#### 1 Article

# 2 Evaluation of Hand-dug Wells in Rural Haiti

#### 3 Hayley E. Schram <sup>1</sup>, Peter J. Wampler <sup>1</sup>\*

4 1 Department of Geology, Grand Valley State University, 1 Campus Drive, Allendale, Michigan 49401;

- 5 E-mails: schramh@mail.gvsu.edu (H.S.); wamplerp@gvsu.edu (P.W.)
- 6 \* Correspondence: wamplerp@gvsu.edu Tel.: +01 616 331 2834 7

8 Abstract: Water resources, especially safe, potable water, are limited for many Haitians. In areas 9 where shallow groundwater is available, many household water needs such as laundry, bathing, and 10 cooking are supplied by hand-dug wells. In order to better understand the water quality and 11 prevalence of these household wells, 35 hand-dug wells were surveyed and sampled near the Hôpital 12 Albert Schweitzer (HAS) in Deschapelles, Haiti. Water samples were collected and tested for fecal 13 coliform and E. coli using the IDEXX Colilert-18 method. Of the samples collected, 89 percent were 14 determined unsafe to use as a drinking water source based on the World Health Organization 15 standard of 1.0 colony-forming unit (cfu) Escherichia Coli (E. coli) per 100 mL. 66 percent of the wells 16 exceeded recreational/body contact standards for the state of Michigan (130 cfu/100 mL). Some of 17 these wells were deemed suitable for conversion to a new well type called In-Situ Filtration (ISF) 18 wells. ISF wells are installed with an internal sand filter pack, PVC casing, pump, and cap which seals 19 the well from surface contamination and provides additional water treatment as water is pumped. 20 Previous ISF installations have reduced E. coli to safe drinking water levels within 90 days.

Keywords: groundwater, Haiti, filtration, water treatment, developing country, point of use
 treatment, household treatment

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### 24 1. Introduction

25 According to the World Health Organization, 663 million people worldwide use unimproved 26 water sources, including springs, surface water, and unprotected wells [1]. This means that 27 approximately 10 percent of the world population does not have access to clean water. Many 28 developing countries like Haiti lack water access due to limited water resources, infrastructure, 29 contamination, and/or political instability. Haiti is located on the western one-third of the island of 30 Hispaniola, has a population of roughly 10.7 million people. It is divided into three regions: the 31 northern, central, and southern regions. The central region largely consists of the Artibonite Valley, 32 named after the Artibonite River, which is the longest river on the island. This river, which serves as 33 a collector for contamination through tributary rivers and streams, contains high concentrations of 34 bacteria including coliform, Escherichia Coli (E. coli), and cholera [2]. Hand-dug wells located near the 35 river and on the floodplain act as primary water sources for many Haitians living near the Artibonite 36 River. In rural mountain areas, women and children walk, often multiple times a day, to retrieve 37 water in buckets, plastic bottles, or jugs from springs. Water quality in these springs is also poor by 38 United States standards [3]. Hand-dug wells are typically used for water needs such as cooking, 39 laundry, and bathing. 40

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and other karst aquifers (Figure 2) [3,4]. In 2010, Haiti was the most underserved country in the
 western hemisphere in terms of water and sanitation infrastructure [8]. Despite this, sustainable

- 78 effective treatment methods remain problematic. Point-of-use (POU) water treatment methods have
- 79 become the preferred method in many developing nations to improve water quality by treating water
- 80 in small batches in the home [9]. Methods such as Sawyer Filters, Biosand Filters (BSF), chlorination
- 81 tablets, and boiling water are the most popular practices among Haitians. Sawyer fiber-membrane
- filter technology is promising for in-home treatment due to its low cost and potential longevity [10].
   In 2005, a field study of 107 households was conducted to evaluate the performance of Manz
- 84 Concrete BSF. In a five-year period, nearly 2,000 BSFs were installed around Deschapelles by Hôpital

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85 Albert Schweitzer (HAS). Through networking, conducting interviews, and making observations, it 86 was found that the average lifespan of a BSF was 2.5 years. By conducting water sampling, it was 87 found that 97 percent of the BSF samples contained 0-10 E. coli cfu per 100 mL. The hand-dug wells 88 located near these households contained an average of 234 E. coli cfu per 100 mL [11]. In a follow-up 89 study conducted in 2011, 55 BSF were visited and assessed. These BSF were previously installed by 90 three separate organizations. Of the 55 BSF installed, only 29 (53 percent) remained in use at the time 91 of the sampling [5]. 86 percent of the water treated by the BSF contained *E. coli* concentrations of less 92 than 10 most probable number (MPN) per 100 mL, suggesting the filters were still effective when in 93 use. In addition to BSF methods, other water treatment interventions have been implemented to 94 provide safe and sustainable water including solar water disinfection (SODIS), reverse osmosis, 95 ultraviolet disinfection, ozone disinfection, Sawyer Filters, and a new treatment method described 96 here as an In-Situ Filtration (ISF) well.

