The Effects of Site and Well Characteristics on Groundwater Quality in Lagos, Nigeria

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ABSTRACT

The paper attempts an examination of the relationship between groundwater quality and some site and well characteristics of 30 hand-dug wells in Lagos, Nigeria. Multivariate procedures of correlation and stepwise regression were used in the study. The results showed that zinc, TDS and EC have the greatest number of correlation with other water parameters while pH and temperature had no significant relationship at all with other parameters. Furthermore, three levels of relationships were identified between water parameters and well/site attributes. a) temperature, pH and chloride were found to be significantly correlated with site/well features namely i) temperature with depth of well, type of well cover and nature of surrounding ground; ii) pH with the nature of surrounding ground and iii) chloride with the age of well. The stepwise regression analysis showed that the well features had significant effects on these parameters. b) Significant relationship was established between the concentration of i) iron and distance to septic tank, ii) manganese and depth of well, iii) e-coli and height of well rim above ground surface, iv) zinc and depth of water in the well, v) magnesium and nature of surrounding ground. However, the stepwise regression indicates that none of the well / site features had significant effect on water parameters. c) No significant relationship was identified between parameters (like nitrate, turbidity, TDS and EC) and well/site features. The paper calls for further research.

Keywords: Groundwater, water quality, Lagos, well features, hand-dug wells

INTRODUCTION

Usually, groundwater quality is linked to various physical factors and processes such as geology, climate, mineral dissolution and mixing of saltwater with freshwater. However, there are other local factors that can affect groundwater quality, particularly in the urban environment. For instance, Craun (1979) and Katz et al., (2009) identified the septic system as one of the major sources of groundwater pollution. A septic system is an on-site waste-water treatment system for individual home (Kaplan, 1987). The septic system comprises a septic tank and the drain field constructed beneath the ground. The solid components are retained in the septic tank for decomposition while the liquid part is released through the drain field into surrounding soil for a natural process of purification. High septic system density areas have had numerous cases of groundwater contamination reported (Yates, 1985). In the United States, it has been determined that areas with greater than 40 septic systems per square mile (that is one system per 16 acres) are regions of potential groundwater contamination EPA (2005).

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According to Egboka et al., (1989), pathogenic microorganisms are present in groundwater especially in the vicinity of facilities that are discharging contaminated surface waters. It follows, therefore that the nearer these sources of pollution are to groundwater sources, the greater the chance of successful seepage of these microorganisms. Shallow wells and some deep boreholes are prone to contamination by these pathogens.

The effectiveness of the soil as a treatment system will vary considerably with a number of changing environmental factors. Such factors include soil and air temperatures, the level of the groundwater table, and the amount of oxygen that is in the soil. As the concentration of effluent in the soil increases, the ability of the soil to treat it may reduce. Even with a soil absorption system operating well, ground- water contamination is inevitable because the soil is not equally effective at removing all constituents of the percolate (Viraraghavan and Warnock, 1976).

In environments where adequate sanitation is not being provided, both surface and ground water are vulnerable to contamination. The groundwater gets contaminated by seepage from polluted surface waters particularly through the digging of wells. More often than not, wells are sunk less than 5m away from obvious sources of pollution like pit latrines. Worse still, the water wells are usually not lined at all and may not be covered.

For instance, metropolitan Lagos is characterized by an array of blighted communities much so that almost 70 percent (70%) of Lagos' population consequently live in the slums (Adelekan, 2009). It is normal to have families of five or more persons all live together in one small room, (average size of 4.30 m^2). Many homes are in poor conditions and the scanty facilities in them are shared. Okafor (1985) noted that in major parts of Nigeria, feces are disposed of on ordinary dry ground, bucket latrines, the pit-latrine, and septic tank latrine. Sewage systems are non-existing. This observation is typical of the Lagos environment.

