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Original Research Article

Impact of Unregulated Borehole Siting on Groundwater Quality

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ABSTRACT

This study was on the impact of unregulated borehole siting on groundwater quality. The study areas were World Bank housing and Federal low-cost housing estates in Umuahia South local government area of Abia State Nigeria. A total of 20 samples were collected from boreholes, 10 samples from boreholes sited with separation distances from septic tanks above 30 m, and 10 samples from boreholes sited with separation distances from septic tanks below 30 m. Standard laboratory methods were used to determine the physicochemical and microbiological parameters of the water samples. Tests of hypothesis at 5% level of significance showed that for 11 out of the 16 parameters tested which represents 68.75% of the parameters, no significant difference existed between boreholes sited with regulations and those sited without regulations. Also, most of the water quality parameters satisfied the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards, except total coliform count and Streptococcus in regulated boreholes, and total coliform count, fecal coliform count, E. coli and Streptococcus in unregulated boreholes. The pH value and concentration of phosphate was higher in regulated boreholes and these could be attributed to influence of other septic systems not considered and within the vicinity area studied. It was concluded that proximity of septic systems adversely affects groundwater sources.

1. INTRODUCTION

It has been observed that groundwater sources close to septic systems are contaminated thereby giving rise to waterborne diseases (Mlipano *et al.*, 2018). Water is important for the existence of any forms of life (Khadsan and Mangesh, 2003). It is also one of the earth's most important, renewable and widely distributed resources of which 97.2% constitute groundwater (Rajesh, 2012). Groundwater constitutes 97% of global fresh water (Bharti *et al.*, 2011), whose quantity, quality, accessibility and recharge depend mostly on geology, geomorphology, land use and levels of precipitation (Elisante and Muzuka, 2015). On-site wastewater (water collected from indoor flush toilets, bathrooms, laundries and kitchen via septic tanks/soak away pits) treatment systems are point sources of pollution, therefore, they are expected to exert great impact on groundwater sources in their vicinity (Gideon *et al.*, 2004). For instance, a study on groundwater that was conducted in 2010 in selected areas of Lusaka prone to risk of contamination by effluents from dump sites showed high levels of contamination of groundwater by bacteria (Mlipano *et al.*, 2018). There are a lot of guidelines, standards and regulations on drinking water quality that can offer public health protection (WHO, 2011). Drinking water is defined as potable water intended for human consumption. Safe water is important for human health and sustainable development (Sungsitthisawad and Pitaksanurat, 2013). In many developing countries, citizens' access to reliable and safe water is a challenge (Kapongola *et al.*, 2014). Groundwater is commonly an alternative water resource in areas where surface water is not accessible (Sungsitthisawad and Pitaksanurat, 2013).

There are many factors that have to be considered when assessing the quality and safety of groundwater as the drinking water. The water quality and safety indicator include the testing for total coliforms, faecal coliforms (*E. Coli*), inorganic contaminants, organoleptic (appearance, taste and odour) salinity, hardness, natural and artificial organic pollution and pH (TBS, 2019). The quality of groundwater is the result of the processes and reactions that act on the water and varies from one place to another depending on the depth of the water table (Mohan *et al.*, 2014; Abong'o *et al.*, 2017). Groundwater can be contaminated by chemicals as well as microorganisms (Bharti et al., 2011). For instance, groundwater resources in coastal areas like Dar Es Salaam in Tanzania are always in danger of contamination by sea water intrusion (Mtoni *et al.*, 2012). Lacking sanitation facilities constitutes a major pollution source to groundwater, both in terms of microbiological and inorganic contamination, i.e. mainly nitrates. If water supply boreholes are located in direct neighbourhood to malfunctioning pit latrines or septic tanks, microbiological pollution of the bore hole will trigger a vicious faecal-oral infection cycle threatening public health (Andrea *et al.*, 2010).

Generally, groundwater becomes purer with increase in depth (Ojo et al., 2012). For instance, boreholes in Tanzania are classified as shallow (0-30 m), medium (31-50 m), deep (51-80 m), and very deep (>80 m) (Baumann *et al.*, 2005; Kashaigili, 2012). It has been reported by Likambo (2014) that the further the distance from the borehole from the potential source of pollution, the more difficult it will be to become contaminated. In drilling water boreholes, there are guidelines, specifications and regulations that must be strictly followed and observed to ensure production of good water quality and these include the NIS (2010), WHO (2003, 2011) and UNICEF standards.

