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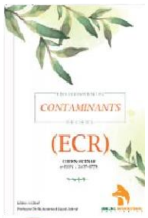

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RESEARCH ARTICLE

SPATIAL VARIABILITY OF WATER QUALITY FROM HAND-DUG WELLS AND THEIR CONTAMINANT SOURCES IN PERI-URBAN AREAS OF KOFORIDUA, GHANA

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ABSTRACT

This paper assesses the main sources and physicochemical and microbial properties in drinking water samples from hand-dug wells in peri-urban areas of Koforidua, the Eastern regional capital of Ghana. A social survey was used to gather data on water sources being used in five locations of the city. In addition, the quality of the hand-dug wells was assessed. The physicochemical parameters assessed are pH, electrical conductivity, total dissolved solids, alkalinity and total hardness. Metals and anions analysed were Ca, Mg, Fe, Mn, NO_3^-, NO_2^-, SO_4^{2-}, PO_4^{2-}, F^- and Cl. Total coliform, faecal coliform, Escherichia coli and total heterotrophic bacteria were also assessed. Also, a checklist of observation of ten water sources were assessed to determine the routes of exposure to the wells. The findings show that hand-dug wells, pipe-borne water and sachet water are the main sources of water for domestic use. Findings on physicochemical parameters of the samples are: pH, 6.36-7.17; conductivity (EC), 197-1040 µS/cm; PO_4^{3-}, 0.022-0.191 mg/L; NO_3^-, 0-0.1.38 mg/L; NO_2^-, 0-0.323 mg/L; SO_4^{2-}, 1.0-59.6 mg/L; Fe, 0.020-0.080 mg/L; Mn, 0.044-0.145 mg/L. These are at normal levels, however, total coliform, faecal coliform, escherichia coli and total heterotrophic bacteria values are all above recommended standards. It is concluded that water from the hand-dug wells is unhealthy for human consumption therefore not sustainable. There is a need for the municipal authorities to embark on aggressive testing of water points. Also, simple water testing technologies should be employed to test the water points in the municipality.

KEYWORDS

Koforidua, physiochemical analysis, microbial analysis, hand-dug wells, water points, contaminant sources

1. INTRODUCTION

Koforidua is a strategically located city in the Eastern Region of Ghana. It can be found on longitude 6° 4′ 59.9988″ N and latitude 0° 15′ 0.0000″ W. Most residents in this city depend both primarily and secondarily on hand-dug wells for their water supply (GSS, 2014; Danquah et al., 2020). During the rainy season, the city experiences heavy downpours which sometimes leads to flooding. Naturally, some of these overflowing waters enter the soil and ultimately the underground water system. Since city dwellers do not have any other means of acquiring domestic and agricultural water, they rely heavily on underground water in the form of hand-dug wells. The GSS (2014; 54) points out that, "the major water source for households is pipe-borne water inside the dwelling (35.2%), protected well (28.0%), bore-hole/pump/tube well (8.8%), pipe-borne water outside the dwelling (15.2%), public tap or standpipe (6.7%) and river or stream (2.8%)". Fetching water from the protected wells boreholes and streams for domestic purposes needs more than just boiling to make it safe for consumption.

Unfortunately, the health risks associated with water contamination (both physical and chemical) are constantly being neglected and ignored by most residents and authorities. While others are ignorant of the risk contaminated water poses to their health, those who are aware do not care as long as there is no outbreak of epidemic in the community. The situation of relying on hand-dug wells for domestic use in the study area becomes compounded by the fact that most houses do not have suitable places of convenience forcing most people to engage in open defecation (Aryee, 2024). This assertion is buttressed by the GSS (2014; 55) report which indicated that more than 35.9% of households use public toilets, 30.3% use water closets (W.C) facilities, 16.9% use the KVIP and 13.1% of the households in the Koforidua municipality still use Pit latrines. The use of these sanitation facilities can pose problems to the water sources which was noted to be mainly hand-dug wells.