More than 67% of households within the Lagos environment depend on groundwater for domestic water needs (Lagos Household Survey, 2011) including drinking purposes. This figure is huge bearing in mind that in the 2006 census, Lagos recorded a population figure of more than 9 million people (NPC, 2006). The estimated population of Lagos is more than 15 million currently. Governmental agencies responsible for water provision are unable to meet up with the demand, and most homeowners have resorted to the construction of private wells within the living premises. It implies that the groundwater resource is exploited mainly through boreholes, and hand-dug wells with the use of hand–dug wells being more prevalent probably due to the low cost of construction.

Consequently, there is a high density of hand-dug wells within the living environment. Usually, there is no requirement for licensing of wells or obtaining of permits before constructing wells as is the practice in many parts of the world. There are no standards to comply to in the construction of wells neither is there any governmental agency responsible for the supervision of well construction. Digging of wells is carried out by untrained locals with the use of simple tools such as shovels. Such poorly constructed wells are the primary sources of domestic water supply both in the cities and the rural areas.

With this heavy dependence on groundwater and unregulated practices of groundwater extraction, contamination of groundwater has become a potential health risk. Contamination becomes a major source of concern for those households that get their drinking water from

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untreated wells. Several studies have revealed that Lagos groundwater is not potable (e.g. Osibanjo and Majolagbe, 2012; Akoteyon and Soladoye, 2011).

OBJECTIVES OF THE STUDY

This study is focused on how site and well features affect groundwater contamination. The specific objectives were to:

1) describe the relationship between groundwater parameters.
2) examine the relationship between the concentration of some physicochemical elements in groundwater and well features such as depth of well, depth of water in a well, age of well and nature of well casing; and
3) study the effects of site factors on groundwater quality. Results from the study could be used to explain the variation in quality of water in wells located near each other.

METHODS

Study Area

By virtue of the physical characteristics of the Lagos environment and the totality of human activities therein, the megacity is at risk of groundwater contamination. Lagos State is located in the south-western coast of Nigeria approximately between latitudes $6^{0}22^{1}$N and $6^{0}52^{1}$N and longitudes $2^{0}42^{1}$E and $3^{0}42^{1}$E. It shares boundary towards the west with the Republic of Benin and on the south is the 180km long Atlantic coastline. Lagos lies within the wet equatorial climate and has a mean annual rainfall above 1800mm. The rainy and the dry season alternates on an annual basis from April to October and October to March respectively.

According to Coode Blizzard et. al. (1996), Lagos State lies within the Dahomey sedimentary basin and has no basement outcrop. The geology of Lagos State is mainly sedimentary of tertiary and quaternary sediments. Tertiary sediments consist of unconsolidated sandstones, grits with mudstone band and sand with layers of clay. Quaternary sediments, on the other hand, are recent deltaic sands, mangrove swamps and alluvium near the coast. The relief pattern in Lagos reflects the location of the area along the coast. Water is a prominent topographical feature in the area as water and wetlands cover over 40% of the total land area. Another 12% of the land area is subject to seasonal flooding (Iwugo, et.al.,2003).The environment is characterized by wetlands, sandy barrier islands, beaches, low-lying tidal flats and estuaries. However, the surface water in Lagos is polluted. Sources of pollution of the Lagos estuary include the industries, domestic sewage and solid wastes from homes. The water bodies within the study area is a sink for waste for the entire city.

Braimoh et. al., (2007) reported that nowhere in West Africa is the rate of urbanization as unprecedented as the city of Lagos. Lagos has a total area of 3,577 km^2 about 22 percent of which is water. The small land area means that its large population has to be crowded in a small space, resulting in high population density. The population density of the study area was 20,000 persons per km^2 in 1988 (Bilsborrow, 1998). This figure has increased significantly to as high as 4,000 people per hectare in several parts of the city (Lagos State Ministry of Economic Planning & Budget, 2004). With about 17,500 hectares of built up area

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(Oduwaiye, 2007), the metropolitan area of Lagos takes up to 37 percent (37%) of the land area. The metropolis alone houses about 90 percent (90%) of its population (Aina, 1994).

