CONTEXTUALLY DRILLING WITH GEOLOGY AND LOCAL CAPACITY
A STUDY OF THE TRAIN-THE-TRAINER MODEL’S
IMPACT ON MANUAL BOREHOLE IMPLEMENTATION

by

Wyatt R. Lindsey
A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Geophysics Program Humanitarian Engineering & Science)

Golden, Colorado
Date _____________________

Signed: _____________________
Wyatt R. Lindsey

Signed: _____________________
Richard Kranhenbuhl
Thesis Advisor

Golden, Colorado
Date _____________________

Signed: _____________________
Richard Kranhenbuhl
Professor and Department Head
Humanitarian Engineering and Science
ABSTRACT

Access to safe drinking water and sanitation are fundamental human rights recognized by the United Nations. However, many developed countries have achieved this ideal but millions of people around the world, especially in rural areas, still lack access to clean water due to various challenges. In Benin, Africa, there are increasing populations, surface water contamination issues, and declining rainfall all of which have decreased surface and groundwater resources in the region, driving the need for alternatives to meet the growing water demand. This study focuses on understanding the potential of manual drilling methods as a cost-effective solution to expand groundwater extraction and contribute to the demand of potable water. This project seeks to show the benefits of a sociotechnical approach in a manual borehole drilling project that combines education and co-implementation to develop a more successful project. In addition, geoscientific applications are integrated to inform drilling methods and site selection to reduce the uncertainty of the subsurface. Educational objectives include presenting best practices of manual wellbore drilling projects and community development practices to provide a framework for developing manual borehole drilling water projects. To better manual borehole drilling education implementation, this study evaluates the impact of a train-the-trainer model integrated with Humanitarian Engineering and Science themes through a case study description and analysis. The expected outcome is to provide a better understanding of how focusing on education, and co-implementation can aid water relief projects and promote self-reliance on water resources.
# TABLE OF CONTENTS

ABSTRACT ................................................................................................................................... iv

LIST OF FIGURES ...................................................................................................................... vii

LIST OF TABLES ........................................................................................................................ ix

ACKNOWLEDGEMENTS ........................................................................................................... x

CHAPTER 1 BUILDING BLOCKS FOR IMPLEMENTING MANUAL BOREHOLE DRILLING ........... 1

1.1 Introduction and Motivation ............................................................................................... 1

1.2 Fundamental Information .................................................................................................... 3

1.2.1 Manual Drilling Methods ............................................................................................... 3

1.2.2 Geophysically Informed Drilling .................................................................................. 9

1.2.3 Area of Focus and History ......................................................................................... 11

1.3 Purpose and Research ...................................................................................................... 13

CHAPTER 2 SUPPORTING MANUAL DRILLING DEVELOPMENT AND IMPLEMENTATION .................. 15

2.1 Introduction ....................................................................................................................... 15

2.2 Methods ............................................................................................................................ 15

2.2.1 Stakeholder Engagement ............................................................................................ 15

2.2.2 Train-The-Trainer (T³) ............................................................................................. 16

2.2.3 Project Evaluation Metrics ......................................................................................... 18

2.3 Previous Projects ............................................................................................................. 21

2.3.1 Analysis and Discussion ......................................................................................... 21

2.4 Conclusion ...................................................................................................................... 23

CHAPTER 3 TECHNICAL CONSIDERATIONS OF MANUAL DRILLING ...................................... 26

3.1 Introduction ..................................................................................................................... 26

3.2 Role of Geoscience in Manual Drilling ......................................................................... 27

3.3 Selecting a Drilling Method ............................................................................................. 27

3.5 Conclusions ................................................................................................................... 30

CHAPTER 4 IMPLEMENTING A MANUAL DRILLING PROJECT IN BENIN, AFRICA ... 32

4.1 Introduction ................................................................................................................... 32

4.2 Background .................................................................................................................... 32

4.3 Implementation of a Sociotechnical Manual Drilling Project ........................................ 34

4.4 Discussion ...................................................................................................................... 39
4.5 Summary ........................................................................................................................................ 40

CHAPTER 5 CONCLUSIONS ............................................................................................................. 42

REFERENCES ..................................................................................................................................... 44

APPENDIX A 2022 GWB MANUAL DRILLING WORKSHOP SLIDES ............................................ 49

A.1 Manual Drilling Methods ........................................................................................................ 49
A.2 Community Development Practices For Manual Drilling Projects ................................... 60
A.3 Project Planning ..................................................................................................................... 64

APPENDIX B BAPTIST DRILLING METHOD IMPLEMENTATION VIDEO ............................... 65

B.1 Implementing The Baptist Manual Drilling Method Video: 2022 GWB
     Hydrogeological Workshop ................................................................................................... 65
LIST OF FIGURES

Figure 1.1 Shows a conceptual 2D diagram of how water extraction impacts the freshwater-salt water interface ("Saltwater Intrusion" U.S. Geological Survey, 2019). (a) Shows the natural conditions without groundwater extraction. (b) Upconing of the saltwater interface due to groundwater extraction. ............................................................... 2

Figure 1.2 (a) A drilling crew pulls up the rope, lifting the drill bit off the bottom of the hole, which closes the check valve. When the check valve closes, water is pushed up the drill stem. (b) On the downstroke, the check valve is momentarily open, letting water and sediment from the bottom of the hole flow into the drill stem, allowing the mixture to be pushed up to the surface. (c) As the crew pulls, the check valve closes, pushing the mixture to exit the mouth into the decanter (settling pit). The decanter allows sediments to settle and water to flow back into the borehole for wellbore stability. (Not to scale) ... 7

Figure 1.3 Baptist Method drill bit modification schematic (not drawn to scale). A downward force applied from the drill stem onto the drill bit collar causes the drill bit and the drill head to rotate. The rotary action is caused by the internal pins that provide a pivot point for the milled-out sections on the drill bit. Note: The check valve is also known as a foot valve. .................................... 7

Figure 1.4 Formation of the mud cake. .................................................................................. 8

Figure 1.5 The global location of Benin, Africa (Wikipedia). .................................................. 11

Figure 1.6 Visualization of the climatology of Benin, Africa, from 1991-2020 (Climate Change Knowledge Portal). ................................................................................. 12

Figure 2.1 Project assessment of life cycle stages of manual borehole drilling projects or reports. ............................................................................................................ 23

Figure 3.1 Manual drilling method family tree that considers multiple methods based on local context and geoscientific data. Adapted from Santos et al. (2020). ..... 29

Figure 3.2 Demonstrates areas of manual drilling feasibility and local characteristics based on GIS information and borehole data. .................................................. 30

Figure 4.1 GWB 2022 workshop drilling team acquiring metal drill stem pipe. ............... 34

Figure 4.2 Images of the Baptist drill bit used in fieldwork. (a) Carbide drill bit with check valve cap welded to the top of drill bit inserted through a reducer coupling. Drill head wings were cut from angle iron scraps. (b) Drill head wings welded and ground to insure strong weld. (c) Male 1½ inch drill collar welded to reducer coupling. (d) Internal view of the drill collar. (e) View of completed Baptist drill bit. .............................................................. 35

Figure 4.3 The total cost of drilling supplies, equipment, and two lunches for the drilling team was 118,000 F or $175 US. The exchange rate can vary. ................. 36

Figure 4.4 Fabrication of drill stem material. (a) Getting the drill stem cut into usable lengths for the drilling process at a roadside shop. (b) Rethreading the cute
ends of the metal pipe to allow connection using metal couplings. (c)
Université d’Abomey-Calavi drill team students return with 6-meter-long
drill stem sections. ......................................................................................................... 37

Figure 4.5 Preparations for implementing the Baptist manual drilling method. (a)
Digging settling pit. (b) Attaching a pulley straight above the settling
pit to overhanging tree, instead of building a tripod. .................................................. 37

Figure 4.6 Implementing the Baptist drilling method. (a) A rope is attached to a handle
threaded through the pulley in figure 4.5; this rope is pulled by the drilling
crew to lift and drop the drill stem. (b) Drillers guide the drill stem in the
borehole. (c) Drillers provide an extra downward force on the drill stem
while others fill the borehole with water to provide wellbore stability and
maintain the necessary water quantity for the drilling process. ......................... 38

Figure 4.7 Project assessment of life cycle stages of my manual borehole drilling
project .................................................................................................................................. 40

Figure B.1 Video of Université d’Abomey-Calavi and Colorado School of Mines
student implementing the Baptist drilling method during the GWB 2022
Manual Drilling Workshop.............................................................................................. 65
LIST OF TABLES

Table 1.1  Suitable geological conditions for manual drilling methods (Danert, 2015)...... 10
Table 1.2  Suitability and the limitations of manual drilling methods (Martinez-Santos et al., 2020). While these methods have a drilling limit range, ideal geological conditions allow for wells drilled below the maximum depth range presented. .................................................................................................. 10
Table 2.1  This table outlines the strengths and weaknesses observed by Brion and Cordeireo (2018) in the Train-The-Trainer method. ......................................................... 17
Table 2.2  Project assessment tool for water relief projects in community development adapted from McConville and Mihelcic’s (2007) five life cycle stages of a water and sanitation development project. ................................................................. 19
Table 2.3  Project assessment tasks to be performed during water relief projects for community development adapted from McConville and Mihelcic (2007). ....... 20
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following organizations and individuals who have contributed to the completion of my thesis. Organizations are Colorado School of Mines, Geoscientists Without Borders, and Université d’Abomey-Calavi for providing the opportunity to implement my manual drilling project in an international setting. Thank you to my committee members Richard Kranhenbuhl (Advisor), Elizabeth Reddy (Co-Advisor), Jeffrey Shragge (HES Faculty), and Lia Martinez (External Expert) for their support and guidance.

I am deeply grateful to my advisor, Richard Kranhenbuhl, for his guidance, support, and encouragement throughout my research. His expertise and insights have been invaluable in shaping my work. I would also like to thank my co-advisor, Elizabeth Reddy, for her insightful comments, feedback, and support. Her expertise and encouragement have been instrumental in shaping my research.
1.1 Introduction and Motivation

Safe and accessible water is a critical resource that affects health, economics, and society. The United Nations' goal of providing "sufficient, continuous, safe, acceptable, physically accessible, and affordable water for personal and domestic use" (World Health Organization, 2022) to everyone remains a challenge, particularly in rural areas where issues such as contamination, infrastructure problems, lack of local government participation, and scarce water access points persist (Odeloui et al., 2022; Sutton, 2017; Vouillamoz et al., 2017; N’Tcha M’Po, 2017; Heidecke, 2006). Inadequate water access leads to reduced physical activity, increased risk of waterborne diseases, and decreased economic and cultural activity (World Health Organization, 2022).

Despite past efforts of internal and external groups participating in water relief projects, the problem of water vulnerability in Africa remains significant (Liddle et al., 2014; World Health Organization, 2021; Rural Water Supply Network, 2022). In Africa, where the population is expected to grow and urbanize, particularly in western Sub-Saharan countries, water infrastructure has been primarily focused on urban areas. This results in a high-water poverty rate in rural areas (Odeloui et al., 2022; Sutton, 2017; Vouillamoz et al., 2017; N’Tcha M’Po, 2017; Heidecke, 2006; Neumann et al., 2015). The situation is particularly dire in Benin, where declining rainfall, contamination, and expanding population demands have led to a decrease in surface and groundwater resources, with saltwater intrusion in freshwater aquifers becoming a significant issue along the coastlines due to deep water extraction (Figure 1.1) (Liddle et al., 2014; Vouillamoz et al., 2017; N’Tcha M’Po, 2017; Sutton, 2017; Lindsay et al., 2015; Odeloui et al., 2022).

Groundwater sources, which are less vulnerable to contamination and more resilient to the impacts of climate change than surface water and catchment systems, can help address the water demand and safety concerns (Vouillamoz et al., 2017). Shallow groundwater sources in unconsolidated or consolidated sediments offer a cost-effective solution with reduced impact on the fresh/saline water interface (Odeloui, 2022). Shallow groundwater sources are desirable in
regions with ideal hydrogeological settings, shallow water tables, and manual laborers (Santos et al., 2020).

However, improved water sources like mechanized boreholes are often too expensive for rural communities (Martínez-Santos, 2020). As a result, cost-effective methods for accessing groundwater resources are crucial for these rural communities. Manual drilling is a discipline in its own right that provides a cost-effective alternative to mechanized drilling, with the potential to significantly lower the cost of accessing groundwater. In places where manual drilling is an established technology, it is typically controlled by local private enterprises and households that pay for the borehole construction (Danert, 2015). Manual drilling can be considered appropriate technologies if materials are obtained locally, and users can be trained to drill and maintain their boreholes, reducing the need for external technical support. The technique involves replicating mechanical drilling methods by hand, resulting in smaller diameter boreholes that can be cased and equipped with pumps to transport water to the surface (Danert, 2015; MacCarthy, 2013). On Figure 1.1 Shows a conceptual 2D diagram of how water extraction impacts the freshwater-salt water interface ("Saltwater Intrusion" U.S. Geological Survey, 2019). (a) Shows the natural conditions without groundwater extraction. (b) Upconing of the saltwater interface due to groundwater extraction.