Sustainable Development Goal 6.1 calls for universal and equitable access to safe drinking water, however, the majority of people in Ghana and Koforidua municipality in particular lack access to safe drinking water (GSS, 2014). Large portions of the populace in this city might be drinking contaminated water that transmits diseases like cholera, typhoid, diarrhoea, etc. The high health risk posed by these hand-dug wells cannot be quantified until a proper chemical and physical investigation of these hand-dug wells have been conducted. In the light of the United Nations (UN) Sustainable Development Goal (SDG) 6: Clean Water and Sanitation, there is a need to investigate the physical, chemical and biological characteristics of hand-dug wells in the Koforidua municipality. This is imperative both for the health risks associated with the direct consumption of this water source and to play a part in meeting the UNSDG 6 of 2030. Also, the municipal authorities have never done any water quality analysis on hand-dug wells in the study area making it important that this study is carried out.

No government or authority in Ghana can indeed eliminate the use of water from hand-dug wells for domestic purposes but what can be done is to carry out a detailed investigation to show how good or bad this water source is to human health. Using water from shallow hand-dug wells comes with water quality issues (Bakobie et al., 2015; Lutterodt et al.

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2018). There is a need to assess the quality of water being used by residents of peri-urban areas of Koforidua municipality because water sources affect human health and well-being (Boelee et al., 2019). The aim of this paper is thus to assess the quality of water in hand-dug wells and the contaminant sources in the Koforidua municipality and compare it with the World Health Organization standard parameters of clean water.

2. MATERIALS AND METHODS

2.1 Geology of the Study Area

The study area comprises the Voitain sedimentary rocks and Birimian intrusive granitoids. The intrusive rocks are basin-type granitoids (Saka et al., 2013). The granitoids are mostly granitic gneiss and biotite granitoids (Asante-Annor et al., 2020). The Voltaian rocks in the study area form part of the Kwahu Group. This group consists of sandstones, which are fine-grained around the base of group and are in some areas cross bedded, and poorly sorted (Coueffe and Vecoli, 2011). The area is controlled by tectonic structures (faults, fractures, and lineament) trending Northeast-Southwest, Northwest-Southeast, East-West and North-South as shown in Figure 1.

