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Full Length Research Paper

A review of fresh water programming and access options in Ghana West Africa

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Abstract

This paper seeks to provide insight into progress addressing secure fresh water access for citizens in Ghana, as well as the work remaining to ensure continuing, universal access to fresh water. Significant progress has been made, but sizable areas do not yet have safe, sustainable potable water supplies. Current ground water source options within the country include drilled, driven, hand-augered, and hand-dug wells. Fresh water is needed throughout the country for domestic use. A broad search of technical, business, and government sources was used for this review. Through this effort, current fresh water programming efforts and the key factors affecting the investment in potable water systems are identified. Future fresh water program planning and implementation suggestions are provided. A brief economic analysis provides insight into the cost-to-benefit ratio for community members and the price points that they are willing to pay for water. The overall literature review suggests that a revamp of significant initiatives aimed at addressing the severe lack of current fresh water resources and disparities by region within the country could have a positive effect on the achievement of universal water access.

Keywords. Augered wells, dug wells, drilled wells, driven wells, Ghana, potable water, WASH, water systems.

0.0 HIGHLIGHTS

- Ghana has been successful in providing safe, sanitary fresh water access to 4 out of 5 residents.
- Pipe-based community water systems supply over 2 out of 5 Ghana residents.
- The unserved residents are in difficult to reach, rural areas with high associated installation costs.
- Ghana is facing a water system sustainability crisis based in both funding and trained personnel.

1.0 INTRODUCTION

Approximately 1.8 billion people world-wide use an unimproved source of drinking water with no protection against contamination from feces. Combined with good hygiene and improved sanitation, safe water could prevent an estimated 842,000 annual deaths world-wide (United Nations, 2019). This paper seeks to look specifically at Ghana and provide insight into the progress in addressing the sixth U.N. Sustainable Development Goal (SDG), access of fresh water goal: "To ensure availability and sustainable management of water and sanitation for all." Progress across many other SDGs is tied to the initial achievement of this goal. Addressing this SDG includes the production, storage, transportation, treatment, and testing of potable household water sources (United Nations, 2019). Out of the 193 examined U.N. members, Ghana is currently ranked 100th in terms of its progress toward accomplishing these water security goals for its population (Sachs et al., 2020).

This literature review examined the current larger perspective of water, sanitation, and hygiene (WASH) programing efforts within West Africa, with a critical

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examination of progress within the country of Ghana. The WASH acronym specifically stands for water access, sanitation, and hygiene. The water access portion means the availability of safe water, which is free from chemical and biological pollutants, for drinking and household use. Sanitation includes access to a toilet or latrine that safely separates human excreta from the human environment, and hygiene focuses on public health and the transmission of fecal-oral diseases (Sweetman & Medland, 2017).

Undoubtedly, progress has been made with respect to achieving basic drinking water access. Ghana has achieved the national SDG goal of 77%, seven years ahead of schedule (Appiah-Effah et al., 2019). However, significant work remains to provide universal access to clean, safe, sanitary, and sustainable potable water throughout the countryside. According to current projections, Ghana, with hard work, should be able to achieve universal access to potable water by the year 2030 (Monney & Antwi-Agyei, 2018). However, market economies operate effectively to the point where the marginal benefits from any activity equal the marginal costs. Market failure describes the situation where the high cost of an activity leaves specific difficult-to-reach potential customers with unfulfilled needs. This describes the position that Ghana is rapidly approaching with regard to fresh water sourcing. Unfortunately, it is a central economic truth that the last access will be the most difficult to complete and the most expensive to implement (Marshall, 2013). To ensure that everyone has something means that the high-cost, difficult, final fulfillments must be completed. It is an undeniable humanitarian fact that this goal must be achieved. In Ghana, 12.2% of all deaths are reported to be from a lack of sanitation and hygiene, which are obviously related to a shortage of fresh available water (Aalto et al., 2012). To achieve the water supply goal by 2030, an estimated US$237 million in capital investment is required annually (World Bank, 2011). However, it is clear that the anticipated investment needed to reach the fresh water goals is not sufficient to achieve the sector targets.These deficiencies can only be addressed through improved project management that utilizes increased and more innovative financing, sector planning, better targeting, greater efficiency, and cost recovery approaches (World Bank, 2011). More investment will not be forthcoming without a clear scope of need and an improved cost estimate. This paper presents the first step of a comprehensive review needed to document the progress made thus far and address the present gaps within the fresh water sector, so that eventually all Ghanaians can have access to fresh water, a basic humanitarian need for quality of life and a precursor to all economic development.

The objectives for this review paper are to:

- identify the types and impact of water source options common in Ghana;
- identify the current access to potable drinking, household, and washing water by distribution mode across Ghana by region, along with areas without adequate access;
- qualify the resilience and system redundancy of fresh water production in Ghana, along with the status of current fresh water testing and treatment programs;
- provide an economic analysis of various fresh water access options;
- identify existing fresh water programs currently operating in Ghana to expand access;and
- provide suggestions for the direction of future fresh water access programming in Ghana.

2.0 METHODS

This study sought to review the pre-existing WASH literature related to earlier, current, and future efforts regarding fresh water access in Ghana. This review was conducted using the Purdue University Library databases and search engines. A total of 20 search phrases with 22 unique words were used to retrieve potentially relevant materials for this review. The search ran on 692 unique databases, eight of which were Ghana government branch sites. The sources reviewed were primarily peer-reviewed technical journals and government reports. To reduce out-of-date references, only sources from the last ten years were tagged for review within this project. This study closely examined in-country reports from various branches of the Government of Ghana, such as those reports and assessments related to WASH programing. These reports and assessments are published by regional and district assemblies or government-funded research institutions. It should be noted that within Ghana, the universities have less focus on publishing metrics of success or methods of research into specific practices, because they have a predominate focus on teaching. Therefore, branches of the government and government research institutions primarily report and publish in-country findings. Reports or publications from non-governmental organizations (NGOs), country aid agencies, and universities were reviewed, where available and appropriate. Recent specific census and district analytical reports for the country were also scrutinized. Overall, 138 papers were examined, and 46 were found to be relevant to the current study. Separately, 74 Ghanaian government published documents were studied, and 13 were found to be pertinent to this review. This body of literature provided significant insight regarding the current state of WASH programing and the proposed direction of future efforts outlined in the balance of this review.

3.0 Literature Review

This review was conducted to examine the current state of water resources within Ghana. A preliminary exploration of the standard terminologies and classifications in WASH reporting is presented first, and then the means to secure water from underground aquifers, upon which Ghana is heavily dependent, is discussed. The current specific circumstances within Ghana regarding drinking water, household water, and wash water access are provided next. This section closes with a review of the resilience level and water quality of the overall Ghanaian water supply system.

3.1 - Current Water Source Options

Water sources are often classified as "improved" or "unimproved." However, the term 'source' refers to the means of distribution to the end consumer, not the mode of supply production. Improved sources are piped public water into homes, public standpipes, water wells or boreholes, protected (lined or cased) hand dug wells, hand augered wells, protected springs, and bottled water (World Health Organization, 2013). Unimproved sources are unprotected wells or springs, sachet water, vendors, tanker-trucks, rainwater collection, and surface water (World Health Organization, 2013). Common components within current international water access programming efforts include: community intervention by establishing a community-led WASH committees, construction of new improved water access points, rehabilitation of pre-existing water sources, installations of wells or community boreholes, small town water delivery systems, and pipe extensions of existing water delivery systems (Millennium Challenge Corporation, 2017).

In many cases, women, poor households, and marginalized groups disproportionately experience the impacts of inadequate nearby fresh water. This primarily occurs, because these groups are more likely to have limited access to potable water sources and are forced to commit significant manpower resources to transporting water from distant sources away from the home (Graham et al., 2016; Mekonnen & Hoekstra, 2016; Stevenson et al., 2016; Bisung & Elliott, 2017). Marginalized groups often have less input, both at the household and at the community level, in the decision-making processes, governance of resources relating to fresh water access, and the siting of new water access points (Routray et al., 2017). In Ghana, studies show that income, education, household size, and region are all significant predictors of sufficient access to improved potable water sources (Mahama et al., 2014; Adams et al., 2016). Therefore, many WASH programs and interventions try to utilize methodologies that empower all beneficiaries, attempting to increase equitable access, and the sustainability of water and sanitation infrastructure (Sheuya, 2008; World Water Assessment Program, 2015; Leahy et al., 2017).

3.2– Wells

Wells are the recommended 'improved' water production source for household water. There are four primary types of wells: drilled wells, driven wells, augered wells, and dug wells. In Ghana, as in much of the rest of the world, the terms 'well' and 'borehole' are used interchangeably, although a well can be dug by hand and have a significantly larger diameter. A borehole is the generalized term for any narrow shaft drilled into the ground. It almost always contains a circular cross-section casing to prevent the collapse of the borehole and a well screen to prevent the entrainment of sand and gravel in the withdrawn water (H2O for Life, 2019). In Ghana, 29.1% of the dwelling units obtain their drinking water directly from protected wells and boreholes, while 46.5% of households were using pipe-borne water in the dwelling, outside the dwelling, at a public tap, or at a standpipe as their main source of drinking water). In most cases, the likely original production source of the household water was a well. There has been a 6.6% increase in the number of households using pipe-borne water since the year 2000, implying that modernized distribution networks are slowly increasing their zones of coverage. (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013.

A drilled well is constructed by either a cable tool with a percussive process or a rotary-drilling machine (Wellowner, 2015). A well drilling machine configured for drilling operation is shown in figure 1. These machines provide high quality wells, but they are very capital-intensive investments. The significant up-front cost limits the ability of developing regions to provide drilled wells (Sonou et al., 1997). Drilled wells are able to penetrate both consolidated and unconsolidated material, and they require the installation of a casing and a screen to prevent inflow of sediment in the inlet zone and to keep the well from collapsing (Wellowner, 2015). A cross-section of a drilled well is presented in figure 1. A drilled water well can be installed to tremendous depths of more than 300 *m*. All drilled wells must be developed after reaching their design depth to properly function and achieve maximum output (Driscoll, 1986). Developing or finishing a well is basically a process to remove silt and cutting debris from the inlet zone near the well screen. Surging and jetting are the two primary methods of developing for a drilled well (Driscoll, 1986). The space around the casing near the surface has a segmented or concrete pad that is constructed to prevent the contamination of well water from drainage of the surrounding surface downward around the outer portion of the casing. Pads are most often constructed out of neat cement or bentonite clay (Wellowner, 2015). The pad is then left to cure for a modest period of time, during which a well casing cap remains on the newly drilled well to prevent contamination.The pump pad typically cures in about two weeks. After the pad has cured, the well cap is removed, and the pump head can be installed. Installing the pump head prior to the pad curing, can lead to breakage of the pad when the pump head is in use, thus it is vital to allow a proper cure time for the pad (Wellowner, 2015).