However, improved water sources like mechanized boreholes are often too expensive for rural communities (Martínez-Santos, 2020). As a result, cost-effective methods for accessing groundwater resources are crucial for these rural communities. Manual drilling is a discipline in its own right that provides a cost-effective alternative to mechanized drilling, with the potential to significantly lower the cost of accessing groundwater. In places where manual drilling is an established technology, it is typically controlled by local private enterprises and households that pay for the borehole construction (Danert, 2015). Manual drilling can be considered appropriate technologies if materials are obtained locally, and users can be trained to drill and maintain their boreholes, reducing the need for external technical support. The technique involves replicating mechanical drilling methods by hand, resulting in smaller diameter boreholes that can be cased and equipped with pumps to transport water to the surface (Danert, 2015; MacCarthy, 2013). On
average manual boreholes are better protected from contamination than surface water, providing a stable water supply during prolonged dry spells. Having a readily available water source is essential for human health and economics, and manual drilling has the potential to decentralize water supply sources to make them closer to rural communities (Martínez-Santos, 2020). Groundwater sources, particularly shallow ones in suitable hydrogeological settings, offer a cost-effective and dependable solution to meet the growing water demand and manual drilling methods can provide a viable option for rural communities. Considering this, the project described in this thesis aims to add to on-going goals of providing groundwater water access by exploring the potential of manual drilling methods as a cost-effective solution through education and co-implementation of a manual borehole drilling project.

1.2 Fundamental Information

1.2.1 Manual Drilling Methods

There are several types of manual drilling methods; however, they all must break or cut the subsurface formation, remove the sediment from the borehole, and provide the necessary support for wellbore stability to prevent collapsing (Practica Foundation, 2011). Manual drilling methods are growing in use because manual drilling equipment costs significantly less than commercially drilled boreholes, and can provide local employment (Practica Foundation, 2011; Danert, 2015; Liddle et al., 2014; Martínez-Santos, 2020). Manual drilling methods can contribute to employment because non-experts can learn how to implement manual drilling methods without professional guidance or advice (Martínez-Santos, 2020). While manual drilling methods have been implemented before, many rural regions remain behind in water supply goals due to the lack of availability of technical expertise and equipment (Martínez-Santos, 2020; World Health Organization, 2017).

While there are limitations to manual drilling methods, they have demonstrably provided water resources that aid social and economic development by reducing health vulnerabilities and producing resources for agriculture (Santos et al., 2017). Pricing a borehole project depends on several factors, such as geological constraints, drilling depth and width, equipment, mobilization, commercial profits, and available resources (Santos et al., 2017). Manual drilling methods are advantageous over mechanized drilling systems because they allow for a lower cost per meter for a well (Resto et al., 2017). Manual drilling methods available are auguring, sludging, jetting, and
percussion, with each method stemming from an adaptation to different regional contexts (Danert et al., 2015; WASH Cluster SOMALIA, 2020).

Augering: Augering is a method of drilling a hole into the ground by rotating a handle at the surface, which is linked to a drilling bit via a sequence of extendable rods made of steel. The bit is equipped with a shaft that collects material from the bottom of the hole, and as the bit fills up, the auger is removed and emptied. The process is repeated until the desired depth is reached, and a temporary casing may be used to prevent the hole from collapsing, mainly when working below the water table.

One of the advantages of augering is that it can quickly drill shallow wells through soft formations, and the equipment is cheap and simple to build, making it easy to learn and conceptually straightforward. However, augering has several limitations. It is less effective in highly permeable sediments such as coarse gravels, restricting its use in theoretically favorable terrains such as alluvial plains. Additionally, drilling becomes slower and more complex with depth, and it can be challenging to maintain a straight borehole. Augured boreholes typically have a drilling crew that is typically made up of four to six people, with a complete borehole able to be drilled in less than a week.

Percussion: Percussion is a drilling technique that dates back to ancient times, and it involves using a heavy bit tied to a cable, which runs through a pulley attached to a tripod above the hole. The cable is pulled to lift the bit and then released, allowing it to fall and break the rock. Loosened material is removed from the bottom of the borehole using a bailer equipped with a no-return valve, which can be loaded with water and moved up and down to loosen the rock. The bit must be removed from the hole every few strokes during the bailer process.

Percussion drilling is useful for hardened materials such as gravel or boulders, and it is relatively simple and requires only a small investment. However, it is slower than other drilling techniques, and the bailing process becomes cumbersome as the borehole gets deeper beneath the surface. Percussion is sometimes combined with water circulation, allowing quicker debris removal from the bottom of the hole.

Sludging: Sludging is an improvement over augering and percussion, as it eliminates the need to stop the drilling process from removing debris from the bottom of the hole. This
method requires the borehole to be full of water at all times, with water circulation used to bring the loosened material to the surface. Sludging can be combined with percussion by incorporating an improved drilling tool comprising a heavy drilling bit, a hand- or check valve, a series of hollow tubes, and an outlet. The drilling tool is lifted and allowed to fall repeatedly into the hole, with the valve opening on the downstroke and closing on the upstroke. The mixture of water and sediment from the bottom of the hole rises to the surface and is released into a mud pit, where thickening agents such as polymers or bentonite may be used to facilitate the rise of the drilling cuts and prevent the hole from collapsing. A drilling crew typically consists of six to ten people who take turns operating the tool, pulling the rope, and resting.

Jetting: Jetting is a manual drilling method that uses high-pressure water to wash away soil and rock from the bottom of the borehole. This method requires a water source, a high-pressure pump, a series of hoses, and a jetting tool that comprises a series of nozzles. The jetting tool is inserted into the borehole, and high-pressure water is directed into the hole to wash away the subsurface material. The mixture of water and sediment from the bottom of the hole is expelled at the surface and collected in a sediment pit.

Jetting is often used in areas with softer subsurface materials, such as sand, gravel, or silt, and can be used to drill to depths greater than those achievable with sludging or percussion methods. A drilling crew typically consists of four to six people, who operate the pump, handle the hoses, and monitor the progress of the drilling.

Manual drilling can work in sedimentary rocks, but it depends on the specific type of rock and the hardness of the formation. In sedimentary rocks, the success of manual drilling will depend on the rock’s hardness and the type of drilling method used. For example, percussion drilling methods, such as hand augers, can be used in sedimentary rocks that are not too hard or consolidated. However, manual drilling may not be effective in harder sedimentary rocks, such as sandstone or limestone, and a more advanced drilling method may be required. The success of manual drilling in sedimentary rocks will depend on the local geological conditions, the availability of suitable drilling equipment, and the skill and experience of the drillers.

These drilling methods can also be hybridizations; for example, the combination of percussion and sludging method creates the Baptist method used by Cloesen (2007). Terry
Waller of Water for All in Bolivia developed the Baptist drilling technique in 1993 (Waller 2009). The Baptist drilling system incorporates the sludging technique by using a check valve incorporated into the drill bit at the bottom of the drill stem (Figure 1.3). A check valve allows fluid to flow in one direction but prevents it from flowing back in the opposite direction. It works by using the downward force which lifts the check valve cap, allowing fluid into the drill stem, and closes on the upstroke, preventing backflow of the cuttings. The drill bit point can vary in design based on local geology and fabrication capabilities. The Baptist method works in the sand, weathered overburden, gravel, and clays using standard drill bits, although a variety of different bits can achieve better results in varying conditions (Colsen, 2007; Danert, 2009; Danert, 2015). For softer and clay-holding soils, a heavy moveable drill head is recommended, as the moving drill head helps to keep the check valve clean. Meanwhile, fixed point bits are better suited for sandy and rocky layers with no risk of sticky material obstructing the check valve.

The Baptist method is implemented by lifting and dropping the drill stem with the drilling crew and guided by a driller to force the drill stem down. On the downstroke, the force of the drill bit breaks the downhole sediment on impact, while on the up-stroke, the inertia of the fluid brings these soil cuttings up through the drill stem and the mouth (Figure 1.2) (Forsyth et al., 2010; Waller, 2009). The drill cuttings are suspended in the drilling fluid and pumped to the surface through the drill stem, and the drill pipe and bit are removed from the borehole when drilling is finished. This technique is particularly suited for sand, loam, and light rock.

As a representative cost, a complete Baptist rig capable of drilling up to 30m deep is around US$150 (Colsen, 2007; Danert, 2009). Over 2,000 Baptist wells have been drilled in twelve countries, with most in Bolivia, followed by Nicaragua, Sri Lanka, and Cameroon, and trials in several other countries, including Ethiopia, Kenya, and Tanzania (Danert, 2009; Danert, 2015).
Figure 1.2 (a) A drilling crew pulls up the rope, lifting the drill bit off the bottom of the hole, which closes the check valve. When the check valve closes, water is pushed up the drill stem. (b) On the downstroke, the check valve is momentarily open, letting water and sediment from the bottom of the hole flow into the drill stem, allowing the mixture to be pushed up to the surface. (c) As the crew pulls, the check valve closes, pushing the mixture to exit the mouth into the decanter (settling pit). The decanter allows sediments to settle and water to flow back into the borehole for wellbore stability. (Not to scale)

Figure 1.3 Baptist Method drill bit modification schematic (not drawn to scale). A downward force applied from the drill stem onto the drill bit collar causes the drill bit and the drill head to rotate. The rotary action is caused by the internal pins that provide a pivot point for the milled-out sections on the drill bit. Note: The check value is also known as a foot value.
The Baptist method is advantageous because it uses drilling fluid to avoid borehole collapse and prevent the influx of fluids from the surrounding sediment by increasing the hydrostatic pressure of the drilling fluid by adding bentonite. Using bentonite creates a filter (mud cake) on the wellbore wall that prevents fluid loss by clogging the formation grains (Figure 1.4). Controlling the hydrostatic pressure of the drilling fluid is a critical part of the Baptist drilling method that must be monitored and adjusted to lift sediment through the drill stem but not exceed excessive hydrostatic pressure that can lead to a loss of circulation in the drilling process (Schlumberger Limited, 2023). The Baptist method is efficient at drilling through silt and sand layers, with the ability to break through sedimentary layers (Waller, 2009). However, it involves significant manual labor, requires a water supply, and using sludging makes it challenging to predict when the water table has been reached (Forsyth et al., 2010). Manual drilling methods are commonly used to create small-diameter wells for household or community water supply, with diameters ranging from 2-6 inches. The Baptist drilling method typically has a diameter of 2-4 inches leading to a lower yield than other drilling methods. Despite its limitations, the Baptist drilling method can be a practical and affordable solution rural families or those who may not have access to other, more expensive drilling techniques.
1.2.2 Geophysically Informed Drilling

Geophysical prospecting is a well-recognized and practical approach to understanding groundwater resources as it is non-invasive, provides information at depth, and has the potential to be inexpensive when low-cost instrumentation is available (Forsyth et al., 2010). Using geophysical exploration can help map the subsurface geology, provide estimates of volume and flow rate within a groundwater system, and inform regional flow models to evaluate better sustainable hydrogeological aspects of a wellbore and the region (Minsley et al., 2011). To reduce the barrier of entry for pre-drill geophysical prospecting, manual drilling project developers can use or produce DIY low-cost geophysical instrumentation such as DC resistivity and seismometers (Sirota, 2022). These DIY systems can then be supplemented with commercial systems for verification of data accuracy. The information from these survey methods combine to inform well placement by providing an understanding of the subsurface geology and the locations of groundwater systems within the geology (Martinez-Santos et al., 2017). The subsurface models generated from geophysical surveys can enhance communication by providing images instead of technical terms to facilitate stakeholder communication (Larson et al., 2021). Geophysical data are valuable to investigate whether and demonstrate how manual drilling methods represent a viable technology (Martinez-Santos et al., 2017).

Subsurface geology, which is highly regionally variable, is the primary condition impacting the efficiency of a drilling method, which in turn impacts labor, drill time, and cost. Thus, there is no one-size-fits-all manual drilling system that is appropriate for every environment or geologic setting. Geophysical information can help one reduce this uncertainty and select an appropriate drill system at a site by identifying the depth to water, estimating hardness factors of the geology, and thus predicting the general performance, labor, and cost for the different systems (Fussi et al., 2016; Martinez-Santos et al., 2017). For example, Tables 1.1 and 1.2 by Danert (2015) and Martinez-Santos et al. (2020) demonstrate that an appropriate manual drill method can be selected for a site by determining if the system will be drilling through consolidated versus consolidated or unconsolidated rock, clay versus sand, or weathered rock versus basement. Each piece of information can be interpreted or inferred from appropriate geophysical surveys for informed drilling decisions.
Table 1.1 Suitable geological conditions for manual drilling methods (Danert, 2015).

