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Exploratory study of Groundwater quality use for Drinking in the Duport Road and Soul Clinic Diamond Creek communities, Paynesville City, Republic of Liberia

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ABSTRACT

Background: Provision of quality and safe potable water remains a challenge and a significant public health issue in developing nations.

Objectives: In this study, we worked with the community leadership to estimate the safety and the quality level of groundwater use for drinking and domestic use.

Method: The study selected 100-homes in the Paynesville City, Greater Monrovia meeting the inclusion criteria to complete the survey questionnaire. 57-water infrastructure (WI) were identified, sampled and analyzed for the physio-chemical and microbial parameters of the groundwater in the communities. The physio-chemical parameters investigated include total alkalinity, total dissolved solids, total hardness, pH, temperature, nitrate, and nitrite. Total coliform bacteria were analyzed for the microbial properties in the groundwater. Groundwater is the primary source of water for drinking and domestic use by approximately 90% of the homes in the Shara, Soul Clinic, and Cow Field communities of Montserrado County, Liberia.

Results: After adjusting for other variables and other socio-demographic confounder, participants/families consuming groundwater were more likely exposed to contaminated groundwater with a potential health outcome, ($p < 0.001$). Also observed, the more improved WI, the hand pump nitrate concentration was between 60-70 ppm, above the acceptable range from the WHO 2017 drinking water guidelines. The microbiological analysis showed that 93% of the water infrastructure (hand pumps and shallow wells) were contaminated with total coliform bacteria.

Conclusion: By investigating the quality of drinking water, the results of this study will inform community members and policymakers that action is needed for proper management and treatment of groundwater to reduce the risk of potential waterborne disease outbreak.

Keywords: LaMotte kit, groundwater, Nitrate, Nitrite, Total coliform bacteria, Paynesville city, Greater Monrovia, Duport Road, Soul Clinic

I. INTRODUCTION

Water is the most valuable resource for supporting the ecosystems, providing life-support services for people, animals, and plants [1]. Provision of potable water remains a challenge in developing nation. About 780 million people in the world, mostly in developing countries, lack access to safe drinking water [2]. Continuous world population growth is accompanied by an increased need for quality drinking water [3] and thus improved management of available water resources [4] fundamental. The proper management of groundwater benefits not only human health but also essential for domestic and agricultural activities [5]. Groundwater is typically less polluted as compared to surface water but is still subject to contamination through human developmental [6] and geological [7] activities. Groundwater is used for drinking by more than 80% of the residents of low-income countries [8]. In the study, approximately 90% of the study population used groundwater for drinking and domestic purposes.

The study was designed to explore the water quality being consumed by the community populations. Water physio-chemical and microbial properties can define the quality of potable water (groundwater or surface water). The design study was an exploratory study to assess the water quality of water infrastructures in the community. Water infrastructure for this research is defined as hand pump/borehole, and shallow wells (Figure 1) that are used for fetching groundwater for drinking or domestic activities. The results from this study are intended to develop a future research work. The water quality research is novel in the study area, but not new to the field of Public Health.

Inadequate water supply and sanitation are restricted to occasional outbreaks affecting vulnerable sub-population and has been attained in the developing world [9] like Liberia. The importance of the availability of quality drinking water is the challenge for developing country. Every year there are approximately 2 million diarrhoeal deaths related to unsafe water, sanitation and hygiene; and the most affected are children under age five [10]. Every year there are approximately 2 million diarrhoeal deaths related to unsafe water, sanitation and hygiene; and the most affected are children under age five [10].

Significance. The provision of drinking water of adequate quality and quantity remains a significant public health concern in developing countries, where diarrheal diseases continue to cause extensive morbidity and mortality [11]. In the study area, Paynesville City, Greater Monrovia, Liberia, groundwater is the primary source of water for domestic use and drinking. Selectively, within the Duport Road (Cowfield and Shara) and Soul Clinic Diamond Creek, Paynesville city, approximately 90% of the families rely on groundwater for domestic and drinking purposes. Despite the large-scale dependence on groundwater sources, the safety and quality of the groundwater are unknown. Outcomes from the study are expected to guide the development of proper management of existing water infrastructure in the communities. The findings from the survey will also be necessary for providing insight into other community water infrastructure and guide future research on identifying novel water sources.

