makes a conservative assumption that 5% of the population have their own manually drilled tube wells, serving a family of ten people. This would mean one million manually drilled tube wells in Uttar Pradesh.
- Dave (2014b) estimates that a million new tube-wells (drilled manually) are drilled in India every year.

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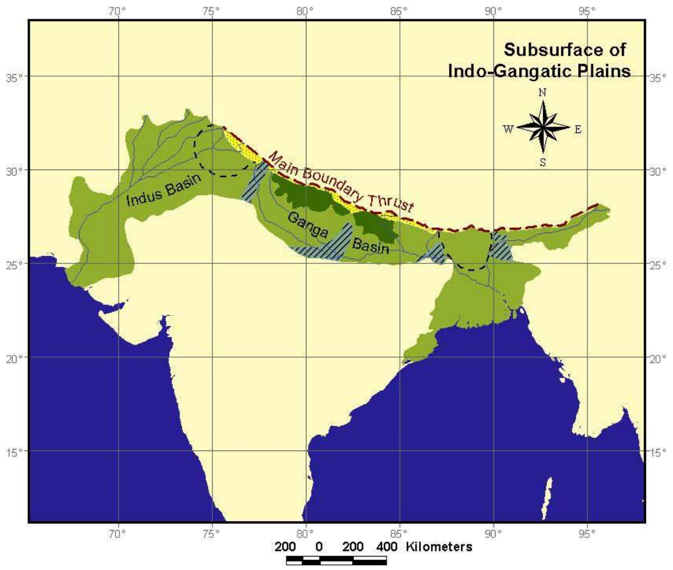
The WASH Network estimates that 15% to 20% of India's population continues to use their tube wells despite the fact that they have another improved water source as their primary supply (Dave, 2014a). This is attributed to unreliable public services, lack of assurance regarding water quality (World Bank, 2010) and the fact that not all community members are able to access public supplies.

Groundwater resources

India's tube wells are constructed either by drilling machines or using manual drilling methods i.e. sludging, jetting, and augering (Daw, 2014). In areas with soft formation and shallow water tables, manual drilling has contributed to fulfilling the drinking water needs of millions of people. Such formations are particularly found in the Indo-Gangetic plains and the eastern coastal areas (Figure 8).

Figure 8: Areas with alluvial strata where manual drilling is popular



Groundwater, including through manually drilled wells, is also used for an estimated 60% of India's irrigated agriculture. World Bank (2005) notes that if current abstraction trends continue, within 20 years, 60% of all aquifers in India will be in a critical condition. The enactment of groundwater legislation and promotion of rainwater harvesting measures are among the steps being taken by some states to address groundwater depletion (Meenakshisundaram 2011).

An indigenous and improved technology

Sludging is an age-old practice in India, undertaken by local enterprises, known as mistries. It was the expansion of irrigated agriculture that encouraged more entrepreneurs to engage in it to support their livelihoods. From irrigation manual drilling subsequently expanded to provide drinking water supplies to households.

The Danida-assisted Odisha (then Orissa) Drinking Water and Sanitation Project (1985-1994) introduced well jetting, as well as improved practices of: sealing off different aquifers, using bentonite rather than cow dung slurry as a drilling fluid, taking drilling samples, preparing drill logs, well cleaning. The project itself undertook considerable documentation and research, but this was before the digital age and much of it seems to be scattered or may even be lost.

However, Daw (2014) and Dave (2014b) believe that the Odisha project may have been instrumental in improving construction quality and bringing manual drilling into the formal economy. The Public Health Engineering Department of West Bengal recently issued tender documents for jetted wells, including specifications for soil sampling, well "washing", water quality analysis and submission of reports. It is likely that other states are doing the same.

If estimates of a million new manually drilled wells per year are correct, this industry provides a livelihood for ten thousand local enterprises (assuming each enterprise drills 100 per year). Despite the tremendous contribution of manual drilling to the Indian economy, and to its drinking water supply in the form of private tubewells, reliable data, documentation and research remain remarkably low.

Dave (2014b) calls for modernisation of manual drilling in India with respect to well diameter, drilling fluid, well development, drilling techniques and pump technologies. However, with over half a billion tube well users, and thousands of enterprises, reaching out and raising awareness remains a formidable challenge.

Madagascar

Access to drinking water in Madagascar is estimated to be around 61% and 42% in urban rural areas respectively (MINEAU, 2012). The remoteness of some rural communities in Madagascar is particularly pronounced.

There is a significant unsubsidised self-supply market for "driven wellpoints" fitted with suction pumps in shallow alluvial aquifers, primarily along the east coast of Madagascar. MacCarthy et al (2013b) estimate that over 12,000 of these household systems, which use 'Pompes Tanys', or 'Pitcher Pumps' have been installed. In the eastern port city of Tamatave, there are over 50 independent, small-scale manufacturers of Pitcher Pump systems. Abric (2014a) raised concerns about the suitability of these supplies to provide potable drinking water and Akers et al (2015) raise concerns about lead poisoning from the Pitcher Pump components.

Well jetting in particular, was introduced Madagascar in 2004 with about 350 wells drilled over the subsequent two years. In 2006, rota-sludge technology was introduced to the country, with support from UNICEF/Practica. Over 2,000 manually drilled wells have been constructed in Madagascar using these techniques. About 63% of these have been drilled by private enterprises. About 94% of these wells were financed through WASH projects (Abric, 2014b).

A national map of manual drilling feasibility was published in 2010 (MEM, 2010). Abric (2014b) notes that the manual drilling efforts in Madagascar to date have not properly exploited the western sedimentary areas, which are likely to have a higher potential. To date the WASH projects that have exploited manual drilling have been concentrated in areas where weathering is relatively low and water is often rich in iron. Also, problems have been encountered in siting manually drilled wells for schools, given that many are located on elevations that are not always appropriate.

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Standards for manual drilling (referred to as "alleges" or "light" drilling) are included in the procedures manual of the Ministry of Energy and Mines (MEM, 2005) and include requirements for water quality testing, well development and pumping test as well as the sanitary seal. However, in practice, striving for low-cost solutions has been central for manual drilling in Madagascar with the result that these standards are not always adhered to. Stakeholders are currently undertaking improvements of well development but Abric (2014b) recommends that WASH projects should push for higher standards with respect to diameter, casing quality, drilling fluid and well development. Factory-slotted casing is not readily available.

Figure 9: Masons cut slots in casing in Madagascar

Niger

There is need to improve drinking water in the many small villages and hamlets of Niger, where people mainly drink from open ponds or traditional wells. Despite the dangers of consuming such water, communities that do not meet the national criteria of being populated by 250 or more inhabitants are not eligible for government-supported water supply improvements. Such hamlets risk being left behind. Another problem is the per capita cost of improving water is high for these small villages and hamlets. Manually drilled wells could be a solution for the small villages and hamlets where the technology is feasible.

Manual drilling is particularly suitable for the sandy, alluvial and soft formations of Niger, where groundwater is shallow (less than 40m). The technology is used extensively in Niger for irrigation (Danert 2006), with some manually drilled wells that were constructed in 1990 still in operation (Naugle, 2014a).

Since 2005 efforts have been taken to utilise manual drilling to provide drinking water (Box 7). However, national authorities need to be more convinced of the performance and the effectiveness of the technology before incorporating it into the national strategy for drinking water (Ministère de l'Hydraulique et al, 2009). This is an on-going process.

Box 7: Summary of UNICEF and Partner Activities to Promote Manual Drilling since 2007

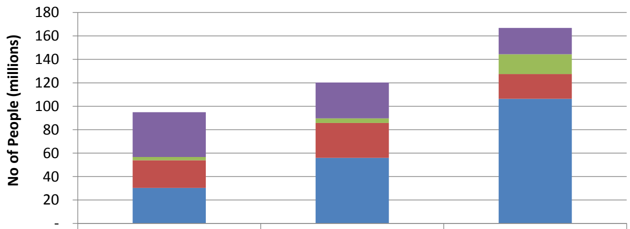
UNICEF and its partners have focused on Maradi and Zinder regions, where 290 and 35 wells respectively had been drilled by March 2014. These have been mainly drilled in the sedimentary formations, where there are shallow water tables (<40m). Drill depths range from 10m to 38m, providing 0.5 to 1.6m^3/h of water in Maradi and more than 4m^3/h in the Koromas in Zinder Region. There has been a focus on policy and institutional development from the outset. Key milestones are:

- 2007 - An Open Day on manual drilling for national and regional authorities as well as NGOs and other partners. This opened the eyes of many stakeholders who were not familiar with the technology.
- Training of artisan drillers and government staff on manual drilling.
- 2009 – study of the performance of the technology in order to integrate it into the national strategy, including (Ministère de l'Hydraulique et al, 2009):
  - Mapping of manual drilling potential, indicating many areas in the south of Niger are favourable, or moderately favourable for the technology (MEELCD, nd).
  - Water quality testing (by the regional Directorate of Water).
  - Proposed technical standards for manual drilling for drinking water.

Nigeria

Over the last 20 years, Nigeria has become increasingly dependent on groundwater, which is now estimated to provide drinking water for over 100 million people (from hand dug wells, boreholes/tubewells and springs). The popularity of boreholes for drinking water has grown enormously in the country, which were used by 32% of Nigerians in 2011 compared to 10% in 1999. Most boreholes drilled on the sediments in the south and north east of the country are constructed using manual drilling techniques.

Figure 10: Drinking water source used by population in Nigeria (Source: DHS 1990, DHS 1999, NBS/UNICEF 2013 in JMP 2014)[ii]



	1990	1999	2011
Surface Water	38	31	22
Cart/tank	3	4	17
Piped	24	30	21
Groundwater	30	56	106

Nigeria is witnessing a process whereby manual drilling (mainly jetting) for domestic water supplies is becoming a main-stream and accepted approach in the feasible areas of at least 25 of Nigeria's 36 states. Uptake of the technology is being driven

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primarily by households, but the public sector also contract manual drillers.

"[Manual Drilling] is the order of the day. Before you start building a house you must have money to put a borehole there"
General Manager,
Rural Water and Sanitation State Agency (RUWASSA),
Oyo State

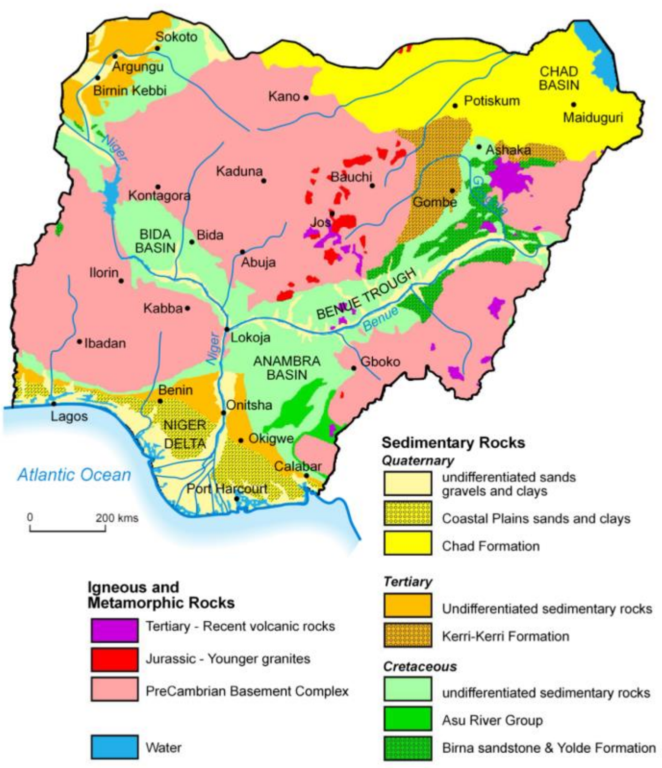
The soft sediments along Nigeria's coast, in the Niger Delta and the north and north east of the country are particularly suitable for manual drilling (Figure 11). However, manual drilling is also being undertaken in highly weathered material above crystalline rocks.

Manual drilling for drinking water supply in Nigeria was an adaptation of jetting for agricultural boreholes in the north and north east. In the south, the technology used to undertake seismic drilling was the origin. Recent innovations by the private enterprises are the use of a hardened drill bit and heavier drill pipe to penetrate compacted formations (Danert et al, 2014)

A recent study (Danert et al, 2014) estimated that there are about 200 enterprises, employing about 1,000 people as manual drillers in Lagos alone. Countrywide there may be thousands of enterprises and tens of thousands of manually drilled boreholes. In urban areas particularly, manually drilled wells fill the gap left by unreliable piped water supplies.

Water quality testing of manually drilled wells appears to be minimal, and there is no centralised information. The recent study by Kumpel et al (2014) found 29% of boreholes in Port Harcourt have detectable faecal contamination (Box 8).

Figure 11: A generalised geological map of Nigeria
(Adapted from MacDonald et al 2005)



Box 8: Water Quality in Port Harcourt (Kumpel et al, 2014)

Over 600 samples were collected from approximately 400 locations in Port Harcourt, representing all of the city's hydraulic zones and covering both planned and unplanned areas (informal settlements or slums). Samples came from taps, household storage containers, or from sachet or bottled water brands supplied by the respondents or purchased nearby. The main study finding is that despite the fact that the city's piped supplies reaches very few people, residents still manage to obtain drinking water with relatively low levels of contamination.