<table>
<thead>
<tr>
<th>Method</th>
<th>Silt, sand &amp; gravel</th>
<th>Unconsolidated Clay</th>
<th>Soft weathered rock</th>
<th>Consolidated Basement rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augering &amp; Bailing</td>
<td>Yes</td>
<td>Limited</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Jetting</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Percussion &amp; Bailing</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sludging</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 1.2 Suitability and the limitations of manual drilling methods (Martinez-Santos et al., 2020). While these methods have a drilling limit range, ideal geological conditions allow for wells drilled below the maximum depth range presented.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Drilling Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augering</td>
<td>Unconsolidated sediments</td>
<td>Simple, cheap, fast in soft sediments</td>
<td>Limited to soft materials and to relatively small depths. May be problematic when drilling below the water table.</td>
<td>15-20</td>
</tr>
<tr>
<td>Jetting</td>
<td>Unconsolidated sediments</td>
<td>Fast in soft sediments</td>
<td>Potentially expensive equipment. A large volume of water is needed.</td>
<td>25-50</td>
</tr>
<tr>
<td>Percussion and bailing</td>
<td>Unconsolidated sediments and soft weathered rock</td>
<td>Can drill through moderately hard rocks. May be coupled with sludging.</td>
<td>Slower and potentially more expensive than other methods.</td>
<td>25-50</td>
</tr>
<tr>
<td>Sludging</td>
<td>Unconsolidated sediments</td>
<td>Ease of use. Fast in soft sediments.</td>
<td>Limited to soft materials.</td>
<td>25-50</td>
</tr>
</tbody>
</table>

By using near-surface geophysics techniques, such as electrical resistivity tomography (ERT) or seismic refraction, the subsurface geology can be characterized before drilling. This information can help to identify the most appropriate location for drilling, the expected depth of water, and the type of materials that will be encountered during drilling. For example, ERT can provide a detailed image of subsurface materials, such as rock, gravel, sand, clay, or water. This information can be used to determine the best location to drill to access water at the shallowest possible depth. Seismic refraction can be used to determine the depth and thickness of subsurface layers, which can inform the drilling process and help to minimize the risk of unexpected complications during drilling. Overall, near-surface geophysics can significantly improve the efficiency and execution of manual drilling by providing critical information about the subsurface geology and enables drillers to make informed decisions about the best drilling method and location.
1.2.3 Area of Focus and History

Africa is expected to have increasing population growth and urbanization, predominantly in western Sub-Saharan countries, where historically water infrastructure has been more closely related to the urban areas rather than the rural areas, leading to an imbalance of water poverty (Odeloui et al., 2022; Sutton, 2017; Vouillamoz et al., 2017; N’Tcha M’Po, 2017; Heidecke, 2006; Neumann et al., 2015). There is a long history of NGOs, collaborative water relief projects and vocational training programs on water access that have not mitigated the issue of water vulnerability to an acceptable level across African countries (Liddle et al., 2014; Rural Water Supply Network, “Water” World Health Organization, 2021). A specific country facing challenges in securing safe water is Benin, which is in West sub-Saharan Africa (Figure 1.5).

![Figure 1.5 The global location of Benin, Africa (Wikipedia).](image)

Benin's surface and groundwater water resources are facing a significant volumetric decrease due to reduced total rainfall, contamination of water resources, and the expanding extraction to meet the growing population demand (Liddle et al., 2014; N’Tcha M’Po, 2017; Sutton, 2017; Vouillamoz et al., 2017). Due to the expanding population along African coastlines, many areas have been participating in over-extraction with deep wells that have led to saltwater intrusion into the freshwater aquifers (Lindsay et al., 2015; Odeloui et al., 2022). At a particular concentration, saltwater intrusion is problematic because the water cannot be consumed or used to irrigate crops, reducing the total amount of usable water (USGS, 2019).

From 1990 to 2017, the population without access to safe water resources rose from 244 million to 270 million in Sub-Saharan Africa, and during this time the total number of surface water users has decreased, which has put more stress on groundwater resources or the consumption of unfavorable water (Sutton, 2017). Within sub-Saharan Africa, Benin is an ideal location to research manual boreholes because of the suitable geological setting, lack of training
resources on manual drilling, the difference between rural-urban settings, and previously established connections to the area and stakeholders. Two West African air masses move the Intertropical Convergence Zone (ITCZ) North and South to create two rainy seasons in Benin that occur from mid-March to mid-July and from mid-August to October (N’Tcha M’Po, 2017). The total annual rainfall in Benin is on a downward trend due to the significant decrease in wet days and the annual maximum rainfall from 1960 to 2000 (Hounkpe et al., 2015; N’Tcha M’Po, 2017). From 1991 to 2020, Benin's annual precipitation average reported 1047.65 mm of rainfall, but Southern Benin experiences more significant year-on-year rainfall variability (Figure 1.6) (Heidecke, 2006).

Since gaining independence in 1960, Benin has undergone many political and economic changes. The idea of political decentralization was introduced in Benin in the early 1990s, and it did not become a fully democratic republic until 2002 when the first communal elections took place (Heidecke, 2006). Each commune has its own elected council in charge of managing the local water supplies, which has been considered inadequate (Heidecke, 2006). This can be attributed to the limited financial reasons, technical resources, and the lack of responsibilities in institutional structures (Höllermann et al., 2017). To evaluate regional water access in Benin, Heidecke (2006) applied the Water Poverty Index (WPI), which clearly distinguished between water scarcity in the north versus south and rural versus urban. Statistically, Benin's urban
population tends to have access to reliable potable water, but the rural water supply does not meet the needs of that population (Heidecke, 2006; Höllermann, 2017).

1.3 Purpose and Research

This study explores the benefits of using low-cost geophysical instrumentation and manual drilling methods for sustainable water resource access in Cotonou, Benin. The study redefines the concept of "community" in water relief projects and evaluates the benefits of using a sociotechnical approach in manual drilling selection and wellbore construction. The study provides a background review of relevant topics and information, presents the methodology for a wellbore drilling project, and discusses the application of manual drilling education and manual drilling application through a case study description and analysis. Through this work, this study provides a better understanding of how education and co-implementation can aid water relief projects and promote self-reliance on water resources. The study is shaped by three research questions related to a sociotechnical approach in manual drilling selection and wellbore construction and a train-the-trainer ($T^3$) model that incorporates the principles of Humanitarian Engineering and Science (HES) along with evaluation matrices to enhance manual drilling projects.

The first research question asks how a sociotechnical approach identifies areas where manual drilling systems would apply. The expected outcome is that geophysical surveys provide subsurface information to locate groundwater water depth and subsurface material to estimate the feasibility of a manual borehole drilling project. While social engagement methods provide local contexts on available resources, physically and financially, to determine a suitable drilling application. The second research question investigates how a $T^3$ model in manual borehole drilling education can incorporate HES to aid community development. This study suggests that a $T^3$ model can incorporate HES themes by explaining the importance of stakeholder engagement and conveying the positive benefits it produces to bring about a contextual manual drilling project. HES themes of sustainability and community development will be implemented with crucial terminologies in the relevant literature to make them more applicable to manual borehole drilling. Finally, the third research question asks how can co-implementing a low-cost drilling project employ appropriate technologies in water relief projects to promote self-reliance. This study looks to properly engage with relevant stakeholders to force a consideration of local
knowledge about water resources, technical resources, and their capacity to implement manual drilling methods to aid in identifying appropriate technologies.

This chapter has provided a background review of relevant topics and information to provide the context for manual drilling methods and information that can support the need or application of manual drilling. To understand education impact on manual borehole drilling projects, Chapter 2 demonstrates the need to use the T3 model that incorporates HES principles. To enhance manual drilling projects, Chapter 2 also explains the methodology implemented to contextually develop a manual drilling project. For selecting appropriate technologies, Chapter 3 covers selecting a manual drilling method using geoscientific techniques and available literature. The chapter suggests questions that will lead to selecting the most appropriate technology to develop a manually drilled wellbore. Chapter 4 discusses the application of manual drilling education and manual drilling implementation through a case study description and analysis. The long-term significance of this research is to show that a sociotechnical process will provide participants with education and training on manual drilling methods to reduce reliance on external expertise.
2.1 Introduction

This chapter will examine methods that can lead to success in water relief projects by promoting stakeholder identification and communication, sustainable community educational practices, and critical analysis of past and current projects. Methodologies will report on why specific methods might be selected and how local educational systems can influence the best type of engagement and material dissemination. Additionally, this chapter aims to evaluate past manual drilling projects to provide a comprehensive understanding of the approaches required for successful water relief projects. By examining past projects from sources such as Rural Water Supply Network (RWSN), PRACTICA Foundation, and Geoscientists Without Borders (GWB) published papers, this chapter will identify current issues and challenges faced by past projects using a provided evaluation matrix. Finally, this chapter reviews literature and humanitarian engineering concepts, highlighting issues of interest for developing a water relief project.

2.2 Methods

2.2.1 Stakeholder Engagement

When designing and installing manual water supply systems, that will respect social, cultural, and environmental values, appropriate identification of stakeholders is necessary (Santo et al., 2017). Stakeholder engagement becomes advantageous in manual drilling projects as they can occur over large study areas and are subject to time constraints in unfamiliar locations. Engaging with stakeholders allows researchers to "obtain consensus decisions on the locations of boreholes that are both socially favorable and have a high probability of producing reliable water supplies" (Larson et al., 2021). Water projects need to understand proactive and reactive stakeholders due to the prolonged maintenance, incremental improvements, and contextual expansion plans on manual resources for water (Carty, 2015; Narayan, 1995). Larson et al. (2021) illustrated that using a proactive prolonged sociotechnical stakeholder engagement approach made it possible to understand how cultural and political influences cause issues with wellbore sustainability.

For proper stakeholder engagement, I will use the Three Pillars of Social Responsibility posed by Winner (1990). Smith (2020) offers five criteria to translate and adapts the suggested...
pillars into geoscientific contexts while still being able to work with differing constraints (Smith and Lucena pg. 668 2020). For this project, I used the stakeholder theory for disaster risk management (DRM) proposed by Mojtahedi and Lan Oo (2017). This theory categorizes stakeholders into three groups based on their attributes: power, legitimacy, and urgency. This categorization aims to understand how organizations and projects can benefit from the social and political forces these three stakeholder groups possess with a short amount of fieldwork time. The framework differs from previous practices as it expands the identification of stakeholders, allowing geoscientists to better understand to whom they are accountable.

Knowing the attributes of the stakeholders is critical for identifying, classifying, and defining the forms of participation that these stakeholders can provide. The stakeholder theory for DRM can be applied in proactive and reactive ways. A proactive approach to stakeholder engagement can help provide local context, resources, and local solutions for the design of a project, while reactive framing can help identify the relevant stakeholders for maintenance or workovers. However, the framework has limitations, two of which are the accessibility to the site of concern and the availability of communication with stakeholders. Effective communication is crucial for geoscientists to listen to all stakeholders and create a more sustainable project.

2.2.2 Train-The-Trainer (T3)

The T3 method is a method of education dissemination that focuses on empowering individuals within a community to take on the role of trainers and educators. This method is often used to promote the dissemination technical information and skills related to community interventions. T3 models provide an adaptive pedagogical blended learning approach that has proven effective in educational approaches in urban and rural communities (Brion and Cordeiro, 2018; Conn, 2017). T3 models are flexible, and their adoption would allow manual borehole drilling projects to have various social and technical aspects that affect project workflow. The T3 model builds capacity by using local trainers who can understand the culture and speak the language or dialects of community members, allowing them to understand the local traditions and habits, making them a preferable point of contact (Brion and Cordeiro, 2018). As a trainer in a T3 model, one must demonstrate a willingness to learn about other cultures and listen to stakeholders to adapt training materials to fit the local context of your project (Brion and Cordeiro, 2018). Brion and Cordeireo (2018) gave a explanation of the strengths and challenges of the T3 method through past projects in Burkina Faso, Ghana, Liberia, Rwanda, and Ethiopia.
shown in Table 2.1. These strengths and challenges will be used as pivotal aspects that will be integrated into my project development and completion lifecycle design.

Table 2.1 This table outlines the strengths and weaknesses observed by Brion and Cordeireo (2018) in the Train-The-Trainer method.