Very crucial in borehole location and construction is its minimum safe distance requirement to possible source of contamination and pollution. When this is not observed, the water quality can be compromised, and the water will be unsuitable for drinking (NIS 2010; WHO 2011). According to WHO (2003, 2011) the recommended minimum distance between septic system and any borehole system should be between 30 m-40 m depending on the soil structure and minimum depth of 100 m to 150 m. A standard borehole is a hydraulic structure drilled by a drilling machine properly designed and constructed to permit economic withdrawal of water from an aquifer. Guidelines/regulations on drinking water quality that can offer public protection are recommended by WHO (2011) and NIS (2010). Therefore, the aim of this study was to investigate the impact of not regulating the siting of boreholes on the quality of groundwater resource. This has been the case with developing countries such as Nigeria, where boreholes are drilled indiscriminately without observing the standard separation distances approved by the World Health Organization (WHO) and similar bodies.

2. MATERIALS AND METHODS

2.1. The Study Area

The study area covers World Bank Housing Estate (WBHE) and Federal Low-Cost Housing Estate (FLCHE). These are fast growing estates both located in Umuahia South Local Government Area in Umuahia Capital Territory of Abia State, Nigeria. Umuahia South is in the Central Senatorial District of Abia State. Umuahia South Local Government Area has its Administrative Headquarters at Apumiri Ubakala. It is located at Equatorial Rain Forest Zone and share boundaries with Umuahia North Local Government Area to the North, Isiala Ngwa North Local Government Area to the South and South-East, and Ikwuano Local Government Area to the North East and Imo River on the other side. Umuahia South lies between Latitudes 5^{o} $20^{'}$ and 5^{o} 33' North and Longitude 7^{o} 25' and 7^{o} 35' East.

The study area falls within the high permeability of Benin formation and the intercalation of the sands with clay/clayey shale layers, with its overlaying lateritic earth and underlying Bende - Ameki formation, giving rise to a favourable multi-aquifer system (Igboekwe and Uhegbu,2014). These two estates do not have any pipe borne water supply system from the Abia State Water Agency (ASWA). They depend solely on groundwater supply from borehole system.

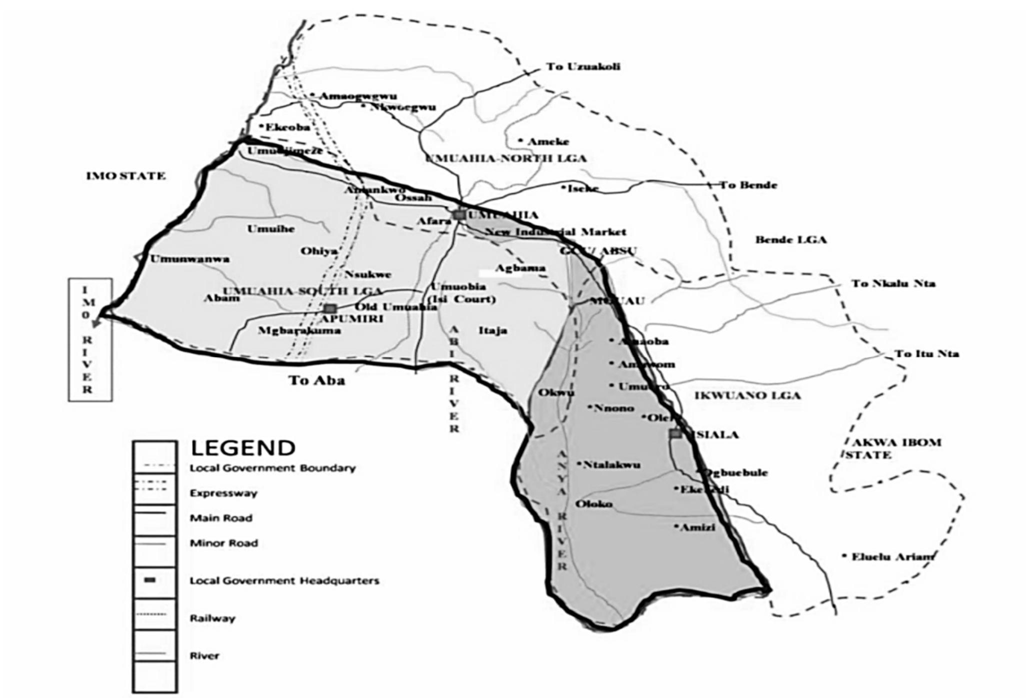

Figure 1a: Map of Umuahia South Local Government Area, Abia State Nigeria (Igboekwe and Uhegbu, 2014)