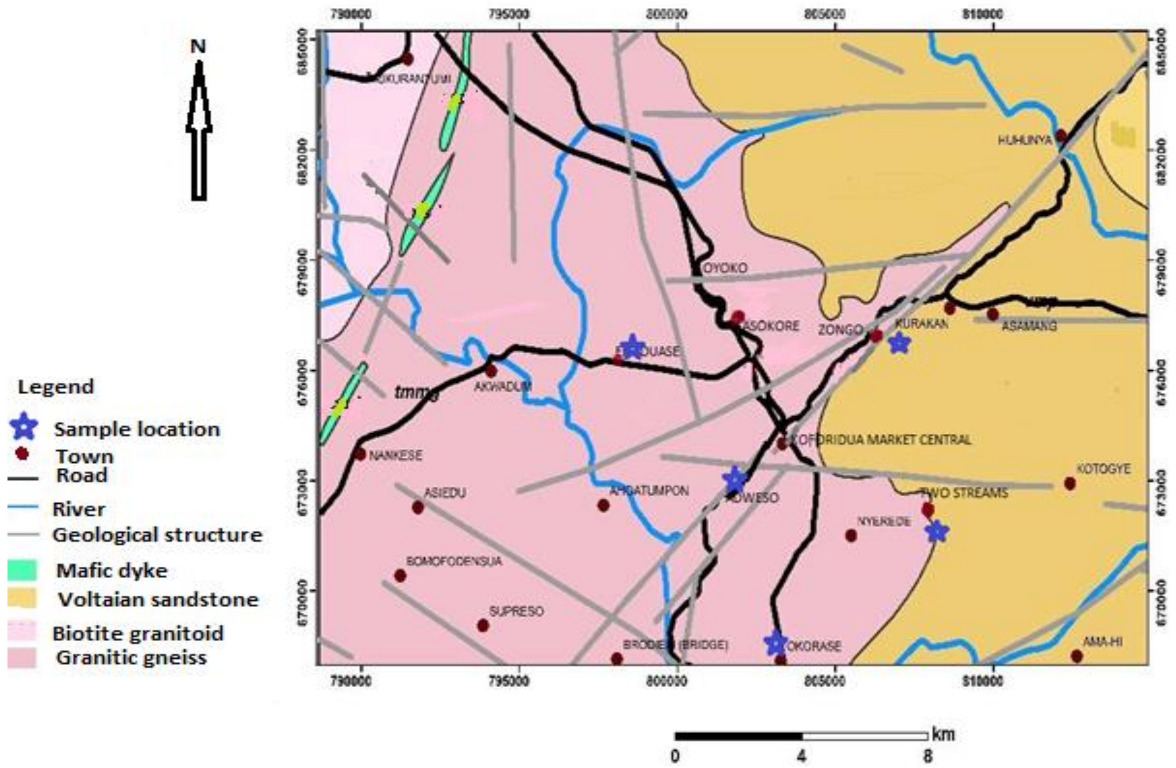

Figure 1: Study site and sampling locations. Source: Adapted from Asante-Annor et al., 2020 Asante-Annor

2.2 Sample collection

Two water samples were taken from five different hand-dug wells in various suburbs of the Koforidua municipality. The samples were taken in March and April which are the tip end of the dry season in Ghana and the start of the raining season. This time of the year was chosen because surface water percolation is in its lowest and ground water recharge is also not much due to the dry season. Similar to semi-arid areas, the study area has dry and wet seasons, but recharge of the groundwater occurs mainly after very heavy rainfall (Jaafarzadeh et al., 2021). The communities are Effiduase, Koforidua Zongo, Adweso, Okorase and Two-Streams.

Two streams is the name of a community. This name was given to the area due to the presence of two streams in the area. Samples from the hand-dug wells were taken after several litters of water was collected from the wells by residents or water users. The rationale for doing this is to remove as much stagnant water from the wells as possible. The water samples were collected into 1 litre pre-washed polyethene bottles. The bottles were made clean by washing them with 5% concentrated nitric acid. After emptying the nitric acid, the bottles were rinsed six times with distilled water to make certain that the bottle is clear of foreign materials. The pH of the samples was measured on-site. This was done with a Suntex® SP-707 portable pH meter. On-site testing of pH was done because this parameter is likely to change during the day and transportation to the laboratory.

Table 1: Geographical location of well sites

Area	Latitude	Longitude	Global positioning system (GPS)
Effiduase	6.11089	-0.26950	6° 6' 39.204'' N , 0° 16' 10.2'' W
Zongo	6.11685	-0.26255	6° 7' 0.66'' N , 0° 15' 45.18'' W
Adweso	6.06392	-0.27143	6° 3' 50.112'' N , 0° 16' 17.148'' W
Okorase	6.03430	-0.26109	6° 2' 3.48'' N , 0° 15' 39.924'' W
Two Streams	6.06563	-0.24393	6° 3' 56.268'' N , 0° 14' 38.148'' W

The water samples were collected in duplicates, stored on ice in the laboratory before they were analysed. The required physicochemical properties of the water samples like total iron, manganese, nitrite, nitrate, sulphate, phosphate, and fluoride were performed in the lab on the same day of sampling. Test on samples for bacteria was conducted about 5 hours after the samples were gathered. As is standard practice, test for anions was done after two weeks (14 days) of sample collection (Asamoah and Amorin, 2011).