Therefore, the primary hypothesis statement is groundwater in the communities is safe for drinking and domestic users. *Objective:* To work with the community through its leader to identify reliable, safety and quality level of groundwater use for drinking water and internal use.

II. METHOD

Ethical. The approved Institutional Review Board (IRB) for the exploratory study was secured from Indiana University Bloomington Institutional Review Board, and a written consent form was distributed to the selected household. The study was conducted from May 2016 to September 2016.

Study Area. The study took place on Duport Road (Shara and Cowfield communities) and Soul Clinic communities, Paynesville City, Greater Monrovia located 5.55 kilometer away from Monrovia, Liberia's capital city. Geographically, Liberia is situated on the

West Coast of Africa at a coordinate of 6.411513 N and -9.323492 E. Paynesville city is one of the densely populated cities in Liberia and is located at latitude 6.276 and longitude -10.718 [12]. The geological terrain of the Republic of Liberia is divided into quadrangles, and the study area is in the Monrovia Quadrangle. The lithology of the study is underlying with the Paynesville sandstone formed by white or brown unconsolidated sandstone. The Jurassic diabase sills and dikes intrude the Monrovia Quadrangle.

Recruitment. The research team identified two communities in Paynesville city, Greater Monrovia because of the increased use of groundwater. The two communities are the Duport Road and Soul Clinic communities. The Duport road community was further divided into the Shara and Cowfield communities. From the three communities, recruitment base upon participants that meet the inclusion criteria. The inclusion criteria for the selected participants are: (1) reside in the community for five years or more, (2) stored water at home because the source is outside the home, (3) saved water in a wide-mouthed container, and (4) primary user of groundwater for drinking and domestic activities. The research team in collaboration with the community leadership identified 100-home and 57-water infrastructure. However, the number of participants/homes was not equally selected per community because some family or participant was not willing to participate.

Groundwater was sampled from three types of water infrastructure, hand pump, shallow wells with and without cover (Figure 1) in the selected communities. Sampling and analysis of the groundwater were done from May to August 2016. The location of infrastructure was recorded using a GARMIN ETREX 10 GPS. The GPS data is best used in the describing the distribution of contaminant in the environmental terrain of the study areas.

Procedure. The research was divided into two parts, (1) survey questionnaire completion by selected participants, and (2) groundwater sampling and testing from the 43-water infrastructure.

(1) Survey Questionnaire. The survey questionnaire was categorized into four sections; (a) socio-demographic, (b) drinking water sources, (c) storage facility of drinking water at the household, and (d) sanitation. The selection criteria were designed to select participants who residency in the community is more than four years and a primary user of groundwater and meets the inclusion criteria. The completion of the study questionnaire was done at homes of a participant in the presence of the research team. Before the visitation of the research to participants home, the selected participants are served with a consent form two-day in advance. Participants were asked to identify a proxy if desire or at some point a face-to-face interview is conducted relative to the questionnaire if the participant is unable to locate a proxy.

(2) Well water sampling & measurement. Groundwater was sampled and tested for physio-chemical and microbial properties. A sample of the groundwater was collected from either the opened or closed wells or hand pump/borehole. The physio-chemical property includes total dissolved solids, temperature, pH, total hardness, total alkalinity, nitrate, and nitrite. For the physio-chemical analysis, the HACH DR 900 Handheld equipment was used to test the nitrate and nitrite concentration. The HACH 2755250 5-in-1 Water Quality Test Strips were used to examine total hardness and total alkalinity as calcium carbonate, and total and free chlorine. The pH, total dissolved solids, and temperature were determined from handheld field equipment. The microbial property was based on total coliform bacteria. The LaMotte Total Coliform Test Kit was used to analyze the total coliform bacteria in the groundwater sample. The test was based on present/absent method of the total coliform bacteria.

HACH DR900. The equipment was power to the imperative language (English) selected follow by the selection of the more appropriate method to analyze either the nitrate or nitrite concentration in the groundwater. The equipment is designed according to Beer-Lambert law[13] to show the linear relationship between absorbance and concentration. For HACH DR900, the percent transmittance, absorbance was switch on for the passage of light through the groundwater sample. The light absorbed by the groundwater sample reaches the detector displaying the concentration reading on the monitor of the handheld equipment. The analysis begins with a blank sample been inserted in the cell compartment of the equipment for calibration. 10 ml groundwater sample was collected, and

Hand Pump Opened Well Covered Well

Figure 1. Water Infrastructure use in the three communities to collect groundwater for drinking and domestic work

the requisite reagent was added. The sample was inserted into the cell compartment and Read button was pushed to display the concentration of either nitrate or nitrite in the groundwater.