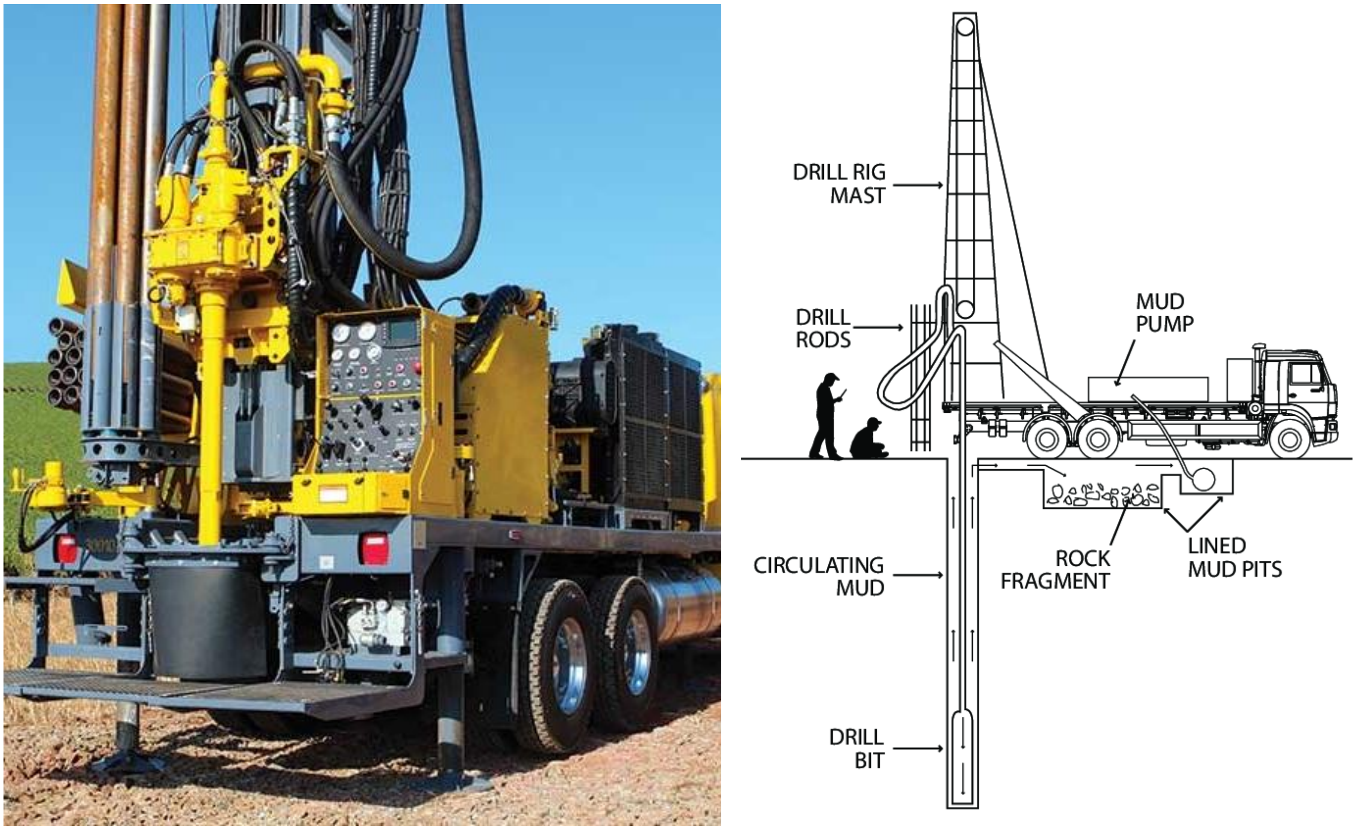

Figure 1. Typical truck-mounted rotary well drilling apparatus showing the derrick, rotary table, and draw-works winch for lifting the drill stems on the left (BPN Media - National Driller Magazine, 2020) and underground cross-section of rotary well drilling in operation, showing the circulation of drilling mud within the system on the right (Saguaro Well and Pump, 2018).

Driven wells or shallow tube wells are an outstanding, low cost way to access shallow groundwater in developing regions (Kundu et al., 2016; Sonou et al., 1997). They are constructed by driving a small diameter pipe into a shallow water-bearing soil profile composed of primarily sand or gravel (Driscoll, 1986; U.S. Army, 1994). A screened well point is attached to the bottom of the casing before driving (U.S. Army, 1994). Pipe couplings in the driven column are also specially designed to insure pipe-to-pipe contact, rather than depending upon the threads between the coupling and pipe, like a standard pipe coupling. A cross-section of a driven well is shown in figure 2. Driven wells also require a developing process for optimal output, and surging is typically used. No additional casing is required for a driven well, because the driven pipe serves as the casing and the water withdrawal pipe. Driven wells are simple and economical to construct, but with manual installation they are only able to achieve relatively shallow well depths of approximately 10 *m*. Hand-driven wells have significant difficulty penetrating consolidated soil layers. Purdue University has a machine-based tube well installation process that they plan on testing to 20 *m* (Horn & Stwalley, 2018; Horn & Stwalley, 2019; Horn & Stwalley, 2020). The Purdue device is shown in operation in figure 2. Tube wells represent an economical means to access shallow aquifers, and where feasible, they are a great economical alternative potable water source. Horn and Stwalley (2020) hypothesized that a mechanized tube well installer could actually represent the lowest installed wellcost for the developing regions of the world.

Augered wells are boreholes constructed with a hand-operated earth auger (U.S. Army, 1994). Typically, two people spin the auger to cut material and pull it to the surface. Augered wells require significant physical effort and are limited in depth by the torque that can be applied to the drill stem. Motorized augers exist, but the counter-torque to bore the earthen hole must still generally be applied by individuals. Additional drill stems are added as the bottom of the borehole moves deeper. Casings and developing for an augered well hole are no different than for a traditionally drilled well. Figure 3 shows a cross-section of an augered well under construction.

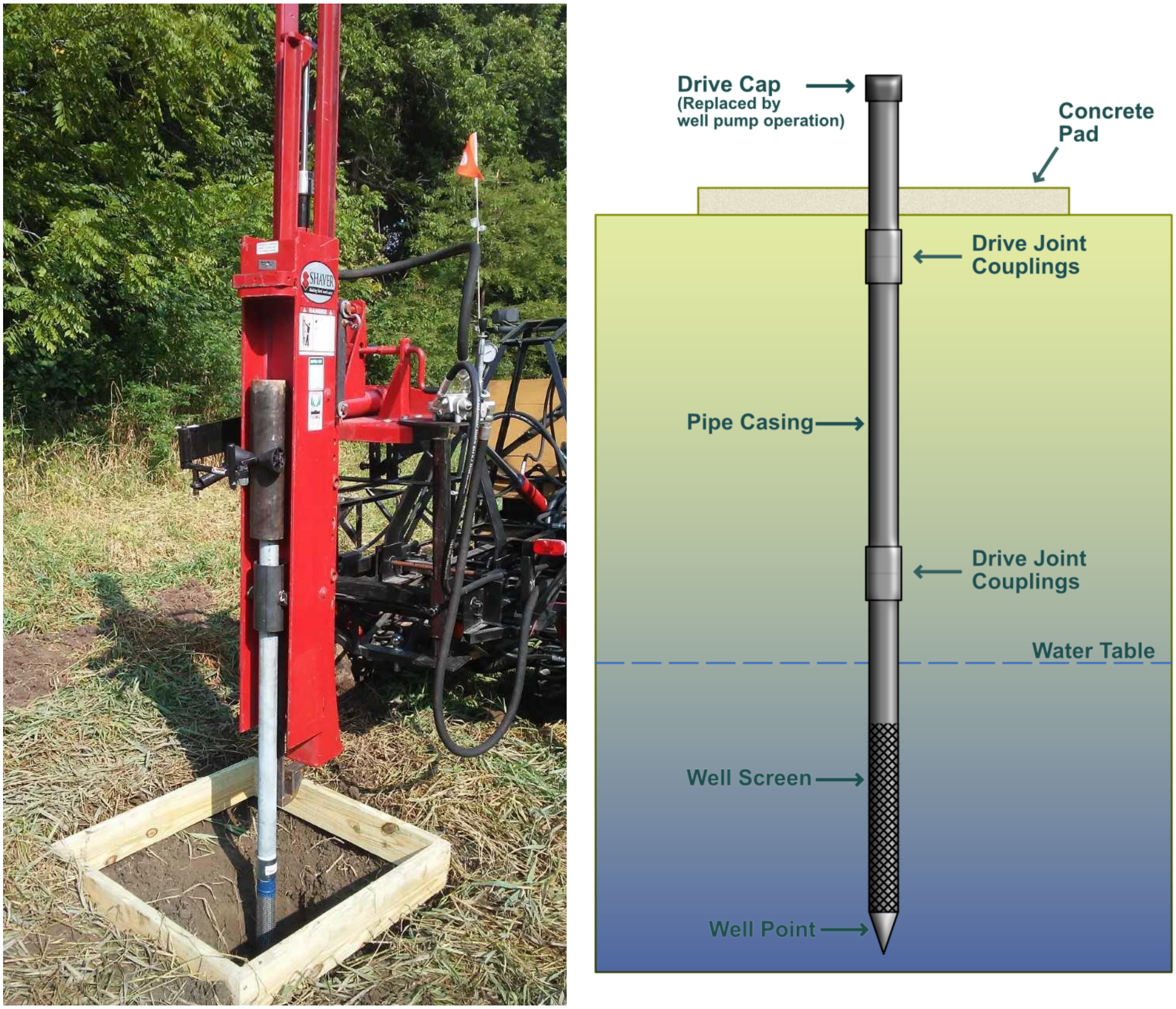

Figure 2. Well Driver PUP in position over a test well in west-central Indiana during proof-of-concept tube well mechanization experimentation on the left and cross-section of driven well showing well point and drive joints couplings on the right.