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being Culturally Responsive to Ensure Sustainability</td>
<td>Self-reflection</td>
</tr>
<tr>
<td>Keeping in Mind How Adults Learn Best</td>
<td>Language</td>
</tr>
<tr>
<td>Script, Feedback, and Follow up</td>
<td>Finding Qualified Committed Trainers</td>
</tr>
<tr>
<td>Building Relationships and Trust</td>
<td>The Clock Is Ticking</td>
</tr>
<tr>
<td>Investing in Quality</td>
<td></td>
</tr>
</tbody>
</table>

With the creation of materials and training structures for the T³ models, developers need to understand that stakeholders learn differently so that learning techniques can apply to the stakeholder’s background and personal livelihood (Brion and Cordeiro, 2018). The authors pointed out the need to have a local team for follow-ups on specified guidelines from trainers and trainees through feedback letters or mobile technology to support local teams, answer questions, receive feedback, and maintain the established relationship with relevant stakeholders.

In the context of technical intervention, the T³ method provides individuals within a community of participants with the knowledge, skills, and resources necessary to effectively train and educate others within their community. For example, a technical expert may provide training to individuals within a community on the proper use of a specific tool or technique, and then those individuals can go on to train others within the community.

The benefits of the T³ method in this context include the following:

1. **Sustainability**: By empowering individuals within a community to take on the role of trainers and educators, the knowledge and skills being disseminated can continue to be passed on, even after the original trainer has left the community.

2. **Cultural Relevance**: Individuals within a community are likely to better understand their community's cultural context and specific needs. This can lead to more effective and relevant training and education.
3. Increased Participation: The T³ method can increase the participation of individuals within a community in disseminating technical information and skills. This can lead to a greater sense of ownership and engagement among community members.

4. Cost-effectiveness: By training individuals within a community to become trainers and educators, the cost of education dissemination can be reduced, as there is no need to bring in outside trainers for each training session.

Carty (2011) evaluated potable water projects and argues that those participating in water projects should expand their evaluations of the training itself and the trainers themselves to identify the gaps to improve training. To emphasize the role of trainers and the quality of manual borehole drilling development, this project will use case studies and evaluation metrics to determine what areas of manual drilling to focus on during project development and implementation education later in this chapter. In conclusion, the T³ method can be a highly effective way to disseminate technical information and skills related to community interventions, particularly in contexts where sustainability, cultural relevance, and cost-effectiveness are essential considerations.

2.2.3 Project Evaluation Metrics

Something that needs to be added to the manual borehole literature are practical evaluation tools that can help enhance a project's development before, during, or after project completion (Brion and Cordeiro, 2018; Conn, 2017). Using appropriate evaluation tools provides insight into how a project integrates cultural aspects, education, and fosters capacity building (McConville and Mihelcic, 2007). Building a framework for assessing the effectiveness and viability of manual borehole projects can provide insight into ways to mitigate issues across the life cycle of a water project and evaluate the technical and social components of a water relief project (McConville and Mihelcic, 2007). To improve existing projects, there is a need to have a defined system to provide a subjective score to aid engineers, organizations, or individual approaches to water development projects in developing countries. With the difference in contextual factors in a wellbore drilling project, it is the responsibility of the users of the evaluation matrix to adapt their scoring to the individual project appropriately (McConville and Mihelcic, 2007). Table 2.2 shows the five stages of a water relief project: 1) needs assessment, 2) conceptual designs and feasibility studies, 3) design and action planning, 4) implementation, and 5) operation and maintenance. The process starts with a needs assessment to determine the
motivation and extent of the need, followed by generating and evaluating possible solutions in the conceptual design and feasibility study stage. The next stage is design and action planning to finalize the technical design and implementation plan, followed by the physical implementation of the project. The final stage is operation and maintenance, including project monitoring and evaluation. Table 2.3 shows the social and technical components of water development projects to identify tasks to be completed and provide a score to be used in Table 2.2. For each task completed, a point is earned. Then each point is multiplied by a factor to score life cycle stages in manual drilling projects from one to ten.

Table 2.2 Project assessment tool for water relief projects in community development adapted from McConville and Mihelcic’s (2007) five life cycle stages of a water and sanitation development project.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Tasks Completed</th>
<th>Multiplier</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needs Assessment</td>
<td>x/8</td>
<td>1.25</td>
<td>x/10</td>
</tr>
<tr>
<td>Conceptual Designs and Feasibility</td>
<td>x/6</td>
<td>1.67</td>
<td>x/10</td>
</tr>
<tr>
<td>Design and Action Planning</td>
<td>x/5</td>
<td>2</td>
<td>x/10</td>
</tr>
<tr>
<td>Implementation</td>
<td>x/5</td>
<td>2</td>
<td>x/10</td>
</tr>
<tr>
<td>Operation and Maintenance</td>
<td>x/7</td>
<td>1.42</td>
<td>x/10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>x/50</td>
</tr>
</tbody>
</table>
Table 2.3 Project assessment tasks to be performed during water relief projects for community development adapted from McConville and Mihelcic (2007).

<table>
<thead>
<tr>
<th>Needs Assessment</th>
<th>Conceptual Designs and Feasibility</th>
<th>Design and Action Planning</th>
<th>Implementation</th>
<th>Operation and Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>✅ Receive a request for project intervention</td>
<td>✅ Brainstorm potential solutions with stakeholders ✅ Consider multiple designs ✅ Consider parameters for system operation, maintenance for disposal (project life cycle)</td>
<td>✅ Finalize Design ✅ Budget ✅ Identify tasks</td>
<td>✅ Procurement of supplies and financing ✅ Site preparation ✅ Construction</td>
<td>✅ Daily operation of the system ✅ Routine maintenance ✅ Unexpected maintenance</td>
</tr>
<tr>
<td>✅ Determine the demand for service</td>
<td>✅ Solicit community feedback</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>✅ Obtain community liaisons</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>❌ Gather information on sociocultural, political, environmental, economic, and technical constraints</td>
<td>✅ Site visits</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>❌ Participatory evaluations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>❌ Stakeholder interviews</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>❌ Literature reviews</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The scoring system aims to aid engineers, organizations, and individuals in improving their project approach and achieving sustainability in development work. It is not intended to provide a universal tool for comparing the success of different projects but rather to offer a logical...
framework for managing the complexities involved. However, users must recognize the
generality of the framework and adapt it to their individual projects as necessary. The adapted
learning objectives for Engineering and Sustainable Community Development (ESCD) from
*Engineering and Sustainable Community Development* (2010) below aim to:

1. Identify and analyze relevant events, institutions, and actors in the history and politics of
   sustainable community development.
2. Evaluate the role of engineering in the different aspects of sustainability: economic,
   environmental, ethical, and sociocultural.
3. Assess the strengths and limitations of past engineering design methodology and working
   with communities.
4. Analyze and evaluate project-based case studies in sustainable community development
   to develop new and better projects.
5. Provide definitions of sustainable community development and their relationships with
   engineering, and critically assess them.

### 2.3 Previous Projects

This section evaluates case studies of water relief community development projects that
use manual drilling methods. I used a scoring system to visually represent the strengths and
fallacies of past projects. The scoring system is subjective and should be treated as such. Case
studies are evaluated through the lens of water relief development projects using manual drilling
methods based on available data in the reports to aid in project development. For data
visualization, Table 2.3 will provide a scoring system and will be represented on a radar map.
The score does not reflect project success but serves as an aid in improving my manual drilling
project to achieve sustainable implementation of manual drilling methods by reviewing project
tasks presented in the life cycle stages. Due to the availability of data, my case study analysis
will be used to identify the strengths of past projects and use the graphic to identify stages that
require more vigor. The scoring system is subjective and should be treated as such.

### 2.3.1 Analysis and Discussion

Case study analysis showed that a sociotechnical process can improve borehole
construction success in rural areas (Forsyth et al., 2010; Larson et al., 2021). For example, a
study used participatory rural appraisal (PRA) to engage stakeholders and identify the best
location for a manually drilled well, along with geophysical techniques for feasibility
assessments and participatory mapping (Larson et al., 2021). The PRA method was "used to elicit a local understanding of available resources" and "existing needs and offers space for reconciliation between technical experts and stakeholders" (Larson et al., pg. 3 & 8, 2021). The project’s stakeholder engagement allowed non-technical considerations to be considered, offering valuable insights for improving borehole construction in rural areas. This provided project developers with information on the sociocultural, political, and technical constraints of a manual borehole drilling project that is not presented in publicly accessible available data.

Forsyth et al. (2010) implemented the Water for All International Method or the Baptist drilling method presented in Chapters 1 and 3. The project focused on economic, environmental, and social development, with community involvement and microfinancing. Lessons learned included the importance of education and building rapport with the community, as well as logistical considerations like material availability and cost. Throughout the report, the authors reported on the impact of time, showing the importance of having a clear design and action plan to implement manual drilling.

Using case study analysis of wellbore drilling history in an African country identified several causes of well failure, including inadequate attention to well design, inferior material, inadequate construction practices, little knowledge of hydrogeology, inappropriate sitting of the borehole, and a general absence of quality control and accountability (UNICEF 2009). Studies showed that to improve the sustainability of water access in rural areas, the wellbore installation and repair should be in the same hands as the user to reduce costs and improve maintenance response (Pattnaik & Dhal 2015, UNICEF 2009). Project evaluation revealed that project sustainability could be improved by providing training on proper drilling implementation and maintenance of wellbores in the project design and education. Project evaluation revealed that sustainability could be improved by ensuring proper use and maintenance of a wellbore in project design and education. Based on the report’s literature background, there is a need for centralized data collection that can refine the mapping of hydrogeological conditions and address problems with specific manual drilling methods. Using the project assessment tool, Figure 2.1 shows two life cycle stages that need more focus: the design and action planning and the operation and maintenance phase. The graphic determines areas that can be more heavily focused on when implementing my manual drilling project during fieldwork addressed in Chapter 4.
Manual drilling is a viable and affordable way to provide water sources in unconsolidated sediments, particularly in rural contexts and with low economic barriers. Over time, the effectiveness of manual drilling techniques and the quality of well construction have substantially improved, leading to more acceptance of manual drilling. To ensure sustainable manual drilling projects, it is essential to use a sociotechnical approach for wellbore site selection, educate stakeholders on wellbore maintenance and operation, empower users through co-development, and have a centralized data repository for identifying hydrogeological conditions and addressing problems with specific manual drilling methods. The various reports on manual drilling projects in rural areas highlighted the importance of stakeholder engagement, careful selection of water point locations, and the need for education on hydrogeological principles and procurement methods for manual drilling. The reports suggest that the success of manual drilling projects depends on a range of factors, including quality of well design, availability of local materials, involvement of the community in the drilling process, and the establishment of water committees to secure funding for materials and wellbore construction.

### 2.4 Conclusion

To address project shortcomings identified in case study analysis, I will provide resources to the participants that can be used after the workshop is completed to self-educate on operational and maintenance topics. Due to time constraints that will not allow for multiple spuddings of wellbores, I will have to provide this information in this manner. This prevents providing participants with a comparative operational analysis of implementing manual drilling methods or common maintenance workovers. To aid in the operation and maintenance of my project, I will provide more information beyond manual drilling methods to the participants that
cover wellbore maintenance, protection, and how to select appropriate technologies. Research time constraints were a common comment that impacted long-term project success making action planning an important part of developing my fieldwork timeline.

The case studies show that implementing a sociotechnical process, such as participatory rural appraisal, can improve borehole construction success in rural areas. The reports highlight the importance of stakeholder engagement, careful selection of water point locations, and education on hydrogeological principles and methods for manual drilling. Sustainability can be improved by ensuring proper use and maintenance of a wellbore in project design and education, as well as empowering users through co-development and having a centralized data repository for identifying hydrogeological conditions and addressing problems with specific manual drilling methods. The most common maintenance methods include regular cleaning of the borehole to remove sediment, debris, bacteria, monitoring water quality. It is important to note that maintenance requirements will vary depending on the specific drilling method used and local conditions. For example, in areas with high levels of sediment or bacteria, more frequent cleaning may be necessary. The success of manual drilling projects depends on various factors, including quality of well design, availability of local materials, involvement of the community in the drilling process, and the establishment of water committees to secure funding for materials and wellbore construction. Information made available to the public for manual drilling methods is often limited to fundraising materials and needs more detailed documentation or analysis. Best practices for sustainable water projects include proactive stakeholder engagement, providing transferable knowledge, providing self-educational resources, and the use of appropriate evaluation tools for technological and social aspects.