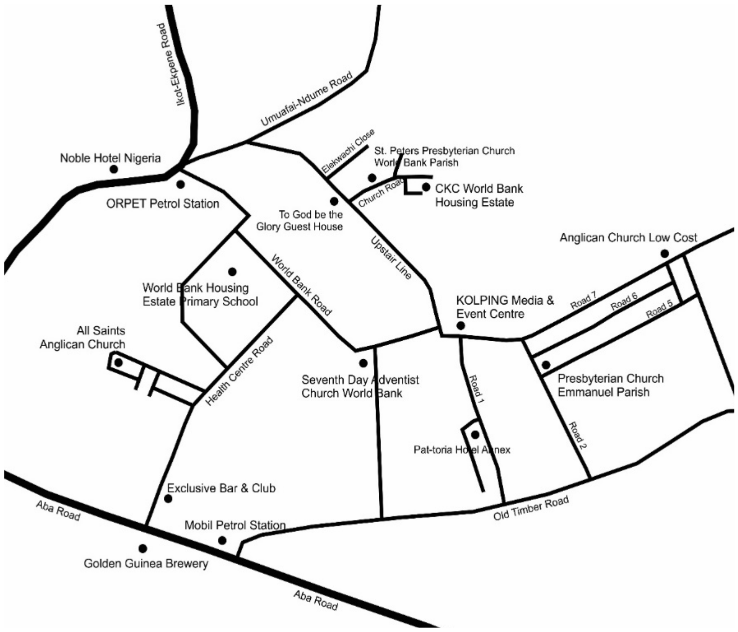

Figure 1b: Map of Study Area (World Bank Housing Estate and Federal Low-cost Housing Estate)

2.2. Samples and Sampling Techniques

Water samples were randomly collected from World Bank Housing Estate and Federal Low-cost Housing Estate from designated locations and residences. A total of 20 water samples were collected, 10 samples from boreholes drilled observing the safe siting distances from septic systems (Regulated). The distances were 36.5 m, 35.8 m, 37.4 m, 35.5 m, 32.5 m, 30.4 m, 32.0 m, 34.0 m, 37.0 m and 33.5 m. The other 10 samples were from boreholes drilled not observing the safe siting distances from septic systems (Unregulated), with distances 7.5 m, 8.5 m, 14.2 m, 10.5 m, 10.0 m, 13.5 m, 12.5 m, 11.0 m, 9.5 m and 11.0 m. Regulated boreholes are those that met the minimum safe distance of (30 - 40 m) according to (WHO, 2011, NIS, 2010). While the unregulated are those that are not in compliance with the above guidelines.

The water samples were collected directly from taps on the boreholes. Each tap was sterilized by a flame from cotton wool soaked in methylated spirit as a source of heat to destroy microorganisms and avoid contamination of the water. After sterilization, the tap was allowed to flow for at least 60 seconds before water samples was collected into 50 ml of sterile bottles. The water samples were taken to laboratory for physicochemical and microbiological tests. The tests conducted were odor, taste, colour, temperature, pH, turbidity, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen (DO), Nitrate, Nitrite, Ammonia, Phosphate (PO_4), BOD, COD, total coliform count, fecal coliform count, *E. coli.* and *Streptococcus* respectively. These tests were conducted using standard methods as in APHA, AWWA, WEP (1992).

2.3. Hypothesis

The two-tailed tests of hypothesis were carried out on each of the parameters at 5% level of significance to ascertain if there exist significant differences between bore-wells sited observing the minimum separation distances and the ones not meeting up with this regulation.

Null Hypothesis, H_o: $\mu = \mu_0$, and there is no significant difference between the quality of water from the boreholes sited with the minimum separation distances observed and the ones sited without observing the minimum separation distances.