2.3 Physiochemical and microbial analysis

Total Iron, Manganese, Nitrite, Nitrate, Sulphate, Phosphate, and Fluoride were determined using a photometric method (Nkansah et al., 2010; Borges and Reis, 2011). In line with analytical water test tablets that has been prescribed for Palintest® Photometer 5000 series were used to determine the physiochemical parameters (Nkansah et al., 2010). Each sample was analysed for Fe, Mn, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{-3} and F^-. The procedure outlined in the Palintest Photometer 5000 for the examination of water were used. Parameters such as total hardness, Magnesium and Calcium concentrations of the samples were determined with the use of complexometric titration with EDTA. The Chloride concentration was obtained from argentometric titration. The total dissolved solids and electrical conductivity (EC) were obtained by multifunctional WTW® cond. 730 series conductivity meter (Munich, Germany). As far as the microbial analysis was concerned, standard methods were used to obtain a total coliform, total heterotrophic bacteria, faecal coliform and escherichia coli (APHA, 1995; Brenner et al., 1993).

2.4 Social survey of water sources and water points

The target population for the study is residents living in the peri-urban areas of the municipality who are 18 years old or older. The study did not use as a sample two people from the same age group living in the same household. The focus was on the household as an analytical unit. This was used because the questions asked were specific to the household to which the respondent belonged.

Since the study is a hybrid of both scientific experimental research design and social science survey, the sample size for the study was just 55 people belonging to households (Mutz 2011). A quota was assigned to each of the five communities of the study and approximately 11 respondents were sampled using simple random sampling technique. The respondents were randomly sampled from houses around the water points being studied. In addition to the 5 water points tested and 55 social surveys undertaken in the study area, an additional 10 water points that are about 500m radius of the sampled water points were assessed. The researchers undertook a systematic random sampling of these community water points with a pre-structured observation sheet.

The observation sheet is a checklist prepared to assess each of the 10 water points based on the checklist that was similar to one developed by (WHO/UNICEF, 2017). Items ticked are whether the water point is: protected from outside contamination; general cleanliness near the water point; the closeness of the water point to a toilet/open defecation site; the presence of livestock farms in the area; closeness to open waste dump sites; the presence of unlined household/industrial grey/wastewater channels and other unsanitary conditions. These are indicators that can lead to contamination of water points in the study area. A cross-mark symbol (X) is indicated on the sheet to show the absence of such conditions around the water point and a check-mark symbol (✓) is indicated on the sheet to show the presence of such conditions around the water point.

3. Results And Discussion

3.1 Main sources of water for drinking and domestic use

As can be seen from Table 2, the main source of water for drinking and domestic use is hand-dug wells and this take about 30.9% of the responses. This is closely followed by pipe-borne water which takes about 29% of the responses. Borehole and sachet water took 20% and 16.4% of the response of the households studied. This finding reveals that, a high percentage of the households relies on improved water sources.

Table 2: Main drinking and domestic water sources

Source of water	Frequency	Percentage (%)
Pipe-borne	16	29
Bore-hole	11	20
Hand-dug well	17	30.9
Sachet water	9	16.4
River/Stream	2	3.7
Total	**55**	**100**

This finding is consistent with the Ghana population and housing census (2010) figures. In the population and housing census, it was revealed that "*pipe borne water in their dwellings as their main source of drinking water. It further reveals that sachet water, pipe born outside dwelling, public tap, and protected wells are the main source of drinking water for most of the population in the Municipality*" (GSS 2014; 54). Only a few households depend on rivers or stream or other unprotected water sources. Because majority of the respondents in our current study mentioned hand-dug well, it is prudent to undertake water quality test of these water sources to ascertain the cleanliness of these water points to be used for domestic purposes. The next section will be used to present the results of the physicochemical analysis of the five hand-dug water points.