Traditionally, dug wells were excavated by hand to the water table level during the dry season, or during the rainy seasons, until the incoming water exceeded the digger's bailing rate (Wellowner, 2015). Developing a dug well consists of driving and extracting metal rods deep into the soil at the bottom of the well hole to provide enhanced channels for water to move upward into the excavated volume. A dug well is typically lined with stones, bricks, tile, or other material to prevent the void space from collapsing inward (Wellowner, 2015). A typical dug well cross-section is shown in figure 3. This type of well is more prone than other types of wells to contamination from surrounding surface sources, if it is not properly crowned or covered above the surface, or if it does not have a good casing through the first 5 *m* of depth. Dug wells have a larger diameter and expose a large area of the aquifer. These wells are able to obtain water from less-permeable materials, such as very fine sand, silt, or clay (Wellowner, 2015). Most wells of this type are fairly shallow and are not able to achieve the depths of a drilled well. A limit of 15 *m* is generally found in dug wells (U.S. Army, 1994). However, in Ghana, there are some hand dug wells that have achieved 60 *m* in depth. This type of well often goes dry during droughty periods, because the water table drops below the well bottom. It is during the dry season that maintenance can be performed on a dug well, if it is needed. However, performing maintenance is always quite risky, because someone must be lowered into the well. Dangers include the lack of ventilation, unexpected flooding, and sidewall

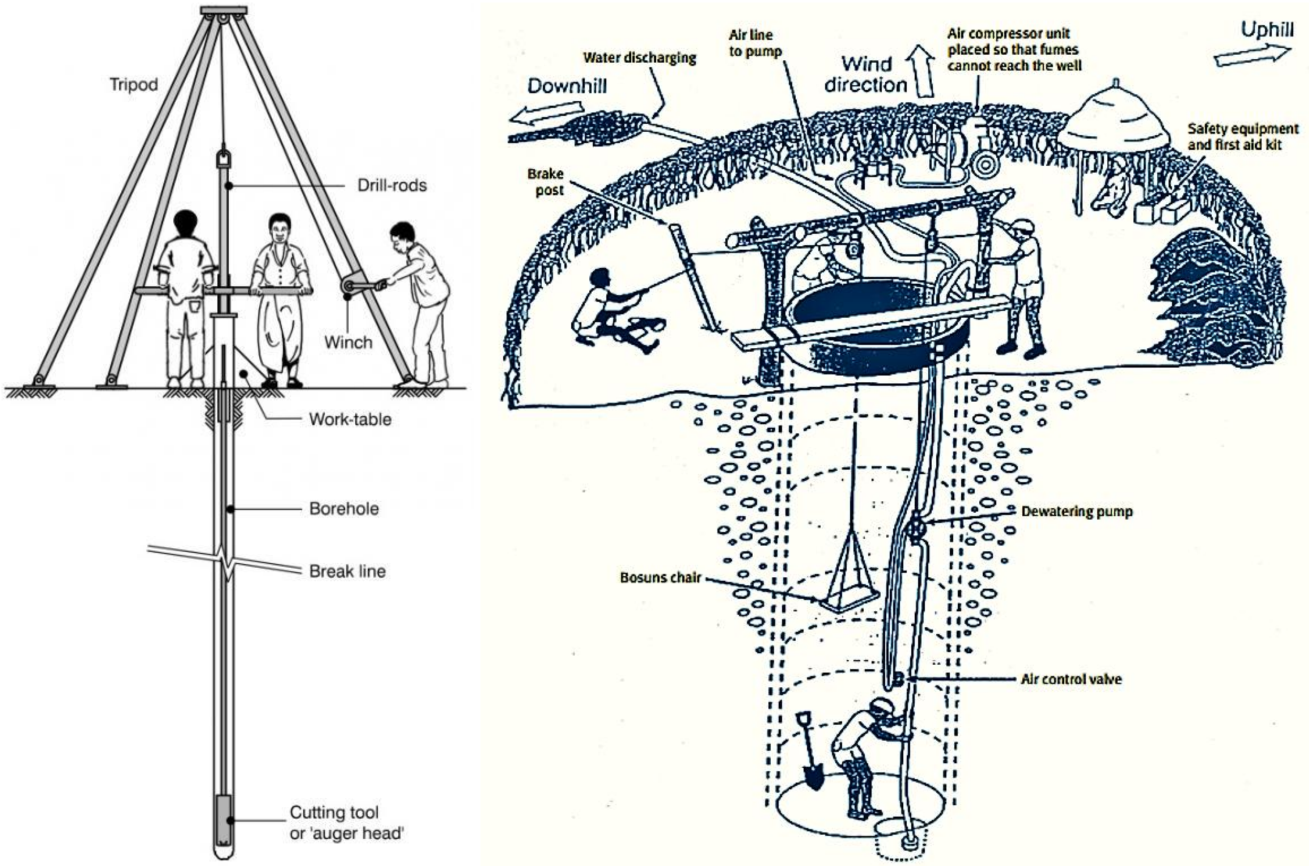

Figure 3. Cross-section of an augered well under construction showing derrick, torque handles, and cutting head on the left (Seencon International GmbH, 2020a) and hand dug well under construction showing ingress/egress, ventilation, and water bailing mechanisms (Seecon Internatioinal GmbH, 2020b).

cave-ins. Precautions must be provided to prevent all of these potentially hazardous circumstances.

3.3 - Drinking Water Source Options

Globally, drinking water coverage that is safely managed is 70.6% and basic coverage at 18.9% (UNICEF, 2017b). In comparison, Ghana only has 36.4% safely managed drinking water coverage and 45.0% basic coverage (UNICEF, 2017a). In Ghana, the main sources of drinking water are: boreholes including pumps or tube wells, 23.2%; pipe-borne water outside the dwelling,19.0%; pipe-borne water inside the dwelling, 14.5%; public taps or standpipes, 13.0%; rivers or streams, 9.2%; and sachet water, 9.0%. The classification scheme of the water ‘source’ data refers to the customer delivery method, rather than the physical source, and this hides the origin of much of the potable water. However, it is likely that the sources of many of the ‘pipe’ systems, whether delivering into or nearby a residence, are boreholes, which increases the numerical dominance of this physical origin for potable water within Ghana. The remaining percentages of reported sources were significantly smaller. Urban households were more likely to have ‘system’ delivered water, with pipe-borne water outside the dwelling, 25.9%, and pipe-borne water inside the dwelling, 23.9%. Comparatively, rural households predominately utilized a borehole with a pump or tube wells, 40.6% (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013).

In February 2019, President Nana Addo Dankwa Akufo-Addo implemented a mandate of creating six new regions, increasing the number of regions within Ghana from ten to sixteen (Business Ghana, 2019; Communications Bureau, 2019). Survey data prior to this and utilized in this paper, does not account for the sixteen-region distribution, rather only the prior ten. Since the national accounting adjustment for this new distribution of regions has not yet been completed, survey data accounting for both drinking water and domestic water use within the country utilizes the older regional scheme. Based-on available data, the main source of drinking water per household varies greatly by region.

Specifically, the highest reported source for the Western

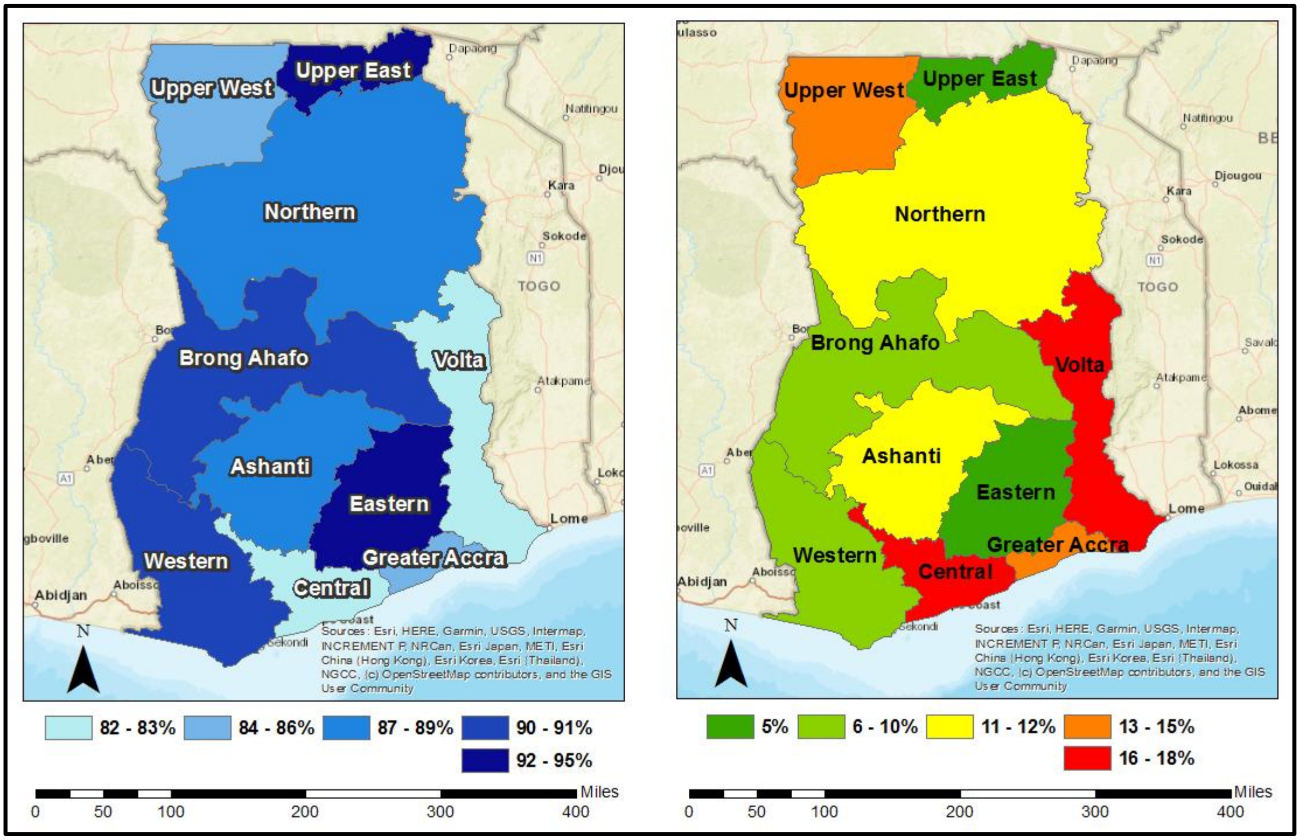

Figure 4. Sufficient access to fresh water by region given on the left and insufficient access to fresh water by region on the right (Ghana Statistical Service, 2018).