Alternative Hypothesis: $\mu \neq \mu_0$, and there is significant difference between the quality of water from the boreholes sited with the minimum separation distances observed and the ones sited without observing the minimum separation distances.

The test statistic is given as:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s/\sqrt{\left(\frac{1}{N_1}+\frac{1}{N_2}\right)}} \quad (1)$$

$$s = \frac{s_1^2 + s_2^2}{2} \quad (2)$$

Where $\bar{x}_1$ and $\bar{x}_2$ are the sample means for each of the parameters for regulated and unregulated boreholes.

s= standard deviation, t= t-score, s_1^2 and s_2^2 are the standard deviations for each of the parameters for regulated and unregulated boreholes and N_1 and N_2 are the sample sizes for each of the parameters for regulated and unregulated boreholes.

Decision: If the computed $|t|$ is smaller than the tabulated $t_{0.95,9}$ the result is not significant at 5% level of significance so that the null hypothesis will be accepted that no significant difference exist between the qualities of water from regulated boreholes and unregulated boreholes. On the other hand, if computed $|t|>t_{0.95,9}$ the null hypothesis is rejected and the alternative hypothesis that significant difference exist between the qualities of water in regulated and unregulated boreholes is accepted.

3. RESULTS AND DISCUSSION

The indicators used in this study to determine the impact of separation distances between septic tanks and boreholes are shown in Tables 1 and 2. BH means borehole while the subscripts denote the borehole number (i.e. BH_1 means borehole number 1). Tables 1 and 2 show the results from laboratory tests. The appearance of the water samples was clear, while odour and taste were unobjectionable at ambient temperatures. The pH for regulated boreholes ranged from 6.0 to 7.8 which is within the NSDWQ standard of 6.0 to 8.5, while the unregulated borehole gave 4.7 to 5.6 which is acidic and unfit for human consumption. Water samples from both regulated and unregulated boreholes satisfied turbidity standard as can be seen from Tables 1 and 2 because their values were appreciably low. The range for total dissolved solids (TDS) is 5 - 500 m for both NSDWQ and WHO standards so that both regulated and unregulated boreholes met the standard but TDS for unregulated boreholes was higher indicating contamination due to proximity of septic systems to wells. The highest value was 9.5 mg/l for regulated borehole No. 9 while it was 17.8 for unregulated borehole No. 10.

The highest value of total suspended solids (TSS) was 8.4 mg/l for regulated borehole No. 8 and 13.8 mg/l for unregulated borehole No. 5, the mean value of dissolved oxygen for regulated borehole was 2.96 mg/l as against 4.23 mg/l for unregulated borehole. This increase in dissolved oxygen in the unregulated borehole is an indication of lower microbial activity, a reverse of widely accepted concept as one would expect higher microbial activity because organic matter contents are supposed to be higher. This result could be as a result of unknown factors taking place which were not considered in this work.

Table 1 Physicochemical and microbiological water quality parameters for regulated boreholes (≥ 30 m)