Data collection methods

A total of thirteen water parameters were considered in the study. This includes five physical parameters namely acidity (pH), temperature (^{0}C), total dissolved solids (TDS), electrical conductivity (EC), turbidity. Four chemical parameters namely chloride (Cl), nitrate (NO_3), magnesium (Mg), manganese (Mn); one biological parameter (e-coli) and trace elements of iron (Fe), lead (Pb), zinc (Zn) were also studied.

Total Dissolved Solids (TDS) in water supplies originate from several sources such as sewage, industrial wastewater and other natural sources. pH is a good indicator of water quality as it is a measure of the alkalinity or acidity of water. Conductivity was selected because it can be used as an indicator of human activity. A higher EC indicates more dissolved material, which may contain more contaminants. Turbidity is an important indicator of suspended sediment and erosion levels. Such sediments could be sewage sludges, organic and biological sludges that are as a result of human presence in a place. Chloride (Cl) exists in all natural waters. A high result of chloride may indicate pollution of water by sewage effluent. Thus, it is a good indicator of pollution from both residential and industrial sources.

Nitrate comes mainly from organic and inorganic sources such as waste discharges and artificial fertilizer. The presence of nitrate in groundwater is cause for suspicion of past sewage pollution or excess levels of fertilizers or manure on land. Apart from geological formations, the origin of iron (Fe) can also be traced to effluent discharges. Lead (Pb) originates from leaching from ores, effluent discharges, and it is highly toxic. Zinc (Zn) also originates from natural geological occurrence and wastes. Magnesium (Mg) is naturally present waters and is a major contributor to water hardness. Water from areas where the mineral is abundant may contain magnesium at high concentration, but industrial effluents may also contain similarly high levels of magnesium. E-coli is an indicator of a possible presence of pathogenic micro-organisms.

The factors used in explaining the variation in water quality were derived from both the site of the well and the well features. Factors such as nearness to septic tanks, nearness to contaminated drainage channels, type of housing unit where well is, and the nature of surrounding ground were the site factors in this study. Some other factors are linked to the well features namely depth of well, age of the well, nature of the well wall and well cover.

A field survey carried out to collect water samples from and to take inventory of thirty hand-dug wells within the study area. The process of water samples collection and the laboratory analysis of chemical and trace metal parameters were in accordance with the standard methods. (APHA, 2005).

The well inventory included the estimation of the depth of the well. A calibrated weighted line was lowered into the bottom of the well. The point at the ground level end of the line was marked, and the line pulled out of the water. The length from the weight to the marked point was the depth of the well (m). The well water depth was also determined following the same procedure. When the weighted line was let down into the well bottom, the point at which the

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rope touched the surface of water within the well was marked. The distance between the weighted line and the water surface point marked the depth of the water within the well.

The distance between each well and the nearest septic tank was measured. Also measured were the distance between each well and the nearest drainage channel; and the height of the rim of the well from the ground surface. The owners either gave the age of each well or as in some cases, written on concrete posts around the well. The nature of the well wall and cover were identified as this could influence the quality of water within the well. Activities in surrounding areas of wells such as washing, cooking and general hygiene were observed. Furthermore, the land use around each well was assessed as this was to help in the determination of the land use category.

Data generated from the well inventory were then subjected to both correlation and stepwise regression methods. In the regression analysis**,** each of the water parameters under study was used as the dependent variable while attributes of the well inventory taken on the field are the predictors. Such predictors were the depth of well, the depth of water in the well, the age of well and the height of well above the ground surface. Other predictors used include the distance from the nearest septic tank and the distance from drainage channels.

FINDINGS AND DISCUSSIONS

Relationship between selected water parameters

The results from the laboratory analysis of samples were subjected to correlation analysis. The correlation results are in Table 1. The partial correlation was also carried out to confirm the same relationship. The correlation analysis also revealed that zinc, TDS and conductivity have the greatest number of correlation with other parameters.