Through my research, I have concluded that the reason that manual drilling methods have not had major success in the long-term sustainability of water supplies or are still lagging in meeting water access goals is due to past organizations/projects failing to:

1. Properly engage with identifying relative stakeholders.
2. Leave behind qualified educated trainers to teach others.
3. Provide transferable applications of science or engineering.
4. Perform appropriate evaluation of projects.
In addition to these criteria, successful development work also requires researchers and engineers to implement the following qualities social sustainability factors presented by McConville and Mihelcic (2007):

1. Sociocultural respect: A socially acceptable project is built on understanding local traditions and core values.
2. Community participation: A process that fosters empowerment and ownership in community members through direct participation in development and decision-making.
3. Political cohesion: Involves aligning development projects with host country priorities and coordinating aid efforts at all levels.
4. Economic sustainability: Sufficient local resources and capacity should exist to continue the project without outside resources.
5. Environmental sustainability: Nonrenewable and other natural resources should not be depleted or destroyed for short-term improvements.
CHAPTER 3
TECHNICAL CONSIDERATIONS OF MANUAL DRILLING

3.1 Introduction

In rural and low-income communities of Sub-Saharan Africa, traditional, infrastructure for groundwater extraction is often viewed as too expensive or not contextually suitable. One approach to reducing groundwater access costs is using low-cost, do-it-yourself (DIY) geophysical survey systems and manual drilling methods. These systems can provide valuable information about subsurface geology and potential groundwater resources without invasive techniques. The concept of self-supply, using appropriate technologies and Simple, Market-based, Affordable, and Repairable Technologies (SMART), is introduced in this chapter to address issues of local capacity and self-reliance (Danert and Sutton, 2010; Helweg and Smith, 1978; Pattnaik and Dhal, 2015; Practica Foundation, 2010). The chapter emphasizes the importance of contextually designing a project to meet the needs and resources of the community. Overall, the combination of low-cost geophysical survey systems and manual drilling methods can reduce the barrier of entry for communities to access groundwater and improve their water security.

This chapter highlights the significance of geophysical prospecting in manual drilling projects and selecting an appropriate manual drilling method. The chapter focuses on using low-cost DIY geophysical instrumentation, such as DC resistivity and seismometers, to better understand subsurface geology and groundwater resources (Sirota et al., 2021). The data obtained from these surveys play a crucial role in wellbore placement and can help reduce uncertainty when selecting a manual drilling method.

Using geophysical methods and geological survey data, the chapter aims to help practitioners select the most appropriate manual drilling method for their specific needs and improve water supply in rural regions. The chapter outlines ten important questions to consider when selecting a manual drilling method, including subsurface geology, water depth, available resources, local capacity, and stakeholder engagement. The chapter includes a graphic that can assist in determining a suitable manual drilling method after considering these questions and familiarizing oneself with manual drilling techniques.
3.2 Role of Geoscience in Manual Drilling

The role of geoscience in manual drilling methods is critical for a successful water wellbore project. Adapting drilling methods to local geology and resources is important in maximizing efficiency and can be done through informed decision-making based on geoscientific data, economics, and available resources. By utilizing geophysical prospecting, practitioners can gain valuable information about the subsurface geology and groundwater resources, which helps one make informed decisions about well placement. Using low-cost DIY geophysical instrumentation, such as DC resistivity and seismometers, combined with commercial systems for accuracy verification, provides a cost-effective and non-invasive way to understand the subsurface geology and potential volume and flow rate of groundwater systems. These data helps to communicate project feasibility to stakeholders by providing visual models, reduce uncertainty, and allow us to select the appropriate drilling system.

Geology plays a critical role in selecting a manual drilling method for making a wellbore, as the water depth and material of the subsurface are two important factors when making this decision. Deeper subsurface materials are often harder and more compact, requiring more advanced manual drilling techniques to break through and reach the groundwater (Santos et al., 2017). In contrast, shallower subsurface materials may be easier to access, requiring less advanced manual drilling techniques (Santos et al., 2017).

Different subsurface materials have different levels of permeability, strength, and stability. For example, sandstone is a porous and permeable material that can be easily drilled using manual techniques, while granite is a hard and dense material that requires more advanced manual drilling techniques. In addition, underground fractures and fissures in the subsurface material can also impact the drilling process and may require special techniques to ensure wellbore stability or can be used at targets for wellbore placement. In conclusion, a comprehensive understanding of the subsurface geology, including the subsurface layer depths and materials, can inform decision-making and help ensure the success and sustainability of the manual drilling project.

3.3 Selecting a Drilling Method

The mechanized approach for groundwater extraction has been viewed as too expensive or not a contextual option for rural and low-income communities of Sub-Saharan Africa (Danert et al., 2015; Sutton, 2017). Contextually designing a project is pertinent for low-income
developing regions due to the difference in obtainable resources and local capacity to implement or pay for a project. Failure to contextually design causes projects to promote methods that do not fit the level of investments of households or communities, leading to no adoption of the projects or technologies (Danert and Sutton, 2010). Effective communication with relevant stakeholders plays a large role in project sustainability, cost estimations, and reduce the barrier of entry to manual borehole drilling technology.

Project development will implement the following terminologies and factors addressed in this section to contextually design a borehole drilling system and promote self-sufficiency. Self-supply is a concept based on the idea of users making affordable, incremental improvements to their private family or neighborhood water supply system and is common in sub-Saharan Africa (Danert and Sutton, 2010; Holtslag and Gill, 2015; MacCarthy et al., 2017; Sutton, 2011). Self-supply addresses issues of maintenance and affordability through the utilization of appropriate technologies. Appropriate technologies are “tools that allow individuals and communities to meet their needs with limited reliance on external industry-based processes” that “encompasses a common set of features, including small scale, labor intensiveness, and local control” (Helweg and Smith, 1978; Pattnaik and Dhal, 2015; Santos et al., pg. 1, 2017). Along with this, implementing SMART provides ideologies to develop manual drilling systems that are economically viable to build, operate, and maintain using local resources creating more local capacity.

When selecting a manual drilling method for a water relief project, it is important to consider the following questions:

1. What is the subsurface geology like in the area, and how will it impact the drilling process?
2. What is the estimated water depth?
3. What resources, both physical and financial, are available for the drilling project?
4. What is the capacity of the community to build, maintain, and repair the drilling system; what kind of technical support will they need?
5. What are the community's local social and cultural contexts, and how will they impact the success of the drilling project?
6. How can stakeholder engagement be incorporated into the project to ensure its success?
7. What kind of training will the community need to effectively build and use a manual drilling system, and how can this training be delivered?
8. How can the drilling system be sustainable and promote community self-reliance?
9. What are the humanitarian and social implications of the drilling project, and how can they be addressed to ensure its success?
10. What is the project's cost-benefit analysis, and how can the costs be reduced while ensuring its success?

After considering the following questions and familiarizing yourself with manual drilling techniques, Figure 3.1 below helps one select an appropriate drilling method.

![Manual drilling method family tree](image)

Figure 3.1 Manual drilling method family tree that considers multiple methods based on local context and geoscientific data. Adapted from Santos et al. (2020).

To better understand the applicability of manual drilling from a research perspective, use manual drilling feasibility maps. The feasibility study of manual drilling in Benin identified favorable areas for manual drilling by collecting geological data and water point characteristics on a geographic basis. The study categorized the feasibility of manual drilling into four categories based on the potential for manual drilling and outlined hydrogeologic characteristics. Some areas have thick weathering layers or granular sediments with good permeability, while others are not feasible due to the presence of saline intrusions or hard formations.
These maps are published resources in the RWSN online library. This study used the Republic of Benin: Feasibility Study of Manual Drilling, which produced this map in Figure 3.2:

Figure 3.2 Demonstrates areas of manual drilling feasibility and local characteristics based on GIS information and borehole data.

3.5 Conclusions

With majority of manual drilling literature found in online project documents formatted and executed by differing individuals or organizations, created inconsistency and gaps in manual drilling resources. Compendia that brings together information on the extent and status of manual drilling methods worldwide have been created to address this knowledge gap. RWSN and UNICEF provide compendia that include maps of countries where manual drilling is applicable, or has been undertaken, to provide context for manual drilling implementation from start to
finish. Specific manual drilling method compendiums summarize what is known about the technique, materials needed, construction, and implementation or operations. These compendia provide a valuable resource for anyone interested in learning about manual drilling methods and the challenges associated with their use. For my thesis, I have chosen the Baptist Drilling method as it is a well-established, replicable, and cost-efficient way to drill a personal well with shallow water table depths and has been used successfully in Bolivia, Kenya, Nigeria, and Uganda (Cloesen, 2007; Danert, 2015). According to research, the Baptist method is not frequently used in manual drilling projects across Africa (Danert, 2015; Santos et al., 2017).

To advance the Baptist drilling system, future experiments could examine whether the effectiveness and efficiency of this method can be enhanced by using a drill bit as the internal check valve (Figure 1.3). When the drill bit contacts the bottom of the wellbore, internal pins engage the spiral grooves on the drill bit collar to transform the downward motion into a rotational spin. This rotational spin will aid in cutting and downhole shearing of subsurface material. This would make a manual drilling system that combines sludging, percussion, and rotary; however, it would be confined by its mechanical replicability.
CHAPTER 4
IMPLEMENTING A MANUAL DRILLING PROJECT IN BENIN, AFRICA

4.1 Introduction

This project seeks to contribute to on-going developments for sustainable groundwater solutions in the water-scarce region of Benin, West Africa. Doing so, it demonstrates the benefits of a sociotechnical approach to manual drilling implementation and wellbore construction by combining attention to the geophysical and mechanical aspects of drilling with education and stakeholder participation. This study will inform participants’ on determining suitable drilling methods using geoscientific and local contexts. This case study is party of a GWB hydrogeological workshop with the Université d’Abomey-Calavi (UAC) in Cotonou, Benin. Over two weeks in December 2022, workshop leads trained participants on methods to determine suitable drilling methods and develop wellbore drilling projects to reach shallow aquifers using geoscientific and contextual logistics. Educational objectives include presenting best practices of manual wellbore drilling projects and community development practices to show how a blended approach benefits manual drilling projects to participating stakeholders. To better educational objectives, prior background research determined the best method of teaching intervention, which led to the T³ method selection. This project was successfully able to spud a proof-of-concept borehole and provide educational information to allow participants to develop their own manual drilling instrument. Drilling implementation and experiences will be described and reflected upon later in this chapter. Overall, the study showcases the potential of manual drilling methods in addressing the water crisis in Africa and promoting sustainable and self-reliant entrepreneurship in groundwater development.

4.2 Background

Manual drilling methods are used in Benin due to their low cost and simplicity, but there is a lack of understanding of what constitutes the total cost of a wellbore drilling project in Benin because projects have missed the inter-sectional flow of information about water uses, needs, and contextual planning negatively impacting projects (Danert and Sutton, 2010; Danert et al., 2015; Sutton, 2017; Hollerman et al., 2010). To learn more about the pricing of boreholes, see Danert (2015).
In Benin, county or countrywide hydrogeological assessments allow practitioners to determine rainfall patterns, aquifer recharge, user applications, contamination, volumetric water assessments, and manual drilling feasibility studies (Heidecke, 2006; Höllermann, 2017; Houkpe et al., 2015; N’Tcha M’Po, 2017; Silliman et al., 2010; UNICEF, 2009; Vouillamoz et al., 2014). To date, the results of these papers show that Benin’s surface water and deep wellbores are being contaminated by surface pollution, saltwater intrusion, and anthropogenic contaminants from urban areas (Silliman et al., 2010). Geological assessments show that Benin exhibits an ideal hydrogeological setting and moderately shallow water tables (Danert, 2015; Odeloui et al., 2022). Studies have also shown that the rural water supply does not meet the needs of the rural population in Benin (Heidecke, 2006; Höllermann, 2017). While there are still current water indices that satisfy the food and water needs of the country, it might not be able to meet the needs of a 2.8% annual population growth and an increasingly inconsistent amount of annual wet days (Heidecke, 2006; N’Tcha M’Po, 2017). These trends will increase the pressure on water resources and decrease groundwater recharge (Höllermann et al., 2017). These assessments produce beneficial information, but the projects did not provide solutions to obtain safe drinking water for those in need.

To better educational practices this project analyzed the academic structures of the region to determine the best form of educational intervention to train trainers. Formal education in Benin is divided into pre-primary, primary, and secondary education, but the educational attainments are low (Caves et al., 2019). Outside the formal education system, multiple forms of educational intervention are led by governments, NGOs, and academics. Conn (2017) provided a meta-analysis of effective educational interventions in sub-Saharan Africa, which showed pedagogical programs that instrumented assisted learning in teacher-trainer programs were effective in education intervention in sub-Saharan Africa. Based on the literature, the T3 method was selected as an effective way to disseminate technical information and skills related to manual drilling projects, particularly in contexts where sustainability, cultural relevance, and cost-effectiveness are important considerations. Because Carty (2015) stated that the "likelihood that all people in the community will be directly addressed or participate in training is low", projects should place more emphasis on the role trainers play in their communities, which is another reason to redefine community in manual drilling projects to a community of trainers. Conn (2017) notes that education programs in sub-Saharan Africa often try to increase learning
through the number of participants, which causes the quality of instruction to reduce. This impacts the utility of the educational intervention. To prevent quality issues, the manual drilling team will consist of at most what is needed to implement the Baptist drilling method. This will ensure that all members of the selected community can participate and that the training has a lasting impact by providing hands-on experience and time to ask complex questions.