The heath-based target for faecal coliforms is 1 cfu/100mL. Of the samples (n=566), 25% were found to exceed this target. However, in cases where faecal coliforms were present, the concentrations were low (geometric mean for all countable samples was 4.5 cfu/100mL). Only 15% of sachet water exceeded the target for faecal coliforms, compared to bottled water (26%), borehole water (29%) and vended water (32%). Comparisons with piped water and open wells cannot be made as the sample sizes were too small.

70% of the borehole samples did not show any detectable faecal contamination. However, water quality testing was undertaken in the dry season (November to February), when contamination of boreholes from surface runoff and flooding is likely to be at its lowest. It should also be noted that the presence of faecal contamination in 29% of boreholes means that there is considerable risk of waterborne disease transmission during an epidemic.

In Port Harcourt, 89% of the samples (n=629) had pH levels that failed to meet national guidelines. For the parameters turbidity, arsenic, fluoride, nitrate, there were less than 2% that exceeded the guidelines or health-based targets.

Although some manual drillers learned their skills from machine drilling and are aware of basic drilling standards, others have no knowledge about the importance of a sanitary seal to prevent contamination, or of good practices for screening, gravel packing and borehole development. Drilling equipment costs are low (~$2,500) and markets are growing, with the result that untrained drillers are also entering the business.

The lack of general understanding of groundwater, and what constitutes a high quality borehole by the general public, as well as building construction supervisors mean that those investing in wells are at the mercy of private enterprises to ensure construction quality.

National regulations exist (SON, 2010). However, have not been widely popularised and are not extensively known about or understood. The federal nature of Nigeria also means that regulation is undertaken at state level. Regulations for manual drilling at this level are extremely limited.

However, associations such as the Water Resources Technicians Association of Nigeria (WRTAN) and Association of Water Well Drilling Rig Owners and Practitioners (AWDROP) may provide solutions for self-regulation, but are likely to require outside support.

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Figure 12: Jetting Cutting Shoe used in Lagos, Nigeria
(Source: Kerstin Danert)

B. Countries where manual drilling is taking-off

Manual drilling technology is at the tipping point to becoming established in Chad, Senegal and Zambia as explained below.

Chad

Water Resources

With its north-south axis of over 1,000 km Chad comprises the Sahara desert, the Sahel and the more humid Sudanese Savannah. Population densities are highest in the south. One of Chad's most defining features is the movement of people and livestock for water. Some of the transhumance people migrate hundreds of kilometres every year. Chad's diverse cultures have been shaped by its water resources.

Manual Drilling History and Industry

Manual drilling has its origins around Lake Chad in the early 1960's (Practica Foundation et al, 2009). According to Boudouma (2013) of Bol town, the augering method was introduced to Lac Region by the U.S. Peace Corps Volunteers. Others, including CARE, subsequently picked up the technique which spread more widely, including into the private sector (Practica Foundation, 2009).

Figure 13: Jetting a household supply in Clesoum, N'Djamena

Unfortunately, many of the wells drilled in the early years failed due to the inflow of fine sands through the well screen (see also Box 3). These negative experiences led the Government and other donors to reject manual drilling as a viable technology (Practica Foundation, 2009). Meanwhile, manual drilling technologies (augering, sludging and later, jetting) continued to be used by private enterprises constructing supplies for private households. In addition, there are reportedly cases of machine drilling contracts being sub-contracted to manual drillers.

Obed Mutu (Box 9) is among those who have shaped Chad's manual drilling story by bringing the jetting method (also known as washboring) in from Nigeria in 2005. Initially this method provided drinking water supplies for individuals and was later taken up by development agencies (Mutu, 2013).

The drillers interviewed by the author in Chad in late 2013 believe that the change in methods from sludging and auguring to jetting triggered a much wider uptake of manual drilling in the country. Jetting takes considerably less time in sandy formations than augering or sludging thanks to the small petrol pump that circulates the drilling fluid. Wells to a depth of 45m can be completed in one day depending on the experience of the crew and the formation, with harder layers taking longer to drill

Skills Development & Low Cost Drillers Association

UNICEF, together with Practica Foundation and Enerprise Works/Vita provided technical and business training to manual drilling enterprises in 2009. Training was also given to government staff to supervise manual drilling. The Association of Low Cost Drillers[iii] grew out of this initiative and it has subsequently expanded from 45 to about 100 members, most of whom are small-enterprises specialising in manual drilling. However, in late 2013, leaders of the Association of Low Cost Drillers estimated that there may actually be as many as 200 manual drilling enterprises operating from N'Djamena (Danert, 2014a).

Hand dug wells are common in N'Djamena and are now being augmented by manually drilled wells. Private groundwater supplies provide an alternative to the irregular public piped water. For those living on the expanding periphery of the city, there is currently no piped network anyway. As N'Djamena's population grows, many people are investing in their own private manually drilled wells through self-supply.

The lack of permits or mapping of supplies means that the extent of manual drilling in N'Djamena is simply not known. However leaders of the Association of Low Cost Drillers esti-mate that there may be as many as 10,000 manually drilled wells in the capital already.

Figure 14: Blue plastic pipe against the shop wall is the trade symbol for drilling services, often with a mural

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Manual drilling extends beyond N'Djamena but data is scant, particularly for household sources. In Chad, massive, uncontrolled und partly unqualified drilling takes place. Not all drillers uphold the same quality standards.

Box 9: Manual Driller Profiles

Mallah Mohamed Boudouma (left) from Bol town, Lac Region worked as a driver for an Italian organisation in different parts of Chad for 18 years before setting up as a driller. With the skills he picked up observing and drilling over the years and money collected from his family he travelled to Nigeria to purchase equipment and start his own business in 2001. Boudouma (2013) explains that demand has grown over the years, with hundreds of wells drilled for agricultural as well as domestic use (e.g. 130 wells drilled between August and November 2013). While most of the wells are drilled for projects, individuals are also investing in wells for both domestic and agricultural use (multiple use). Mallah registered the «Groupement au L'eau Potable Pour la Population du Bol» in 2013. The enterprise currently has two drilling teams, employing up to 14 drillers, depending on the workload.

Obed Mutu (right) was born in Nigeria to Chadian parents. In 1987 he was trained in China on jetting (also known as washboring) and then worked in Nigeria for state government in what is now Yobe State on projects drilling wells for agriculture. In Nigeria, the washboring technology subsequently took off like wildfire among the farmers (Adekile and Olabode, 2009). He claims to have trained about 40 crews.

Senegal

Low Cost Drilling technologies were first introduced into Senegal in the early 1990's. Mamadou and Diouf (2014) estimate that over 4,000 manually drilled wells have been drilled by about 50 enterprises operating in the country. The evolution of manual drilling in Senegal comprises of several milestones:

In 1992: injecting a wrapped filter into the bottom of hand dug wells by jetting was introduced by Richard Cansdale. This increased well capacity and overcame problems of sand ingress in certain parts of the country.

In 1997: hand augering was introduced by Enterprise Works in areas where there were sandy soils and shallow aquifers. The technique would typically drill between 6 to 12 m. This was undertaken as part of a small scale irrigation programme. From the 7 businesses that were trained initially there are now 40 hand auger teams operating in Dakar, Thies and Ziguichor regions. An estimated 3,000 wells have been installed in gardens and population centres without access to piped water (for building construction). The wells are also often used for domestic purposes.

In 2002 the rota-sludge method was introduced by Enterprise Works and the Practica Foundation in order to drill deeper wells (where rope pumps were installed for domestic water supply), but only ten wells were drilled with this technique.

In 2009 rota-jetting, percussion drilling and hand augering was introduced under the auspices of a USAID/PEPAM project (Naugle and Mamadou, 2013). These manual drilling techniques could be drilled to a depth of 30 to 35 meters but the techniques were not able to penetrate solid rock. A total of 13 enterprises have been trained in these techniques in Ziguinchor, Sédhiou, Kolda (Casamance region) and Tambacounda region. The enterprises also received training on hydrogeology, business management and how to respond to tenders. There has been local manufacture of the drilling equipment. The project has also enabled the well drillers to buy the tools from the project at full cost (US$3,000). After five wells, they owned the equipment and can thus drill for other organizations and individuals (Naugle and Mamadou, 2013).

In 2011 a small portable mechanised rig (Lone Star LS-300) was introduced in the USAID/PEPAM project to penetrate harder formations and drill deeper. After a test phase, two local manual drilling businesses were selected and trained. These enterprises are now paying off the equipment cost with the work that they are currently undertaking.

Between 2010 and mid-2013, over 300 wells had been drilled by these 13 businesses for the USAID/PEPAM programme as well as for individuals, businesses and a UNICEF-supported project. Most of the wells serve villages with between 80 and 300 inhabitants and are equipped with India Mark II or rope pumps. Some wells, particularly those used for irrigating gardens and for use in tourist locations, have been equipped with electric submersible pumps. One of the challenges currently faced is obtaining well casings on the open market.

Figure 15: Well jetting in Senegal (Source: Jon Naugle)

The wrap filter jetting and augering techniques are most often used in areas where there are shallow, sandy aquifers. These areas can be found along the coast from Dakar to Saint Louis (Niayes) as well as in the Thiès and Kaolack regions. The rota-jetting and percussion drilling methods are used in the south and middle of Ziguinchor, Sédhiou and Kolda regions which have harder formations.

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Mamadou and Diouf (2014) estimate that about 95% of the irrigation wells are paid for by water users themselves (i.e. self-supply). In contrast only 5% of the wells for domestic use are paid for by the end users with 95% funded by projects or NGOs.

Kenya

There are three major geology types in Kenya: volcanic (26% by area), Pre-Cambrian Crystalline Basement (17%) and Sedimentary (55%). Groundwater quality is highly variable and one of the major limiting factors of groundwater use in Kenya.

Manual drilling techniques (referred to locally as "low-cost" or "small scale drilling") have been used in marginalised rural and peri-urban areas in Kenya to construct water supplies for irrigated agriculture since the late 1970s (Adenya, 2013). The ten-year Dutch-funded "*Rural domestic Water Supply Programme*" from 1982 was among initiatives to utilise the manual drilling methods for domestic use. Government, civil society and other bilateral programmes followed suit.

Hands-on training was given to community members. Some went on to work for NGOs and water companies. Some who remained in the rural areas propagated the practice. Figure 16 maps out the various part of Kenya where manually drilled boreholes have been constructed specifically for drinking by 2013. Adenya (2013) estimates that there are 10,000 manually drilled boreholes in Kenya.

Figure 16: Locations where manual drilling for Drinking Water has been undertaken in Kenya (Adenya 2012)

The popularity of manual drilling in the country is growing but remains on the periphery of government programmes. It is considered as something to be used when there are no other options (Adenya 2014). Anecdotal evidence suggests that manually drilled wells are growing in popularity in informal settlements due to the high cost of buying water or lack of access to the main water supply.

However, in a conversation on 30th April 2013 Adenya stated that there is generally a poor understanding of hydrogeology by manual drillers. This, coupled with complete lack of regulation raises concerns about construction quality, water quality, and even aquifer contamination.

Adenya (2012) lists 12 Kenyan enterprises that employ manual drillers in four out of Kenya's eight provinces (Coast, Nyanza, North Eastern and Western). In 2014, the WASH Coordination Committee pulled together an inventory of 13 organisations undertaking manual drilling or using small conventional rigs.

Groundwater statutory requirements for the country are set out in the *Fourth Schedule: abstraction of groundwater: Kenya Gazette Supplement, Acts 2002 and The Kenya Gazette Supplement No 92, The Water Resources Management Rules 2007: Part IV Groundwater Development Authorisation*. Currently, Kenya does not have a clear policy with respect to manual drilling. The institutional reforms now taking place (new Bills for Water and Agricultural awaiting enactment) provide a window of opportunity to make sure that manual drilling is officially endorsed.

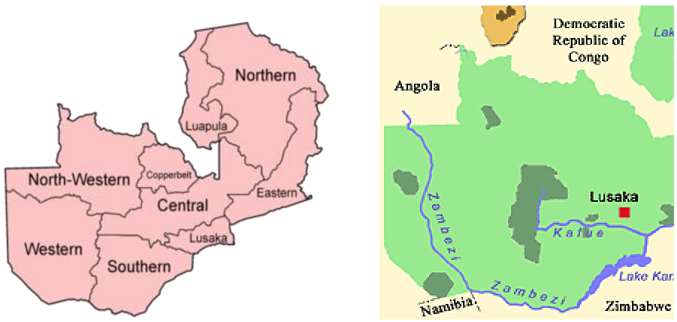
In Kenya, the amount of advocacy materials such as briefing notes (UNICEF Kenya 2012a and 2012b), as well as the WEDC paper (Adenya and Donde 2013) are of particular note. UNICEF Kenya, with Edwin Adenya in particular has undertaken considerable effort to ensure that manual drilling is taken seriously politically, and that implementation is professionalised. In fact, manual drillers are now formally recognised by the Ministry of Water and Irrigation and can be awarded tenders up to a value of US$ 55,000 (Adenya 2014)

Zambia

Zambia's Western Province contains four of the country's 16 most vulnerable districts (UNICEF, nd) and the province has one of the lowest water coverage rates in the country. The sandy terrain is flood-prone and the sands limit access for conventional drilling equipment off the main road. Areas west of Zambezi River, especially in Lukulu District suffer from both the sandy conditions and crossing of the river. During the rainy season, even the small boats and the small pontoon used to ferry people and cars cannot cross.