Table 1. Correlation matrix showing relationship between water parameters

	^{O}C	*Turbidity*	*pH*	*EC*	*TDS*	*NO_3*	*Cl*	*Mg*	*Fe*	*Mn*	*Zn*	*e-coli*
^{O}C	1.0000	-0.0528	-0.1479	-0.1095	-0.1000	-0.0526	-0.0978	0.1657	-0.1122	0.0991	-0.1302	-0.0368
Turbidity		1.0000	0.0994	0.2901	0.2859	0.1974	0.1191	0.0270	-0.1385	0.0460	0.2835	0.8239
pH			1.0000	0.1059	0.0937	0.1040	0.2674	0.0614	-0.0234	0.1337	0.0194	-0.0420
EC				1.0000	0.9974	0.8558	0.5573	0.4923	0.5741	0.6503	0.9217	0.4147
TDS					1.0000	0.8774	0.5610	0.5218	0.5829	0.6498	0.9318	0.3920
NO_3						1.0000	0.3839	0.7358	0.5656	0.6073	0.8741	0.2400
Cl							1.0000	-0.0614	0.1232	0.5421	0.4618	-0.0560
Mg								1.0000	0.5253	0.4348	0.4810	0.0551
Fe									1.0000	0.3417	0.6730	-0.0857
Mn										1.0000	0.5089	-0.0004
Zn											1.0000	0.3825
e-coli												1.0000

The pairwise correlation results revealed that there is significant correlation between TDS and conductivity (EC) at R = 0.9974, nitrate (NO_3) and conductivity at R = 0.8558, nitrate and TDS at R = 0.8774, chloride (Cl) and conductivity at R = 0.5573, chloride and TDS at R = 0.5610, chloride and nitrate at R = 0.3839, magnesium and conductivity at R = 0.4923, magnesium (Mg) and TDS at R = 0.5218, magnesium and nitrate at R = 0.7358, iron and conductivity at R = 0.5741, iron (Fe) and TDS at R = 0.5829, iron and nitrate at R = 0.5656, iron and magnesium at R = 0.5253, manganese (Mn) and conductivity at R = 0.6503, manganese and TDS at R = 0.6498, manganese and

Table 2. Significant Pairwise Correlation among Water Parameters

Variable	*by Variable*	*Correlation*	*Count*	*Signif Prob*	
TDS	EC	0.9974	30	0.0000	++
NO_3	EC	0.8558	30	0.0000	++
NO_3	TDS	0.8774	30	0.0000	++
Cl	EC	0.5573	30	0.0014	++++++++++++++++++++++++++
Cl	TDS	0.5610	30	0.0013	++++++++++++++++++++++++++++
Cl	NO_3	0.3839	30	0.0362	++++++++++++++++++
Mg	EC	0.4923	30	0.0057	++++++++++++++++++++++++
Mg	TDS	0.5218	30	0.0031	++++++++++++++++++++++++++
Mg	NO_3	0.7358	30	0.0000	++++++++++++++++++++++++++++++++++++
Fe	EC	0.5741	30	0.0009	++++++++++++++++++++++++++++
Fe	TDS	0.5829	30	0.0007	++++++++++++++++++++++++++++
Fe	NO_3	0.5656	30	0.0011	++++++++++++++++++++++++++++
Fe	Mg	0.5253	30	0.0029	++++++++++++++++++++++++++
Mn	EC	0.6503	30	0.0001	++++++++++++++++++++++++++++++++
Mn	TDS	0.6498	30	0.0001	++++++++++++++++++++++++++++++++
Mn	NO_3	0.6073	30	0.0004	++++++++++++++++++++++++++++++
Mn	Cl	0.5421	30	0.0020	++++++++++++++++++++++++++
Mn	Mg	0.4348	30	0.0164	++++++++++++++++++++
Zn	EC	0.9217	30	0.0000	++
Zn	TDS	0.9318	30	0.0000	++
Zn	NO_3	0.8741	30	0.0000	++
Zn	Cl	0.4618	30	0.0102	++++++++++++++++++++++
Zn	Mg	0.4810	30	0.0071	++++++++++++++++++++++++
Zn	Fe	0.6730	30	0.0000	++++++++++++++++++++++++++++++++
Zn	Mn	0.5089	30	0.0041	++++++++++++++++++++++++
e-coli	Turbidity	0.8239	30	0.0000	++
e-coli	EC	0.4147	30	0.0227	++++++++++++++++++++
e-coli	TDS	0.3920	30	0.0322	++++++++++++++++++
e-coli	Zn	0.3825	30	0.0370	++++++++++++++++++