Nitrate measurement: The nitrate solution is prepared by 10-ml of the groundwater sample in the cell. A content of the NitraVer 5 nitrate reagent Powder Pillow is added to water sample in the cell to determine the concentration of nitrate in the groundwater. Further analysis was done at the University of Liberia Chemistry Department using Spectrophotometer.

HACH 2755250 5 – in – 1 test strips. The test strips analysis followed a colorimetric analytical method. A colorimetric assay determines the concentration of sample by measuring the amount of light absorbed by the reagent. The test strip was immersed in the groundwater sample and test strip held for 270-second reaction time. At the end of the reaction time, the test strip was exposed to sunlight, the intensity of the color of the test strip was compared to the reference scale of five-color corresponding to a variety of concentration measure in ppm (part-per-million or milligram of sample presence in a liter of the groundwater). The test strip was used to test for the level of total hardness and total alkalinity as calcium carbonate, and total and free chlorine simultaneously.

For the pH, temperature, and total dissolved solids multi-parameter handheld equipment was used. The water sample was added to the 250-ml beaker and the handheld equipment immersed. Within 60-second, the reading on the equipment monitor become stable. All three readings are displayed simultaneously with the pH reading at the bottom, the TDS in the upper right corner and the temperature appearing in the middle. The buffer solution to calibrate the handheld equipment was in the range of 6 – 8 ppm.

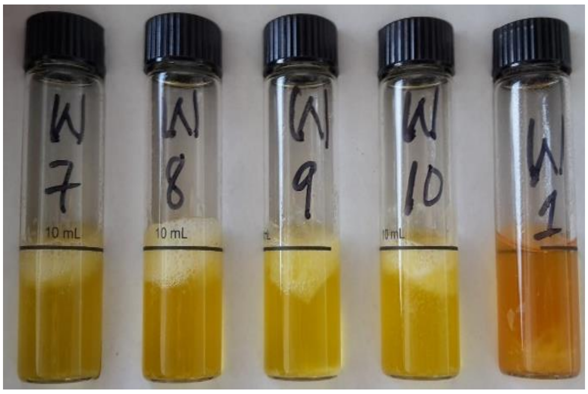

Figure 2. Results from the total coliform bacteria analysis from selected wells. From the selected W7 – W10 show a positive result for total coliform bacteria and W1 is negative.

LaMotte Total Coliform kit. The LaMotte Total Coliform kit was used to determine the total coliform in the groundwater sample. For the microbial contaminant testing, 10-mL of water was added to five different vials containing one Coliform Test Tablet with MUG (4-methylumbelliferyl-β-D- glucuronide), and incubated at ambient temperature for 48 hours. The Coliform Test Tablet with MUG provides nutrients to support bacterial growth, a gel-like substance, an indicator for the detection of *E. coli*, and a pH indicator. A positive test for the presence of total coliform in the water sample involves a change in the yellow color of the medium and the presence of gas bubbles after the 48-hour incubation period (Figure 2).

III. RESULTS AND DISCUSSION

In the research area, Paynesville city, three communities were identified because of the increase used of groundwater. The three communities are the Shara, Soul Clinic and Cow Field. The cow Field and the Shara communities are part of the Duport Road community, acceptable national name. The data analysis was performed using the Statistical Package for the Social Sciences (SPSS) software version 24.

1.Sample Profile

During the study, we first compare the three communities of participants that completed the research questionnaire (Table 1). The average household size that is primary user of groundwater for either drinking or domestic work is 10.8 ± 5.13 and 12.5 ± 4.64, $p = 0.14$ in the Duport Road and Soul Clinic communities respectively. No significant differences between the three communities were found for primary person responsible for transporting water from source to household; container used to carry drinking water, the drinking water storage period, and drinking source.

Primary Drinking Source. The primary drinking source (Figure 1) is defined as either Shallow closed and opened wells and hand pump/borehole. In the Duport Road, 44.8% and 60% of the participants in the Shara and Cow Field communities respectively collect

drinking water from a hand pump. 51.6% of the participants in the Soul Clinic also relied on a hand pump for drinking water. The study showed a significant difference for animals having access to the primary water infrastructure use for drinking, $p = 0.002$. In the Shara community, 31.4% of the water infrastructure have access to bird (chicken and duck). 41.9% and 50.0% of the water infrastructure in the Soul Clinic and Cow Field communities respectively has access to cat or dog. The water infrastructure was vulnerable to fecal contamination.