However, in "*much of western Zambia's Kalahari sands, groundwater occurs in shallow perched aquifers and deeper semi-confined aquifers*" (Imasiku 2002). This makes most of Zambia's Western province (Figure 17) suitable for manual drilling. Manual drilling equipment is particularly appropriate to reach these areas as it is lightweight and can even be transported on an ox-cart or dug-out canoe.

Figure 17: Zambia's Provinces and the Zambezi River



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Well jetting is not new to Zambia, having been used in the 1980's to construct wells that were installed with the Blair Pump. However, the unavailability of pumps and spares from Zimbabwe lead to the decline in jetting.

Village Water Zambia reintroduced the jetting techniques, as well as rota-sludging and augering into the Western Province in 2010 (Muyangwa 2014), drilling about 60 wells. By early 2014, about 150 manually drilled wells had been constructed in the Province, the majority by private enterprises. Of these, about ten wells have been paid for by citizens themselves. Awareness of the manual drilling techniques is growing, particularly in farming areas as well as on the outskirts of towns (Muyangwa 2014). According to Vuik (2014b), jetting is now the most commonly used method in the country and there are now over 500 manually drilled wells in Zambia as a whole.

"[Manual drilling] has revolutionized the provision of safe drinking water to these hard to reach areas given it is much cheaper, and the drilling enterprises are available locally. The District Councils in Western province are now floating manual drilling tenders to the trained local enterprises" Abuuru (2014)

Manual drilling has also been successfully introduced on the Lake Mweru Islands in Luapala Province on the North of the country (Abuuru, 2014) as well as in Western Province. Zambia's potential for manual drilling was mapped in 2011, and UNICEF entered into a contract with Practica to undertake training in 2012. UNICEF plans to support the certification of manual drillers, training of quality controllers and simplification of tender documents.

C. Introduction of Manual Drilling

Manual drilling is currently being introduced into almost 30 African countries (Figure 5). An overview of what has taken place in Guinea, Ethiopia, Malawi, Kenya and Sierra Leone is given below.

Ethiopia

In Ethiopia, an initiative by government and development partners to promote manual drilling commenced in 2012. National policies and water supply programmes are favourable for manual drilling for drinking water and for irrigation, the latter to boost food security.

In Ethiopia, manual drilling is primarily considered as a suitable technology within the context of the country's self-supply approach. Self-supply is defined as "improvement to water supplies developed largely or wholly through investments by households or small groups of households". Within the national strategy, manual drilling is expected to contribute significantly to raising drinking water coverage.

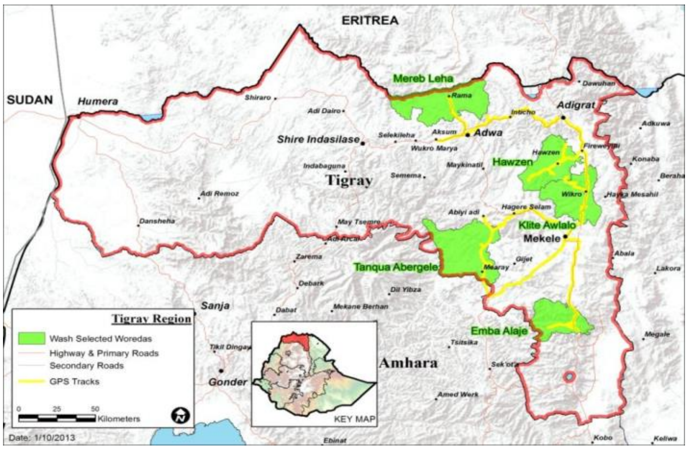
Manual drilling is currently supported by the Government of Ethiopia, UNICEF and International Development Enterprises (iDE) as part of the water supply programme. The technology is being introduced into areas where groundwater is shallow within four regions (Amhara; Oromia; Southern Nations, Nationalities, and Peoples - SNNP and Tigray). The partnership focuses on self-supply, water services for multiple use (e.g. irrigation, livestock and drinking water), household water treatment and marketing technologies to householders.

Since 2012, development partners and government- supported activities with respect to manual drilling were:

- Mapping shallow groundwater to identify areas with potential for manual drilling in 15 Woredas (districts) in the four regions of Amhara, Oromiya, SNNPR and Tigray (Figure 18).
- Preparation of well designs & rope pump standards.
- Rope pump adaption for drinking water.
- Training tools and resources have been developed.
- Training of 35 manual drillers & 22 rope pump manufacturers and registration of manual drillers as "small and micro-enterprises".
- Test drilling to identify suitable Kebeles (sub-districts).

Manual drillers receive work from the Woredas (districts) as well as directly from households.

Figure 18: Areas with Shallow Groundwater in Tigray, Ethiopia



UNICEF is concerned about inadequate quality control and supervision of manually drilled wells, although this is also a problem for mechanised drilling and other construction.

Overall, the Government would like to be more involved in manual drilling, with more skills transfer within the current iDE partnership. The Government sees a need to improve the selection of areas for manual drilling and siting, so that failure rates are reduced, as well as to standardise manual drilling equipment for the country.

The Government would also like to see more uptake of water treatment options in conjunction with the technology to ensure compliance with national water quality standards (zero FC/100ml). Finally, there is need to explore how the micro enterprises that are undertaking drilling can compete with larger contractors.

Guinea

It is estimated that 35% of Guinea's rural population do not use an improved water supply (Ministère du Plan, 2013). In fact 15% of the rural population of Guinea (about 1.1 million people) rely on surface water, primarily from rivers (Ministère du Plan, 2013).

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The first introduction of manual drilling in 2011 comprised of using imported equipment to drill ten boreholes in the coastal region. In 2012 UNICEF supported a more systematic process, based on the Technical Manuals for the Professionalization of Manual Drilling in Africa (UNICEF et al 2010):

- Suitable areas for manual drilling in the country were mapped (UNICEF et al, nd-c).
- In 2012 four local companies were selected (two in the coastal area and two in Forest Guinea). They were trained in the jetting and rota sludge techniques, equipped, and drilled twenty wells as part of the training. Participants at a workshop in Conakry were also trained to manufacture drilling equipment.
- In 2013 four other enterprises were given drilling training, and a workshop was trained in equipment manufacture to cover the eastern region of Guinea.

The professionalization of manual drilling in Guinea has involved four main actors (Service National d'Aménagement des Points d'Eau – SNAPE), UNICEF, Gestione e Ricerca Ambientale Ittica Acque – GRAIA and Practica Foundation are working with the local enterprises. To ease repairs, manufacturing workshops and drilling enterprises are located in the same areas. Over a three year period, 116 wells have been drilled, of which 71 have been successful. A total of 45 wells were not equipped with handpumps because the drilling was not successful due to hard formation, as well as low yields and salinity along the coast (Camara, 2014).

Currently, the drilling methods and tools are being adapted to suit the particular geological settings of the country including the introduction of percussion technology for harder rock types. Manual drilling operations along the coastal zone have been suspended due to salinity and rocks at shallow depth (Camara, 2014). The main outstanding questions for Guinea concern the contractual arrangements for the drilling enterprises, and who should bear the cost of a non-successful well (Camara, 2014). This is a question that plagues mechanised drilling as well.

Figure 19: Drill Rig Tool Manufacture in Guinea

Malawi

It is estimated that about 66% of rural households use a protected well or borehole in Malawi, while 15% use an open well as their main source of drinking water (NSO, 2011). The government is trying to tap groundwater for domestic use as well to boost irrigation. Robins et at (2013) caution that in some parts of Malawi, demand for groundwater may exceed long-term resource potential and that falling water tables are also a cause of water point failure.

Although it has been estimated that up to 1,000 manually drilled wells exist in Malawi (Tauzie, 2014), documentation is scant. Manual drilling is believed to have potential in many parts of Malawi, but suitable areas have not been specifically documented or mapped out.

Neither manual drilling nor self-supply is explicitly mentioned in Malawi's National Water Policy (Malawi Government, 2005). There are no national standards for either machine, or manual drilling for the country but there are standards for borehole and shallow well water quality (MSB, 2005).

Although government support of self-supply in Malawi is limited, the private sector is responding to demands by households that can afford to improve their own water supplies. Promotional activities such as through the SMART Centre are considered key for building government interest (Box 10).

Sierra Leone

Borehole drilling is relatively underdeveloped in Sierra Leone, despite its tremendous potential. 40% of the population relies on hand dug wells and springs (MICS 2010). And overall, an estimated 40% of water points in the country are seasonal (Hirn, 2012). It is believed that there is a high potential for manual drilling in the unconsolidated sediments along the coast (the Bullom Series) and in the inland valley swamps that overly the crystalline basement (Figure 20). However, concerns have been raised about possible salinity in some parts of the coastal aquifers.

Box 10: SMART Centre Training Local Enterprises in Malawi

Mzuzu University Centre of Excellence in Water and Sanitation SMART Centre in Northern Malawi opened in 2012. Since then, it has trained local entrepreneurs to make money through providing services and products that improve access to water at household level. Businesses are being trained in both the technical and business aspects of manual drilling using the Baptist/SHIPO method.

Nine small drilling companies have been established and by March 2014, about 100 manually drilled wells had been constructed. Training will continue in the future, and there are also plans to certify the drillers after they have completed 20 wells.

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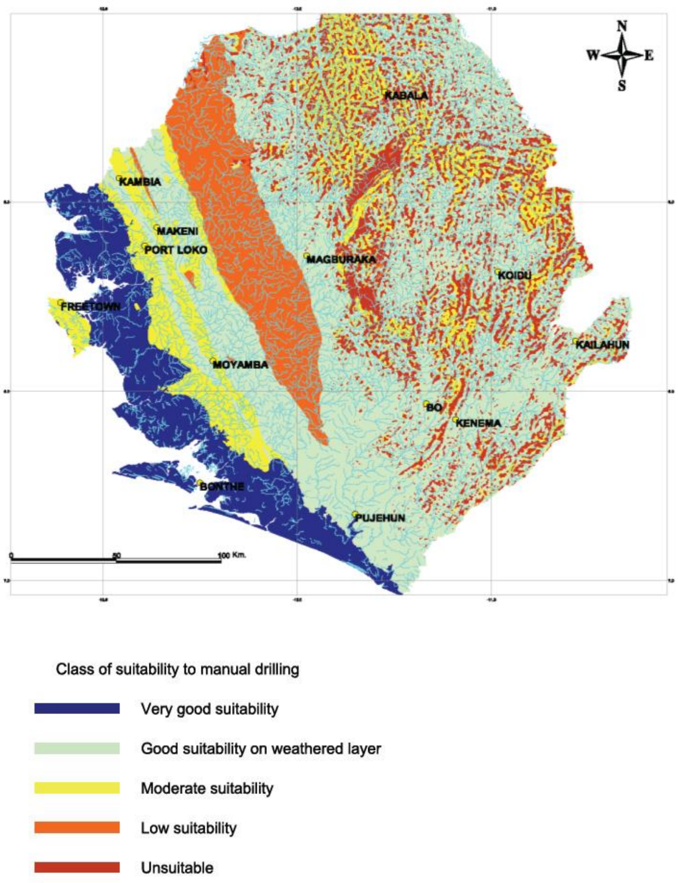
Manual drilling was first introduced to Sierra Leone in 2011. In mid-2014, two organisations, Willamette International and Welthungerhilfe were promoting the technology in several parts of the country on a small scale. Less than 100 manually drilled wells have been constructed in total. Both EMAs drilling and the Water4 kit are being used.

Drilling techniques, time to drill, well designs, costs and pumps installed vary between these two organisations And whereas Welthungerhilfe is training enterprises so that they drill directly for households (who also pay, i.e. self-supply), Willamette's drilled wells are paid for by donations from overseas. Willamette has also supported two private enterprises to branch into manual drilling.

Government are supportive of manual drilling technology but want to understand more, in particular how it can contribute to improving rural water supplies in rural areas of the country.

Figure 20: Geological Suitability for Manual Drilling in Sierra Leone



D. Countries where manual drilling was used in the past

Uganda

Access to safe water in the rural areas of Uganda is 64% (MWE 2012b). Boreholes are the most widespread technology in rural areas serving an estimated 42% of the rural population (NBS 2009). According to MWE (2012b) an estimated 74% of shallow wells and 83% of deep boreholes are functional. With a rural population growing at 3.2% per year, the construction of new infrastructure is hardly keeping up with population growth (MWE 2012b).

There is a growing consensus among policy-makers of the need for more investment in expensive technologies including deep borehole drilling and piped systems based on surface water sources because "*the low cost water supply technology options have to a good extent been exhausted and the fact that climate change has resulted into lowering of yields from traditional water sources* (MWE 2012b).

In parallel, the Ministry of Water and Environment is also committed to complement government-funded rural water supplies and enabling self-supply (MWE 2012b; MWE 2012c). Manual drilling is particularly relevant for this.