nitrate at R = 0.6073, manganese and chloride at R = 0.5421, manganese and magnesium at R = 0.4348, zinc (Zn) and conductivity at R = 0.9217, zinc and TDS at R = 0.9318, zinc and nitrate at R = 0.8741, zinc and chloride at R = 0.4618, zinc and magnesium at R= 0.4810, zinc and iron at R = 0.6730, zinc and manganese at R = 0.5089, e-coli and turbidity at R =

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0.8239, e-coli and conductivity at R = 0.4147, e-coli and TDS at R = 0.3920, e-coli and zinc at R = 0.3825.

The correlation analysis also revealed that zinc, TDS and EC have the greatest number of correlations with other parameters. Zinc had eight significant correlations with other parameters namely EC, TDS, NO_3, Cl, Mg, Fe, Mn and e-coli. In a similar vein, TDS had eight significant correlations with EC, NO_3, Cl, Mg, Fe, Mn, Zn and e-coli. Also, EC had eight significant correlations with TDS, NO_3, Cl, Mn, Fe, Mg, Zn and e-coli. However, pH and temperature were not significantly correlated with other parameters.

Table 3. Correlation between selected water parameters and site/well attributes

Attributes	*^0C*	*Turbidity*	*pH*	*EC*	*TDS*	*NO_3*	*Cl*	*Mg*	*Fe*	*Mn*	*Zn*	*e-coli*
Depth	-.419*	-.265	-.057	-.218	-.236	-.237	-.212	-.288	.112	-.362	-.124	-.157
DWW	-.275	-.179	.098	-.253	-.276	-.267	.055	-.264	-.229	-.190	-.326*	-.192
Age	-.051	.293	.141	.157	.179	.248	.450*	-.060	-.021	.166	.300	.070
Septic	-.004	-.078	-.075	-.295	-.280	-.210	-.113	-.265	-.352*	-.132	-.213	-.029
Height	-.084	-.300	.258	.056	.062	.045	.161	.099	.111	.153	.007	-.312*
Drain	-.007	-.189	-.267	-.213	-.190	-.122	-.130	-.022	-.117	-.185	-.147	-.173
Surround	-.393*	-.049	-.396*	-.077	-.078	-.097	-.051	-.313*	-.118	-.333*	.008	.087
Well wall	-.058	.097	.008	-.005	.000	-.037	.252	-.092	-.243	-.012	-.073	-.034
Well cover	-.322*	-.071	-.236	-.095	-.112	-.132	-.048	-.283	-.165	-.114	-.073	.023
House	.262	.165	-.103	-.095	-.098	-.061	.087	.096	-.272	.130	-.195	.063

*Correlation is significant at the 0.05 level (1-tailed).

Depth = the depth of the well; DWW = the depth of water in the well; Age = the age of the well; Septic = the distance between well and the nearest septic tank; Height =the height of well rim above ground surface; Drain = the distance between well and the nearest drain channel; Surround = the nature of well surrounding; Well wall = the nature of the well wall; Well cover = the nature of well cover; House = the type of house where well is located.