97 An ISF well is an efficient and sustainable water treatment method that over time produces safe 98 potable water. These wells use a sand pack to filter water slowly before it is drawn through the well 99 screen. ISF wells may enhance natural biological activity within the outer layer of the well similar to 100 the Schmutzdecke layer in a BSF [12]. Since most of the bedrock in this region is limestone, over time 101 rock is dissolved, creating pockets where pathogen populations can dwell. This results in 102 contaminated groundwater and aquifers. Successful treatment methods have included installing 103 deep wells into the underlying aquifer as a means of bypassing the surface contamination and 104 improved sanitation methods to reduce surface contamination. An ISF well costs roughly one-tenth 105 the price of a traditional drilled well, and the materials can be found locally in country. The ISF wells 106 are similar to those described by others as "bank filtration wells" [13,14]. ISF wells are a relatively 107 new application of "bank filtration" that uses a combination of PVC casing and a natural sand pack 108 to clean water over the course of 60 to 90 days (Figure 3).

Studying hand-dug wells provides valuable information about bacterial water quality and aquifer characteristics including groundwater behavior and aquifer volume and recharge. In order to determine if hand-dug wells are a safe water resource, wells were evaluated for total coliform and *E. coli* contamination. From the collected data, further methods of safe water intervention can then be





Figure 3. (a) Biosand Filter components [12]; (b) In-Situ Filtration well components.

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126 introduced to reduce and minimize dangerous bacteria exposure. From this study, it is possible to 127 further understand and evaluate the appropriate uses for hand-dug wells and explore the 128 possibilities of safe water intervention through various methods including ISF wells.

#### 129 2. Materials and Methods

130 Data was collected using pseudo-randomized sampling of 35 hand-dug wells (20 wells in June 131 2016 and 15 wells in May and June 2017) located in Deschapelles and Borel, Haiti. This process 132 involved locating a hand-dug well, asking the homeowner's permission to sample the well, recording 133 well information (including the owner's name and the amount of water seasonally withdrawn from 134 the well), and concluded by inquiring about additional locations of hand-dug wells in the area. 135 Deschapelles and Borel were selected due to the high density of hand-dug wells and close proximity 136 to HAS where the bacterial testing would take place.

#### 138 2.1 *Physical Characteristics*

139 The distance between the hand-dug wells ranged from 0.1 to 0.5 kilometers (km) in 2016 and 140 2017. Global Positioning System (GPS) locations were determined at each well using a Garmin 141 GPSMap 64s GPS (WGS84). Each well was photographed using a Nikon Coolpix AW130 and 142 georeferenced. A physical description was recorded for each well consisting of the type of well collar, 143 and general surroundings of the well. A Bosch Laser Distance meter in addition to materials 144 improvised in the field including sticks and rope were used as measuring devices. Measurements 145 included total well depth, static water depth, and depth from the ground surface to the water surface.

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#### 147 2.2 Bacterial Testing

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149 One hundred mL water samples were taken at each hand-dug well location (N=35). These 150 samples were evaluated for total coliform and E. coli contamination using the IDEXX Colilert-18 151 Quanti-Tray System (IDEXX Laboratories, Westbrook, ME). Water samples were collected using 152 sterile 100 mL Whirl-Pak® bags (NASCO, Atkinson, WI), and were transported back to HAS in 153 Deschapelles for bacterial analysis, within two hours of being sampled. The process began by adding 154 a Colilert-18 reagent to each individual 100 mL Whirl-Pak® sample until it fully dissolved. The 155 mixture was placed in a Quanti-Tray, which was sealed and incubated at 35 ± 0.5 degrees Celsius for 156 18-24 hours. The results were read using the IDEXX results table, where the number of colored and 157 fluorescing large and small

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169 cells determined the MPN for *E. coli* and coliform bacteria (Figure 4). Control samples of filtered
170 Culligan® water were included with well samples to evaluate cross-contamination. Control test
171 results were negative for *E. coli* contamination, and positive for total coliform in one case.

#### 172 **3. Results**

173 Detailed well characteristic data were collected in 2016 for 20 wells. The physical appearance, 174 and the dimensions of each of the 20 hand-dug wells varied minimally from well to well. The well 175 collar, which guards the well from surface runoff contaminants, was the most variable among wells. 176 They included single or multiple tires, medium to large rocks, elevated concrete, well-developed 177 collars with square concrete molds, flat covered wells, and no collar. The 2016 percentages of each 178 collar type from our samples (N=20) are shown in Figure 5. Of the 20 wells sampled, 9 (45%) were 179 found to have an elevated concrete collar, and only 2 (10%) had no collar. From our survey, we found 180 no correlation between collar type and decreased amounts of coliform or *E. coli* contamination.