District groundwater resources maps have been prepared for most of Uganda (MWE, 2012a). Analysis of these maps by Carpenter (2014) indicates that large areas of Uganda may be appropriate for shallow wells (< 15m) and shallow boreholes (<30m), particularly in Central, eastern, mid-northern, north-western, and someof western Uganda

The Vonder Rig's success was primarily in the soft formations in southern Uganda (Table 7). Hard materials within the weathered formation mean that manually drilling attempts are not always successful and need to be re-sited.

Manual Drilling Experiences

In the late 1980's and early 1990's Uganda's manual drilling in meant hand augering, using the Vonder rig. Hand augered boreholes were drilled within donor-funded projects. The Vonder rig was popular and successful at the time but had limited technical capability (i.e. its inability to drill through laterite). According to Enangu (2013) some boreholes were sited badly, either in swampy areas (resulting in poor water quality) of there was not sufficient water to sustain pumping throughout the year.

Technical issues, coupled with privatisation, inadequate supervision and competition from low-cost small machine rigs meant that it became less popular and had fallen out of use by the late 1990's. The relatively high labour costs meant that manual drilling was not necessarily considered cheaper than using a small machine either. In fact, manual drilling came to be perceived as a low grade (and non-desirable) technology; and water from shallow wells became considered as providing poor water quality.

From 1998 to today, improved manual drilling techniques have been repeatedly introduced into Uganda by various organisations. To date, none of these have gone beyond testing or pilot projects. In 2013/14 three international organisations (Connect

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International, Mercy Corps, World Vision and Water4) were trying to take manual drilling forward in Uganda.

Table 7 summarises Uganda's manual drilling experiences to date. Initiatives have all focused on domestic, rather than productive water supplies. The recently completed project in Gulu included training of private enterprises, is encouraging but it is still too early to know whether uptake will be extensive.

The Ministry of Water and Environment's encouragement of self-supply approaches for raising drinking water coverage and the establishment of the Appropriate Technology Centre (ATC) to develop and promote water and sanitation technologies illustrate Uganda's commitment to innovation in WASH. However, since the discontinuation of manual drilling in the late 1990's, the government is relatively ambivalent on the method.

Table 7: Manual Drilling in Uganda: 1980s to 2013

Year	Initiative
Late 1980s - early 1990s	Vonder rig used to drill boreholes in soft formation and high water table, particularly in Southern Uganda, Jinja and the Buganda region more generally in UNICEF and Danida-funded projects.
1990's	Dispersed use of hand augering continues in some place with little reporting.
1998 - 2001	Low-cost drilling project by Cranfield University to develop and introduce the Pounder Rig to the private sector (Danert, 2003). Technology not widely taken up once the project ended.
2008-2009	Practica Foundation trained ICRC staff in Rota-Sludge drilling in Gulu, Kitgum and Pader in. About 30 wells drilled for community supplies but hard formation posed challenges in some areas.
2013	A few small faith-based organizations using Baptist Drilling but not well documented (Carpenter, 2013). Water4 partnered with two organizations to drill donor-funded manually boreholes (invarious districts in north, central and south-western Uganda) and have drilled boreholes in a few places the south (Carpenter, 2013). Practica Foundation worked with HEWASA in the Rwenzori region. Demonstration manually drilled boreholes completed & low-cost pumps installed (Vuik, 2014). World Vision trained local drilling enterprises & rope pump pump manufacturers in Gulu 20 self-supply boreholes drilled by Aug 2013 (Carpenter, 2013).

Figure 21: Installing Rope Pump during World Vision Self-supply Training, Gulu in July 2012 (Photo: Jake Carpenter)

Zimbabwe

Experience with hand drilling in Zimbabwe is limited to the Vonder Rig designed some years ago. It was backed by the government in the late 1980's and early 1990's and boreholes were fitted with Blair and bucket/bailer pumps. However this period passed into an era of poorer rains and groundwater levels fell leaving many hand drilled tubewells dry and difficult to deepen without specialis equipment. In Zimbabwe, hand drilling of tube wells with the Vonder rig faded away.

Home-owned hand dug wells installed with a hand pump (Bush Pump) subsequently took over as a priority in the shallow aquifers. The Bush Pump has long been the backbone of the rural water supply in Zimbabwe, and family-owned wells have been known for generations. They can be deepened relatively easily by the owners or local well diggers using local equipment.

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7 Professional and Cost-Effective Drilling

Manual drilling methods are providing numerous urban and peri-urban dwellers with a water supply directly at their home or business premises. The supplies are often paid for by businesses, or domestic users themselves. The water meets peoples' domestic needs and enables businesses to operate. It has been demonstrated that manual drilling can provide water supplies for remote, rural communities who would otherwise be left out due to difficulty in reaching them with machine drilling equipment.

Manual drilling provides employment for tens of thousands of people globally. The technology is here to stay. The low initial investment costs mean that manual drilling has a very low entry barrier for NGOs who want to promote it, or for enterprises that want to venture into the business.

Unfortunately some promoters and local enterprises are undertaking manual drilling without a basic understanding of good drilling practices. In such cases, borehole design, well development and installation are learned through trial and error. Poor gravel packing, the wrong screen and/or inadequate well development can result in a water supply that goes out of service within days, months or years. Siltation, due to poor drilling and installation practices will produce turbid water and can result in pump failure. A sanitary seal may be left out, risking contamination by surface pollution.

The term "cost-effective" means optimum value for money invested over the long term. Boreholes are drilled to function for a lifespan of 20 to 50 years. Thus, the lowest cost is not always the most cost-effective, particularly if construction quality is compromised to save money. Cheap drilling or poor construction quality can lead to premature failure of the well or contamination of the water supply. Boreholes that are subsequently abandoned by the users are clearly not cost-effective.

As manual drilling spreads within the private sector and is taken up by enterprises that do not have sufficient knowledge and skills, minimum standards are in danger of not being upheld. Inadequate supervision of the drilling and installation process as well as lack of adequate regulation exacerbates this problem.

Manual drilling offers an incredible opportunity for raising access to safe, reliable and affordable drinking water supplies. Frequently, the boreholes can also be used for productive purposes or multiple-use. It also offers tremendous benefits for local employment. The question is how to set and uphold adequate minimum standards for the industry, as well as those that promote it. There is need to raise professionalism.

Professionalism is the skill, good judgment, and behaviour expected from a person or organisation who can undertake a job well. All professions, including manual and machine drilling require special education or training, and skills.

UNICEF and RWSN have published appropriate guidance for manual drilling as well as drilling in general:

- Toolkit for the Professionalisation of Manual Drilling (Box 11) – for more details see UNICEF (2010b) on http://www.unicef.org/wash/index_54332.html
- Code of Practice for Cost Effective Boreholes (Danert et al, 2010) with its supporting guidelines – Box 12.

Box 11: Toolkit for the Professionalisation of Manual Drilling

The UNICEF et al (2010) *Toolkit for the Professionalization of Manual Drilling* is intended for UNICEF Country Offices and other development agencies interested in promoting the emergence of a professional manual drilling sector. It was developed alongside a UNICEF supported project to professionalise manual drilling in Chad, and drew on previous experiences from Enterprise Vita in Niger.

The toolkit, which recommends five steps to be followed, has encouraged and influenced initiatives in several countries in Africa. UNICEF is involved some, but not all of these initiatives.

Steps to Professionalise Manual Drilling (UNICEF et al, 2010):

- Rural Water Supply Sector Assessment
- Selection of Drilling Enterprises
- Training of Drilling Enterprises
- Training of Supporting Businesses
- Certification of Drilling Enterprises

The toolkit emphasises building the capacity of private enterprises over a period of 3 to 5 years on manual drilling technology, hydrogeology and business management. A nationally recognised certification process for the drillers is recommended. The toolkit also includes guidance for the training of "supporting businesses" to the actual drilling, i.e. quality control firms, drilling tool makers, social mobilisation firms and pump installers.

It is clearly stated in the toolkit that there is need to tailor the guidance to the needs and means of different country programmes, be based on a specific assessment. Recommended implementation approaches are given for three different scenarios (i.e. no local manual drilling capacity; local manual drilling capacity; and local manual drilling capacity with self-supply).

Alongside the toolkit, work has been undertaken to map the potential for manual drilling in 12 African countries. The mapping reports comprise colour-coded national scale maps and a description of the manual drilling potential. The toolkit also includes manuals and teaching materials on manual drilling methods, finance and business practices.

The toolkit makes it very clear that professionalising manual drilling is not just a one-off training activity by external agents, but rather a multi-year process. UNICEF is currently implementing a four-year project in the Democratic Republic of Congo more or less in line with the toolkit. Projects, in other countries, including Chad, Guinea Uganda and Sierra Leone have been more start and stop due to staff changes, funding modalities and other constraints. Not all projects have involved UNICEF.

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Box 12: Code of Practice for Cost-Effective Boreholes

RWSN, with the support of UNICEF, the World Bank and USAID published a Code of Practice for Cost-Effective Boreholes in 2010. It provides a basis for the realisation of economical and sustainable access to safe water. The Code of Practice sets out nine principles that relate directly to the practicalities of borehole construction (below). They should be adhered to in order to provide cost-effective boreholes. Each principle is broken down into sub-principles which recommend procedures to be followed and call for the definition of and adherence to minimum standards.

Principles for Cost-Effective Boreholes

Principle 1: **Professional Drilling Enterprises and Consultants** - Construction of drilled water wells and supervision is undertaken by professional and competent organisations which adhere to national standards and are regulated by the public sector.

Principle 2: **Siting** - Appropriate siting practices are utilised and competently and scientifically carried out.

Principle 3: **Construction Method** - The construction method chosen for the borehole is the most economical, considering the design and available techniques in-country. Drilling technology needs to match the borehole design.

Principle 4: **Procurement** - Procurement procedures ensure that contracts are awarded to experienced and qualified consultants and drilling contractors.

Principle 5: **Design and Construction** - The borehole design is cost-effective, designed to last for a lifespan of 20 to 50 years, and based on the minimum specification to provide a borehole which is fit for its intended purpose.

Principle 6: **Contract Management, Supervision and Payment** - Adequate arrangements are in place to ensure proper contract management, supervision and timely payment of the drilling contractor.

Principle 7: **Data and Information** - High quality hydrogeological and borehole construction data for each well is collected in a standard format and submitted to the relevant Government authority.

Principle 8: **Database and Record Keeping** - Storage of hydrogeological data is undertaken by a central Government institution with records updated and information made freely available and used in preparing subsequent drilling specifications.

Principle 9: **Monitoring** - Regular visits to water users with completed boreholes are made to monitor functionality in the medium as well as long term with the findings published.

The Code of Practice is supported by a set of five publications that provide more detailed guidance on

- Understanding Groundwater
- Siting
- Procurement and Contract Management
- Costing and Pricing
- Drilling Supervision

The Code of Practice and accompanying guidance has influenced drilling policies, practices and training in a number of countries including Ghana, Kenya, Nigeria, Mozambique and Sierra Leone.

The UNICEF et al (2010) Manual Drilling toolkit provides guidance on the capacity building of private enterprise. However, there is very little guidance on the roles and responsibilities of local and national government, other than generally involving them and finding way to overcoming biases that they may have against manual drilling. Within the toolkit, guidance for regulatory mechanisms is limited and unproven.

Although the different manual drilling methods are described in detail, there is little reference to good drilling practices from mechanised drilling, such as ensuring verticality, borehole development and test pumping and maintaining drill logs. The manual drilling profession should not be considered in isolation of machine drilling, particularly when it comes to standards, practices, regulation and associations.

The Code of Practice sets out principles to be adhered to but, unlike the Manual Drilling Toolkit, does not set out a step by step process for stakeholders wishing to get there.

In order to harness the incredible opportunity that manual drilling has to offer, there is need for governments, private enterprises, water users and manual drilling promoters to jointly strive towards more professionalism. This means adapting and applying the guidance provided by the Toolkit, as well as the Code of Practice and supporting material. In practical terms, this boils down to several recommendations:

- Assess whether in-country and organisational policies and standards are adequate.
- Assess whether good drilling practices are being followed in specific projects, as well as for the country as a whole.
- Educate political and opinion leaders about good drilling policies, standards and practices, and the implications of these not being adhered to or regulated.
- Raise awareness among the general public of the need for good drilling construction, and how they can help this to be realised.
- Train and mentor programmes which enhance the knowledge and skills of drillers and develop certification mechanisms. This needs need to include extensive practical work.
- Enhance skills in procurement and contract management for the staff of programmes and projects that procure drillers.
- Train and mentor organisations and individuals so that they can properly supervise borehole drilling and ensure a good quality product.
- Increase the amount of research undertaken into the social, political and economic as well as technical aspects of manual drilling, including water quality and sanitary inspections. There is so much to be learned in this area.
- Support initiatives by the drilling and manual drilling industry themselves such as the formation and running of associations or self-regulation.
- Enable manual drillers from different countries to share their experiences face-to-face and thus learn from each other.

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Annex 1: Manual Drilling Status

Annex 1 and 2 synthesise the available information on manual drilling for drinking water supplies for 36 countries. There are many gaps in the tables. This does not mean that nothing is happening, but rather that there is little information readily available or that scarce data cannot be reliably triangulated.