and Greater Accra regions is pipe-borne water located outside the dwelling, while for the Central and Volta regions, public taps or standpipes were the most common. For the remaining six of the old regions, the main source of drinking water was a borehole. Both the Upper West and Upper East regions relied primarily on a borehole for their drinking water at 70.1% and 67.8%, respectively. Water from rivers and streams was the main source of drinking water for 17.4% of dwelling units in the Northern region, for 16.3% of the households in the Volta region, and for 16.5% of the dwellings in Western Region. Sachet or bagged water was the main source of drinking water for 8.5% of the homes in Eastern region and 8.1% of the households in Central region, and with 28.0% of consumption, it represents the second largest source of drinking water within the Greater Accra region (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013). Drinking water source information with the most common, second most common, and the balance of the served population percentage by region is displayed in table 1. Figure 4 graphically shows that more than 82% coverage exists in all regions. However, the Central and Volta Regions have the greatest insufficent access to water, followed by Greater Accra and the Upper West Region. Unfortunately, not all of the water available in Ghana is of high quality. The World Health Organization states that per 100 *mL* sample of drinking water, no E. coli should be detectable in any sample (World Health Organization, 1997). Despite Ghana's 82% water coverage, figure 5 highlights that within drinking water sources of every region, the risk of E. coli is present. Both the Volta and Northern regions report a high to very high risk of E. coli present within drinking water sources at greater than 50% testing incidence (Ghana Statistical Service, 2018).

3.4 - Water for Domestic Use

The primary source of water for domestic use in Ghana closely mirrors the results of drinking water, with the exception of sachet water, which is only used for drinking. The main domestic water sources were: boreholes including pumps or tube wells, 23.4%; pipe-borne water outside the dwelling, 19.9%; pipe-borne water inside the dwelling, 16.6%; public taps or standpipes, 12.9%; rivers or streams,10.8%; and protected wells, 8.5%. The remaining percentages of reported sources were

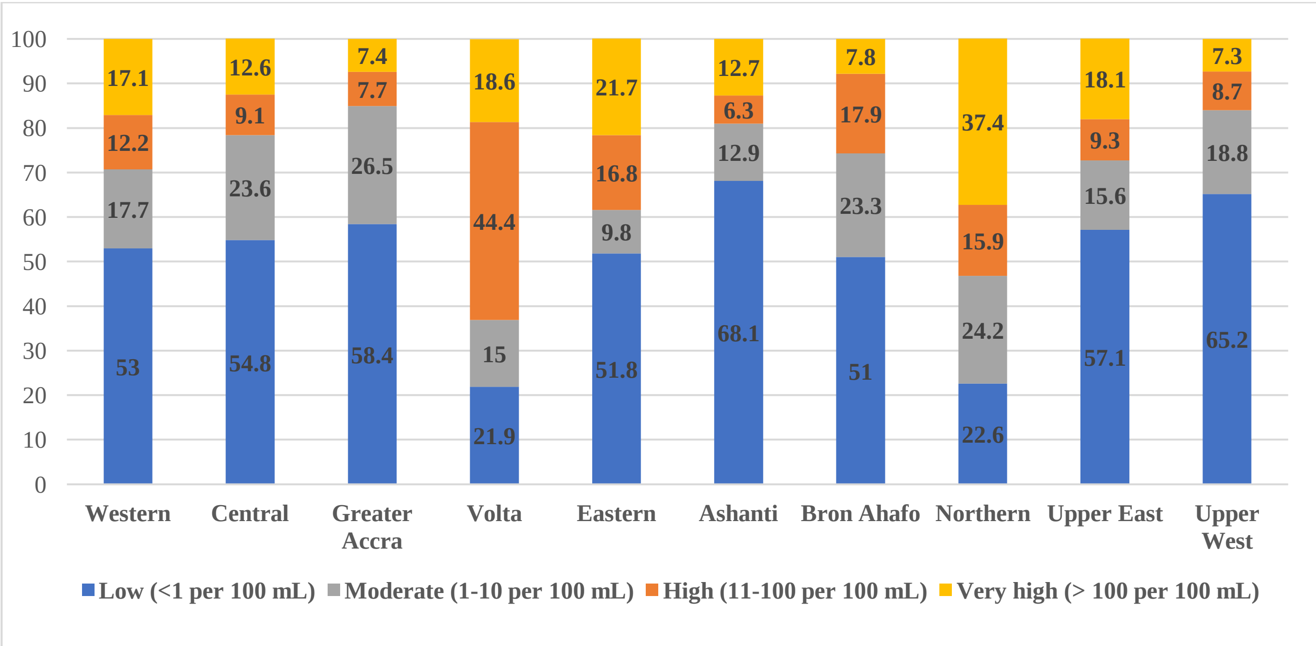

Figure 5 – Percentage of household population at risk of fecal contamination based on number of E.coli detected in drinking water source (Ghana Statistical Service, 2018).

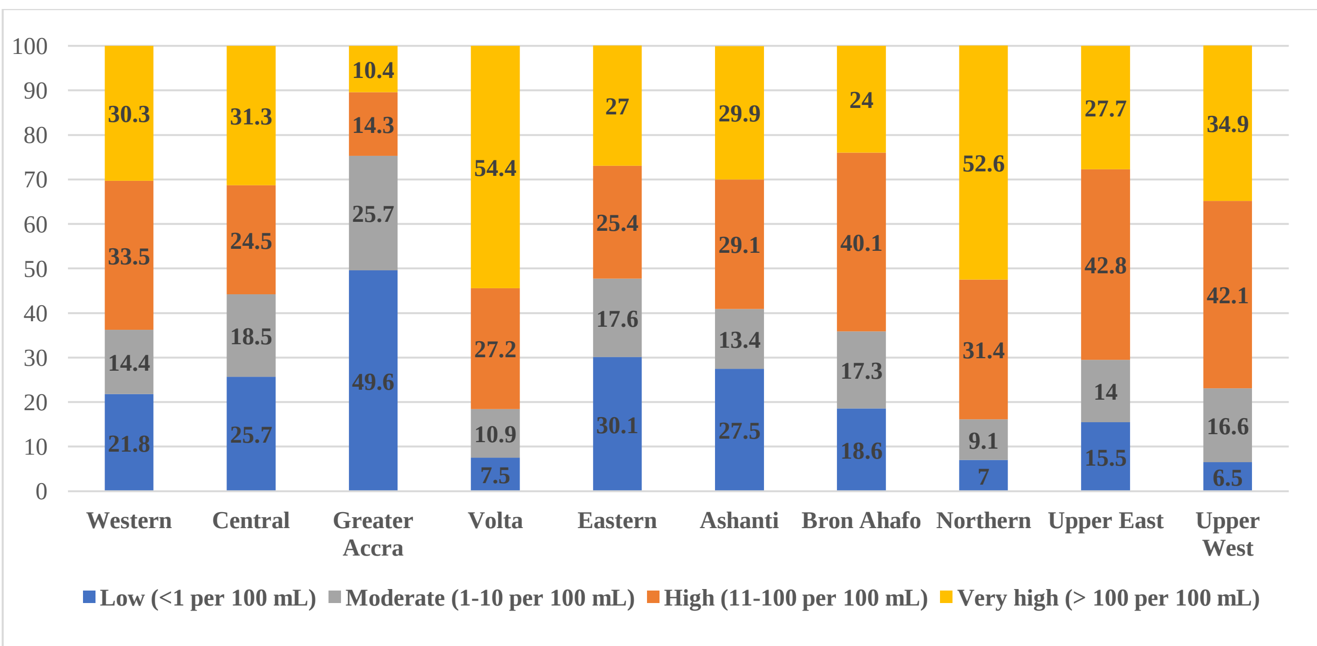

Figure 6. Percentage of household population at risk of fecal contamination based on number of E. coli detected in household drinking water (Ghana Statistical Service, 2018).

significantly smaller. The highest reported domestic water source for urban households was pipe-borne outside dwelling at 28.0% and pipe-borne inside dwelling at 27.5%, compared to rural households utilizing boreholes including pumps or tube wells at 39.3% (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013).

The main source of domestic water per household by region strongly followed the results of drinking water source, with again the exception of sachet water. The use of tankers, at 6.2%, was reported as a primary source in the Greater Accra region, but less than one percent in all other regions, except Central region at 3.8%. Overall,