Parameters /Units	BH_1	BH_2	BH_3	BH_4	BH_5	BH_6	BH_7	BH_8	BH_9	BH_{10}	$\sum \bar{x}_i$	$\bar{x}_i$	NSDWQ	WHO
Dist. b/w borehole & Septic Tank	36.5	35.8	37.4	35.5	32.5	30.4	28	28	27	26.5				
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	_	_		
Odour	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	_	_		
Taste	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	_	_		
Colour (HU)	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Temperature (°C)	27	26.5	28	27.5	27	26.5	27.8	29	27.8	26.8	273.9	27.39	Ambient	
pH	6	6.9	6.5	6.5	7.0	7.5	6.8	6.4	6.5	7.8	67.9	6.79	68-85	6.5-8.5
Turbidity (NTU)	0.005	0.005	0.001	0.001	0.002	0.001	0.003	0.005	0.006	0.004	0.033	0.0033	01-5	01-5
TDS (mg/L)	3.55	3.45	4.06	4.04	8.40	8.51	9.2	9.0	9.5	9.2	68.91	6.891	500	500
TSS (mg/L)	2.00	2.10	3.80	3.50	3.7	3.90	3.40	8.4	8.0	7.0	45.80	4.580	500	500
DO (mg/L)	2.30	2.35	3.55	3.60	2.30	2.40	2.80	3.8	3.8	2.65	29.55	2.955		
Nitrate (mg/L)	2.80	2.89	2.70	2.89	2.89	3.50	2.60	2.63	4.20	2.51	26.72	2.672	0.2	3
Nitrite (mg/L)	1.40	1.45	1.03	1.02	0.25	0.50	0.57	0.23	0.24	0.25	6.94	0.694	1-50	
Ammonia (mg/L)	5.60	5.70	4.80	4.80	4.50	4.70	4.20	5.50	5.60	5.50	5.09	5.09.		
Phosphate PO_4 (mg/L)	0.03	0.025	0.5	0.61	0.62	0.65	0.66	0.61	0.59	0.67	4.965	0.497	.005-.05	
BOD (mg/L)	1.4	1.45	1.48	1.57	1.58	2.04	2.50	2.90	3.10	3.50	21.52	2.152	1-8	
COD (mg/L)	2.64	2.65	2.55	2.8	0.38	0.41	0.77	0.90	1.90	1.70	16.70	1.670	<40	
Total Coliform Count (cfu/100 ml)	137	134	136	132	140	145	445	420	350	400	2439	243.9	10	
Fecal Coliform Count (cfu/100 ml)	0	0	0	0	0	0	0	0	0	0	0	0	0	
E. coli. (cfu/100 ml)	0	0	0	0	0	0	0	0	0	0	0	0	0	
Streptococcus (cfu/100 ml)	25	20	36	33	50	45	60	50	70	60	444	44.4	0	

Table 2: Physicochemical and microbiological water quality parameters for unregulated boreholes (<20 m)

Parameters /Units	BH_1	BH_2	BH_3	BH_4	BH_5	BH_6	BH_7	BH_8	BH_9	BH_{10}	$\sum \bar{x}_i$	$\bar{x}_i$	NSDWQ	WHO
Dist. b/w borehole & Septic Tank	7.5	8.5	14.2	10.5	10.0	13.5	12.5	11.0	9.5	11.0				
Appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	_	_		
Odour	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	_	_		
Taste	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ	UOBJ				
Colour (HU)	5	5	5	5	5	5	5	5	5	5	.	.	5	5
Temperature (°C)	27.8	28.10	27.90	29.0	26.80	27.10	28.10	26.50	27.0	27.50	275.8	27.58	Ambient	
pH	4.70	4.80	5.45	5.4	5.5	4.5	5.3	5.40	5.5	5.6	52.15	5.215	6.0-8.5	
Turbidity (NTU)	0.035	0.007	0.008	0.005	0.006	0.012	0.013	0.009	0.007	0.002	0.074	0.007	0.1-5	0.1-5
TDS (mg/L)	16.40	16.35	16.55	15.88	17.00	8.5	15.85	16.3	16.9	17.8	167.53	16.75	5-500	5-500
TSS (mg/L)	13.8	13.5	12.68	12.7	13.5	12.5	11.8	10.8	11.2	8.90	121.38	12.14	5-500	5-500
DO (mg/L)	3.50	3.55	3.45	4.55	3.55	3.60	4.55	4.95	5.00	5.60	42.30	4.230		
Nitrate (mg/L)	8.40	8.45	9.0	9.50	8.95	7.85	8.50	8.50	9.10	10.15	88.40	8.840	1-50	
Nitrite (mg/L)	2.80	2.95	3.10	3.20	2.0	2.70	2.80	3.20	2.90	3.30	29.65	2.965	0.2	3
Ammonia (mg/L)	12.48	12.53	12.80	13.10	12.30	12.50	11.90	13.10	13.50	12.80	127.01	12.70		
Phosphate PO_4 (mg/L)	0.340	0.340	0.410	0.415	0.441	0.470	0.350	0.400	0.410	0.415	3.978	0.398		
BOD (mg/L)	3.60	3.50	2.40	3.10	3.00	2.90	2.90	2.90	1.89	1.90	28.14	2.814	2 < 5	
COD (mg/L)	4.34	4.20	4.30	4.20	4.50	4.55	5.00	6.00	5.90	5.50	48.49	4.849		
Total Coliform Count (cfu/100 ml)	8330	8200	3500	560	5700	3700	4500	5030	6050	4900	55510	5551	10	10
Fecal Coliform Count (cfu/100 ml)	1050	1000	950	1250	1300	1200	1050	1000	1200	1300	11300	1130	0	0
E. coli. (cfu/100 ml)	200	50	70	80	50	90	100	70	50	70	830	83.0	0	0
Streptococcus (cfu/100 ml)	100	150	150	100	250	80	150	100	200	180	1460	146.0	0	0