The table below provides an overview of the estimated number of manually drilled wells for drinking water supplies; which parts of the country these have been drilled and the methods or kits used. The data has been primarily drawn from grey literature, as well as interviews and email exchange with key informants that are living and working, or have worked in the country.

Manual drillers tend to be either local private enterprises or NGOs. To date only four cases have been found of private enterprises from one country undertaking manual drilling in another country. In three cases (Chadian enterprises in DRC, Ethiopia and the Republic of Congo, and other countries), the author was informed of this by owners or representatives of theenterprises themselves. In the fourth case (Nigerian drillers operating in Ghana), the information came from other drillers in Nigeria. Other undocumented examples may also exist.

Readers are advised to be very cautious of making generalised statements or comparisons between the "claimed costs". The data is anecdotal, has not been systematically collected and does not include the same parameters. In some cases the "claimed cost" includes overheads of foreign NGOs, in other cases it is just the local enterprise. In some cases the pump is included, in some it is not, in others it is not defined.

The pump type data refers to the pumps that have been installed on manually drilled wells from available documentation. There may also be others. The clients column sets out whether the manually drilled borehole and pump installation is being paid for by households themselves, or by others on their behalf (such as NGOs or governments). In some countries household investment (self-supply) is happening on a very small-scale while in others there are thousands, or even millions of self-supply boreholes.

The final column provides the date that manual drilling has been undertaken in the various countries. As not all of the attempts have been well-documented, there may be gaps in this data. Annex 2 lists all the references for the information in both Annex 1 and Annex 2.

Country	Estimated Number[1]	Where drilled?	Who drills?	Clients	Methods/*Kits*	Claimed Costs	Pump types	When[2]
Angola	<200		Water4		*Water4*			2014
Bangladesh	millions	Most sedimentary areas	Private enterprises	Households	Sludging	~USD 1/meter	Suction pump[3] (mainly No. 6)	1900's - date
Benin					Rota-sludge			1990's 2012 - 2012
Bolivia	~30,000		Private enterprises, EMAS, Water for All International	Households	*EMAS*, *Baptist*	~USD 300	EMAS	1983 - date
Cameroon	few				Jetting, *Baptist*			1980's
Central African Republic	<50	Bangui & Ouham	Private enterprise[4]	CICR, MSF Spain Solidarités International	Augering, jetting, sludging		India II Vergnet	2009 - date
Chad	thousands	Central Chad	Private enterprises	Households, UNICEF, NGOs				1960's to date

1 Refers to the estimated number of manual drilled wells constructed for drinking water.

2 Refers to when manual drilling was introduced specifically for drinking water. Where different dates are given this is because manual drilling techniques were introduced at different times. However, in some countries, notably Bangladesh, Chad, India and Niger there is a considerable overlap between manual drilling for agricultural and domestic use.

3 Suction pumps are used in areas where the water table is less than 7-8 meters depth. It is estimated that there are also more than 1.3 million treadle pumps used for irrigation, mainly on manually drilled wells.

4 According to Sieyadji (2013) the NGO, Solidarités International contracted a Chadian refugee and entrepreneur, with skills in jetting to undertake manual drilling. Solidarités International also equipped the enterprise, which has subsequently gone on to drill for other NGOs (see Annex 2).

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Country	Estimated Number[1]	Where drilled?	Who drills?	Clients	Methods/*Kits*	Claimed Costs	Pump types	When[2]
Congo Brazzaville	few		Private enterprise (from Chad)	Households	Jetting			2014
Democratic Republic of Congo	few	West, south and some in the east.	Private enterprises, Water4	CICR	?[5], jetting, *Village Drill*		Rope pump	Before 2013[5] 2007 and 2013 to date
Ethiopia	few	Four regions[6]	Private enterprise, Water4, Water for All International	Households	Sludging		Rope pump	2012 - date
Gambia	<100				Baptist			2014
Ghana	few	Wale Wale	Private enterprises	GWASH	Augering, rota sludge, percussion	USD 2,000 to 4,000	Rope pump	2000 - date
Guinea	~100	South east and western coastal area[7]	Private enterprises	SNAPE-UNICEF Programme	Sludging and rotary-jetting	USD 4,000 -5,000 (including pump - about 50% of cost)	Vergnet, HPV30-2000[8], Kardia	2010, 2011 2012 -date
India	millions	Various[9]	Private enterprises	Households	Sludging, jetting, augering		No. 6, Tara/ Direct Action Pump[10]	Indigenous technology
Ivory Coast			Private enterprises		Rotary jetting			2014
Kenya	~10,000	Various[11]	CSOs/NGOs, Private enterprises Water4		Augering, sludging, percussion, Baptist & *Village Drill*	~$4,000 (augered to 40 m)	Afridev Solar Pumps	1979 - date
Liberia	~40	Coastal areas	NGOs: SALAOE, ECREP		Rota-sludge		Afridev	2009
Madagascar (driven wells)	~10,000	East coast and some along the west coast[12]	Private enterprises	Households	Driven wells,	$ 35 to $50	Pompes Tany/ Pitcher pump[13]	1960's – date
Madagascar (Jetting, rota-sludge & Mad Drill)	~2,000	Throughout the country	Private enterprises BushProof, MEDAIR	Households, projects	Jetting, rota-sludge & *MaDrill*	~$ 1,000 to $3,000 (<30m depth	Rope pump, Canzee & various hand pumps	Early 2000's - date

5 Baron (2013) refers to manual drillers enterprises operating in the four western provinces of Bas Congo, Kinshasa, Equateur and Bandundu prior to training in the jetting method in 2013.

6 In the four regions of Amhara, Oromiya, SNNPR and Tigray

7 N'zerekore, Conraky, Kankan and Faranah regions.

8 New pump designed for wells with depths <30m. Introduced in 2014.

9 Within Delhi as well as the States of Bihar, Gugurat, Haryana, Orissa, Punjab, Uttar Pradesh and West Bengal.

10 Limited mainly to West Bengal & Assam.

11 Ahero, Bura, Busia, Garissa, Kakamega, Kilifi, Kwale, Loitoktok, Mandera, Msambweni, Mwingi, Nyando, Rabondo, Siaya, Tana Delta, Tana river and Turkana Counties.

12 In Toloara and Morondava

13 The Tany pump is installed on driven wells

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Country	Estimated Number[1]	Where drilled?	Who drills?	Clients	Methods/*Kits*	Claimed Costs	Pump types	When[2]
Malawi	~100	Northern Malawi	Private enterprises	Households	Augering, *SHIPO*, *Village Drill*	Too early to say	Afridev, Malda, Mark V, Elephant, Canzee & rope pump	2011 - date
Mali	~250[14]	Inner Niger Delta near Mpoti[15]			Rotary jetting, jetting	Too early to say		2008 2013-date
Mauritania	<10	Senegal river valley	Private enterprises, Practica and Atica Mauritania	AECID, FAMSI and Ministry[16]	Rota-sludge	USD 4,000 – 5,000	Solar[17]	2012 and 2013
Mozambique	~50	Sofala & Nampula Province & Pemba	Private enterprises, DAPP, GSB	Government, farms	Sludging, rotary jetting, *SHIPO drill*	~USD 1,500	Submersible & rope pumps	2008 - date & 2013
Nepal	>100,000[18]	Terai (lowland)	Private enterprises	Households & donor/NGO programmes	Sludging	USD 20 - 450		1950's 1980's[19]
Nicaragua	>100	Managua, Chinandega, Bluefield, Porto Cabeza	Private enterprises, (AMEC/Perfor)		*Baptist*, *EMAS*, Rota sludge	USD 700 – 1,500	Rope Pump	2000 to date
Niger	>10,000	Maradi and Zinder Regions	Private enterprises	Households	Augering, jetting, rota-sludge, percussion		Rope Pump, India II	1990s (irrigation) 2005-date
Nigeria	>10,000	In at least 27 of the 36 states	Private enterprises	Households, Government	Jetting, augering, percussion, *Baptist*	USD 2,500 or less	Submersible pumps, India II	Early 1980's - date
Rwanda	few			WHOLIVES	*Village Drill*	Too early to say		2014
Senegal	>4,000	Parts of Dakar, Thiès, Kaolack, Ziguinchor, Sédhiou, Kolda and Tambacounda	~50 private enterprises	USAID/PEPAM, UNICEF, Households, Buisenesses	Augering, jetting, percussion, rota-jetting	$1,600 to $2,000	India II, rope pump, vergnet, electric submersible	1991 - date
Sierra Leone	< 100	Various[20]	Willamette & Welthungerhilfe < 10 enterprises	Households NGOs	*EMAS* *Willamette Tools*	$1,000 to $4,000 depending on method, pump and who drills	Canzee India II Solar Pumps EMAS pump	2011 - date

14 Note that manual drilling for small scale irrigation has been promoted for at least 15 years in Kenya, Mali, Niger as well as Burkina Faso and Ghana.

15 Efforts to professionalise manual drilling in Mpoti from 2013 (PROTOS et al, 2014)

16 Ministry of Hydraulic and Sanitation

17 The trials planned for 2014/15 should drill 30 boreholes and install them with solar pumps.

18 An estimated 1.12 million people in Nepal use tubewells (Datta, 2011). Assuming 10 people per tubewell results in 112,000 tubewells.

19 According to Yoder (2012) manual drilling was introduced into Nepal by manual drillers (mistries) from India. According to Mahato (2013) it was introduced by UNICEF in the 1980's.

20 Bo, Potloko, Bombali, Tonkolili, Koinadugu, Kono, Moyamba and Kenema.

Country	Estimated Number[1]	Where drilled?	Who drills?	Clients	Methods/*Kits*	Claimed Costs	Pump types	When[2]
South Sudan	No reliable estimates	In select parts of the country only.		Development projects including ACF	Augering, *Vonder rig*		India Mark II	1980s-date
Tanzania	thousands	Ifacara, Iringa, Morogoro	Private enterprises, MSABI	Households	Hand augering, *Village Drill*, Rota Sludge, *Shipo Drill*		Includes rope pump	1970s 2007 - date
Togo			Water4					2008
Uganda	100 – 1,000	Hand augering around Lake Victoria in the 80's. Recent efforts in west, north[21] and south.	Few private enterprises (recently trained), HEWASA, Water4	Households[22], World Vision	*Vonder rig* (no longer used), Rotary-sludge, rotary jetting, *Village Drill, Baptist*	Too early to say for recent piloting	India II, U3M, Rope pump	Late 1980s-early 1990's; and several pilot projects from 1998 to 2013.
Vietnam	>100,000		Private Enterprises		Sludging			1980's
Zambia	>500	In Western, Luapala and Southern Provinces[23]	Village Water Zambia, Private enterprises, Water4, WaterAid, DAPP	NGOs & households	Baptist, rotary jetting, jetting, augering & rota sludge, *Village Drill*	~$3,000 and $1,000 to 2000	India Mark II, Rope Pump	1980's 2007 – date
Zimbabwe	thousands		Private Enterprises,	Households	Augering, *Vonder rig* (no longer used)		Bucket/bailer pumps, Bush pump	1980s, 1990s to early 2000's

21 Gulu and Fort Portal

22 Manually drilled boreholes are also being sold to cattle keepers in Fort Portal (Vuik, 2014b).

23 Western Province: Lukulu &S hangombe districts; Luapala Province: Milenge & Nchelenge Districts; Northern Province (including Mbabala and Chishi Island, on Lake Bangweulu).

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Annex 2: Manual drilling potential, government acceptance, support, training, policies and documentation

The table below provides information regarding select steps of the UNICEF et al (2010) toolkit on manual drilling, namely the estimates, or maps of the potential for manual drilling, and extent to which the technology is accepted by government. The table lists the organisations that are funding, or providing in-country support for the introduction and/or professionalisation of manual drilling. The organisations providing technical as well as business training are also listed.

Key policies, standards and regulations that are relevant for manual drilling are also listed, where it has been possible to ascertain this information. Last but not least, the table provides the references for the information obtained on the country in question, as well as other pertinent information that will be useful for future research on this topic.

As with Annex 1 above, it there are considerable gaps in the table below. This does not necessarily mean that nothing has taken place, but rather that no reliable information was readily available when preparing the compendium or that data could not be sufficiently triangulated.

Country	Estimates or maps of potential	Government acceptance of manual drilling for drinking water supplies	Organisations that supported technology introduction & professionalisation		Organisations/consultants that provided training		Policies, Standards & Regulation	Documentation
			Funding	In-country support	Technical	Business		
Angola			World Vision		Water4			Cotner (2013), World Vision (2013), Naugle (2014c) Hangen (2014b)
Bangladesh		Yes	-	-	-		DPHE uses maps of arsenic contamination to identify areas where shallow tubewells can be installed.	Annis (2013), BBS (2011), Johnston (2014), MLG (2011), NIPORT et al (2013), WSP (2000)
Benin	National estimate[24]	Little interest	DGIS, Dutch Water Alliance	PROTOS, UNICEF	Practica[25]			Abric (2014c), UNICEF et al, (nd-a)
Bolivia			-		EMAS, Water for All International		None, but plans for decree whereby water wells drilled are to be registered	MacCarthy et al (2013), UNICEF (2014b)
Cameroon								Danert (2009)
Central African Republic	National estimate[24]	Positive attitude (by ANEA and DGH)	DGIS	Solidarités International, UNICEF				UNICEF et al (nd-b) Seiyajdi (2013)
Chad	National estimate[24]		UNICEF, World Vision	National Government, UNICEF, World Vision	Practica	✓	Published national standards. Low cost drillers association. No regulation.	Danert (2014a, 2014b), MPHVP et al (2009), UNICEF et al (2009b), (Vuik, 2014c)

[24] Report on feasibility of manual drilling for the country prepared by Practica Foundation, EnterpriseWorks/Vita and UNICEF (note that apart from Guinea, these reports are not dated).