Storage. The storage of drinking in the requisite container reduces direct hand-to-water contact and adding any utensil directly to the water. The storage container for drinking water is fundamental to the quality of the drinking water. The two types of vessel widely used in the research community are narrow-mouthed and wide-mouthed containers. The narrow-mouthed container is identical to either the CDC Jerry Can or the Oxfam Bucket (Figure 3). A narrow-mouthed container discourages the user from placing potentially contaminated items,

Figure 3 . Left: *The 14-liter Oxfam bucket was designed to provide safe storage to drinking water at the household. The lids snap on to prevent entry of hands or objects in the bucket.* Right: *The CDC 20-liter Jerry can initially use to transport vegetable oils are cleaned and used to transport and store drinking water.*

such as hands, cups or ladles into the stored drinking water. The storage of drinking water was statistically significant, p = 0.005. 54.3% of the participants in the Shara community stored drinking water in the wide-mouthed container. Narrow-mouthed container is also used to stored drinking water by 54.8% and 70.0% of the participants in the Soul Clinic and Cow Field communities respectively. Large-mouthed containers have significantly higher odds of recontamination than small-mouthed vessels [14]. Household water treatment and safe storage (HWTS) interventions are promoted to improve drinking water quality. Proper storage of pre-treated HWTS for drinking is used to reduce microbial drinking water contamination and diarrhea [15].

Because of the distance from the household to the water infrastructure, family or participants stored water for a considerate amount of days. 85% and 80% of participants/family in the Shara and Cow Field communities respectively stored drinking water for less than six-day while 93.5% in the Soul Clinic community stored drinking for less than six-day. The storage of water for hours or even days allows the possibility of fecal contamination of otherwise good-quality drinking water inside the household [16].

Table 1. Sociodemographic Data from the three communities

Variables	Shara Community Mean ± SD n (%)[a]	Soul Clinic Community Mean ± SD n (%)[a]	Cow Field Community Mean ± SD n (%)[a]	p-value (X^2 test)
Respondent status				
- **Husband**	29(27.6)	26(83.9)	8(40)	
- **Son**	14(13.3)	-	6(30)	
- **Wife**	49(46.7)	2(6.5)	6(30)	< 0.001
- **Daughter**	13(12.4)	3(9.7)	-	
Employment				
- **Not Employ**	6(5.7)	11(35.5)	4(20)	
- **Self-employ**	48(45.7)	14(45.2)	10(50)	< 0.001
- **Employed**	51(48.6)	6(19.4)	6(30)	
Type of Animal				
- **Cat/Dog**	9(8.6)	13(41.9)	10(50)	
- **Chicken/Duck**	33(31.4)	8(25.8)	6(30)	0.002
- **Sheep/Goat**	4(3.8)	-	-	
Primary Drinking Source				

- Community Hand Pump	47(44.8)	16(51.6)	12(60.0)	
- Private Hand Pump	35(33.3)	6(19.4)	6(30.0)	0.344
- Private Well	23(21.9)	9(29.0)	2(10.0)	
Time(min) to transport water from source to home (roundtrip)				
- Water source at resident	20(19.0)	13(41.9)	2(10.0)	
- 5 to 10 minutes	35(33.3)	4(12.9)	10(50.0)	
- > 10 minutes	18(17.1)	8(25.8)	8(40.0)	0.001
- Don't know	32(30.5)	6(19.4)	-	
Person responsible for fetching water				
- Male/Female < 15 Years	41(39.0)	22(71.0)	8(40.0)	0.58
- Adult (Male/Female)	64(61.0)	(729.0)	12(60.0)	
Treatment method				
- Add Bleach	70(66.7)	17(54.8)	14(70)	
- Use water guide	3(2.9)	6(19.4)	-	
- Boil water	6(5.7)	-	-	0.012
- Don't know	26(24.8)	8(25.8)	6(30.0)	
Does Primary source smell?				
- No	72(68.6)	23(74.2)	8(40.0)	0.026
- Yes	33(31.4)	8(25.8)	12(60.0)	
Does Primary source have a foul taste?				
- No	48(45.7)	19(61.3)	4(20.0)	0.015
- Yes	57(54.3)	12(38.7)	16(80.0)	
Container used to transport drinking water				
- Wide-mouthed container	57(54.3)	21(67.7)	4(20.0)	0.070
- Narrow-mouthed container	48(45.7)	10(32.3)	16(80.0)	
Drinking water storage container				
- Wide-mouthed container	57(54.3)	14(45.2)	6(30.0)	0.005
- Narrow-mouthed container	48(45.7)	17(54.8)	14(70.0)	
Drinking water storage period at home				
- < 6 days	90(85.7)	29(93.5)	16(80.0)	0.35
- > 6 days	15(14.3)	2(6.5)	4(20.0)	
Is storage container safe?				
- No	29(27.6)	8(25.8)	14(70.0)	0.001
- Yes	76(72.4)	23(74.2)	6(30.0)	
Type of toilet facility				
- Flush	78(74.3)	16(51.6)	14(70.0)	
- Pit Latrine	18(17.1)	15(48.4)	6(30.0)	0.003
- Open Defecation	9(8.6)	-	-	
Do you share Toilet Facility?				