3.2 Physiochemical analysis

Table 3: Physiochemical results of the five hand-dug wells and WHO standards

Parameters	Value of Samples					Ghana Standards GS 175-1	WHO Guideline
	Effiduse	Zongo	Adweso	Okorase	Two Streams		
Turbidity (NTU)	<1.00	<1.00	<1.00	<1.00	<1.00	5	5
Color (apparent) (Hz)	<2.50	<2.50	<2.50	<2.50	<2.50	15	15
Odour	-	-	-	-	-	Inoffensive	Inoffensive
pH (pH units)	6.36	6.55	6.68	6.68	7.17	6.5 – 8.5	6.5 – 8.5
Conductivity (µS/cm)	1040	332	447	197	602	-	300
Tot. Susp. Solids (SS) (mg/l)	<1.00	<1.00	<1.00	<1.00	<1.00	0	-
Tot. Dis. Solids (TDS) (mg/l)	624	199	268	118	362	1000	1000
Sodium (mg/l)	65.0	37.0	35.0	9.00	90.0	200	200
Potassium (mg/l)	7.60	2.90	2.30	2.80	5.40	30	30
Calcium (mg/l)	56.6	21.6	46.1	14.7	33.8	200	200
Magnesium (mg/l)	20.9	4.49	10.4	5.72	15.0	150	150
Total Iron (mg/l)	0.080	0.050	0.030	0.070	0.020	0.3	0.3
Ammonia (NH_4-N) (mg/l)	<0.001	<0.001	0.028	0.090	<0.001	0.00 – 1.5	0.00 – 1.5
Chloride (mg/l)	187	23.3	28.0	18.2	78.7	250	250
Sulphate (SO_4) (mg/l)	32.3	21.5	17.9	<1.00	59.6	250	250
Phosphate (PO_4-P) (mg/l)	0.087	0.034	0.022	0.156	0.191	-	-
Manganese (mg/l)	0.241	0.048	0.145	0.021	0.044	0.4	0.4
Nitrite (NO_2-N) (mg/l)	<0.001	<0.001	<0.001	0.323	<0.001	1.0	1.0
Nitrate (NO_3-N) (mg/l)	0.052	<0.001	<0.001	1.38	<0.001	10	10
Tot. Hardness (as $CaCO_3$) (mg/l)	228	73.6	158	60.2	146	500	500
Tot. Alkalinity (as $CaCO_3$) (mg/l)	46.0	103	179	49.8	180	-	-
Calcium Hardness (as $CaCO_3$)(mg/l)	141	54.1	115	36.7	84.6	-	-
Magnesium Hardness (as $CaCO_3$) (mg/l)	86.1	18.5	42.8	23.5	15.0	-	-
Fluoride (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	1.5	1.5
Bicarbonate (as $CaCO_3$) (mg/l)	56.1	126	218	60.8	219	-	-
Carbonate (mg/l)	0.00	0.00	0.00	0.00	0.00	-	-

The values obtained for the results of the physicochemical and microbial tests were recorded in Tables 3 and 4 below. The pH ranged from 6.36 - 7.17. These values are all within the WHO recommended limit for pH except for the Sample from Effiduase which is within ±2 of the range (WHO 2003). The electrical conductivity values of the samples from our sites ranged from 197 to 1040 µS/cm as can be seen in Table 3. The turbidity, colour, and total suspended solids all fall within the WHO and Ghana Standard limit for safe portable drinking water. The total hardness ranged from 60.2 to 228 mg/L and alkalinity from 46 to 180 mg/L. Table 3 also shows that the total hardness and alkalinity concentrations of the samples are below the WHO permissible limits which is good for the people in the study area. Total Iron ranged from 0.020 to 0.08 mg/ L, which is below the WHO permissible limit. Manganese concentrations in the samples ranged from 0.021 to 0.241 mg/L. Calcium and Magnesium concentrations ranged from 14.7 to 56.6 and 4.41 to 20.9 respectively. The levels of total Iron, Manganese, Calcium and Magnesium in all the samples analysed were below the limits permitted by WHO in drinking water. The human body needs much higher quantities of Calcium and Magnesium than Iron and Manganese. The low levels of calcium and magnesium in the drinking water could contribute to deficiencies in the human body.