[25] Practica refers to Practica Foundation

Country	Estimates or maps of potential	Government acceptance of manual drilling for drinking water supplies	Organisations that supported technology introduction & professionalisation		Organisations/consultants that provided training		Policies, Standards & Regulation	Documentation
			Funding	In-country support	Technical	Business		
Congo Brazzaville								Houteune (2013 & 2014)
Democratic Republic of Congo	Various[26]		Water4	UNICEF, Well Drilling School (H. Heuser)	ATPESFORC, EMAS, Fight for the Forgotten, Disciples of Christ, H. Heuser, Methodist Church			Baron (2013), Heuser (2013), Naugle (2014c), Steffensen (2014)
Ethiopia	15 Woredas in four regions[27]	Yes, but with concerns about contamination	National Government, JICA, UNICEF, World Vision, WaterAid	iDE, Local Government,	RI, WAI, Practica, Water4, iDE	iDE	Self-supply is in national policy. Training manual & guideline for manual drilling developed. No formal legalization.	Naugle (2014c), UNICEF Ethiopia (2014), Vuik (2014c)
Gambia					H2O			
Ghana			DGIS, World vision, USIAD, Pumping is Life Netherlands	GWASH, UNICEF, Pumping is Life Netherlands	Church of Christ, RI, Water4, Pumping is Life Netherlands			Danert (2009), Naugle (2013; 2014c)
Guinea	National estimate [24]	YES[28]	DGIS, UNICEF (US Fund)	UNICEF	Practica	✓	National Standards for Manual drilling approved in 2014.	Camara (2014), Labas (2013, 2014), SNAPE et al (nd), Vuik (2014c)
India			-	-			Government contracts include drilling specifications.	Ball and Danert (1998) Dave (2014b)
Ivory Coast	National estimate [24]	Minister of Economic Infrastructure requested pilot project.	DGIS	ONEP & UNICEF	Practica			Abric (2014c), UNICEF et al (2009a)
Kenya			KEFINCO, SIDA, JICA, GIZ, LBDA, CSOs[29]		Water4, Assemblies of God, CCADE		Groundwater statutory requirements. No clear policy on manual drilling. Code of Conduct for Drilling has been drafted.	Adenya (2012), Adenya (2014), Naugle (2014c), Steffensen (2014)

26 Including Kananga Region

27 In the four regions of Amhara, Oromiya, SNNPR and Tigray

28 SNAPE recognises the potential for manual drilling in certain areas and for certain conditions (Labas, 2014)

29 World Vision, Kenya Water for Health Organisation (KWAHO), IWP-Kenya, TAK-Africa, CEDEs, SANA, WaterSan, Living Water Intl, Islamic Relief, Catholic Diocese, & CARE.

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Country	Estimates or maps of potential	Government acceptance of manual drilling for drinking water supplies	Organisations that supported technology introduction & professionalisation: Funding	Organisations that supported technology introduction & professionalisation: In-country support	Organisations/consultants that provided training: Technical	Organisations/consultants that provided training: Business	Policies, Standards & Regulation	Documentation
Liberia	National estimate [24]		Aqua4All	ZOA	Practica		National guidelines do not include manually drilled wells	UNICEF et al (nd-d), Vuik (2014c)
Madagascar (driven wells)		No					None	Abric (2014a), Abric (2014b), Akers et al (2015), MacCarthy et al (2013a; 2013b), MacCarthy (2014), MINEAU (nd), MEM (2005), UNICEF/ Practica Foundation (2012b).
Madagascar (Jetting, rota-sludge & Mad Drill)	National estimate [24]	Yes	WASH Projects	UNICEF	Practica		Standards for manual drilling included in the procedures of the Ministry of Energy and Mines (2005)	
Malawi			Connect International, Aqua for All	Mzuzu University	H Holtslag, Connect International, SHIPO	TEECS	Water quality standards (MSB, 2005)	Mzuzu University (2014), Sutton (2007), Steffensen (2014), Tauzie B (2014)
Mali	National estimate [24]		DGIS, OXFAM, UNICEF, World Vision	PROTOS, UNICEF	Practica, Water4	✓	Standards proposed within pilot project	Abric et al (2011), Naugle (2014c), UNICEF et al (nd-d), PROTOS et al (2014), Vuik (2014c)
Mauritania	National estimate [24]	Ministry on board for trial/plot.	Spanish Cooperation AECID, FAMSI, UNICEF	UNICEF, AECID, FAMSI, Atica, Tenmiya, Practica	Practica, Atica			Danert (2009), Abric (2014c), Practica et al (2012), (UNICEF et al, nd-e), Simon (2014)
Mozambique			Connect International	Connect International	Connect International, ADPP (DAPP)			Vuik (2014c)
Nepal		YES	DGIS	Government, WASH Alliance	Government, Practica			Datta (2011), Mahato (2013), Vuik (2014c), Yoder (2012)
Nicaragua			Rotary Haaksberge	AMEC	H. Holtslag	H. Holtslag		NWP (2006)
Niger	National estimate [24]		World Vision		EW, Practica, Water4	✓		Danert (2006), Kalla (2004), MEELCD (nd), Ministère de l'Hydraulique et al (2009), Naugle (2014c), Vuik (2014c)
Nigeria		Yes					National Code of Practice for Water Well Construction (SON, 2010)	Adekile and Olabode (2009), Adekile (2014) Danert et al (2014a; 2014b)
Rwanda			Africa Transformation Network, Water Access Rwanda		Water4			Naugle (2014c), Steffensen (2014)

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Country	Estimates or maps of potential	Government acceptance of manual drilling for drinking water supplies	Organisations that supported technology introduction & professionalisation		Organisations/consultants that provided training		Policies, Standards & Regulation	Documentation
			Funding	In-country support	Technical	Business		
Senegal	National estimate[24]	Yes	USAID/UNICEF	PEPAM	EW, Practica, Water4, RI			Kane et al (2013), Mamadou and Diouf (2014), Naugle and Mamadou, (2013), Naugle (2014c), UNICEF et al (nd-f), Vuik (2014c)
Sierra Leone	National estimate[24]		DGIS, Private donations, WASH Facility & Welthungerhilfe	UNICEF, WaterAid, Welthungerhilfe	EMAS, Henk Holtslag, Water4		Principles for Drilling Construction and Rehabilitation Published (MWR, 2014)	Moijue and Goba (2014), Naugle (2014c), UNICEF (2014e)
South Sudan			SDC					Danert (2014c), Patel (2013)
Tanzania	>3,000	Njombe, Mwanza, Dodoma, Tabora, Turiani	USAID, Volkhardt Stiftung, Connect International, Winrock, Msabi	Msabi, SHIPO, Winrock	H. Holtslag, Connect International	SHIPO	Licencing & registration for machine drillers; drilling guidelines in preparation (Holtslag, 2013). Discussions about regulation of manual drilling on-going (ibid)	Steffensen (2014)
Togo	National estimate[24]		UNICEF	UNICEF	Practica, Water4			Ministre de L'Eau (2009), Naugle (2014c), Vuik (2014c)
Uganda	District groundwater reports	Tends to be seen as a "second class" solution.		World Vision, Hewasa, ICRC, Young Men Drillers, Mission for Water	Practica, SHIPO, Water4		Guidelines for Shallow Wells (MWE 2007a)	Carpenter (2014), MWE (2012a), Naugle (2014c), Steffensen (2014), (Vuik, 2014c)
Vietnam								Ikin and Baumann (2004)
Zambia	National estimate[24]	Mazambuka	Connect International, UNICEF	DAPP, UNICEF	Village Water Zambia, Practica, Water4, Connect International, H. Holtslag	✓	Technical specifications being developed.	Holtslag (2014), MLGHEEEP (2011), Muyangwa (2014), Naugle (2014c), UNICEF/RWSN (2014e), Carmen (2014), Steffensen (2014), Vuik (2014c)
Zimbabwe		Yes						Morgan (2014)

References

About.com (2014) *Generalized Geologic Map of Bolivia, Geologic Maps of South American Countries*, About.com, Available from http://geology.about.com/od/othernationgeomaps/ss/South-America-Geologic-Maps_2.htm

ABRIC (2014a) *Personal Communication, 25th February 2014*, UNICEF-RWSN 3rd Webinar on Manual Drilling, Available from http://vimeo.com/87747145

ABRIC (2014b) *Le forage manuel à Madagascar/Manual Drilling in Madagascar*, Presentation at the 3rd UNICEF-RWSN Webinar on Manual Drilling, 25th February 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

ABRIC (2014c) *Personal Communication in an email* on 29th October 2014

ABRIC, S, SONOU, M, AUGEARD, B, ONIMUS,F, DURLIN, D, SOUMAILA, A AND GADELLE, F (2011) *Lessons Learned in the Development of Smallholder Private Irrigation for High-Value Crops in West Africa*, Available from http://siteresources.worldbank.org/INTARD/Resources/West_Africa_web_fc.pdf

ABUURU D (2014) *'[handdrilling] Examples of Manual Drilling in Remote, or Difficult to Serve Areas'* [Online] Hand Drilling Cluster Group, 30th May 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

ADEKILE D AND OLABODE, O (2009) *Hand drilling in Nigeria, why kill and ant with a sledge hammer*. Available from http://wwrural-water-supply.net/en/resources/details/163 [Accessed on 16 July, 2014]

ADEKILE, D (2014) *Good Practices in Manual Drilling Construction and Design - The Nigeria Experience*, Presentation at the 3rd UNICEF-RWSN Webinar on Manual Drilling, 25th February 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

ADENYA E (2012) *Manual Drilling in Kenya: The Situational Analysis*, Presented to the Chief of WASH Section, UNICEF Kenya, 8th February 2012, Edwin Aldrin Adenya, Manual Drilling Consultant

ADENYA E (2013) *Personal Communication in Draft Template for Country Information on Manual Drilling, Kenya*, Data collected within the UNICEF/RWSN Project to Document the Professionalization of Manual Drilling in Africa

ADENYA E (2014) *Manual Drilling : the Kenya Case Study/Forage Manuel: Etude de cas du Kenya*, Presentation at the 3rd UNICEF-RWSN Webinar on Manual Drilling, 25th February 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

ADENYA E AND DONDE F (2013) *Manual Drilling in Africa; lets go beyond advocacy*, Briefing Paper at the 36th WEDC International Conference, Nakuru, Kenya 2013, Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment.

AKERS, D.B, MACCARTHY,MF, CUNNINGHAM, J, ANNIS, and J MIHELCIC, JR (2015) Lead (Pb) *Contamination of Self-Supply Groundwater Systems in Coastal Madagascar and Predictions of Blood Lead Levels in Exposed Children*, Environ. Sci. Technol., Just Accepted Manuscript • DOI: 10.1021/es504517r, Publication Date (Web): 21 Jan 2015, Available from: http://pubs.acs.org/doi/pdf/10.1021/es504517r

AKVOPEDIA (2014) *Drilling or digging – general* [online] http://akvopedia.org/wiki/Drilling_or_digging_-_general

ALRAI, M. I. S, GOSSA, T and PABA M (2014) *Promotion of Manual Well Drilling under the Self-Supply Initiative: Government of Ethiopia's Perspective / Promotion du forage manuel via l'initiative d'auto-approvisionnement: Point de vue du Gouvernement éthiopien*, Presentation at the 4th UNICEF-RWSN Webinar on Manual Drilling, 4th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

ANNIS, J. (2013) *Self-Supply at Scale: Lessons from rural Bangladesh*, RWSN Blog Post, http://rwsnblog.wordpress.com/2013/08/28/self-supply-at-scale-lessons-from-rural-bangladesh (viewed 22.11.13)

BALL, P AND DANERT, K (1998) *Hand Sludging. A Report from North West Bengal*, an internal report of the Low Cost Drilling Project of Cranfield University (UK), funded by DFID, in partnership with Government of Uganda, Danida, Sida, and Unicef, Available from http://r4d.dfid.gov.uk/PDF/Outputs/R71261.pdf

BARON R (2013) *Low-cost technology for safe drinking water, Draft, DR Congo manual well drilling techniques strengthened by cooperation with the Chadian private sector association. ATPESFORC*, Unpublished report

BBS (2011) *Bangladesh National Drinking Water Quality Survey of 2009*, Bangladesh Bureau of Statistics, Planning Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Available from http://www.unicef.org/bangladesh/knowledgecentre_6868.htm [Accessed 25 September 2014]

BLAANKWAARDT, B (1984) *Hand Drilled Wells – A Manual on siting, Design, Construction and Maintenance*, Rwegarulila Water Resources Institute, Tanzania

BOUDOUMA, M. M (2013) *Personal Communication with Mallah Mohamed Boudouma* on 7th November 2013

BUCHNER W and MACCARTHY M (2014) *Experiences from Bolivia –EMAS Manually Drilled Wells/ Expériences de la Bolivie –les Forages Manuels EMAS*, Presentation at the 2nd UNICEF -RWSN Webinar on Manual Drilling, 18th Feb 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

Copyright

CAMARA, E. S. (2014) *Guinée: Ce que les Gouvernements aiment et détestent concernant les forages manuels ?/ Guinea: What do governments love and hate about manual drilling?*, Presentation at the 4th UNICEF-RWSN Webinar on Manual Drilling, 4th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

CARMEN (2014) '[handdrilling] *Examples of Manual Drilling in Remote, or Difficult to Serve Areas'* [Online] Hand Drilling Cluster Group, 3 June 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

CARPENTER, J (2013) *Personal Communication in an email* on 21st August 2013.