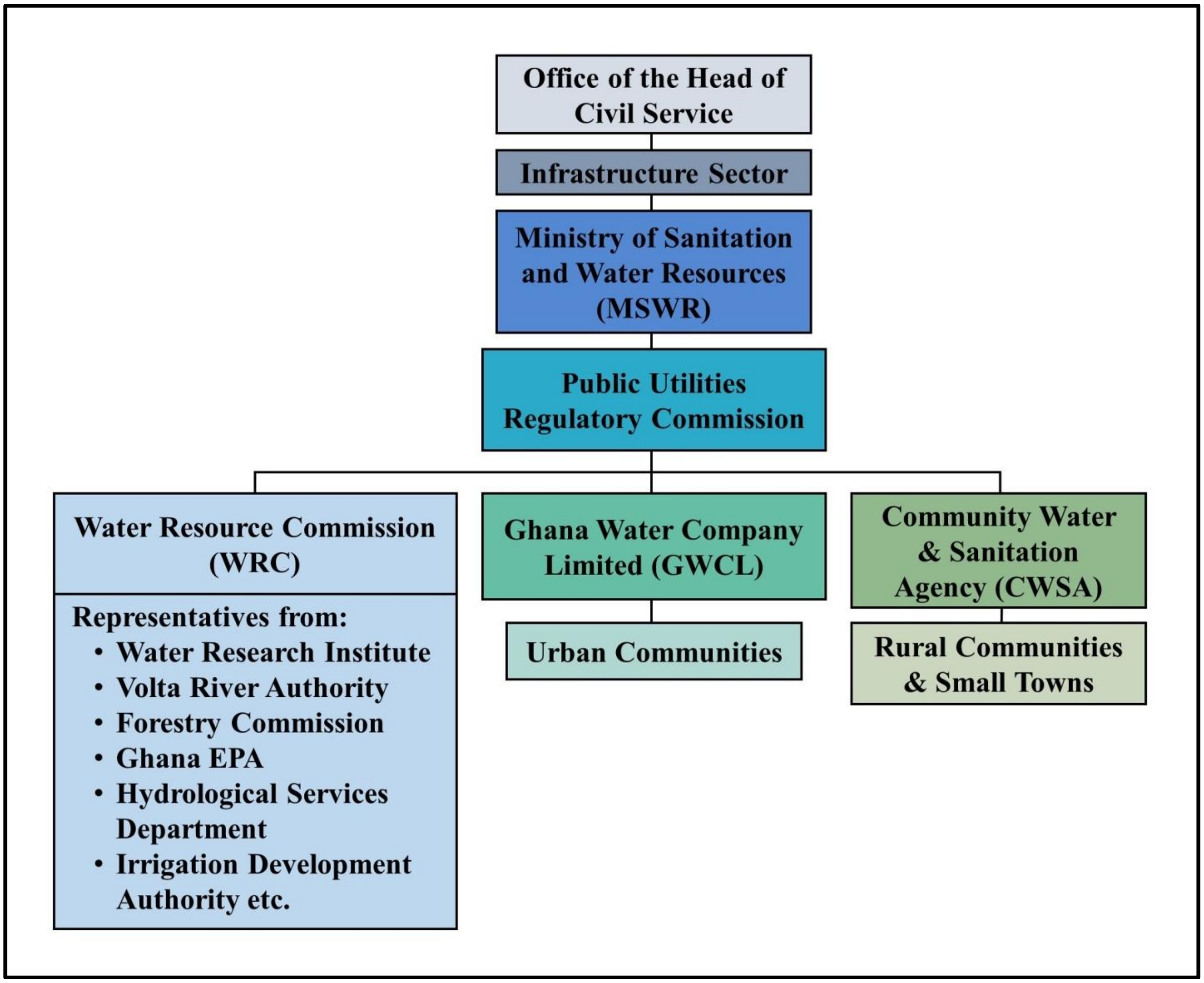

Figure 7. Organizational chart of Ghanaian governmental water-related entities. (Community Water and Sanitation Agency, 2018; Ghana Water Company Limited, 2020; Ministry of Sanitation and Water Resources, 2020; Water Resources Commission, 2020).

less than one percent of households utilized harvested rainwater as a main source of domestic water, except in Volta region where 3% used it, and in the Central and Eastern regions, which each had 1.2% using it (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013). Household water source information with the most common, second most common, and the balance of the served population percentage by region is displayed in table 2. Figure 1 previously showed the insufficient access to water source by region of the country, and figure 2 provided statistics on contamination of drinking water. Figure 6 presents the analogous result for household water, highlighting risk of E. coli per 100 mL for households by region. Specifically, both the Volta and Northern regions have a very high risk of faecal contamination based on the number of E. coli per 100 *mL* (Ghana Statistical Service, 2018). Both regions report greater than 50% very high risk (Ghana Statistical Service, 2018). When considering regions reporting high risk or greater, all regions expect Greater Accra, report a greater than 50% risk (Ghana Statistical Service, 2018).

3.5 - Washing options

Worldwide, hygiene coverage is accessible at a basic level with 60.1% coverage and 21.5% limited coverage (WHO UNICEF, 2017b). Though in Ghana, basic coverage is only 41.1% and has a higher limited coverage of 42% (WHO UNICEF, 2017a). According to WHO, handwashing is the scrubbing of hands using water with plain or antimicrobial soap (World Health Organization, 2009). The purpose of performing hand hygiene is for the physical removal of dirt, organic material, and microorganisms. The intent of handwashing

Table 1. Main source of drinking water for domestic use of households by region and type of locality (Ghana Statistical Service, 2010).

Region	Primary Source of Drinking Water	1st Amount (%)	Secondary Source of Drinking Water	2nd Amount (%)	Other Sources (%)		Protected Water Source (%)	Not Protected Water Source (%)	Population (Thousands)
Urban	Pipe-borne Outside Dwelling	25.6	Pipe-borne Inside Dwelling	14.3	60.1		81	19	3,049
Rural	Bore-hole/ Pump/ Tube well	23.2	Pipe-borne Outside Dwelling	19	57.8		71.1	28.9	2,418
Western	Pipe-borne Outside Dwelling	25.9	Pipe-borne Inside Dwelling	23.9	50.2		72	28	554
Central	Bore-hole/ Pump/ Tube well	40.6	River/ Stream	18.7	40.7		77.9	22.1	527
Greater Accra	Pipe-borne Outside Dwelling	19.6	Bore-hole/ Pump/ Tube well	18.2	62.2		67.1	32.9	1,036
Volta	Public tap/ Standpipe	23.3	Pipe-borne Outside Dwelling	20.9	55.8		69.9	30.1	496
Eastern	Pipe-borne Outside Dwelling	28.1	Pipe-borne Inside Dwelling	26.3	45.6		72.8	27.2	632
Ashanti	Public tap/ Standpipe	19.2	Pipe-borne Outside Dwelling	18.8	62		89.4	10.6	1,126
Brong Ahafo	River/ Stream	15	Pipe-borne Outside Dwelling	14.5	70.5		80.4	19.6	490
Northern	Bore-hole/ Pump/ Tube well	30.9	Pipe-borne Inside Dwelling	22	47.1		69.4	30.6	318
Upper East	Bore-hole/ Pump/ Tube well	33.4	Public tap/ Standpipe	17.1	49.5		88.5	11.5	178
Upper West	Bore-hole/ Pump/ Tube well	35.1	River/ Stream	17.4	47.5		89.5	10.5	110

is to interrupt the transmission of disease agents, and therefore, to significantly reduce potential diarrhea, respiratory infections, skin infections, and blindness in human beings (UNICEF, 2008). A review suggests that handwashing with soap, specifically after contact with human feces, both post-defecation and after handling a

Table 2. Main source of household water for domestic use of household by region and type of locality (Ghana Statistical Service, 2010).

Region	Primary Source of Drinking Water	1st Amount (%)	Secondary Source of Drinking Water	2nd Amount (%)	Other Sources (%)	Protected Water Source (%)	Not Protected Water Source (%)	Population (Thousands)
Urban	Pipe-borne Outside Dwelling	28	Pipe-borne Inside Dwelling	27.5	44.5	92.4	7.6	3,049
Rural	Bore-hole/ Pump/ Tube well	39.3	River/ Stream	21.2	39.5	69.8	30.2	2,418
Western	Bore-hole/ Pump/ Tube well	18.9	Pipe-borne Outside Dwelling	18.2	62.9	75.1	24.9	554
Central	Public tap/ Standpipe	22.4	Pipe-borne Outside Dwelling	20.9	56.7	81.7	18.3	527
Greater Accra	Pipe-borne Outside Dwelling	37.1	Pipe-borne Inside Dwelling	35	27.9	91.4	8.6	1,036
Volta	River/ Stream	20.4	Public tap/ Standpipe	16.8	62.8	65	35	496
Eastern	Bore-hole/ Pump/ Tube well	28.6	River/ Stream	17.8	53.6	77.7	22.3	632
Ashanti	Bore-hole/ Pump/ Tube well	31.5	Pipe-borne Inside Dwelling	22.8	45.7	92.2	7.8	1,126
Brong Ahafo	Bore-hole/ Pump/ Tube well	31.8	Public tap/ Standpipe	17	51.2	81.2	18.8	490
Northern	Bore-hole/ Pump/ Tube well	32	River/ Stream	19.9	48.1	65.8	34.2	318
Upper East	Bore-hole/ Pump/ Tube well	55.4	Protected Well	14	30.6	86.9	13.1	178
Upper West	Bore-hole/ Pump/ Tube well	61.8	Pipe-borne Outside Dwelling	11	27.2	87.2	12.8	110

child's stool, can reduce diarrheal incidence by 42-47% (Curtis & Cairncross, 2003). Another review by Rabie & Curtis (2006) suggested that a 16% percent reduction in respiratory infections is possible through handwashing.

Table 3. Estimated cost of water source option according to Home Guide (2019)[1]; Nyarko et al. (2010)[2]; Horn & Stwalley (2020)[3]; and World Health Organization (2000)[4] assuming appropriate manpower levels and differentiated labor rates for various skill levels.

Drinking Water Source Options	**Depth (*m*)**	**Cost Per Capita Per Year(US$)**	**Total Unit Cost (US$)**
Drilled Borehole	> 15	41 [(2)]	13,130
Driven Well	< 15	6 [(1)]	1,650
Hand-Augered Well	< 15	13[(3)]	4,000
Hand-Dug Well	< 10	21[(4)]	6,300
Small Town Water Supply (Multi-village)	N/A	1,470 [(2)]	441,390

Note: Design population of 300 people and 3.5 L/day of water consumption.

Further studies provide an updated estimate of a 23% reduction in acute respiratory infections (ARIs) through effective handwashing with soap (Luby et al., 2005; Sandora et al., 2005). The Luby et al. (2005) study found that children under 15 years old, living in households that received handwashing promotion and soap, had half the diarrheal rates of children living in control neighborhoods (Luby et al., 2005). The potential magnitude of effective handwashing with soap to significantly reduce neonatal mortality rates has also been thoroughly demonstrated (UNICEF, 2008). Sanitation and the disinfection of the hands in preparation for new born delivery significantly reduces the risk of death for infants within the first month of life (UNICEF, 2008). "Newborns whose mother washed her hands before handling their infants had a 44% lower risk of death compared to those who did not" (Rhee, et al., 2008).

A functional handwashing station within a school or central community setting makes it possible for people to adopt the practice of handwashing with soap and engrain it within their lifestyle (Appiah-Brempong et al., 2018). Handwashing has been demonstrated as critical in the prevention of the transmission of a variety of pathogens. It may be more effective than any single vaccine (UNICEF, 2008). UNIECEF (2008) has stated, "If promoted on a wide-enough scale and with sufficient methodology, handwashing with soap could be thought of as a 'do-it-your-self-vaccine'."