The levels of anions determined in the water samples are shown in Table 3. The values of Cl^- concentration in the water samples from our study sites ranged from 18.2-187 mg/las. These values are far lower than the WHO recommended quality standard for drinking water of 250 mg/L. Phosphate (PO_4^{3-}) ranged from 0.022 to 0.191 mg/L. Fluoride (F^-) was observed to have the same values of less than 0.005 mg/L for all the samples analysed. The permissible limit for F^- concentration is 1.0-1.5 mg/L according to Ghana Standard Authority and WHO. Fluoride helps to protect the teeth from dental cavities provided its concentration is 1 mg/L or less (Nkansah et al., 2010).

It should be noted that, continued intake of concentrations higher than 4 mg/L would lead to dental fluorosis (Dissanayake, 1991). The nitrite concentrations range in the analyzed samples is between 0.001 to 0.323 mg. The nitrate was also ranged from 0.001 to 1.38mg. The range of sulphate in the analyzed samples was less than 1.0 to 59.6 mg/L. The values obtained for nitrite, nitrate and sulphate were all below the WHO permissible limits as shown in Table 3. Almost all the physiochemical parameters such as Sodium, Potassium, Calcium, Magnesium, Total Iron, Ammonia, Chloride, Phosphate Nitrite, Manganese, Nitrate, Total Hardness Total Alkalinity, Calcium Hardness, Magnesium Hardness, Fluoride, Bicarbonate and Carbonate analysed are within the acceptable limit for safe drinking water according to WHO and Ghana Standards even though some of the parameters had a wide range of concentrations. For example, Sodium ranged from 9 – 90 mg/l as against the 200 mg/l standard.

The findings in Table 3 above is in line with who concluded that "the concentrations of the investigated anions and trace metal ions in the water samples from hand-dug wells from the Kumasi Metropolis in the Ashanti region of Ghana were found to be acceptable according to the guidelines for drinking water provided by the World Health Organization (WHO)" (Nkansah et al., 2010). It should be noted that undertook their study on hand-dug wells in Kumasi which has a different geological structure compared to our present study (Nkansah et al., 2010). Also, the period of a decade is long for most of the parameters to change. To make a comparison with a study that is closer to the current study location, we use (Danquah et al., 2020).

This study evaluates the physical parameters in water bodies in the New Juaben Municipality using a survey research design and laboratory analysis. They concluded that levels of manganese, iron and zinc in the samples were extremely high whilst arsenic, copper and lead levels were in lower quantities. The sediment load in the streams and wells without physical barriers were also found to be high (Danquah et al., 2020). It can be said that our present study partially deviates in terms of manganese, iron and zinc concentrations (Danquah et al., 2020). Other findings are similar to our current findings. We now turn to the results of the microbial study. On the other hand, this study is in contrast with that of whose results showed that all the analyzed parameters used in their study were under the permissible limits that have been set by the World Health Organization (WHO) and the Pakistan National Standards for drinking water quality (Haider et al., 2024).

3.3 Microbial analysis

Table 4 below shows the microbial results of the hand-dug wells sampled in the Koforidua municipal area. It is important to ascertain the contamination levels in these wells because asserts that, in totality, external pressures emanating from water-related environmental exposure is a significant determinant of human health (Wild, 2012). The total coliform count ranged from 372 – 744 CFU (colony forming unit) per 100 ml. The acceptable limit of total coliforms is 0 both by the WHO and Ghana Standards. Hence, the water is considered contaminated with coliforms by both standards. The faecal coliform count ranged from 14 – 372 cfu per 100ml with an acceptable count of zero (0).

The Escherichia coli (E. coli) count ranged from 8 – 186 cfu per 100 ml with an acceptable count of zero (0). The total heterotrophic bacteria count ranged from 1114 – 4212 cfu per 1 ml with an acceptable minimum standard of 500 counts per 1 ml. These findings imply that the water sources from the sampled wells in the study area are not good and have to be treated before use due to the high microbial organisms' presence in them. Boiling, filtering and addition of chlorine to these water sources can help to reduce the number of microbial organisms and hence, reduce the public health risk they pose when consumed. It is important to highlight the fact that, "about 75% of people infected with (some diseases like) vibrio cholera do not develop any symptoms, although the bacteria are present in their faeces for 7– 14 days after infection" (Ohene-Adjei et al., 2017).