- **No**	85(81.0)	12(38.7)	10(50.0)	< 0.001
- **Yes**	20(19.0)	19(61.3)	10(50.0)	

Sanitation. In the study area, toilet facility is essential to prevent pollution of the environment. In the study areas, participants either shared toilet facility or used open defecation. In the Shara community, 8.6% of the participants used open defecation. Open defecation is a major cause of fatal diarrhea [17]. Inadequate sanitation is associated with significant morbidity from diarrheal disease [18]. In 2005, the OD prevalence rate in Liberia was 51% with a 16% projected reduction in 2015 [19]. However, the prevalence of open defecation is 2.5% in the Duport Road community, the Paynesville City. With the practice of OD in the Duport community, primary water treatment is significant to keep the water safe for drinking.

In the selected communities, 19.0%, 61.3%, and 50.0% participants from Shara, Soul Clinic, and Cow Field share toilet facility. Facilities that are not shared between households and that hygienically separate human excreta from human contact are adequate. Specific technologies are more likely than others to meet these adequacy standards. Technologies meeting the above requirements are called “improved,” and those that do not are “unimproved.”

Improved sanitation facilities include a flush toilet or pit latrine that flushes to a sewer, septic tank or pit. A ventilated improved pit (VIP) latrine, pit latrines with the pit well covered by a slab, or composting toilets are also considered improved. Open pits or latrines without a proper slab to cover the hole are unimproved.

However, all Pit latrines visited were not covered with slab and unimproved. In the research area, 17.1%, 48.4%, and 30.0% of the participants in Shara, Soul Clinic, and Cow Field communities respectively used unimproved pit latrine as a toilet. The world health organization attributed 4.0% of all deaths and 5.7% of the global disease burden to water-related illnesses resulting from poor water, sanitation, and hygiene [20].

Table 2, Independent T-Test for the continuous from the survey questionnaire. The Duport Road is made of the Shara and the Cow Field communities.

Variables	**Duport Road Community**		**Soul Clinic Community**		**p – value (t-test)**
	Mean ± SD	**Range**	**Mean ± SD**	**Range**	
Respondent Age	34.5 ± 13.8	18 – 67	47.6 ± 11.7	20 – 60	< 0.001
Participant Family Size	10.8 ± 5.13	4 – 25	12.3 ± 4.64	6 – 22	0.14
Male child < 15 years	1.83 ± 1.76	1 – 6	3.23 ± 2.01	1 – 6	< 0.001
Female child < 15 years	1.91 ±	1 – 11	2.87 ±	1 – 5	0.023

	2.17		1.65		
Household sharing Toilet Facility	6.70 ± 6.60	1 – 19	2.84 ± 2.93	1 – 11	0.021
Depth of the WI in meter	9.93 ± 5.41	1.87 - 22.9	4.74 ± 1.73	2.45 – 13.1	< 0.001
Number of homes that are direct beneficiary of the WI	44.8 ± 43.6	4 – 150	21.8 ± 20.2	3 – 75	0.011
Total Dissolved Solids (ppm)	99.1 ± 102	18 – 590	70.3 ± 68.9	14 – 150	0.22
Temperature (^{0}C)	29.3 ± 1.63	27 – 32	29.0 ± 1.59	26 – 32	0.52
pH	5.31 ± 0.64	3.4 – 6.4	5.30 ± 0.88	4.1 – 6.4	0.94
Total Hardness (ppm)	142 ± 106	25 – 525	189 ± 95	112 – 429	0.08
Total Alkalinity (ppm)	65.7 ± 130	0.9 – 720	72.1 ± 64.1	0.98 – 200	0.81
Nitrate (ppm)	44.7 ± 23.4	0.5 – 80	39.5 ± 18.1	10 – 78	0.36
Nitrite (ppm)	0.35 ± 0.26	0.1 – 0.9	0.70 ± 2.00	0.10 – 10	0.32