In many communities, water from a local well or borehole is almost universally used for washing clothes, dishes, and containers, as well as cooking and bathing (Alexander et al., 2015). Keeping clothes clean helps to prevent infestations of dermal parasites (Healthhabit Pty Ltd., 2020), and clean cookware and storage containers are essential to the prevention of food-borne illness (University of Rochester Medical Center, 2020). Convenient household water sources are required for all communities, so that these functions can be part of the inhabitants' daily routine, rather than a luxury.

Bathing is defined as necessary for maintaining human hygiene, good health, and well-being (Healthline Media UK Ltd., 2020). Throughout all regions in Ghana, the most common bathing facilities were: a shared separate bathroom in the same house, 33.3%; a bathroom for exclusive use, 28.1%; a shared open cubicle, 18.3%; a private open cubicle, 7%; and an open space around the house, 6.8%. Various other options were identified at much smaller rates, such as: a public bath house, a bathroom in another home, a river, a pond, a lake, a dam and reservoir, or other sufficiently sized body of water. Within rural areas, the most common reported option, at 32.3%, was a bathroom for exclusive use. The second most common option for rural areas and most common option for urban areas was a shared separate bathroom in the same house at 24.7% and 40.3%, respectively (Ghana Statistical Service, 2014; Ghana Statistical Service, 2013).

3.6 - Water Source Resilience, Redundancies, Testing, and Treatment

Ghana has been forecast to move-out of the International Development Assistance (IDA) eligibility due to their improved gross domestic product (GDP) (African Development Bank, 2016). Unfortunately, that will increase the country's reliance on its national budgetary allocations, bilateral and multilateral donors, internally generated funds from metropolitan, municipal and district assemblies, NGOs, and other non-state actors as the main sources of funding for water source delivery (Ministry of Water Resources, Works, and Housing, 2010). To date, the central government has only made funds available through the annual national budget and from various district assembly's common funds (Ministry of Local Government and Rural Development - Environmental Health and Sanitation Directorate, 2012). This is resulting in serious shortfalls in establishing new water delivery systems. Those installed do not yet reach the entirety of the planned population, nor are they robust enough to retain their functionality into the foreseeable future without continuing maintenance or refurbishment funding. The lack of public funding for a crucial infrastructure system that does not yet entirely meet the needs of the population implies that there is no redundancy to water access in Ghana. It goes without saying that the resilience of the system to a significant disruption is essentially non-existent. A large financial shock or key hardware component failure could likely disable a number of local water delivery systems for a sizable period of time. Additionally, the level of corruption and diversions present within government funding sources prevents the full allocation of funds from being applied for their intended purpose (Forson et al., 2015). These combined factors limit the overall resilience of the water supply systems in Ghana.

Data from the UN-Water Global Analysis and Assessment of Sanitation and Drinking Water (GLAAS) indicates that the government of Ghana reduced its overall WASH budget from US$278 million in 2012 to US$65 million to 2017. This is a drop of 0.66% to 0.15% of GDP (United Nations - Water, 2017). Whereas in 2010, the Ministry of Water Resources, Works, and Housing (MWRWH) and the Ministry of Local Government and Rural Development (MLGRD) received 2.70% and 3.55% of the total national budget, the Ministry of Education and the Ministry of Health received 20.26% and 11.06%, respectively (Appiah-Brempong et al., 2019). This shows how the ministries with WASH oversight received less prioritization compared with the health and education sectors (Ministry of Water Resources, Works, and Housing, 2010).

These total losses to WASH-centered agencies have resulted in significant shortfalls in their ability to install and promote continued maintenance of freshwater systems and programing. This is resulting in significant programming setbacks, lack of capacity development, and poor maintenance of freshwater systems. A specific example is the 45.8% income shortfall of the Community Water and Sanitation Agency's (CWSA) annual budget that cut their ability to achieve their 2019 WASH goals (Community Water and Sanitation Agency, 2018). The lack of funding has led to significant decreases in the following technical areas: water quality testing/analysis, disinfection of source boreholes, borehole cleaning and redevelopment, rehabilitation, and expansion works of pre-existing systems (Community Water and Sanitation Agency, 2020).

Additionally, personnel capacity in the form of human resource development to meet the MDG targets in Ghana is lacking (Monney et al., 2014). Currently, the water source area is primarily dominated by public sector stakeholders, and this underscores the need for increased participation by the private sector and NGOs to meet the unfulfilled demand. Specifically, there is a significant shortage administrative, finance, and social development personnel. These high demand jobs include positions in design, construction, operation, maintenance and community mobilization, and they are required throughout the lifecycle of water facilities. Involving the private sector and NGOs is essential to improving fresh water resource coverage and would allow the Government of Ghana to attract more investment into the water source sector. The necessary labor to add water delivery systems to reach the population, maintain those systems, ensure their sanitary operation, and provide for their refurbishment simply does not exist at this time (Monney et al., 2014). The lack of adequate personnel to perform the strategic functions means that workers to perform standard everyday tactical functions like drawing water samples, testing, monitoring, and assuring the long-term safety of water sources simply donot exist. Those functions are not performed on a regular basis anywhere within Ghana.

4.0 DISCUSSION

The Discussion section contains an analysis which incorporates material from multiple sources to provide a set of average 'benchmarks' for the various potential installed water source costs in Ghana. While recognizing that all installations are unique, a benchmark cost always provides a good reference point from which to review individual projects. Finally, this section explores the Byzantine interrelationships and connections between the various entities with fresh water responsibilities in Ghana to provide a beginning guide for those seeking to establish or invest in water supply ventures within the country.

4.1 –Economic Analysis

A review of the costs per capita per year and unit cost per drinking water source options is provided in Table 3. The design population used for each option's economic comparison was 300 people, matching the Nyarko et al. (2010) study. Individuals were assumed to require 3-4*L/day* (Mayo Foundation for Medical Education and Research, 2020). Within a small town or rural village in Ghana, an approximate cost for a borehole with hand pump or small-town piped system was modeled after the design in Nyarko et al., 2010. Thirty-one rural communities where there are seventy-six water point sources, of which all consisted of a borehole with handpump were reviewed to determine the appropriate average and per capita cost of a water option (Nyarko et al., 2010). Study areas included the following regions: Northern, Ashanti, Volta, Greater Accra, and Central (Nyarko et al., 2010).

The average annual cost for delivering water services from a small-town piped water system was $1,470 for a design population of 300 people. Increasing the design population to 500 would allow the cost to be decreased to an average annual cost of US$85. This study revealed that per capita cost for small town water supply (multi-village) systems could be over 35 times the cost of the boreholes with handpumps, when designed for a population of 300 people. Additionally, the operations and minor maintenance repairs for piped schemes increase dramatically over a simple borehole, and the capital expenditure rises significantly, compared to that of a borehole with a hand pump. The cost per cubic meter of water delivered by a water point source ranged from US$0.01 to US$0.14, while for a small-town piped water delivery system, a cost from US$0.05 to US$1.51 was estimated (Nyarko et al., 2010).

The approximate return on investment for every US$1.00 spent was US$9.40 for a borehole installation, and it was US$14.10 for a borehole rehabilitation. Though the drilled well or borehole is the second highest unit cost of the technologies presented, it is one of the most commonly implemented throughout the country, because of the achievable depths. Manually driven wells, hand-augered wells, and hand-dug wells, are not capable of reaching the significant depths of drilled wells, and therefore are far less common options. However, the low-cost potential of mechanized driven wells may change this economic analysis, if the technology can be proven (Horn & Stwalley, 2020).

The main benefits of access to a community borehole or piped water system are primarily the time saved in fetching water, followed by the economic benefits in averted child deaths. The main drawback is the high cost of installation, which limits the total number of wells that can be installed (Sonou et al., 1994). However, the improvement of pre-existing water sources yields the highest returns under all circumstances. The data show that borehole or water well rehabilitations are far more economically efficient than borehole drilling (Cha et al., 2018). This clearly re-emphasizes the long-term need and economic desirability of funding and personnel to maintain and refurbish existing water source infrastructure.

4.2 – Analysis of Water Source Organizations and their Responsibilities

The Ministry of Sanitation and Water Resources (MSWR) is a division of the Infrastructure Sector under the Office of the Head of Civil Service (Ministry of Sanitation and Water Resources, 2020). Historically, the water source sector was part of the Ministry of Water Resources, and the sanitation sector was part of the Works and Housing Ministry. Both were housed under the Ghana Ministry of Local Government and Rural Development. MSWR is the primary governmental entity responsible for the development of sanitation and water resources throughout the country. Currently, water sub-sector agencies under this ministry include: the Water Resources Commission (WRC), the Ghana Water Company Limited (GWCL), the Community Water and Sanitation Agency (CWSA) (Ministry of Sanitation and Water Resources, 2020). A chart of the governmental water-related organizations is presented in figure 7.

WRC is made up of 15 members with representatives from the following institutions: Ghana Water Company Limited, various organizations producing potable water, the Hydrological Services Department, the Volta River Authority, the Irrigation Development Authority, the Water Research Institute, the Ghana Meteorological Agency, the Ghana Environmental Protection Agency, the Forestry Commission, and the Minerals Commission (Water Resources Commission, 2020). The main intent of the WRC is to regulate and manage the utilization of water resources and provide coordinate relevant government policies related to them (Water Resources Commission, 2020).

GWCL is a utility company that is fully owned by the state and is responsible for potable water supply to all urban communities within the country (Ghana Water Company Limited, 2020). The company operates country-wide and is responsible for 88 urban water supply systems, providing approximately 77% of urban coverage and serving 551,000 customers. The supply production is approximately 0.87 MMm^3 per day, but this should be significantly enhanced. The estimated potable water demand in their coverage area is 1.13 MMm^3 per day. GWCL conducts water quality treatment, in addition to developing, directing, and monitoring of policies and procedures to ensure compliance with Ghana Water Quality standards (Ghana Water Company Limited, 2020).

The CWSA is a public sector organization that facilitates the provision of safe drinking water and related sanitation services specific to rural communities and small towns in Ghana (Community Water and Sanitation Agency, 2018). This organization works at the district and community levels to implement programming, focusing primarily on piped water delivery systems, hygiene promotion, and sanitation (Community Water and Sanitation Agency, 2020). These organizations provide the MSWR with its main tools for the maintenance of existing water sources and the development of new sources.