Carpenter, J (2014) *An Assessment of the EMAS Pump and its Potential for Use in Household Water Systems in Uganda*, University of South Florida MSc Thesis, Available from: http://www.rural-water-supply.net/en/resources/details/621

CARTER R.C (2005) *HUMAN-POWERED DRILLING TECHNOLOGIES an overview of human-powered drilling technologies for shallow small diameter well construction, for domestic and agricultural water supply*. First Edition, May 2005 Cranfield University UK.

CORTEX R (2012) *LOS RECURSOS HIDRICOS SUBTERRANEOS EN BOLIVIA*, 1er CongresoInternacionalde Hidrogeología y Recursos Hídricos, Ministerio de Medio Ambiente y Agua Viceministerio de Recursos Hídricos y Riego

COTNER (2013) *Personal Communication with Christopher Cotner in an email* on 27th March 2013

DANERT K, ADEKILE, D and GESTI CANUTO, J (2014a) *Documentation of Manual Drilling in Lagos and beyond* [online video] Available from: http://vimeo.com/107047730

DANERT K, ADEKILE, D and GESTI CANUTO, J (2014b) *Manually Drilled Boreholes: Providing water in Nigeria's Megacity of Lagos and Beyond*, Skat Foundation, Switzerland. Available from http://www.rural-water-supply.net/en/resources/details/618

Danert, K, Armstrong, T, Adekile, D., Duffau, B., Ouedraogo, I and Kwei, C (2010) *Code of Practice for Cost Effective Boreholes*, Rural Water Supply Network, Available on from www.rural-water-supply.net/en/resources/details/128

DANERT, K (2003) *Technology Transfer for Development: Insights from the Introduction of Low Cost Water Well Drilling Technology to Uganda*, PhD Thesis, Cranfield University at Silsoe, UK

DANERT, K (2006) *A Brief History of Hand Drilled Wells in Niger, Only the beginning, Water and Sanitation Pro-gramme/Rural Water Supply Network, Available from: http://www.rural-water-supply.net/en/resources/details/129*

DANERT, K (2009) *Realizing the Potential of Hand-Drilled Wells for Rural Water Supplies, Waterlines Vol 28 No 2.*

DANERT, K (2013) *Professionalising Manual Drilling*. Survey of Manual Drilling Experiences - May 2013 , Skat Foundation, RWSN

DANERT, K (2014a) *Chad's Growing Manual Drilling Industry*, Skat Foundation, In Press

DANERT, K (2014b) *Chad - Documentation of Manual Drilling* [online video], Available from: http://vimeo.com/84021165

DANERT, K (2014c) *Professionalising Manual Drilling in Nothern Bahr el Ghazal State (South Sudan)*, Unpublished consultancy Report for the Ministry of Water, Cooperatives and Rural Development

DATTA, G (2011) *Research on Mitigation options of Arsenic contaminated Groundwater in Nepal*, Rural Water Supply and Sanitation Project, Western Nepal, Available from http://www.rwsspwn.org.np/wp-content/uploads/2012/05/Arsenic-Research-Report-by-Ganga-Datta-Nepal.pdf

DAVE, S (2014a) *Key findings of the pilot project study to develop participatory water safety and security plan - Jointly implemented by PHED, Government of West Bengal and UNICEF*, Draft presentation-6th August 2010, Available from shdave@unicef.org

DAVE, S (2014b) *Manual Drilling in India / Forage Manuel en Inde*, Presentation at the 2nd UNICEF -RWSN Webinar on Manual Drilling, 18th Feb 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

DAW, R. K (2013) *Personal Communication with Raj Kumar Daw*, former Danida and UNICEF, India on 12th August 2013.

DAW, R.K. (2014) '[handdrilling] *Manual Drilling Family Tree' [Online] Hand Drilling Cluster Group*, 2 Sept 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

DHV (1979) *Shallow Wells, DHV Consulting Engineers*, Amersfoort, the Netherlands

EMAS (2015) *EMASs Videos* [online], EMAS, Available from http://vimeo.com/emas/videos

ENANGU, M (2013) *Personal Communication in an email* on 15th May 2013.

GAYA, S (2015) *Personal Communication in an email* on 20th Jan 2015.

GRAIA (2012) *Identification des Zones Favorables aux Forages Manuels au Guinee*, Rapport Final, GRAIA s.r.l. Available from Fabio Fussi fabio.fussi@usa.net

HANGEN M (2014a) '*[handdrilling] Examples of Manual Drilling in Remote, or Difficult to Serve Areas*' [Online] Hand Drilling Cluster Group, 29th May 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

HANGEN M (2014b) *Personal Communication in an email* on 16th November 2014

Copyright

HEUSER, H (2013) *Personal Communication in an email* on 18th April 2013.

HIRN, M. (2012) *Sierra Leone Waterpoint Report. Review Version – 26th June 2012*, Ministry of Energy & Water Resources , Freetown, Sierra Leone, Available from: http://www.rural-water-supply.net/en/resources/details/640

HOLTSLAG, H (2013a) *Personal Communication in an email* on 5th Feb 2013.

HOLTSLAG, H (2014) *Personal Communication in an email* on 13th Dec 2014

HOUTEUNE, K, H (2013) *Personal Communication in an email* on 13th Dec 2013

IKIN, D and BAUMANN, E (2004) *Promoting Dreams: Setting up Viable Supply Chains for Handpumps in Africa,* Summary Report HTN/Skat Foundation, St Gallen, Switzerland

IMASIKU A (2002) *Compilation of the hydrogeological map atlas for the SADC region: Situation Analysis Report Annex M - Zambia* , SADC Water Sector Coordination Unit, Lesotho, Available from http://www.bgs.ac.uk/sadcreports/zambia2002gwcbbsrkcountryrep.pdf

JMP (2014) Access to Drinking Water Source in JMP (2013), *Joint Monitoring Programme for Water Supply and Sanitation, Estimates of the Use of Water Sources and Sanitation Facilities, Updated April 2014, Nigeria,* Joint Monitoring Programme of UNICEF and WHO, Available from http://www.wssinfo.org

JOHNSTON R.P (2014a) *Re: Manual Drilling in Bangladesh [Online],* Hand Drilling Cluster Group, 24th September 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

JOHNSTON R.P (2014b) *Personal Communication in an email* on 17th Nov 2014

KALLA, L (2014) *Technologie des forages manuels pour l'eau potable au Niger/ Manual Drilling for Drinking Water in Niger,* Presentation at the 4th UNICEF-RWSN Webinar on Manual Drilling, 4th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

KANE, H.C, FUSSI, F, DIÈNE, M and SARR, D (2013) *Feasibility Study of Boreholes Hand Drilling in Senegal —Identification of Potentially Favorable Areas,* Journal of Water Resources and Protection, 2013, 5, 1219-1226

KENYA OPEN DATA (2014) *District Poverty Data Kenya Integrated Household Budget Survey 2005-2006* , Kenya Open Data, Available from https://www.opendata.go.ke [Accessed on 6 June 2012]

KUMPEL, E, ALBERT, J and KHUSH, R (2014) *Final Report (Draft – 4 Apr 2014) Water Quality Testing Study, Port Harcourt, Nigeria*, World Bank Contract#7167983, The Aquaya Institute, CA, USA, Available from info@aquaya.org

LABAS, J (2013) *Personal Communication in completed template for information on manual drilling –Guinea* on 12th August 2013

LABAS, J (2014) *Personal Communication in an email* on 9th December 2014

MACCARTHY, BUCKINGHAM & MIHELCIC (2013a) *Increasing Access to Low-Cost Water Supplies in Rural Areas: EMAS Household Water Supply Technologies in Bolivia*, Rural Water Supply Network, Available from http://www.rural-water-supply.net/en/resources/details/518

MACCARTHY, M (2014) *Personal Correspondence in an email* on 30th September 2014

MACCARTHY, M, ANNIS, J.E and MIHELCIC, J.R (2013b) *Unsubsidised Self-supply in eastern Madagascar*, Water Alternatives 6(3): 424-438, Available from: www.water-alternatives.org

MAHATO, G (2013) *Personal Communication in Draft Template for Country Information on Manual Drilling, Nepal,* Data collected within the UNICEF/RWSN Project to Document the Professionalization of Manual Drilling in Africa

MAMADOU, I and DIOUF, A (2014) *Low cost drilling: experiences from Senegal/Forages à faible coût- Expériences au Sénégal*, Presentation at the 2nd UNICEF -RWSN Webinar on Manual Drilling, 18th Feb 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

MEELCD (no date) *Etude de Faisabilite des Forages Manuels Identification des Zones Potentiellement Favorables*, Ministere de l'eau, le l'environnement et de la lutte contre la desertification, Republique du Niger, Available from http://www.unicef.org/wash/index_54332.html

MEENAKSHISUNDARAM S.S (2011) *Rural Water Supplies - Lessons from India*, Paper presented at the 6th RWSN Forum in Kampala, Uganda, Available from http://rwsnforum.wordpress.com [Accessed on 2 Sept 2014]

MEERH (no date) *FEASIBILITY STUDY FOR MANUAL DRILLING MAPPING OF FAVOURABLE ZONES*, Ministère de l'Environnement de l'Eau et des Ressources Halieutiques, UNICEF, Practica Foundation and EnterpriseWorks/VITA, Available from http://www.unicef.org/wash/files/Chad_manual_drilling_final_report_(FINAL).pdf

MEM (2005) *Manuel de Procedure pour la Mise en Place des Projects Eau et Assainissement.* PEAPAR – Projet Pilot D'Alimentation en Eau Potable et Assainissement en Milleu Rural, Ministry of Energy and Mines, Repiblikan'i Madagaskara

MICS (2010) Access to Drinking Water Source in JMP (2013), *Joint Monitoring Programme for Water Supply and Sanitation, Estimates of the Use of Water Sources and Sanitation Facilities, Updated April 2013, Sierra Leone,* Joint Monitoring Programme of UNICEF and WHO, Available from http://www.wssinfo.org

Copyright

MICS (2010) *Access to Drinking Water Source* in JMP JMP (2013) *Joint Monitoring Programme for Water Supply and Sanitation, Estimates of the Use of Water Sources and Sanitation Facilities, Updated April 2013, India*, Joint Monitoring Programme of UNICEF and WHO, Available from http://www.wssinfo.org

MINEAU (2012) *Base de données sur l'eau, l'hygiène et l'assainissement à Madagascar*, Ministre de l'Eau

MINEAU (no date) *Republique de Madagascar Ministre de l'Eau Etude de Faisabilite des Forage Manuels Identification des Zones Potentiellement Favorables*, available from http://www.unicef.org/wash/index_54332.html

MINISTÈRE DE L'HYDRAULIQUE, PRACTICA FOUNDATION and UNICEF (2009) *Etude des possibilités d'intégrer les Forages à faible coût au dispositif d'Alimentation en Eau des communautés rurales au Niger.*

MINISTÈRE DU PLAN (2013) *2012 Enquête Démographique et de Santé et à Indicateurs Multiples (EDS-MICS)*, Institut National de la Statistique Ministère du Plan Conakry, Guinée, Available from http://dhsprogram.com/pubs/pdf/FR280/FR280.pdf

MINISTRE DE L'EAU (2009) *Etude de faisabilite des forages manuels au Togo, identification des zones potentiellement favorables*, Direction Generale de l'Eau et de l'assainissement, available from http://www.unicef.org/wash/index_49090.html

MINISTRIE DE LA PECHE DE L'HYDRAULIQUE VILLAGEOISE ET PASTORALE, UNICEF, PRACTCA FOUNDATION (2009) *Technical Standards for Low Cost Manually Drilled Boreholes for Depths between 30 and 50 meters*, Ministrie de la pêche de l'hydraulique Villageoise Et Pastorale, Unicef, Practca Foundation

MLG (2011) *Sector Development Plan (FY 2011-25), Water Supply and Sanitation Sector in Bangladesh*, Ministry of Local Government, Rural Development and Cooperatives, Government of the People's Republic of Bangladesh, Available from http://www.psu-wss.org/assets/book/sdpeng.pdf

MLGHEEEP (2011) *Mapping of Suitable Zones for manual Drilling in Zambia – Draft Report*, Ministry of Local Government, Housing, Early Education and Environmental Protection

MOIJUE, M and GOBA, S (2014) *Private Sector and NGO Experiences of Introducing and Developing Markets for Manual Drilling in Sierra Leone Expériences du secteur privé et des ONG pour l'introduction et le développement de marchés pour le forage manuel en Sierra Leone*, Presentation at the 5th UNICEF-RWSN Webinar on Manual Drilling, 11th March 2014, Available on: http://www.rural-water-supply.net/en/resources/details/565

MORGAN, P (2014) *Personal communication* in an email on 24th September 2014

MSB (2005) *Malawi Standard, Borehole and shallow well water quality – specification*, ICS 13.060-10, MS 733:2005, Malawi Standards Board

MUYANGWA M (2014) *Case Study of Western Province in Zambia/Etude de Cas de la Province de l'Ouest en Zambie*, Presentation at the 5th UNICEF-RWSN Webinar on Manual Drilling, 11th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

MWE (2007a) *District Implementation Manual*. Ministry of Water and Environment, Available from: http://www.mwe.go.ug

MWE (2007b) *Shallow Wells Technology Manual – Water and Sanitation Sector District Implementation Manual Annex 6.2*. Ministry of Water and Environment, Uganda.