For the independent t-test (Table 2), the Shara and Cow Field communities were dummy coded to Duport Road. The Duport Road community comprises of the Cow Field and the Shara communities. From the independent t-test, there were significant differences between the respondent age, numbers of a male and female child less than 15-year and household sharing toilet facility. If a facility is shared and poorly maintained, this can undercut the hygienic quality of the facility and discourage people from using it. Such facilities pose health hazards by exposing people directly to human excreta, but in densely populated urban areas, shared or public facilities are often the only sanitation alternative. The results show a significant difference in the respondent age in Duport Road (M = 34.5, SD = 13.8) and Soul Clinic Community (M = 47.6, SD = 11.7); $p < 0.001$. However, there was no significant difference for the participant family size in the two communities.

1. Shallow Well and Hand pump

The physio-chemical and microbial analysis was conducted from a water sample collected from either the shallow well (opened/covered) or the hand pump. The physio-chemical analysis includes total dissolved solids, temperature, pH, total hardness, total alkalinity, nitrate, and nitrite. For the microbial analysis, total coliform bacteria were analyzed. The total of 57-water infrastructure water was sampled and analyzed in the Duport (13.9% Hand pump, 27.8% closed well, 58.3% opened well) and the Soul Clinic (15% Hand pump, 35% closed well, 50% opened well) communities. During the study, the water infrastructure was categorized in term of improved (hand pump and closed well) and unimproved (opened well). In the Duport Road community, 58.3% of the water infrastructure was unimproved while 50% in the Soul Clinic was unimproved.

From Table 2, there was a significant difference of the WI depth measure in meter in the research areas. The results also show no significant differences for total dissolved solids, nitrate, nitrite, temperature, pH, total hardness, and total alkalinity in the Duport Road and Soul Clinic communities.

Physical parameter. Across all sampled WI, the pH value varied between 3.4 - 6.4 in the Duport community and 4.1 – 6.4 in the Soul Clinic community. The total alkalinity ranges from 0.9 – 720 ppm in the Duport Road and 0.98 – 200 ppm in the Soul Clinic community. There was a non-significance difference in the score of the pH in the Duport Road (M = 5.31, SD = 0.64), p = 0.94. The independent t-test depicts non-significance differences in the score of the total alkalinity in the Duport Road (M = 65.7, SD = 130) and the Soul Clinic (M = 72.1, SD = 64.1), p = 0.81 communities (Table 2). The total dissolved solids showed no significance differences in the Duport Road (M = 99.1, SD = 102) ranges between 18 – 590ppm and in the Soul Clinic (M = 70.3, SD = 68.9) ranges between 14 – 150 ppm, p = 0.22. The source of total dissolved solids in water is associated with sewage waste discharge, inorganic ions, runoff, landfill, and soil texture [21]. Total dissolved solids are associated with total hardness in water. Total dissolved solids affect the taste of drinking water, and its maximum acceptable value is 500ppm. Hardness in water and alkalinity may affect the health of human and animals [22]. Hardness in water associated with the increasing concentration of divalent calcium and magnesium ions, which have implications for risk of cardiovascular disease [23].However, there no health-based guideline value or health concern of hardness at levels found in drinking water. The total hardness ranges from 25 – 525ppm in Duport Road and 112 – 429ppm in Soul Clinic communities.