**Figure 5**. Hand-dug well collar variations. (a) Elevated concrete; (b) Tires; (c) Rocks; (d) Well Developed; (e) Flat with Cover; (f) No Collar/Absence.

195Total well depth, and depth to water were used to calculate the volume of water present in each196well in 2016 (N=20) (Figure 6). The average volume per hand-dug well was 0.406 cubic meters, or 406197liters. No data was collected for 3 wells (sample numbers 10, 11, and 17). Of the 35 hand-dug wells198sampled in 2016 and 2017, 30 (86%) of wells exceeded the maximum detection limit (>2419.6 MPN/100199mL) for total coliform, and 4 (11%) exceeded the detection limit for *E. coli*. Table 1 summarizes average200and geometric mean for coliform and *E. coli* bacterial testing.

201 The World Health Organization (WHO) Guidelines for Drinking Water Quality recommend that 202 there should be no detectable *E. coli* bacteria (or the fecal indicator bacteria (FIB)) in a 100 mL drinking 203 water sample [15]. However, in many low-income countries, including Haiti, reports have shown 204 presence of fecal contamination in improved sources often exceeds the WHO Drinking Water Quality 205 recommendation [16]. 31 of the 35 (89%) hand-dug well samples exceeded the WHO standard for 206 E.coli in 100 mL water samples. E. coli in this area not only exceed drinking water standards, but many 207 samples exceeded recreational/body contact standards. In the state of Michigan, the EPA 30-day 208 geometric mean is 130 E. coli per 100mL [17]. 23 of the 35 (66%) samples exceed this value.

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### <sup>1</sup>Values of zero were entered as 0.1 for calculation of Geometric Mean.

 Table 1. Hand-dug well bacterial water quality data

### 233 4. Discussion

Based on the widespread *E. coli* contamination of hand-dug wells, exceeding Drinking Water Quality recommendations, and in many cases body-contact standards, these wells should not be used for drinking, laundry, bathing, or cooking purposes without treatment. Using the water for laundry and cooking are possible if adequate precautions are taken. Precautions would include adequate use of chlorination for laundry and adequate boiling for cooking uses. Additional education in safe water practices could reduce the risk for coliform and *E. coli* contamination spread through food preparation and laundering practices.

241 Because hand-dug wells are heavily relied upon by Haitians in this region, especially during the 242 rainy season, it is important to determine the quantity of water available for use. Data collected in 243 2016 was used to establish an estimate of well water volume available from hand-dug wells for each 244 household. Available water would vary considerably throughout the year as a result of rainy and dry 245 seasons. Based on measurements made in June, 2016 the average amount of water in wells was 0.406 246 cubic meters (406 liters). Assuming approximately 3.4 people per household, this would represent 247 approximately 119 liters per person [18]. According to the United Nations Development Program, 248 the daily amount of water that a family of 4 uses in Haiti for household needs is approximately 15 249 liters (3.75 liters per person), while in the United States a family of 4 uses 2,300 liters (575 liters per 250 person) for daily needs [19]. These data suggest that the volume of water within hand-dug wells

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251 during the rainy season is more than adequate to supply the water needs for a family of 4, although 252 as noted earlier this water is not suitable for drinking or many other uses without proper treatment. 253 Observed bacterial contamination of hand-dug wells may be the result of external or internal 254 sources (Figure 7). External contamination occurs when unsuitable water retrieval and storage 255 methods are used that introduce contamination as water is removed from the well. Common retrieval 256 methods in Haiti include the use of plastic buckets attached to ropes which are lowered down to 257 collect water (Figure 8). Similarly, long-term water storage basins including cisterns, buckets, and 258 tanks can introduce and harbor pathogens. Many people have implemented the use of well collars 259 made from rocks, tires, and concrete which provides a modest barrier for contamination from surface 260 runoff entering the well. Internal contamination is another possible source of observed bacterial 261 contamination. Bacteria introduced to the groundwater through poor sanitation can travel to wells 262 through the aquifer from other wells or from more distal sources. It is also possible that warm 263 groundwater and porous aquifers can result in resident pathogen populations [3]. 264



Figure 7. Flow chart depicting contamination pathways and treatment methods.



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Figure 8. Bucket retrieval methodology.