The Public Utilities Regulatory Commission provides financial regulation to these multiple entities, though it is primarily concerned with the monitoring of GWCL with regard to fresh water resources (Ministry of Works and Housing, 2020). The Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) is one of the 13 institutes within the country that conducts research on behalf of all of Ghana (Council for Scientific and Industrial Research, 2018). This specific institute is mandated to conduct research into all aspects of water resources in order to provide scientific and technical information and services, and strategies to promote sustainable development, unitization, and management of resources within Ghana and to promote economic development. This institute has the ability to generate, process, and disseminate water quality information for end users. This institute also partners with the National University faculty, private and public sector companies, government extension officers, and non-governmental organizations to support research on local water resource topics. The institute is comprised of five technical divisions and three non-technical divisions, of which the following four technical divisions are most important to freshwater testing and treatment: environmental biology and health, environmental chemistry and sanitation engineering, surface water, and groundwater (Council for Scientific and Industrial Research, 2018).

The Environmental Biology and Health Division conducts the following activities: water quality monitoring through microbial, algal, and macro-invertebrate analyses, microbiological analyses of drinking water, wastewater, and research into water related borne parasitic diseases and other infectious diseases, and vectors of diseases of importance to public health. The Environmental Chemistry and Sanitation Engineering Division conducts quality and quantity assessment of industrial, agricultural, and domestic discharges in both urban and rural areas and identifies their impact on aquatic ecosystems. They also conduct water quality monitoring, industrial wastewater studies, and develop strategies for water pollution control and environmental impact studies. The Surface Water Division conducts assessments of surface water resources, sediment transport by streams/rivers and discharges, and development and adaption of appropriate technologies and water conservation techniques for water supply to households, communities, farms, and industries. The Groundwater Division provides research into groundwater resources, providing scientific information to both governmental and non-governmental agencies with respect to groundwater monitoring, assessment studies, and the upkeep of the groundwater database. It also provides technical services on groundwater development related to the geophysical investigations of borehole siting, drilling, supervision, pump testing, pump mechanization, reports, and installation of treatment plants. These four divisions of the WRI represent the primary research and assessment tools of the Ghana government with regard to fresh water resources. The personnel of these oversight divisions represent the CSIR's intellectual assets focused on fresh water issues, a small, under-staffed, and dedicated cadre of water professionals.

The most recent report conducted by the institute, included the details of construction for 20 boreholes, along with six siting and drilling supervisions in the Northern Region of Ghana, all of which were supported by Catholic Relief Services (CRS), a non-governmental organization. Select hydrological studies for drilling sites, and drilling, pumping, and water quality analysis were conducted in the Central Region, with an additional geological survey completed for the region. However, point source water quality testing was not listed as a significant consultancy or service, according to their 2018 annual report (Council for Scientific and Industrial Research, 2018). Within each of the following stakeholder groups mentioned, the ability to deliver point source water quality treatment and testing is strongly dependent on the sufficient availability of funds allotted per year and per stakeholder group, and as shown in figures 5 and 6, is faced with significant challenges.

All of these various stakeholders have significant overlap in their duties. They each conduct design, and implementation of water systems, implementation, training, and maintenance. However, the GWCL and CWSA provide testing capabilities for potable water, though their targeted end uses are different. All the agencies mentioned provide some form of support to generate reporting that can be used for further policy recommendations. Each organization also conducts aspects of their own research related to freshwater testing, though the Water Research Institute is specifically conducting the majority of research on behalf of the country, working the closest with university faculty and graduate students.

5.0 CONCLUSIONS

This review suggests that a significant revamp of initiatives aimed at addressing regional disparities within the fresh water sourcing sector in Ghana is needed to make progress towards sustainable water for all. Significant progress toward universal water access has been made, but the completion of the goal for Ghana will require far more commitment, support, and resources. This review has examined the types of water source technology presently available in Ghana, the current condition of water access in Ghana, the resiliency of the local water supply systems and their quality, the economics of various installation systems in the Ghana marketplace, and an introduction to the assorted organizations within the government of Ghana that hold responsibility for some aspect of the fresh water mission. The following conclusions are suggested from this review of the professional literature:

- cost differentials for potable water source systems vary widely, and Ghana should concentrate on complete coverage before increasing the sophistication of its newer water delivery systems;
- there is a significant investment needed to achieve universal coverage, even when using the least costly techniques; and
- the present quality of delivered water is insufficient, and significant resources are required to develop and support the personnel needed to establish the universal delivery of sanitary water in Ghana.

There is a significant bureaucracy devoted to water resources in Ghana with multiple overlapping duties and responsibilities. Improved coordination between the various organizations and their stakeholders could enhance efforts and end results. The content reviewed in this paper is pertinent to the governmental agencies and various other stakeholders working within the country. This review should be used as a starting point for those new to the sector, those seeking to understand the current stakeholders and the situation of fresh water resources within the country, and those seeking to foster new collaborations and projects. It is recommended that any WASH policies, programs, and extension efforts, be constructed with greater intention to incorporate the insights, needs, and perspectives of community members, within the affected areas. Such inclusions will provide greater opportunity for low-income households to be positively impacted by policy changes, programs, and extension efforts.

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7.0 REFERENCES

Aalto, A., Jarvela, E., Kauhanen, M., & Makela, J. (2012). Dry Toliet Manual. Case Ho Municipality, Volta Region, Ghana. Retrieved November 17, 2019, from lahtibojanala.net/assets/files/DryToiletManual_Case_Ho_Municipal- ity_Ghana2012.pdf.

Adams, E., Boateng, A., &Amoyaw, G. (2016). Socioeconomic and demographic predictors of potable water and sanitation access in Ghana. Social Indicators Research 126(2), 673-687. doi:10.1007/s11205-015-0912-y

African Development Bank. (2016). African Economic Outlook 2016: Sustainable Cities and Structural Transformation. New York: Organization for Economic Cooperation and Development & United Nations Development Program.

Alexander, D., Wilson, N., Gieseker, R., Bartlett, E., Rosseau, N., Amuzu, E. X., . . . Olopade, C. O. (2015). Drinking water infrastructure in the Ashanti region of Ghana: developing a model for sustainable interventions by non-governmental organizations. Journal of Water, Sanitation, and Hygiene for Development 5(1), 127-135. doi:10.2166/washdev.2014.205

Appiah-Brempong, E., Harris, M., Newton, S., &Gulis, G. (2018). Examining school-based hygiene facilities: a quantitative assessment in a Ghanaian municipality. BMC Public Health 18(1), 1-8. doi:10.1186/s12889-018-5491-9

Appiah-Effah, E., Duku, G. A., Azangbego, N. Y., Aggery, R. K., Gyapong-Korsah, B., & Nyarko, K. B. (2019). Ghana's post-MDGs sanitation situation: an overview. Journal of Water, Sanitation, and Hygiene 9(3), 397-415. doi:10.2166/washdev.2019.031

Bisung, E., & Elliott, S. J. (2017). Psychosocial impacts of the lack of access to water and sanitation in low- and middle-income countries: a scoping review. Journal of Water and Health 15(1), 17-30. doi:10.2166/wh.2016.158

BPN Media - National Driller Magazine. (2020). Tips for water well rig selection. Retrieved May 24, 2020, from https://www.nationaldriller.com/articles/91369-tips-for-water-well-drill-rig-selection.

Business Ghanna. (2019). Know the 16 regional capitals of Ghana. Retrieved July 5, 2020, from https://www.businessghana.com/site/news/general/182246/Know-the-16-regional-capitals-of-Ghana.

Cha, S., Cho, Y., Jiae-Kim, S., Lee, Y., Choi, S., Asuming, P., . . . Jin, K. (2018). Cost-benefit analysis of water source improvements through borehole drilling or rehabilitatioin: an emperical study based on cluster randomized controlled trial in the Volta region, Ghana. Global Health Action 11(1), 1-10. doi:10.1080/16549716.2018.1523303

Communications Bureau. (2019). President Akufo-Addo Appoints Regional Ministers for Six New Regions. Retrieved July 5, 2020, from http://presidency.gov.gh/index.php/breifing-room/press-releases/1091-president-akufo-addo-appoints-regional-ministers-and-deputy-regional-ministers-for-six-new-regions.

Community Water and Sanitation Agency. (2018). Ministry of Sanitation and Water Resources 2018 Annual Report. Retrieved June 6, 2020, from cwsa.gov.gh//wp-content/uploads/2019/12/2018-Annual-report.pdf.

Community Water and Sanitation Agency. (2020). About Us. Retrieved June 6, 2020, from cwsa.gov.gh/about-us/.

Council for Scientific and Industrial Research. (2018). Water Research Institute. Retrieved June 6, 2020, from csir.org.gh/index.php/research-institutes/water-research.

Curtis, V., & Cairncross, S. (2003). Effect of washing hands with soap on diarrhoea risk in the community: a