Table 4: Microbial analysis

Sampled Sites	Total Coliform (TC) (cfu/100ml) Method: APHA 9222A	Faecal Coliform (FC) (cfu/100ml) Method: APHA 9222D	*E. coli* (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Effiduase	651	93	22	3276
Zongo	558	32	14	4212
Adweso	372	14	8	1114
Okorase	651	372	186	2340
Two Streams	744	27	14	2340
Ghana Standards GS 175-1	0	0	0	500
WHO Guidelines	0	0	0	-

The findings in table 4 above are in line with what found out in their studies on water sources in Ghana (Lutterodt et al., 2018; Bakobie et al., 2015). A group researcher for instance discovered in their study on microbial contamination of selected boreholes and hand-dug wells in Dodowa in the Greater Accra region of Ghana that "there is widespread faecal pollution of groundwater in the area; both hand-dug wells and boreholes are heavily loaded with faecal matter (Lutterodt et al., 2018). Hand-dug wells are at greater risk to contamination compared to the boreholes". The question that remains unanswered is what are the main reasons why most hand-dug wells and boreholes in Ghana and the community are contaminated? Table 5 below answers this question. It can be seen from Table 5 that some hand-dug some wells in the study area are being put under pressure due to the failure of the people in the community to protect water sources from contamination; poor sanitation around the facilities; high proximity of water points to places of convenience; disposal of human waste or wastewater directly on the land or the water without adequate treatment; improper siting of sanitation facilities near water supplies are the contaminant sources. It can be seen from Table 5 that water points in the Zongo community are close to open dumpsites, have a lot of unlined households and local industrial grey wastewater channels. These are major contaminate sources of the water points. A resident in Two Streams also complained that some people in the community are used to pumping wastewater from their houses onto the streets during the night. This water might enter the stream leading to its contamination because the water source is not protected from outside contamination. The general cleanliness near the water points where people do fetch the water is also not good.

Table 5: Contaminant Sources of Water Points

Water Points	Protected from outside contamination	General cleanliness near water Point	Closeness to toilet/open defecation site	Presence of livestock Farms	Closeness to open dumpsites	Unlined Household/industrial grey/waste water channels	Other insanitary conditions
Effiduase Well 'A'	X	X	X	✓	X	✓	X
Effiduase Well 'B'	X	X	X	X	X	✓	X
Zongo Well 'A'	X	X	X	X	✓	✓	✓
Zongo Well 'B'	X	X	X	X	✓	✓	✓
Adweso Well 'A'	✓	✓	X	X	X	X	X
Adweso Well 'B'	✓	✓	X	X	X	X	X
Okorase Well 'A'	X	X	✓	X	✓	X	X
Okorase Well 'B'	X	X	X	X	✓	X	X
Two Streams Well A	X	X	X	✓	X	✓	X
Two Streams Well B	X	X	X	✓	X	✓	X

These actions might be responsible for the presence of high total coliform and high total heterotrophic bacteria in Effiduase and the Zongo communities. Our finding of sanitation in this Zongo community is not new. Owusu in his conclusion on sanitation in Sabon Zongo, Accra points out that "*the current poor state of sanitation in Sabon Zongo is not an accident. It is the result of the rapid pace of urbanization and its attendant challenges* (Owusu, 2010). *This situation emanates largely from weak local and central government response to the process of urbanization in Ghana, resulting in the underperformance of the Ghanaian urban economy*".