292 One possible way for residents of Haiti to treat water removed from hand-dug wells is through 293 the conversion of open wells to sealed In-Situ Filtration (ISF) wells. ISF well construction utilize

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materials that are found in-country and can be constructed with local labor and expertise promoting
economic development in rural Haiti. Using PVC casing, a natural sand pack, and basic monitoring
well components (PVC screen, well caps, valves, and a hand pump) hand-dug wells can be converted
into an ISF well which will produce treated water that meets WHO drinking water standards in 6090 days (Figure 9) [20].

299 In the summer of 2013 a hand-dug well was installed near the Jaden Nivo spring and monitored 300 for over 90 days. Within that time the levels of *E. coli* contamination decreased from >1,000 MPN to 301 <1.0 MPN (Figure 10). The Jaden Nivo well shows that ISF well design can be an effective method for 302 reducing bacteria, however, it is not yet clear how the reduction is being achieved. Additional data 303 and ISF well construction under more controlled conditions is needed to evaluate the effectiveness 304 and sustainability of ISF wells. Additional data about the quantity and quality of groundwater 305 supply, recharge, turbidity, and monthly precipitation will help understand how and why ISF wells 306 are achieving bacterial reductions and eliminate potential for failure of future wells converted to ISF





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In addition to the implementation of ISF wells, Sawyer Filters could provide an effective treatment method for bacterial contamination in hand-dug wells. Sawyer Filters and other hollow membrane fiber filters are inexpensive, small in size, easy to use, and require minimal maintenance. Overall, homeowners need to understand that hand-dug well water is typically not safe for most uses without treatment and a sustainable and economical way to treat water. In order for any water treatment method to be effective and sustainable it will need to balance appropriate technology, cultural compatibility, and cost.

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346 4.1 Future Studies

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348 In order to better understand how effective and sustainable ISF wells are additional field and 349 lab studies are needed. Additional groundwater flow and bacterial contamination data are needed in 350 the vicinity of the hand-dug well(s). This could include collecting water depths in wells over time 351 using piezometers to determine groundwater flow direction and recharge rates of the aquifers. 352 Another key component of the ISF well is the sand used for filtration. Our study conducted in June 353 2016 used sand from the Artibonite River, which was not decontaminated prior to installation in the 354 wells. Additional experiments are needed to determine if sand sterilization prior to well installation 355 is needed. This could limit the amount of external contamination introduced to the well during 356 construction.

In order to evaluate the contribution of external contamination on water quality in hand-dug wells that are not converted to an ISF well, a well could be isolated from surface contamination through sealing and installation of a pump without the sand filtration. This would help evaluate the contribution of the sand filtration to the observed ISF effectiveness. Bacteriological data could be collected before and after isolation and compared to nearby wells which either included or excluded the use of a sand filter or other variables. Additionally, wells with and without components decontaminated with bleach could help evaluate the contribution of internal contamination sources.

#### 364 5. Conclusions

The data collected on physical characteristics and bacterial analysis of the 35 hand-dug wells determined that water from these wells, without some form of treatment, is unsafe and unsuitable for most uses including drinking, laundry, bathing, and cooking. Some of these hand-dug wells might be suitable for conversion to a new well type called and In-Situ Filtration (ISF) well. All 35 wells are adequate in terms of water volume for supplying a family of four (roughly 60 liters/day) for daily water needs during the rainy season. Surface wells that had improved well collars did not have improved water quality.

In order to gain further understanding of hand-dug wells, water quality and quantity additional monitoring and surveying over time are needed. Recharge rates, groundwater flow direction, turbidity, and precipitation data are needed to increase our understanding of how these wells function and become contaminated. This data could be used to determine which wells are compatible for conversion to an ISF well. A larger sample size of wells would help evaluate correlations between water volume, well collars, and seasonal recharge. If Haitians are to continue to use hand-dug wells as a water source, additional treatment, protection, and study is needed. In the meantime, point-of-

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- use treatment methods such as Sawyer Filters could provide an effective and sustainable watertreatment method, as bacterial contamination was proven to decrease after use.
- 381 Acknowledgments: We thank Rénold Estimé, Hans Renord Pierre, Ellen Bolden, and the entire Wells and Water
- 382 Team at Hôpital Albert Schweitzer for providing us with interpreter personnel, laboratory space, and additional
- 383 help throughout the month-long trip; and Grand Valley State University's Padnos International Center. We also
- thank Danielle DeWeerd, Maria Beelen, and McKenzie Kraft who analyzed the 2017 hand-dug well data.

385 Author Contributions: Hayley Schram, and Peter Wampler designed the research project by collecting and 386 analyzing the data in Deschapelles and Borel, Haiti in June 2016; Hayley Schram; Peter Wampler contributed 387 project administration in Haiti and at GVSU and assisted in editing of the paper; Hayley Schram and Peter 388 Wampler wrote the paper.

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- 390 Conflicts of Interest: The authors declare no conflict of interest.
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