systematic review. The Lancet Infectious Diseases 3(5), 275-281. doi:10.1016/s1473-3099(03)00606-6
Driscoll, F. G. (1986). Groundwater and Wells. Saint Paul, MN: Johnson. LoC 85-63577
Fangmeier, D. D., Elliot, W. J., Workman, S. R., Huffman, R. L., & Schwab, G. O. (2005). Soil and Water Conservation Engineering. New York: John Wiley & Sons. ISBN: 1401897495
Forson, A. J., Buracom, P., Baah-Ennumh, T. Y., Chen, G., & Carsamer, E. (2015). Corruption, EU aid inflows and economic growth in Ghana: cointegration and causality analysis. Contemporary Economics 9, 299-318.
Ghana Statistical Service. (2013). Population and housing census, national analytical report. Retrieved November 17, 2019, from statsghana.gov.gh/gssmain/fileUpload/pressrelease/2010_PHC_National_Analytical_Report.pdf.
Ghana Statistical Service. (2014). Population and housing census, district analytical report Kumasi metropolitan. Retrieved November 17, 2019, from statsghana.gov.gh/docfiles/2010_District_Report/Ashanti/KMA.pdf.
Ghana Statistical Service. (2018). Multiple Indiciator Cluster Survey (MICS2017/18), Survey Findings Report. Accra, Ghanna: GSS.
Ghana Water Company Limited. (2020). Departments - GWCL - Welcome. Retrieved June 6, 2020, from gwcl.com.gh/departments/#1554135894047-e32223b0-e050.
Graham, J. P., Hirai, M., & Kim, S. S. (2016). An analysis of water collection labor among women and children in 24 sub-Saharan African countries. PLoS ONE 11(6), e0155981. doi:10.1371/journal.pone.0155981
H2O for Life. (2019). Borehole well. Retrieved November 17, 2019, from h2oforlifeschools.org/page/borehole-well.
Health habit Pty Ltd. (2020). B2 - washing clothes and bedding. Retrieved May 24, 2020, from housingfor health.com/the-guide/health-housing/washing-clothes-and-bedding.
Healthline Media UK Ltd. (2020). What's the best shower frequency? Retrieved May 24, 2020, from medicalnewstoday.com/articles/324682#showers-and-work.
Home Guide. (2019). 2019 Well drilling costs: average water well installation cost. Retrieved November 17, 2019, from home guide.com/costs/well-drilling-cost.
Horn, Z. J., & Stwalley III, R. M. (2018). Well-Driver PUP. ASABE Annual International Meeting - Detroit. St. Joseph, MI: ASABE doi:10.13031/aim.201801196.
Horn, Z. J., & Stwalley III, R. M. (2019). A low-cost mechanized tube well installer. ASABE 2019 AIM - Boston. St. Joseph: ASABE. doi:10.13031/aim.2019011319
Horn, Z. J., & Stwalley III, R. M. (2020). Design and testing of a mechanized tube well installer. Groundwater for Sustainable Development 11, 100442. doi:10.1016/j.gsd.2020.100442
Indiana Code (Statutes). (1987). Article 39. Water Well Drilling and Pump Installer Contractors.
Kundu, D. K., Van Vliet, B. J., & Gupta, A. (2016). The consolidation of deep tube well technology in safe drinking water provision: the case of arsenic migration in rural Bangladesh. Asian Journal of Technology Innovation, 24(2), 254-273.
Leahy, C., Winterford, K., Nghiem, T., Keheller, J., Leong, L., & Willetts, J. (2017). Transforming gender relations through water, sanitation, and hygiene programming and monitoring in Vietnam. Gender and Development 25(2), 283-251. doi:10.1080/13552074.2017.1331530
Luby, S., Agbaotwalla, M., Feikin, D., Painter, J., Billhimer, W., Altaf, A., & Hoekstra, R. (2005). Effect of handwashing on child health: a randomised controlled trial. The Lancet 366(9481), 225-233. doi:10.1016/S0140-6736(05)66912-7
Mahama, A. M., Anaman, K. A., & Osei-Akoto, I. (2014). Factors influencing householders' access to improved water in low income urban areas of Accra, Ghana. Journal of Water and Health 12(2), 318-331. doi:10.2166/wh2014.149
Marshall, A. (2013). Principles of Economics. London: Palgrave Macmillan.ISBN: 978-1-57392-140-4
Mayo Foundation for Medical Education and Research. (2020, May 24). Water: how much should you drink each day? Retrieved 2020, from mayoclinic.org/healthy-lifestyle/nutrition-and-healthy-eating/in-depth/water/art-20044256.
Mekonnen, M., & Hoekstra, A. Y. (2016). Four billion people facing severe water scarcity. Science Advances 2(2), e1500323. doi:10.1126/aciadv.1500323
Millennium Challenge Corporation. (2017). Measuring results of the Ghana water and sanitation sub-activity. Retrieved November 17, 2019, from mcc.gov/resources/doc/summary-measuring-results-ghana-water-sanitation-sub-activity.
Ministry of Local Government and Rural Development - Environmental Health and Sanitation Directorate. (2012). Rural Sanitation Strategy and Model (RSMS): District resource book for scaling up community led total sanitation & hygiene marketing in Ghana. Retrieved June 6, 2020, from useatoilet.files.wordpress. com/2015/12/rsms.pdf.
Ministry of Sanitation and Water Resources. (2020). About Us. Retrieved June 6, 2020, from mswr.gov.gh/about-us.
Ministry of Water Resources, Works, and Housing. (2010). Water and Sanitation Sector Performance Report. Retrieved June 6, 2020, from sanitationandwaterforall.org/wp-content/uploads/download-manager-files/Final_2010_Sector_Performance_Report%5B1%5D.pdf.
Ministry of Works and Housing. (2020). The Works Sector. Retrieved June 6, 2020, from

mwh.gov.gh/index.php/works-sector.
Monney, I., & Antwi-Agyei, P. (2018). Beyond the MDG water target to universal water coverage in Ghana: the key transformative shifts required. Journal of Water, Sanitation, and Hygiene 8(2), 127-141. doi:10.2166/washdev.2018.176
Monney, I., Oduro-Kwarteng, S., & Odai, S. N. (2014). Assessing human resource capacity needs to meet the MDG targets on water and sanitation in Ghana. Developing Country Studies 4(10), 17-28.
Nyarko, K. B., Dwumfour-Asare, B., Appiah-Effah, E., & Moriaty, P. (2010). Cost of delivering water services in rural and small towns in Ghana. IRC 2010 Symposium Pumps, Pipes, and Promises - Hague. New York: International Rescue Committee.
Rabie, T., & Curtis, V. (2006). Handwashing and risk of respiratory infections: a quantitative systematic review. Tropical Medicine and International Health 11(2), 258-267. doi:10.1111/j.1365-3156.2006.01568x
Rhee, V., Mullany, L., Khatry, S., Katz, J., Leclerq, S., Darmstadt, G., &Tielsch, J. (2008). Maternal and birth attendant hand washing and neonatal mortality in southeastern Nepal. Archives of Pediatrics & Adolescent Medicine 162(7), 603-608. doi:10.1001/archpedi.162.7.603
Routray, P., Torondel, B., Clasen, T., & Schmidt, W. P. (2017). Women's role in sanitation decision making in rural coastal Odisha, India. PLoS ONE 12(5), e0178042. doi:10.1371/journal.pone.0178042
Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G., Fuller, G., &Woelm, F. (2020). The Sustainable Development Goals and COVID-19: the sustainable development report 2020. Cambridge: Cambridge University Press.
Saguaro Well and Pump. (2018). Well Drilling. Retrieved May 24, 2020, from https://www.saguarowp.com/service/5-well-drilling.html.
Sandora, T., Taveras, E., Shih, M., Resnick, E., Lee, G., Ross-Degnan, D., & Goldmann, D. (2005). A randomized, controlled study of a multifaceted intervention including alcohol-based sanitizer and hand-hygiene education to reduce illness transmission in the home. Pediatrics 116(3), 587-594. doi:10.1542/peds.2005-0199
Seecon Internatioinal GmbH. (2020). Factsheet Dug Wells. Retrieved May 24, 2020, from https://sswm.info/sswm-university-course/module-4-sustainable-water-supply/further-resources-water-sources-hardware/dug-wells.
Seencon International GmbH. (2020). Factsheet Dilled Wells. Retrieved May 24, 2020, from https://sswm.info/sswm-solutions-bop-markets/affordable-wash-services-and-products/affordable-water-supply/drilled-wells.
Sheuya, S. A. (2008). Improving the health and lives of people living in slums. Annals of the New York Academy of Sciences 1136(1), 298-306. doi:10.1196/annals.1425.003
Sonou, M. (1994). An Overview of Lowlift Irrigation in West Africa: Trends and Prospects. RAPA 1994/95.
Sonou, M. (1997). Low-cost shallow tube well construction in West Africa. Irrigation Technology Transfer in Support of Food Security: UNFAO Workshop - Harare (pp. 157-168). Rome: UNFAO.
Stevenson, E., Ambelu, A., Caruso, B., Tesfaye, Y., & Freeman, M. (2016). Community water improvement, household water insecurity, and women's psychological distress: an intervention and control study in Ethiopia. PLos ONE 11(2), 1-13. doi:10.1371/journal.pone.0153432
Sweetman, C., & Medland, L. (2017). Introduction: gender and water, sanitation, and hygiene. Gender and Development 25(2), 153-166. doi:10.1080/13552074.2017.1349867
U.S. Army. (1994). US Army Field Manual: Well Drilling Operations (FM5-484). Washington, D.C.: US Department of Defense.
UNICEF. (2008). More than soap and water: taking handwashingwith soap to scale: UNICEF handwashing training module. Retrieved November 17, 2019, from globalhandwashing.org/wp-content/uploads/2015/03/HWWS-More-ThanSoap-and-Water_Training-Module.pdf.
UNICEF. (2017a). Ghana Drinking Water, Sanitation, and Hygene Service Levels. Retrieved March 19, 2021, from https://washdata.org/data/household#!/.
UNICEF. (2017b). World Drinking Water, Sanitation, and Hygene Service Levels. Retrieved March 19, 2021, from https://washdata.org/data/household#!/dashboard/new.
United Nations. (2017). UN - Water GLAAS 2017: Financing universal water, sanitation, and hygiene under the sustainable development goals. Retrieved June 6, 2020, from https://www.unwater.org/publications/un-water-glaas-2017-financing-universal-water-sanitation-hygiene-sustainable-development-goals.
United Nations. (2019). Toliets, sanitation, water, economic and social rights, dignity, SDGs: Sustainable Development Goals. Retrieved November 17, 2019, from un.org/en/events/toilet day.
University of Rochester Medical Center. (2020). In the kitchen: prevent the spread of infection. Retrieved May 24, 2020, from urmc.edu/encyclopedia/content.aspx?contenttypeid=1&contentid=1220.
Water Resources Commission. (2020). About Us. Retrieved June 6, 2020, from wrc-gh.org/about-us.
Wellowner. (2015). Types of wells. Retrieved November 17, 2019, from wellowner.org/basics/types-of-wells.
World Bank. (2011). Water supply and sanitation in Ghana: turning finances into services for 2015 and beyond. Retrieved November 17, 2019, from documents.worldbank.org/curated/en/43841146828108

6437/Water-supply-and-sanitation-in-Ghana-turning-finance-into-services-for-2015-and-beyond.
World Health Organization. (1997). Guidelines for drinking water quality: surveillance and control of community supplies. Retrieved July 5, 2020, from https://www.who.int/water_sanitation_health/dwq/2edvol3a.pdf.
World Health Organization. (2000). WHO/UNICEF joint monitoring programme for global water supply and sanitation assessment report. New York: World Health Organization.
World Health Organization. (2009). WHO guidelines on hand hygiene in health care. Geneva: WHO Press.
World Health Organization. (2013). UNICEF progress on sanitation and drinking water - 2013 update. Geneva: WHO Press.
World Water Assessment Program. (2015). The United Nations world water development report 2015: water for a sustainable world, facts and figures. New York: United Nations.