MWE (2012) *Water Resources Monitoring & Assessment Documents*, Ministry of Water and Environment, Uganda, Available from: http://www.mwe.go.ug/index.php?option=com_docman&task=cat_view&gid=27&Itemid=223)

MWE (2012b) *Water and Environment Sector Performance Report 2012*, Ministry of Water and Environment, Kampala, Uganda, Available from http://www.mwe.go.ug

MWR (2014) *Principles for Borehole Construction and Rehabilitation in Sierra Leone*, Ministry of Water Resources, Sierra Leone, Available from: http://www.rural-water-supply.net/en/resources/details/624

MZUZU UNIVERSITY (2014) *Mzuzu Smart Centre* [Online], Available from http://www.mzuzusmartcentre.com/

NAUGLE (2014c) *Personal Communication in an email* on 19th November 2014

NAUGLE J (2013) *Personal Communication in an email* on 5th Feb 2013

NAUGLE J (2014a) *'[handdrilling] Examples of Manual Drilling in Remote, or Difficult to Serve Areas'* [Online] Hand Drilling Cluster Group, 4th June 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

NAUGLE J AND MAMADOU I (2013) *Building Local Well-drilling Capacity in Senegal using Appropriate Drilling Technologies*, USAID/Millennium Water and Sanitation Program, Available from: http://www.enterpriseworks.org/pubs/Building%20local%20Well%20Drilling%20Capacity%20in%20Senegal%20Final_Vrs%20ltr_600dpi.pdf

NAUGLE, J (2014b) *'[handdrilling] Manual Drilling Family Tree'* [Online] Hand Drilling Cluster Group, 29 Aug 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

Copyright

NBS (2010) *National Household Survey 2009-2012*, Uganda Bureau of Statistics, In JMP (2013) *Estimates on the use of Water Sources and Sanitation Facilities*, Joint Monitoring Programme of UNICEF and WHO, Available from http://www.wssinfo.org

NIPORT, Mitra and Associates, and ICF International (2013) *Bangladesh Demographic and Health Survey 2011*. Dhaka, Bangladesh and Calverton, Maryland, USA: National Institute of Population Research and Training (NIPORT), Mitra and Associates, and ICF International. http://dhsprogram.com/pubs/pdf/FR265/FR265.pdf

NSO (2011) *Third Integrated Household Survey (IHS3) 2010/2011*, National Statistics Office, Malawi, Available from http://www.nsomalawi.mw

NWP (2006) *Smart Water solutions: Examples of innovative, low-cost technologies for wells, pumps, storage, irrigation and water treatment* [online], Netherlands Water Partnership, Den Haag, Available from http://www.samsamwater.com/library/Smart_Water_Solutions_-_EN.pdf

PATEL, D (2013) *New Hand Auger Drilling in Gogrial West County, Warrap State South Sudan* [online video], Available on http://vimeo.com/58336945

PRACTICA FOUNDATION (2009) *The impact of manual drilling for the construction of sustainable water-points in Chad*, Practica Foundation/UNICEF/Enterprise Works, Available from http://practica.org/publications/950/

PRACTICA FOUNDATION (2010a) *Augering*, *Manual Drilling Series*, TECHNICAL TRAINING HANDBOOK ON AFFORDABLE MANUAL WELL DRILLING, Practica Foundation, Netherlands, Available from http://www.unicef.org/wash/files/05.pdf

PRACTICA FOUNDATION (2010b) *Jetting*, *Manual Drilling Series*, TECHNICAL TRAINING HANDBOOK ON AFFORDABLE MANUAL WELL DRILLING, Practica Foundation, Netherlands, Available from http://www.unicef.org/wash/files/06.pdf

PRACTICA FOUNDATION (2010c) *Percussion*, *Manual Drilling Series*, TECHNICAL TRAINING HANDBOOK ON AFFORDABLE MANUAL WELL DRILLING, Practica Foundation, Netherlands, Available from http://www.unicef.org/wash/files/07.pdf

PRACTICA FOUNDATION (2010d) Sludging, *Manual Drilling Series*, TECHNICAL TRAINING HANDBOOK ON AFFORDABLE MANUAL WELL DRILLING, Available from http://practica.org/publications/well-drilling-sludging/

PRACTICA FOUNDATION, AEP-F, AECID (2012) *D'INTRODUCTION DES FORAGES MANUELS DANS LES LOCALITES RIVERAINES DU FLEUVE SENEGAL*, PRACTICA FOUNDATION, Netherlands

PROTOS, PRACTICA FOUNDATION, UNICEF (2014) *Projet pilote sur l'introduction et l'évaluation des techniques manuelles de forage à moindres coûts permettant l'accès à l'eau potable en zone rurale*, PROTOS, Belgium

ROBINS, N, DAVIES, J and FARR, J (2013) *Groundwater supply and demand from souther Africa0s crystalline basement aquifer: evidence from Malawi*, Hydrogeology Journal, February 2013, DOI 10.1007/s10040-013-0956-5

RWSN (2014) *An Introduction to Manually Drilled Wells* http://www.rural-water-supply.net/en/implementation/manual-drilling

SEIYADJI, O, F (2013) *Personal Communication in completed template for information on manual drilling –Central African Republic* on 16th July 2013

SHIPO (2014) *Manual Borehole Drilling*, Southern Highlands Participatory Organisation (SHIPO), Available from http://www.shipo-tz.org/services/training-centre

SIMON, D (2014) *Personal Communication* in an email on 15th December 2014.

SINHAROY, SP (2014) *A Note on the Manual Drilling for construction of water supply Tube wells in West Bengal*, Dr. S. P., Chairperson, Fluoride Taskforce, Government of West Bengal -2014, Unpublished Report, Available from shdave @ unicef.org

SMITH A., LINGAS, E.O. AND RAHMAN M. (2000). *Contamination of drinking-water by arsenic in Bangladesh: a public health emergency*. Bulletin of the World Health Organisation, 78 (9)

SNAPE, UNICEF and Practica (no date) *Controle Qualite des Forages Manuels*, Service national des points d'eau de Guinée

SON (2010) *Code of Practice for Water Well Construction NIGERIAN INDUSTRIAL STANDARD NCP 027: 2010, ICS 23.040.10*, Standards Organisation of Nigeria, Available from: http://www.rural-water-supply.net/en/resources/details/617

STEFFENSEN, M (2014) *Personal Communication in an email on 5th September 2014*

SUTTON, I (2007) *An Assessment of Hand Drilling Potential in Upland and Lowland Dambo Environments of Malawi*, MSc Thesis, Cranfield University, UK, Available from http://www.protos.be/sites/default/files/library_assets/321_SUT_E16_assessment_hand.pdf

TAUZIE, B (2014) *Manual Drilling in Malawi/Forage Manuel au Malawi*, Presentation at the 5th UNICEF-RWSN Webinar on Manual Drilling, 11th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

UN (2012) *Kenya emergency Humanitarian Response Plan 2012+*, United Nations, Available from www.wescoord.or.ke [Accessed on 6 June 2012]

UNICEF (2010a) *Towards an Arsenic Safe Environment in Bangladesh*, UNICEF, March 2010

UNICEF (2010b) *Groundwater Development* [Online], UNICEF, Available from: http://www.unicef.org/wash/index_54332.html

Copyright

UNICEF (2012a) *Manual Drilling in Kenya: UNICEF WASH Issue Paper 001/2012*, Unpublished Paper.

UNICEF (no date) *Reaching the MDGs with Equity: Identifying Zambia's most excluded people* , UNICEF, Available from http://www.unicef.org/zambia/reaching_the_mdgs_with_equity_final.pdf

UNICEF ETHIOPIA (2014) *Promotion of Manual Well Drilling under the Self-Supply Initiative*, Presentation at the 4th UNICEF-RWSN webinar on manual drilling on 4th March 2014, Available from: http://www.rural-water-supply.net/en/resources/details/565

UNICEF Kenya (2012a) *Manual Drilling in Kenya, Briefing Note No 1*, UNICEF Kenya WASH Section

UNICEF Kenya (2012b) *Small Scale Drillers Associations, Briefing Note No 2*, UNICEF Kenya WASH Section

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (2009a) *République de la Cote D'Ivoire, Etude de faisabilité des forages manuels, identification des zones potentiellement favorables.*

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-a) *République du Bénin, Etude de faisabilité des forages manuels, identification des zones potentiellement favorables.* Available from http://www.unicef.org/wash/index_54332.html

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-b) *République Centrafricaine, Etude de faisabilité des forages manuels, identification des zones potentiellement favorables.* Avaiable from http://www.unicef.org/wash/index_54332.html

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-c) *Republic of Liberia, Feasibility Study for Manual Drilling Mapping of Favourable Zones. Available from* http://www.unicef.org/wash/index_54332.html

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-d) *République du Mali, Etude de faisabilité des forages manuels, identification des zones potentiellement favorables.* Avaiable from http://www.unicef.org/wash/index_54332.html

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-e) *Mauritane, Etude de faisabilité des forages manuels, identification des zones potentiellement favorables.* Avaiable from http://www.unicef.org/wash/index_54332.html

UNICEF, PRACTICA FOUNDATION and ENTERPRISEWORKS/VITA (no date-f) *Republique du Senegal- Etude de Faisabilite des Forages Manuels Identification des Zones Potentiellement Favorables.* Avaiable from http://www.unicef.org/wash/index_54332.html

UNICEF/PRACTICA FOUNDATION (2012) *Capitalisation d'expériences sur les forages manuels à Madagascar*, UNICEF/PRACTICA FOUNDATION, Available from : http://practica.org/publications/941/

UNICEF/PRACTICA FOUNDATION/ENTERPRISE WORKS (2010) Technical Manuals for the Professionalisation of Manual Drilling in Africa, Series of Publications can be downloaded from http://www.unicef.org/wash/index_49090.html (follow link: Technical Manuals)

UNICEF/RWSN (2014e) *Learning Note 5: Private Sector and NGO Experiences of Introducing and Developing Markets for Manual Drilling* – Malawi, Zambia and Sierra Leone (11 March 2014), UNICEF, Available from http://www.rural-water-supply.net/en/resources/details/565 [Accessed on 1 Sept 2014]

UNIVERSITY OF CALGARY (2005). *Water Management in Bolivia*, Proposal to the Canadian International Development Agency.

UNIVERSITY OF CALGARY (no date) *Agua Subterránea: Fuente de Vida en Bolivia* [Online Video], Available from http://tlc.ucalgary.ca/projects/audiovideo [Accessed on 5 June 2014]

VUIK, R (2014a), *'[handdrilling] Manual Drilling Family Tree'* [Online] Hand Drilling Cluster Group, 1 Sept 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

VUIK, R (2014b) *Personal Communication in an email on* 29th October 2014

VUIK, R (2014c) *Personal Communication in an email on* 9th December 2014

WALTER W (2014) *'[handdrilling] Examples of Manual Drilling in Remote, or Difficult to Serve Areas'* [Online] Hand Drilling Cluster Group, 29th May 2014. Available from https://dgroups.org/rwsn/groundwater/handdrilling/discussions

WHOlives (2014) *The Village Drill*, http://vimeo.com/87693901

WORLD BANK (2010) *Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India*, World Bank

WORLD VISION (2010) *New drilling technique to get water to a million in need* [Online], World Vision, Available from http://www.worldvision.org/news-stories-videos/new-drilling-technique-get-water-million-need

WSP (2000) *The Growth of Private Sector Participation and Rural Water Supply in Rural Bangladesh*. Water and Sanitation Programme (WSP), Washington DC, USA.

YODER, B (2012) *Personal communication through a note entitled Bob Yoder* (field work jointly with Deepak Adhikari) 14 May 2012

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Endnotes

i Note that the studies give an overview for the country but the small scale of the maps does not provide detailed information that can be used in the field. There is scope for improving how manual drilling feasibility is determined and presented. While providing a useful starting point, the reports are of varying detail and the maps do not all use a standard legend ordering to depict the different rock types. In some of the reports discussion on the hydrogeology and groundwater potential is lacking and the maps resolution makes reading them difficult.

ii Rainwater and bottled water are also used for drinking water supplies but each represents less than 1% and are thus not included.

iii In French: L'association tchadienne pour la promotion des entreprises spécialisées en forage à faible coût (ATPESFORC)

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