Relating water parameters with well attributes

(i) Temperature

The relationship between water temperature and well characteristics was analyzed using the Pearson Correlation method. The result suggests that there is a significant inverse correlation between water temperature and variables of the depth of the well, the nature of the surrounding ground and the well cover. This was at R = -0.419, -0.393, -0.322, respectively at $p < 0.05$ significant level. The adequacy of the variation accounted for in the model is ascertained in the ANOVA result in Table 3.

Table 3. ANOVA using Temperature and Depth of Well

Model		Sum of Squares	Df	Mean Square	F	Sig.
	Regression	9.109	1	9.109	5.971	0.021
	Residual	42.718	28	1.526		
	Total	51.827	29			

a. Dependent Variable: TEMPERATURE, b. Predictors: (Constant), DEPTH

The ANOVA table shows that the variation accounted for by the model is adequate at $F = 5.971$; $p < 0.05$. Hence, the model is acceptable for result utilization and further analysis. Also, the effect of the independent variables on the dependent variable was further examined in the regression analysis.

Table 4. Stepwise Regression Coefficients of Depth of well and Temperature

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	29.657	.324		91.635	.000		
DEPTH	-.052	.021	-.419	-2.444	.021	1.000	1.000

a. Dependent Variable: TEMPERATURE

The stepwise regression analysis method was used to determine the effect of the well characteristics (independent variables) on the water temperature (dependent variable). The result reveals that only the depth of the well, excluding other nine independent variable, is significant at $t = -2.444$, $P < 0.05$. Hence, the depth of the well has indirect significant effect on water temperature. The model is given as: Temperature =29.657 - 0.052Depth. The model implies that, based on the data collected, the mean temperature of the study locations is 29.6^{0}C, and a unit increase in depth of the well will result in lower temperature of about 5.2%.

(ii) pH.

The Pearson's correlation result suggests that there is a significant inverse correlation between pH and the nature of the surrounding ground at $R = -0.396$ since $p < 0.05$ significant level. The adequacy of the variation accounted for in the model is ascertained in the ANOVA result shown in Table 5.

Table 5. ANOVA using pH and the nature of the surrounding ground

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	1.685	1	1.685	5.207	0.030
	Residual	9.060	28	.324		
	Total	10.746	29			

a. Dependent Variable: pH, b. Predictors: (Constant), SURROUNDING GROUND

The ANOVA table shows that the variation in the dependent variable accounted for by the model is adequate at $F = 5.207$ $p < 0.05$. Hence, the model is acceptable for result utilization and further analysis. Again, the effect of the independent variables on the dependent variable was examined in the regression analysis.

Table 6. Stepwise Regression Coefficients between pH and nature of surrounding ground

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	7.196	.328		21.911	.000		
SURROUNDING GROUND	-.474	.208	-.396	-2.282	.030	1.000	1.000

a. Dependent Variable: pH

Stepwise regression analysis was used to determine the effect of the well characteristics (independent variables) on the water pH (dependent variable). The result of the analysis reveals that only the nature of the surrounding ground, excluding other nine independent variable, is significant at t = -2.282, $P < 0.05$. Hence, the surrounding ground has indirect significant effect on water pH. The model is given as: pH = 7.196 - 0.474Surrounding ground.

(iii) Chloride (Cl)

Pearson's correlation result suggests that there is a significant positive correlation between chloride and the age of the well at R = 0.450 since $p < 0.05$ significant level. This result implied that chloride concentration in well water increases as the age of well increases. The adequacy of the variation accounted for in the model is ascertained in the ANOVA table.

Table 7. ANOVA using chloride and the age of well

Model		Sum of Squares	Df	Mean Square	F	Sig.
	Regression	11092.123	1	11092.123	7.127	0.012
1	Residual	43576.044	28	1556.287		
	Total	54668.167	29			

a. Dependent Variable: CHLORIDE, b. Predictors: (Constant): AGE

The ANOVA table shows that the variation in the dependent variable accounted for by the model is adequate at F = 7.127 $p < 0.05$. Hence, the model is acceptable for result utilization and further analysis. The effect of the independent variables on the dependent variable is examined in the regression analysis.