4.3 Implementation of a Sociotechnical Manual Drilling Project

Manual drilling information was disseminated in a workshop setting, where an initial overview of manual drilling methods were presented to all participants. The initial presentation aimed to convey the abilities of manual drilling methods and the technical workflow of constructing and completing a wellbore. Students were actively engaged with the material during the presentation and demonstrated interests in the various manual drilling methods. Following the presentation, a drilling team of five was selected from the participating students. Communicating with the participants in the workshop allowed them to determine who would benefit the most from participating in the manual drilling project by identifying stakeholders that had interest in continuing manual drilling methods beyond the workshop, figure 4.1. Due to language barriers, it was important to identify someone who could provide proper English-to-French translation to be a part of the drilling team. In preparation for the language barrier, educational slide materials were provided in French and English (Appendix A).

The first day with the drilling team of four consisted of a lecture-based discussion on the process and issues associated with the fabrication and implementation of various manual drilling methods. During this lecture, resources on manual drilling methods were provided to them, allowing participants to educate and research manual drilling methods themselves once the

Figure 4.1 GWB 2022 workshop drilling team acquiring metal drill stem pipe.
workshop day was completed. This led to students coming in engaged the next day with about wellbore project development and implementation of the different manual drilling methods.

The educational materials provided the drilling team with a big picture view of a manual borehole drilling project for groundwater resources and exploring issues beyond the drilling process. Information included specifics on differing manual drilling methods and implementation, methods for pumping water to the surface, and how to protect a wellbore by identifying geological layers or structures through geophysics. The educational slides provided during the workshop consisted of images and videos with minimum text to aid in communication between French and English speakers (Appendix A).

There were concerns that more than two weeks would be needed to complete the entire manual drilling process, which included geophysics, health and safety, manual drilling education, fabrication, and implementation. The initial project timeline and action plan had to be modified due to local resource constraints, transportation, and workshop education goals.

Figure 4.2 Images of the Baptist drill bit used in fieldwork. (a) Carbide drill bit with check valve cap welded to the top of drill bit inserted through a reducer coupling. Drill head wings were cut from angle iron scraps. (b) Drill head wings welded and ground to insure strong weld. (c) Male 1½ inch drill collar welded to reducer coupling. (d) Internal view of the drill collar. (e) View of completed Baptist drill bit.
Substantial time was spent on the project's design and action planning phase due to fabrication constraints, leading to the development of several different action plans and additional steps. A Baptist drilling bit was taken to Benin to expedite the fabrication stage, figure 4.2.

A common steel pipe and PVC fitting in Benin is 1½ inch, which led to selecting a male 1½ inch drill collar for the Baptist drilling method. Bringing this to Benin provided the drilling team with multiple options for project implementation as they considered multiple designs of drill stem fabrication. They considered issues related to environmental, market supply, and energy needs to implement the Baptist drilling method. Procuring the necessary supplies for the project proved challenging, even with the participating students familiar with the local prices and availability of products. Materials purchased included metal inch pipe, metal couplings, rope, pulley, shovel, and pick ax. However, the team was unable to find bentonite for the drilling fluid. During supply procurement the participants' local knowledge evaluated many items as overpriced, resulting in more time spent bargaining and visiting different local shops to reduce overall cost. Figure 4.3 shows the costs of supplies and equipment purchased during fieldwork.

The drilling team chose metal pipe over PVC due to the latter being subject to sun-damaged and thinner, which could cause breakage when encountering a shale layer. The team obtained a metal 1½ inch pipe (6m long) for the drill stem, which was threaded on both ends to
attach to the Baptist drill bit. Due to the excessive length of the pipe, the drilling team got the pipe cut into two pieces and re-threaded on the new cut ends by a local machine shop, figure 4.4.

Figure 4.4 Fabrication of drill stem material. (a) Getting the drill stem cut into usable lengths for the drilling process at a roadside shop. (b) Rethreading the cute ends of the metal pipe to allow connection using metal couplings. (c) Université d’Abomey-Calavi drill team students return with 6-meter-long drill stem sections.

Figure 4.5 Preparations for implementing the Baptist manual drilling method. (a) Digging settling pit. (b) Attaching a pulley straight above the settling pit to overhanging tree, instead of building a tripod.
The drilling implementation was delayed due to the fabrication and education portion of the manual drilling group. To make up for lost time, the drilling had to start earlier than the rest of the workshop and prepare the day before; a timing decision which participants supported, figure 4.5. The students disliked the drilling location selected based on areas approved by institutional faculty due to the smell and confining conditions, but the Baptist drilling method was nonetheless successfully implemented, drilling 1.8 m per hour through roots and with insufficient fluid circulation, figure 4.6. This insufficiency was due to the lack of bentonite, which increases the fluid's viscosity and lifts the coarser size grains. The observation was made by analyzing the cuttings during drilling, the mud mixture in the setting pit or well bore, and the sediments inside the drill stem after removal. In substitution of bentonite drill crews can use barite, chalk, or starches to increase the fluid density.

Figure 4.6 Implementing the Baptist drilling method. (a) A rope is attached to a handle threaded through the pulley in figure 4.5; this rope is pulled by the drilling crew to lift and drop the drill stem. (b) Drillers guide the drill stem in the borehole. (c) Drillers provide an extra downward force on the drill stem while others fill the borehole with water to provide wellbore stability and maintain the necessary water quantity for the drilling process.
After the drilling was completed, the drilling team presented their manual drilling project to the rest of the workshop. The students explained how to use geophysics to identify layers that can act as protective seals and how to select a manual drilling method based on the geophysics. They could answer questions from the audience, demonstrating their retention of information and understanding of the material covered.

4.4 Discussion

In this project, a workshop on manual drilling was developed using a “flipped” classroom style to engage those who participated on the drilling team. “Flipping” a classroom means that information was given before the discussion, allowing students to prepare beforehand. Providing this information allowed workshop participants to learn multiple designs for a manual drilling project and consider the life cycle of a wellbore drilling project. This led to productive discussions about multiple designs and helped build rapport with participants. Educational resources could be easily distributed because of the workshop participant’s educational background. Students who participated in the manual drilling project were enrolled in a local hydrology program and knew how to analyze project reports or manual drilling compendiums.

For workshops of this type, it is imperative to have an adaptive management structure due to the differences in participant knowledge and the possibility of unexpected challenges in all stages of implementation. Finding drill materials of high enough quality to be economically viable was also a challenge, suggesting that for projects like this to succeed, it is essential to have someone with enough familiarity with the local area find hardware stores and provide transportation when procuring supplies. By reducing the amount of time spent on education and fabrication, provides the opportunity to spend more time on manual drilling operation and wellbore maintenance during a workshop to improve the overall score in project assessment. This project did not reach the completion stage of drilling a wellbore, and for this reason it was given a lower score in the operation and maintenance phase than it might otherwise have received, figure 4.7. My project’s score on conceptual designs and feasibility were negatively impacted by implementing a single drilling method during the workshop. Using the Baptist drilling method showed the participants how combinations of manual drilling methods can make new drilling methods unaware to them.
Students were engaged throughout the workshop but noted that the manual drilling methods were more labor-intensive than expected. Labor is a crucial aspect of manual borehole drilling methods, as the process often involves physically demanding work such as digging, drilling, and lifting heavy equipment. The amount of labor required can vary depending on the specific drilling method and the geological conditions of the site. Excessive labor need can significantly impact the implementation of a particular manual drilling method. In areas where manual labor is expensive or difficult to come by, the cost and time required to complete a manual borehole drilling project can be prohibitively high. There is also the opposite approach in areas where manual labor is cheap, the manual drilling methods can be implemented cost-effectively or by the user.

4.5 Summary

This manual drilling project seeks to contribute to sustainable groundwater solutions in the water-scarce region of Benin, West Africa, by demonstrating the benefits of a sociotechnical approach to manual drilling implementation and wellbore construction. Research and experience shows that Benin is an ideal location to research or implement manual boreholes due to the suitable geological setting, lack of training resources on manual drilling, the water availability difference between rural-urban settings, ability to fabricate manual drilling equipment, and participant interest in manual drilling disciplines. Over a two-week period in December 2022, five participants of a hydrogeological workshop learned how to determine suitable drilling
methods for extracting groundwater by using geoscientific and local contexts that could impact project execution or operation. During the workshop participants learned best practices of manual wellbore drilling and project development practices to show how a blended approach of technical and local knowledge can benefit manual drilling projects to obtain or protect water sources. To support manual drilling development the educational information disseminated to participants allows for them to develop their own manual drilling rig or a water relief project. This project showcased the potential of manual drilling methods while using other low-cost instrumentation to promote sustainable and self-reliant entrepreneurship in ground water development. This project was successfully able to spud a borehole using the Baptist drilling method.
CHAPTER 5
CONCLUSIONS

In the context of manual drilling development, communities often have knowledge and experience with manual drilling techniques that outside experts or organizations may not be aware of. Co-implementing a manual drilling project with a community of trainers showed that by using local knowledge and expertise, manual drilling fabrication guidelines are not always of high enough quality and manual projects are highly subjective throughout their lifecycle stages, requiring an adaptive management structure. Focusing on educating trainers in the workshop on various methods of manual drilling fostered critical thinking on how to develop and implement drilling methods based on environmental, market supply, and energy needs for drilling methods. To develop a manual drilling workshop prior research on the educational structures should be done to efficiently determine how to provide information on manual drilling and wellbore development. Beyond this, practitioners should also consider the sociocultural, political, environmental, economic, and technical constraints of individual drilling methods to try and reduce uncertainties during project development. For instance, understanding the sociocultural context of the community can help identify potential conflicts and barriers to project implementation.

Environmental factors such as soil type, groundwater depth, and water quality can affect the feasibility and sustainability of a manual drilling system. The use of geophysical applications helps reduce uncertainties and increases the chances of success of the water relief project and allows for contextual design of a manual drilling system by providing subsurface data. When implementing a manual drilling project, economic factors such as labor availability and material costs can affect the affordability and long-term maintenance of a wellbore system, so it important to determine appropriate technologies that meet local contexts. Technical constraints such as local fabrication abilities can affect the selection of drilling methods and lead to developing the design and action plan. Overall, the contextual design ensures that the manual drilling system is appropriate, feasible, sustainable, and locally relevant, ultimately leading to greater impact and long-term benefits for the community.

By involving a community of trainers in the implementation of a manual drilling project, their knowledge and expertise can be leveraged to create more effective and sustainable solutions
and save time by being a resource themselves. When local communities are involved in the development of a project, they are more likely to contribute and take ownership of its implementation. Proper co-implementation can lead to greater participation and sustainability of the project in the long term. While people may be hesitant to participate in manual drilling projects due to the physical demands of the work, it is still a viable option to obtain shallow groundwater resources. The extent of manual labor can make recruiting and retaining skilled workers for manual drilling projects difficult; as a result, it is important for manual drilling projects to consider the labor requirements of the specific drilling method and to provide appropriate training, support, and compensation to the drilling team. This can include measures such as providing protective equipment, offering fair wages and benefits, and ensuring workers have access to adequate rest and medical care for long term projects.

A suggestion for future manual drilling projects is to include more DIY instrumentation education on geophysical surveying equipment and manual drilling methods. Education should involve training trainers on constructing and implement equipment, who can then pass on their knowledge and skills to others, aiding in increasing capacity to implement manual drilling projects. By doing something yourself, you reduce labor costs, which can be a significant expense for many projects. DIY manual drilling projects often allow you to choose and purchase materials at a lower cost than if you hired someone to do the work for you. When you do a project yourself, you have more control over the process, and you can make decisions that help you avoid unnecessary expenses. For example, you may choose to use a less expensive material or skip a step that is not essential.