Chemical Parameters (Table 2). *The d*rinking water in the communities is a source of nitrate and nitrite either acute or chronic exposure can disrupt the body systems and cause illness. The nitrate and nitrite concentrations analyzed in 53-WI varied between 0.50 to 80.0ppm in the Duport Road and 10.0 to 78.0ppm Soul Clinic communities. The nitrite concentration in the Duport Road area was 0.10 – 0.90 ppm and 0.10 – 10.0 ppm in the Soul Clinic communities. The World Health Organization (WHO), 2017 guidelines for drinking water for the acceptable nitrate and nitrite concentration in drinking water, are 50ppm and 3ppm respectively. There was a non-significance difference in the score of the nitrate in the Duport Road (M = 44.7, SD = 23.4), and Soul Clinic (M= 39.5, SD = 18.1), p = 0.36. The independent t-test depicts non-significance differences in the score of the nitrite in the Duport Road (M = 0.35, SD = 0.26) and the Soul Clinic (M = 0.70, SD = 2.00), p = 0.32 communities (Table 2).

However, an epidemiological study estimated that 3% increase in the incidence of colon cancer for 11-European Union member states due to the nitrate concentration in drinking water exceeding 25ppm [24]. A similar study conducted in West Point community, Central Monrovia, Republic of Liberia showed that nitrate concentration in well water range from 4.0ppm to more than 50ppm while nitrite level was between 0.1 to 0.30ppm [25]. However, for the study in the three communities, the nitrate concentration was in the range of 0.00 to 80ppm above the maximum contaminant level (MCL) of 50ppm.

Several epidemiological studies have associated nitrate levels in drinking water with teratogens leading to anencephaly and neural tube defects [26]. Nitrates are a comprehensive source of contamination with concentrations of 50mg/L observed in groundwater in several countries [27].

Table 3. Show the results of the analysis of the water infrastructure. The Water infrastructure for this study is defined as either hand pump, opened well, or covered well in the three communities.

Variables	Shara Community n (%)	Cow Field Community n (%)	Soul Clinic Community n (%)	p-value (X^2 test)
Water Infrastructure (WI)				
- **Hand Pump**	6(37.5)	10(50.0)	5(25.0)	
- **Opened Well**	6(37.5)	2(10.0)	10(50.0)	0.09
- **Covered Well**	4(25.0)	8(40.0)	5(25.0)	
Ownership of the WI				
- **Private**	14(87.5)	20(100)	17(85.0)	
- **Community**	2(12.5)	-	3(15.0)	0.21
WI contaminated with total coliform Bacteria				
- **Positive**	12(75.0)	8(40.0)	18(90.0)	
- **Negative**	4(25.0)	12(60.0)	2(10.0)	0.002
Type of WI				
- **Improved**	10(62.5)	18(90.0)	10(50.0)	0.02
- **Unimproved**	6(37.5)	2(10.0)	10(50.0)	

Microbial analysis. The LaMotte total coliform test kit was used to sample and analyze water from total coliform bacteria in the water sample. The total of 57-water infrastructure was sampled and analyzed. Table 5 depicts the number of homes using the groundwater contaminated with total coliform bacteria in the three communities. From Table 3, the total of 16-WIs groundwater was sampled and analyzed for total coliform bacteria. The 16-WIs made of 37.5% hand pump, 37.5% opened well, and 25% covered well. In the community, 75% of the WI was contaminated with total coliform bacteria. In the Cow Field community 11-WI (50% hand pump, 10% opened well, 25% covered well) was sampled and 40% was contaminated with total coliform bacteria. In the Soul Clinic 20-Wi groundwater was collected and analyzed and 90% found to be contaminated with total coliform bacteria. The 20-WI in the Soul Clinic community comprised of 25% hand pump, 50% opened well, and 25% covered well.

Coliform bacteria are the indicator of animal and human waste [28] and domestic waste disposal and sewage [29]. Coliform bacteria are used as an indicator of possible sewage contamination because of their presence in human and animal feces; thus, they are used to determine the suitability of water for drinking purpose. However, they are not likely to cause illness, but their presence indicates the presence of other disease-causing organisms. Coliform is not part of the natural microbial composition of groundwater; however, their presence serves as an indication of potential outside contamination [30]. Groundwater aquifers naturally harbor microbial communities the specific composition of which co-defines the water quality and its suitability for human consumption and other uses [31].

Table 4. Total number of homes which are a direct user of groundwater extracted from water infrastructure for either domestic activities or drinking in the three communities.