Table 8. Stepwise Regression Coefficients between chloride and age of well

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	45.082	12.038		3.745	.001		
AGE	1.679	.629	.450	2.670	.012	1.000	1.000

a. Dependent Variable: CHLORIDE

Stepwise regression analysis was used to determine the effect of the well characteristics (independent variables) on chloride (dependent variable). The result reveals that only the age of well, excluding other nine independent variable, is significant at t = 2.670, $P < 0.05$. Hence, the age of the well has direct significant effect or influence on water chloride. The model is given as: Chloride = 45.082 + 1.679Age. The model implies that, based on the data

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collected, the mean chloride of the study locations is obtained as 45.082, and a unit increase in the age of well will increase water chloride by 167.9%.

(iv) Magnesium (Mn)

The Pearson's correlation result suggests that there is an indirect significant correlation between magnesium and the nature of the surrounding ground at $R = -0.313$ since $p < 0.05$ significant level. However, the stepwise regression analysis indicates that the nature of the surrounding ground and other well characteristic have no significant effect or influence on magnesium concentration in well water.

(v) Iron (Fe)

Pearson's correlation result suggests that there is a significant correlation between the concentration of iron and the distance from the nearest septic tank at $R = -0.352$ since $p < 0.05$ significant level. The implication of this is that with an increase in distance of wells away from septic tanks, the concentration of iron in well water reduces. However, further results from the stepwise regression analysis indicate that distance away from the septic tank and other well characteristics do not significantly influence iron content of water.

(vi) Manganese (Mg)

The Pearson's correlation result suggests that there is a significant correlation between manganese and site and well attributes. These are depth of well and nature of the surrounding ground at $R = -0.362$, -0.333, since $p < 0.05$ significant level. This implies that magnesium concentration reduces at increased depth of well. Also, the nature of the surrounding ground influences the concentration of manganese. However, the stepwise regression analysis indicates that none of these well characteristics have significant effect or influence on manganese concentration in well water.

(vii) Zinc (Zn)

The Pearson correlation result indicates that there is a significant correlation between zinc and well water depth at $R = -0.326$ since $p < 0.05$ significant level. The implication is that the concentration of zinc in well water reduces with water depth. However, the stepwise regression analysis indicates that the well characteristic has no significant effect on the concentration of zinc.

(viii) e-coli

The Pearson's correlation result suggests that there is a significant correlation between e-coli and the height of well rim from the ground at $R = -0.312$ since $p < 0.05$ significant level. This implies that the content of e-coli in well water reduces the higher the well rim is above the ground surface. However, the stepwise regression analysis shows that the well characteristic has no significant effect or influence on e-coli.

The Pearson's correlation result suggests that there is no significant correlation between some of the tested parameters and the site/well attributes. Such parameters include turbidity, conductivity (EC), TDS and nitrate (NO_3). The stepwise regression analysis also indicates that no variable has a significant effect on the above-mentioned parameters.

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CONCLUSION

The relationship between water parameters was discussed. Some parameters had a positive relationship with one another while some others were negative. For instance, iron concentration in well water had a negative significant correlation with physical parameters such as temperature, turbidity and pH while magnesium and manganese positively and significantly correlated with the same physical parameters. The relationship between well water parameters and selected well/site attributes was also examined. From the findings of the study, it is evident that both site and well features have a tendency to influence the quality of water in wells. Notable here is the relationship between temperature of well water and the depth of the well, the nature of the surrounding ground and the well cover. The stepwise regression between pH and the selected well characteristics showed that the nature of the surrounding ground is inversely correlated with pH. The findings of this study suggest the need for further studies on the impact of a site and the characteristics of a well on groundwater quality.

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