The potential impacts being put on water points in the study area and Ghana are the depletion of surface and groundwater resources, chemical degradation of the quality of potable water sources (surface and groundwater), creation of stagnant (standing) water and supply of contaminated water to households. The impact of these activities is an increase in the transmission of diseases in the area. They are contaminated due to the exposure of these water bodies to excreta leading to diarrheal and parasitic disease. For instance, in March 2020, the Ghana Health Service said it detected a Poliovirus strain (Polimylitis) in the polluted Nsukwao River in Koforidua, the Eastern Regional Capital. This disease is normally transmitted through direct contact with an infected person or contaminated food and water (GSS 2014). Authorities at the municipality said they do not undertake water quality tests of hand-dug wells in the community because of the number and its associated cost (Vordzogbe et al., 2021). For instance, the Centre for Scientific and Industrial Research (CSIR) in Ghana will charge about Ghana cedis 500 (about 80 US$) to conduct a simple physiochemical and bacteriological analysis of a water sample from one well. This cost is too expensive to the municipal authorities whose responsibility it is to make sure that people live in a safe and healthy environment.

4. Conclusion And Recommendations

Physiochemical and microbial analysis of hand-dug wells within the Koforidua municipal area of Ghana were analysed using the photometric method. This study concludes that the concentrations of the physiochemical parameters investigated in the water samples from hand-dug wells from the Koforidua municipal area are within the acceptable limits of the guidelines for drinking water provided by the Ghana Standard Authority and World Health Organization (WHO). It is concluded here that United Nation SDG goal 6.1 which call for universal and equitable access to safe drinking water can be achieved based on the current physiochemical results from this study. However, the conclusion on the microbial analysis of this study is that the quality of water supplied by the hand-dug wells are unacceptable due to high levels of total coliform, faecal coliform, escherichia coli and heterotrophic bacteria indicators in the samples.

The tests of the water sources, according to both Ghana and WHO standards are not safe to be used as drinking water. They can be used to do other domestic chores like cooking and washing. If it has to be used as drinking water, it has to be boiled or treated with hypochlorite solution to kill most of the microbial parasites in the water before drinking. The reason for the high levels of total coliform, faecal coliform, escherichia coli and heterotrophic bacteria in the sampled water sources can be attributed to high levels of usage of KVIP and pit latrines of households within the Koforidua municipality.

The implication from this study is that the microbial pollution of groundwater in the study area and Ghana, in particular, may be widespread and heavily loaded at alarming levels. This study is therefore recommending to the New Juaben Municipal Assembly and the Ministry of Local Government and Rural Development to monitor hand-dug wells within the municipality and the country as a whole. It is impossible to require every household to acquire permits before constructing hand-dug wells, boreholes or toilet facilities but enforcement or adherence to the specifications in the Water and Sanitation handbook for Municipal Assemblies should be enforced. There is a need for the different stakeholders of drinking water quality management in the country to collaborate and ensure that, drinking water sources are analysed as often as possible in the country. Agencies in health and environment protection such as Ghana Health Service, Environmental Protection Agency (EPA) and the Water Resource Commission have to link up with the Metropolitan, Municipal and District Assemblies to ensure that people are using safe drinking water for the attainment of the SDGs.

External testing of water points for contamination is part of the quality assurance mechanisms of water management but this is not being done in Ghana and other developing countries. To help assure safe water to both rural and urban communities, there is a need for the districts and municipalities in Ghana to develop and use simple cost-effective on-site microbial testing of water points. Safe water network's Aquagenx rapid microbial kits for detecting total coliform and E. coli should be rapidly propagated in the country. Good sanitary and hygiene practices should be taken by the municipal assembly. To scale up the study, similar investigations must be conducted to assess the quality of the hand-dug wells in other small towns in the region and at different seasons of the year.

The fact that water samples were not collected from every significant suburb in the New Juaben Municipality is a significant limitation of this study. By taking this action, the study's conclusions regarding the wells' water quality would have gained credibility. This would have made it easier to identify the precise locations inside the municipality where pollution is most prevalent. It is also important to note that the study used a few households for analysis. Due to budgetary constraints, the data sample consisted mostly of small households. This may raise concerns about how pervasive people in the municipality are using contaminated domestic water are in the study area. Despite these drawbacks, we can conclude that this study is a useful starting point for further research on the urban domestic water quality of small and medium towns in Ghana.

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