There are many cases for rural communities who do not have the economic resources to implement or develop their own manual borehole drilling project. By using a low-cost approach and micro financing, manual drilling projects can be made more accessible to communities who otherwise might not have the resources to fund them. Another strategy is to look for project funding through national grants, nonprofit organizations focused on water resources, and local government assistance. By creating partnerships between different organizations and stakeholders can also be helpful in addressing long-term issues related to manual borehole drilling projects. These partnerships can aid in the maintenance and workovers of completed wellbores, ensuring that they remain functional and operational.
REFERENCES


APPENDIX A  
2022 GWB MANUAL DRILLING WORKSHOP SLIDES 

This appendix shows the slides used in the 2022 GWB Manual Drilling Workshop held in Cotonou, Benin. The slides are in English and French to allow for quick translation and teaching to a non-dominant English-speaking group of stakeholders. The slides can be used for finding condensed resources and informational links for manual drilling methods and community development practices. A.1 provides an introduction to manual drilling methods, manual pumping methods, and wellbore development. A.2 provides community development topics and sustainability practices for manual drilling projects. A.3 shows the materials purchased during field work in Cotonou, Benin and the work plan developed by the drilling team.

A.1 Manual Drilling Methods
# What is manual drilling | Qu'est-ce que le forage manuel

<table>
<thead>
<tr>
<th>Anglais</th>
<th>Français</th>
</tr>
</thead>
</table>
| Manual drilling techniques use human energy to construct a groundwater supply  
  - Unconsolidated materials such as sands and silts require relatively little energy to penetrate  
  - Clays, laterite, sandstone, and limestone require more energy to break | Les techniques de forage manuel utilisent l'énergie humaine pour construire un approvisionnement en eau souterraine  
  - les matériaux non consolidés tels que les sables et les silt sont nécessaires relativement peu d'énergie pour pénétrer  
  - les argiles, la latérite, le grès et le calcaire nécessitent plus d'énergie pour se briser |
| Drilling techniques penetrate the formation, remove loose material, and support the hole from collapse  
  - Prevent collapse with the temporary casing, permanent lining, or hydraulic fluid pressure | Les techniques de forage pénètrent dans la formation, enlèvent les matériaux meubles et empêchent le trou de s'effondrer  
  - Empêcher l'effondrement avec le tubage temporaire, le revêtement permanent ou la pression du fluide hydraulique |
| Manual drilling methods are being used in at least 36 countries around the world  
  - Increasing use in Chad and Nigeria | Les méthodes de forage manuel sont utilisées dans au moins 36 pays à travers le monde  
  - Utilisation croissante au Chade et au Nigeria |

---

# Why manual drilling | Pourquoi le forage manuel

<table>
<thead>
<tr>
<th>Anglais</th>
<th>Français</th>
</tr>
</thead>
</table>
| Low cost compared to machine drilling  
  - Easily transported  
  - You can teach yourself  
  - Ability to build your own drill system  
  - Way to obtain groundwater | Faible coût par rapport au perçage mécanique  
  - Facilement transporté  
  - Vous pouvez vous enseigner  
  - Possibilité de construire votre propre système de forage  
  - Manière d'obtenir de l'eau souterraine |

*Training of technicians for low-cost drilling to obtain drinking water in Mali.  
Formation de techniciens pour le forage à faible coût pour obtenir de l'eau potable au Mali.*

https://www.practica.org/projects/low-cost-drilling-drinking-water-mali
Feasibility | Faisabilité

Anglais
Low lying areas of loose unconsolidated sediments (e.g. Ganges Plain, Coastal Plain Sands of Nigeria and the Chad formation). Highly weathered crystalline rocks above the bedrock.

Français
Zones basses de sédiments lâches non consolidés (par exemple, la plaine du Gange, les sables de la plaine côtière du Nigéria et la formation du Tchad). Roches cristallines fortement altérées au-dessus du socle rocheux.

Drilling Methods | Méthodes de forage

Anglais
1. Auger
2. Jetting
3. Sludging
4. Percussion
5. Combination

Français
1. Tarière
2. Jet
3. Boues
4. Percussion
5. Combinaison

Combination example: The “Baptist” method of manual drilling
Exemple de combinaison: La méthode “Baptist” de forage manuel
### Suitability | Pertinence

<table>
<thead>
<tr>
<th>Technique</th>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Drilling range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auguring</td>
<td>Unconsolidated sediments. Silt, sand, gravel, limited in clay.</td>
<td>Simple, cheap fast in soft sediments</td>
<td>Limited to soft sediments and shallow depths.</td>
<td>15-20 m</td>
</tr>
<tr>
<td>Jetting</td>
<td>Unconsolidated sediments. Silt, sand, gravel, and clay.</td>
<td>Fast in soft sediment.</td>
<td>Potentially expensive and large volume of water required.</td>
<td>25 -50 m</td>
</tr>
<tr>
<td>Percussion and bailing</td>
<td>Unconsolidated sediments and weathered soft rock. Silt, sand, gravel, and clay.</td>
<td>Can drill through medium hard rock. Can be combined with sludging.</td>
<td>Slower, maybe more expensive.</td>
<td>25-50 m</td>
</tr>
<tr>
<td>Sludging</td>
<td>Unconsolidated sediments. Silt, sand, gravel, and clay.</td>
<td>Ease of use, fast in soft sediment.</td>
<td>Limited to soft sediments.</td>
<td>25-50 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technique</th>
<th>Matérielle</th>
<th>Avantages</th>
<th>Désavantages</th>
<th>Gamme de forage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarière</td>
<td>Sédiments non consolidés. Limon, sable, gravier, limite en argile.</td>
<td>simple, bien marché, rapide dans les sédiments mous.</td>
<td>Limité aux matériaux mous et aux faibles profondeurs. Problématique lors du forage sous la nappe phréatique.</td>
<td>15-20 m</td>
</tr>
<tr>
<td>Jet</td>
<td>Sédiments non consolidés. Limon, sable, gravier et argile.</td>
<td>rapide dans les sédiments mous.</td>
<td>Potentiellement coûteux et grand volume d'eau nécessaire.</td>
<td>25 -50 m</td>
</tr>
<tr>
<td>Percussion</td>
<td>Sédiments non consolidés et roche tendre altérée. Limon, sable, gravier et argile.</td>
<td>Peut forer à travers de roches moyennement dures. Peut être combiné avec des bouses</td>
<td>Plus lent, peut-être plus cher.</td>
<td>25-50 m</td>
</tr>
<tr>
<td>Buses</td>
<td>Sédiments non consolidés. Limon, sable, gravier et argile.</td>
<td>Facilité d'utilisation, rapide dans les sédiments mous.</td>
<td>Limité aux sédiments mous.</td>
<td>25-50 m</td>
</tr>
</tbody>
</table>

---

**Auguring | Tarière**
**Jetting | Jet**

**Anglais**
- Jetting – injection of fluid (or drill mud) down and out of the bottom of a drilling pipe to wash the sediment to the surface via the annulus (i.e. the gap between the drill pipe and drilled hole). A large amount of water is used. Jetting uses a small petrol pump or manual pump to inject the fluid down the drill pipe.

**Français**
- Jet - injection de fluide (ou de boue de forage) vers le bas et hors du fond d'une tige de forage pour laver les sédiments à la surface via l'espace annulaire (c'est-à-dire l'espace entre la tige de forage et le trou foré). Une grande quantité d'eau est utilisée. Le jet utilise une petite pompe à essence ou une pompe manuelle pour injecter le fluide dans la tige de forage.

---

**Sludging | Boues**

**Anglais**
1. The driller - controls the water flow with his hand and is coordinating the team. The driller is standing next to the drill pipe, facing the mud pit.
2. The arm operator - rotates the drill pipe and drill bit. He is facing the driller.
3. The lever operator(s) - lift and drop the drill pipe by moving the lever up and down.

**Français**
1. Le foreur - contrôle le débit d'eau avec sa main droite et coordonne l'équipe. Le foreur est debout à côté de la tige de forage, face à la fosse à boué.
2. L'opérateur du bras - fait tourner la tige de forage et le trépan. Il fait face au foreur.
3. Le(s) opérateur(s) à levier - soulever et déposer la tige de forage en déplaçant le levier de haut en bas.
Sludging | Boues

Anglais
• The bailer goes down the hole through water or mud.
• On the downward movement the valve at the bottom of the bailer will open. The mud will enter the bailer.
• On upward movement the valve will close. The mud is now inside the bailer.

Percussion | Percussion

Anglais
• The drill bit goes down in the hole through the water or mud.
• It hits the bottom and breaks the soil or rock.
• When the bit goes up, the cuttings mix with the water creating a mud.

Français
• L'écoppe descend dans le trou à travers l'eau ou la boue.
• Lors du mouvement vers le bas, la valve au bas de l'écoppe s'ouvrira. La boue entrera dans l'écoppe.
• Lors du mouvement vers le haut, la vanne se ferme. La boue est maintenant à l'intérieur de l'écoppe.

• Le forêt descend dans le trou à travers l'eau ou la boue.
• Il touche le fond et brise le sol ou la roche.
• Lorsque le forêt monte, les déblais se mélangent à l'eau créant une boue.
**Percussion**

- English: The bailer goes down the hole through water or mud.
- On the downward movement, the valve at the bottom of the bailer will open. The mud will enter the bailer.
- On upward movement, the valve will close. The mud is now inside the bailer.

**Français**
- L’écopée descend dans le trou à travers l’eau ou la boue.
- Lors du mouvement vers le bas, la valve au bas de l’écopée s’ouvrira. La boue entrera dans l’écopée.
- Lors du mouvement vers le haut, la valve se fermera. La boue est maintenant à l’intérieur de l’écopée.

---

**Baptist Drilling Process**

(A) A drilling crew pulls up the rope, lifting the drill bit off the bottom of the hole which closes the check valve. When the check valve closes water is pushed up the drill stem. (B) On the downstroke the check valve is momentarily open, letting water and sediment from the bottom of the hole to flow into the drill stem, allowing the mixture to be pushed up to the surface. On the downstroke, sediment is broken. (C) As the crew pulls, the check valve closes pushing the mixture to exit the mouth into the decanter (settling pit). The decanter allows for sediments to settle and let water flow back into the borehole for wellbore stability.
Baptist Drilling Process | Processus de Forage Baptiste

(A) Une équipe de forage tire la corde, soulevant le foret du fond du trou qui ferme le clapet anti-retour. Lorsque le clapet anti-retour se ferme, l'eau est poussée vers le haut de la tige de forage. (B) Lors de la course descendante, le clapet anti-retour est momentanément ouvert, laissant l'eau et les sédiments du fond du trou s'écouler dans la tige de forage, permettant au mélange d'être poussé jusqu'à la surface. En descente, les sédiments sont brisés. (C) Lorsque l'équipage tire, le clapet anti-retour se ferme, poussant le mélange à sortir par la bouche dans le décanteur (fosse de décantation). Le décanteur permet aux sédiments de se déposer et de laisser l'eau refuser dans le trou de forage pour la stabilité du puits de forage.

Drilling Log | Journal de Forage

<table>
<thead>
<tr>
<th>Anglais</th>
<th>Français</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drilling log</strong></td>
<td><strong>Journal de forage</strong></td>
</tr>
<tr>
<td><strong>Diagram</strong></td>
<td><strong>Diagram</strong></td>
</tr>
<tr>
<td><strong>PVC pipe</strong></td>
<td><strong>PVC pipe</strong></td>
</tr>
<tr>
<td><strong>Formation type</strong></td>
<td><strong>Formation type</strong></td>
</tr>
<tr>
<td><strong>Depth (meters)</strong></td>
<td><strong>Depth (meters)</strong></td>
</tr>
<tr>
<td><strong>Description of the formation</strong></td>
<td><strong>Description of the formation</strong></td>
</tr>
<tr>
<td><strong>Rock/coarse</strong></td>
<td><strong>Rock/coarse</strong></td>
</tr>
<tr>
<td><strong>Cut-off of the sample</strong></td>
<td><strong>Cut-off of the sample</strong></td>
</tr>
</tbody>
</table>

1. Sand, fine, yellow/brown
2. Sand, fine, yellow/brown
3. Sand, fine, yellow/brown
4. Sand, fine, yellow/brown
5. Sand, fine, groundwater
6. Sand, fine, yellow/brown
7. Sandy Clay, brown
8. Sandy Clay, brown
9. Sandy Clay, brown
10. Clay, compact, grey
11. Clay, compact, grey
12. Clay, compact, grey
13. Clay, compact, grey
14. Sand, coarse, yellow
15. Sand, coarse, yellow
16. Sand, coarse, yellow
17. Sand, coarse, yellow
18. Sand, coarse, yellow
19. Sand, coarse, yellow
20. Sand, coarse, yellow
21.5 Sandy Clay, grey/brown
22. Sandy Clay, grey/brown

1. le sable, fin, brun jaune
2. le sable, fin, brun jaune
3. le sable, fin, brun jaune
4. le sable, fin, brun jaune
5. le sable, fin, eau souterraine
6. le sable, fin, brun jaune
7. argile sablonneuse, brune
8. argile sablonneuse, brune
9. argile sablonneuse, brune
10. argile compacte, grise
11. argile compacte, grise
12. argile compacte, grise
13. argile compacte, grise
14. argile compacte, grise
15. argile compacte, grise
16. sable grossier, jaune
17. sable grossier, jaune
18. sable grossier, jaune
19. sable grossier, jaune
20. sable grossier, jaune
21.5 sable grossier, grise brun
22. argile sablonneuse, grise brun

56
Casing | Enveloppe

Hand Pump | Pompe a main

a) Pompe EMAS
b) Pompe EMAS Fonction
c) Pompe a corde
Techniques for Siting

Anglais
- Remote sensing
- Hydrogeological field surveys
- Geophysical surveys

Français
- Télédétection
- Relevés hydrogéologiques de terrain
- Levés géophysiques

Example of DC resistivity geophysics survey showing the water table on the dotted line and the saline water (McInnis et al. 2013).
Exemple de levé géophysique de résistivité DC montrant la nappe phréatique en pointillé et l’eau salée (McInnis et al. 2013).