Table 3: Computed t-scores for water quality parameters at 5% level of significance

Parameter	t-score	Parameter	t-score
Temperature	-0.111	Ammonia	-6.743
pH	1.129	phosphate	0.242
Turbidity	-0.192	BOD	-0.434
TDS	-2.349	COD	-1.664
TSS	-1.716	Total coliform	-1.329
DO	-0.785	Fecal coliform	-5.343
Nitrate	-3.032	*E. coli.*	-1.180
Nitrite	-2.655	*Streptococcus*	-1.146

Mean values of Nitrate, Nitrite and Ammonia for regulated borehole Nos. 1 to 10 were 2.67 mg/l, 0.694 mg/l and 5.09 mg/l, but for unregulated boreholes they were 8.84 mg/l, 2.97 mg/l and 12.70 mg/l respectively. These are evidence of higher contamination due to proximity to septic systems since sewage is associated with high content of these compounds such as nitrate and nitrite.

Mean values of BOD and COD were 2.152 mg/l and 1.670 mg/l for regulated boreholes as against 2.814 mg/l and 4.849 mg/l for unregulated boreholes. Total Coliform count in the 10 regulated boreholes exceeded the permissible value of 10 cfu/100 ml for NSDWQ standard with a mean concentration value of 243.9 cfu/100 ml, the reason for this is beyond our comprehension since standard separation distances were observed. This could be as a result of other septic systems such as dump sites within the vicinity studied, which influence were not considered in this work. Though a worse scenario was observed in the unregulated boreholes with mean concentration value in the neighborhood of 5551 cfu/100 ml sample.

From the two-tailed hypothesis tests carried out at 5% level of significance and 9 degrees of freedom, the tabulated t-score was 2.26 an indication that most water quality parameters satisfy the Null Hypothesis that there is no significant difference between the qualities of water from boreholes sited with the minimum separation distances observed and the ones sited without the minimum separation distances observed. It was also noted that for 11 out of the 16 parameters tested, no significant difference existed between boreholes sited with regulations and those sited without regulations. In Table 3, the t-scores in temperature, pH, turbidity, TSS, DO, Phosphate, BOD, COD, Total coliform, *E. coli* and *Streptococcus* respectively showed that there is no significant difference in the water quality of these parameters. Nevertheless, t-scores in TDS, Nitrate, Nitrite, Ammonia, and Fecal coliform indicated significant difference between the bore-wells sited with observation of minimum separation distances and those sited without minimum separation distances observed.

Despite the fact that virtually all the water quality parameters met the NSDWQ and WHO standards, it was observed that fecal coliform count and *Streptococcus* did not meet these standards in the boreholes sited with regulation. This is because the 10 boreholes showed traces of these organisms, a scenario beyond our comprehension since minimum separation distances were observed before siting these wells.

The quality of water in unregulated boreholes is acidic which is justified, but concentration of Phosphate was higher in regulated boreholes. One would expect the result to be the other way since the nearer the wells are to septic systems, the greater the chances of contamination. These could be as a result of some factors not considered in this study.

4. CONCLUSION

The results of the study on the impact of unregulated borehole siting on groundwater quality showed that most of the water quality parameters met the WHO and NSDWQ standards. It was noticed that total coliform count and Streptococcus exceeded both WHO and NSDWQ standards. However, higher concentrations in the water quality parameters were observed in the unregulated boreholes which indicates that proximity of septic systems to groundwater sources have adverse effect on them. About 31.25% of water parameters measured showed higher concentrations in the regulated boreholes, a situation which contradicts widely accepted concept that the nearer the septic system, the higher the contamination. However, this could be as a result of other septic systems such as dump sites within the vicinity studied, which influence were not considered in this work. The test of hypothesis carried out at 5% level of significance, 68.75% of parameters tested agreed with the Null hypothesis that there is no significant difference between qualities of water in regulated and unregulated boreholes.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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