Outcome	Shara Community			Cow Field Community			Soul Clinic Community		
	Total Coliform Bacteria			Total Coliform Bacteria			Total Coliform Bacteria		
	Pos.	Neg	OR(95%CI)	Pos.	Neg	OR(95%CI)	Pos.	Neg	OR(95%CI)
Number of homes Drinking water from the WI									
- **Yes**	170	28	*2.64(1.5-	285	250	**7.14(5.3-	390	50	**5.38(3.2-
- **No**	99	43	4.5)	75	470	9.6)	58	40	8.9)
Ownership									
- **Private**	152	43	1.59(0.98-	360	400	**0.54(0.41-	318	50	**2.65(1.7-
- **Community**	100	45	2.6)	200	120	0.71)	120	50	4.1)
Type of WI used for drinking	197	35	0.45(0.20-	350	185	**4.0(3.1-	145	38	0.81(0.51-
- **Hand Pump**	100	8	1.01)	175	370	5.2)	293	62	1.3)
- **Opened/covered well**									

* p-Value < 0.05; ** p-value < 0.001

Table 4, depicts the number of participants/family that are beneficial to groundwater collected from the water infrastructures. After adjusting for socio-demographic variables, the odds of participants/families drinking water contaminated with total coliform bacteria in the Shara, Cow Field, and Soul Clinic was 2.64 (95% CI: 1.5 – 4.5), 7.14 (95% CI: 5.3 – 9.6), and 5.38 (95% CI: 3.2 – 8.9) times respectively the odds of family/participant who used different source of drinking water. Participants or families collecting drinking water from the hand pump was 55% and 19% less likely in the Shara and Soul Clinic communities respectively to be exposed to the water-borne contaminant as compare to family getting water from identical water infrastructure in the Cow Field community.

Supply of safe, clean, and abundant water for drinking purposes is essential for good health. In many developing nations, microbial contamination in water is highly correlated with various diseases. Primary sources of surface or groundwater contamination in developing countries are fecal matter deposited in or outside of pit latrines, runoff, and septic system intrusion from sewage leakage [32].

Drinking water or potable water is water that is free from any form of microbial contamination and meets the maximum contaminant level [33] set by either WHO or an individual country. Groundwater is used for drinking by approximately 80% of the residents of low-income countries [34]. Groundwater quality depends on the recharged water, precipitation and hydrologic cycle [8].

The study areas over 90% of the population rely on groundwater for drinking. However, it is evident from the results that these individuals are not accessing potable water. The groundwater in the communities is prone to microbial contamination and significantly contaminated with nitrates. Contaminated drinking water has a severe health impact predominantly among women, children, the elderly, and populations with comprised immune systems leaving them susceptible to infectious diseases. All the 57-water infrastructure samples tested at 0.00ppm for free and residual chlorine.

The United States Centers for Disease Control (CDC) and Prevention define free chlorine as the available chlorine to inactivate disease-causing organism, and thus an indicator for potable water. The CDC and Prevention Safe Water System project recommends that a free chlorine level of 0.50ppm is sufficient to maintain the quality of water through the distribution process but not adequate for managing disinfection when the water is stored for over 2 hours. Increased free chlorine in drinking water is highly correlated with decreased bacteria concentration; however, in the absence of free chlorine, bacteria concentrations may increase from 1.1x105cells/mL to 1.8x105cells/mL in approximately two hours [35].

Microbiological contamination [36] in water distribution systems is associated with more significant morbidity and mortality than chemical contamination [37]. Diarrheal disease, such as that attributed to consumption of contaminated drinking water, accounts for approximately 9% of the mortality rate among children less than five years of age [38]. Reportedly, diarrhea and dysentery together account for 2.5 million children deaths per year in developing countries [39]. Diarrhea is one of the top ten diseases that cause death among children under 5years in Liberia [40].

IV. LIMITATION OF STUDY

Limitations of the survey included small sample size and the refusal of some households to cooperate. During the rainy season, surface runoff into water infrastructure may have generated increased variation in the level of contamination detected. The identification of either fecal or E. coli bacteria could has provided the researcher with relevant information in the association of the microbial source in the groundwater.

V. CONCLUSION

In this study, groundwater samples were taken from three types of water infrastructure (Figure 1) sources. The hand pump water infrastructure is the most improved water source for drinking and domestic use. The hand pump provides groundwater for the consumers through a piping system. The most improved water infrastructure, hand pump was contaminated with nitrate exceeding the permissible standard limits (50ppm) provided by WHO.

The survey of groundwater samples in the three communities of Paynesville City, Liberia suggests that immediate action is required to protect against potential water-borne disease outbreak. The results of the water analysis are an indicator that groundwater management within the study area does need attention.

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