Organizations for Manual Drilling Resources

EnterpriseWorks/VITA
A Division of RELIEF INTERNATIONAL

PRACTICA FOUNDATION

skat foundation

unicef
Videos | Vidéos

- Webinar 1: Introduction to Manual Drilling and its Potential to Improve Rural Water Supplies
- Webinar 2: Manual Drilling at Scale (Senegal, India & Bolivia)
- Webinar 3: Good practices in Manual Drilling Construction and Design (Nigeria, Madagascar, & Kenya)
- Webinar 4: What do governments love and hate about manual drilling? (Guinea, Niger & Ethiopia)
- Webinar 5: Private Sector and NGO Experiences of Introducing and Developing Markets for Manual Drilling (Malawi, Sierra Leone and Zambia)
- Plaidoyer pour le forage manuel
- Professionalisation des forages manuels en Afrique 1
- Professionalisation des Forages Manuels en Afrique 2
- Comment Professionaliser le forage manuel en Afrique 1
- Comment Professionaliser le forage manuel en Afrique 2
- Webinar 1: Introduction to Manual Drilling and its Potential to Improve Rural Water Supplies/Introduction sur les technologies de forage manuel et leur potentiel pour améliorer l'approvisionnement en eau potable en milieu rural
- Webinar 2: Manual Drilling at Scale (Senegal, India & Bolivia)/Développement à l'échelle du forage manuel (Sénégal, Inde et Bolivie)
- Webinar 3: Good practices in Manual Drilling Construction and Design (Nigeria, Madagascar & Kenya)/Bonnes pratiques pour la conception et la construction de forage manuel (Nigeria, Madagascar, et Kenya)
- Webinar 4: What do governments love and hate about manual drilling? (Guinea, Niger & Ethiopia)/Ce que les gouvernements aiment et détestent à propos du forage manuel (Guinée, Niger, & Éthiopie)
- Webinar 5: Private Sector and NGO Experiences of Introducing and Developing Markets for Manual Drilling (Malawi, Sierra Leone and Zambia)/Expériences du secteur privé et des ONG pour l'introduction et le développement de marchés pour le forage manuel (Mali)
- Plaidoyer pour le forage manuel
- Professionalisation des forages manuels en Afrique 1
- Professionalisation des Forages Manuels en Afrique 2
- Comment Professionaliser le forage manuel en Afrique 1
- Comment Professionaliser le forage manuel en Afrique 2

Useful Links | Liens utiles

- https://akvopedia.org/wiki/Drilling_or_digging
- https://www.rural-water-supply.net/en/
- https://www.practica.org/
- https://www.youtube.com/playlist?list=PLFF4A85497A6D2410
- https://www.practica.org/?s=manual+drilling+french
A.2 Community Development Practices For Manual Drilling Projects

Pratiques de Développement Communautaire

Wyatt Lindsey
Geophysics Department
Colorado School of Mines

Sustainability Factors | Facteurs de durabilité

<table>
<thead>
<tr>
<th>English</th>
<th>Français</th>
<th>English</th>
<th>Français</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-cultural respect</td>
<td>Respect socioculturel</td>
<td>A project is built on understanding the local traditions and core values.</td>
<td>Un projet est construit sur la compréhension des traditions locales et des valeurs fondamentales.</td>
</tr>
<tr>
<td>Community Participation</td>
<td>Participation Communautaire</td>
<td>A process that causes empowerment and ownership in a community through direct participation.</td>
<td>Un processus qui provoque l'autonomisation et l'appropriation dans une communauté grâce à la participation directe.</td>
</tr>
<tr>
<td>Political Cohesion</td>
<td>Cohérence politique</td>
<td>Involves increasing the alignment of development projects with host country priorities and coordinating aid efforts at all levels (local, national, and international) to increase ownership and efficient delivery of services.</td>
<td>Implique d’accroître l’alignement des projets de développement sur les priorités du pays hôte et de coordonner les efforts d’aide à tous les niveaux (local, national et international) pour accroître l’appropriation et la prestation efficace des services.</td>
</tr>
<tr>
<td>Economic Sustainability</td>
<td>Durabilité économique</td>
<td>Implies that sufficient local resources and capacity exist to continue the project in the absence of outside resources.</td>
<td>Implique qu’il existe suffisamment de ressources et de capacités locales pour poursuivre le projet en l’absence de ressources extérieures.</td>
</tr>
<tr>
<td>Environmental Sustainability</td>
<td>La durabilité environnementale</td>
<td>Implies that renewable and other natural resources are not depleted nor destroyed for short term improvements.</td>
<td>Implique que les ressources renouvelables et autres ressources naturelles ne sont pas dépassées ni détruites pour des améliorations à court terme.</td>
</tr>
</tbody>
</table>
### Project Life Cycle Factors | Facteurs du cycle de vie du projet

<table>
<thead>
<tr>
<th>Needs assessment</th>
<th>Conceptual design and feasibility</th>
<th>Design and action planning</th>
<th>Implementation</th>
<th>Operation and maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Évaluation des besoins</td>
<td>Études conceptuelles et faisabilité</td>
<td>Conception et planification des actions</td>
<td>Mise en œuvre et Exploitation et maintenance</td>
<td></td>
</tr>
<tr>
<td>- Recevoir une demande d’intervention</td>
<td>- Recevoir une demande pour les services</td>
<td>- Finaliser le plan de projet design, incluant plans, schémas, budget, et ressource</td>
<td>- Procurement of supplies et financing</td>
<td>- Daily operation of the system</td>
</tr>
<tr>
<td>- Déterminer le besoin de la construction</td>
<td>- Obtenir des informations sur les contraintes socioculturelles, politiques, environnementales, économiques et techniques</td>
<td>- Mise en œuvre et utilisation de la ressource</td>
<td>- Site preparation</td>
<td>- Route maintenance</td>
</tr>
<tr>
<td>- Déterminer les besoins de la construction</td>
<td>- Collecter des informations sur les contraintes socioculturelles, politiques, environnementales, économiques et techniques</td>
<td>- Planification des actions</td>
<td>- Construction</td>
<td>- Unexpected maintenance</td>
</tr>
<tr>
<td>- Étudier les besoins des utilisateurs</td>
<td>- Étudier les besoins de la construction</td>
<td>- Planification des actions</td>
<td>- Progress monitoring</td>
<td>- Monitoring</td>
</tr>
<tr>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Planification des actions</td>
<td>- Technical training and community education</td>
<td>- Management</td>
</tr>
<tr>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Planification des actions</td>
<td>- Evaluation des mesures et des objectifs</td>
<td>- Continued education and training in community</td>
</tr>
<tr>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Étudier les besoins des parties prenantes</td>
<td>- Planification des actions</td>
<td>- Evaluation des mesures et des objectifs</td>
<td>- Evaluation et mesures des objectifs du projet</td>
</tr>
</tbody>
</table>

### Project Evaluation Scorecard | Tableau de bord de l’évaluation du projet

<table>
<thead>
<tr>
<th>Life Stage</th>
<th>Sociocultural Respect</th>
<th>Community Participation</th>
<th>Political cohesion</th>
<th>Economic sustainability</th>
<th>Environmental sustainability</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needs assessment</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Conceptual design and feasibility</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Designing and action planning</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Implementation</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Operation and maintenance</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total score</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Étape de la vie</th>
<th>Respect socioculturel</th>
<th>Participation communautaire</th>
<th>Cohérence politique</th>
<th>Durabilité économique</th>
<th>La durabilité environnementale</th>
<th>Score total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Évaluation des besoins</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Études conceptuelles et faisabilité</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Conception et planification des actions</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Mise en œuvre et Exploitation</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Score total</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
Key Terms | Mots clés

**Self-supply**: incremental improvements to water supplies financed by the users themselves

**Auto-appropriation**: améliorations progressives de l'approvisionnement en eau financées par les utilisateurs eux-mêmes

**Appropriate technologies**: affordable tools that meet a community’s needs without external aid

**Technologies appropriées**: des outils abordables qui répondent aux besoins d’une communauté sans aide extérieure

**Contextual design**: Develop a project based on the available resources and the capacity of shareholders

**Conception contextuelle**: Développer un projet en fonction des ressources disponibles et de la capacité des actionnaires

**SMART**: Simple, Market-based, Affordable, Repairable Technologies

**SMART**: Technologies simples, basées sur le marché, abordables et réparables

---

Stakeholder Engagement | Engagement des parties prenantes

- **Why?**
  - Obtain consensus decisions that are respectful to the social, cultural, and environmental values
  - Define local contexts

- **How?**
  - Sociotechnical approaches
  - Co-developing with local community in need

- **Examples?**
  - Participatory mapping
  - Traffic Light Mapping

- **Pourquoi?**
  - Obtenir des décisions consentielles respectueuses des valeurs sociales, culturelles et environnementales
  - Définir les contextes locaux

- **Comment?**
  - Approches sociotechniques
  - Co-développer avec la communauté locale dans le besoin

- **Exemples?**
  - Cartographie participative
  - Cartographie des feux de circulation

A participatory mapping exercise with the local community (Larson et al. 2021). A) Base map of the study area based on scientific knowledge. B) Community interpretation of local boundaries, settlements, and water sources.

Stakeholder Engagement | Engagement des parties prenantes

- Why?
  - Obtain consensus decisions that are respectful to the social, cultural, and environmental values
  - Define local contexts
- How?
  - Sociotechnical approaches
  - Co-developing with local community in need
- Examples?
  - Participatory mapping
  - Traffic Light Mapping

- Pourquoi?
  - Obtenir des décisions consensuelles respectueuses des valeurs sociales, culturelles et environnementales
  - Définir les contextes locaux
- Comment?
  - Approches sociotechniques
  - Co-développer avec la communauté locale dans le besoin
- Exemples?
  - Cartographie participative
  - Cartographie des feux de circulation

Identifying Stakeholders | Identification des parties prenantes

- Classify stakeholders to determine roles and responsibilities for those involved with project development, implementation, and maintenance

  Classification
  - Power
  - Legitimacy
  - Urgency

  Social, economic, & political resources
  - Ability to carry out the project
  - Ability to respond

  Du pouvoir
  - Légitimité
  - Urgence

  Ressources sociales, économiques et politiques
  - Capacité à mener à bien le projet
  - Capacité à répondre
A.3 Project Planning

### Materials

- PVC pipe drill stem
- Metal Drill stem (if budget allows)
- Pulley
- Welder
- 1 inch rebar pieces
- Water
- Saw
- Bentonite
- Bucket
- Gravel
- Tripod
- Rope (35 m)
- Shovel
- Spout (top of drill stem)
- Drill bit
  - 2" metal pipe
  - Reduction coupling
  - Drill bit or bolt
  - Angle iron
  - Muscle

### Work Plan

- Price materials and cuttings/samples
- Geophysics...
- Site selection
- Collect materials
- Dig mud pit
- Set-up tripod
- Attach pulley
- Dig pilot hole
- Fill mud pit and pilot hole with water
- Attach rope to spout and pull through pulley
- Begin to drill
- Make observations about drilling speed
- Drilling log
- Fill in the hole
APPENDIX B

BAPTIST DRILLING METHOD IMPLEMENTATION VIDEO

Below is a video that shows the Baptist drilling method being implemented in the 2022 GWB Manual Drilling Workshop held in Cotonou, Benin. Participants rotated throughout roles shown in the video. The drilling process was messy and tiring but successfully drilled through sand and clay layers.

B.1 Implementing The Baptist Manual Drilling Method Video: 2022 GWB Hydrogeological Workshop

Link: https://youtube.com/shorts/s9JP9byfInc?feature=share

![Figure B.1 Video of Université d’Abomey-Calavi and Colorado School of Mines student implementing the Baptist drilling method during the GWB 2022 Manual Drilling Workshop.](image)