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Logistic Regression Model Study of the Effects of Site Environment on Microbial Contamination of Drinking Water Boreholes

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ABSTRACT

*Water boreholes are popular means of drinking water delivery in the developing countries. Current assessments of water quality of these boreholes tend to focus on microbial or chemical contaminants, but largely neglect the effects of the proximate biophysical environment on the quality of water. In this study a logistic regression model was used to investigate the effects of site environment on the likelihood of a water borehole being microbial contaminated. Water samples from 110 water boreholes were investigated over a six-month period in Afikpo North Local Government Area, Ebonyi State, Nigeria. Detection of coliform organisms was assumed an indication of microbial contamination. General sanitary conditions of the boreholes' immediate environments were assessed using a modified sanitary inspector's checklist. The distance of borehole head from the nearest septic tank/latrine (m), type of pump, and location of pump were determined. The logistic regression model was statistically significant, $\chi 2$ (4) = 65.950, p < .0005. The model explained 63.9% (Nagelkerke R^2) of the variance in microbial contamination and correctly classified 83.7% of cases. The model indicated that the sanitary condition had the overall significant effect on the microbial contamination of drinking water boreholes (*Wald *=27.582,* df =1, p <.000*). Motorized pump was about 1.93 times more likely to be microbial contaminated than hand pump. Borehole located in the open environment was 1.81 times more likely to be contaminated than one in the confined environment. Increasing the distance between the drinking borehole and the septic tank was associated with a reduction in the likelihood of contamination. The study recommends that use of a simple sanitary inspector's checklist to monitor proper operation of drinking water boreholes be enforced by government agencies.*

KeyWords: Logistic, Microbial, Borehole, Environment, Drinking water

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I. INTRODUCTION

The drinking water borehole (or well) is emerging as a major source of drinking water in developing countries. There is however a need for a proper understanding of the issues pertaining to the protection of the environment and maintenance of water quality for the preservation of public health. Ordinarily a modern approach to delivery of safe drinking water to a large number of people, especially in urban and *peri*-urban areas, would typically be through an integrated public water supply system, consisting of a source- to-tap or catchment- to- consumer supply chain [1], [2]. However, in many developing countries, especially in sub-Saharan Africa, all levels of government have generally failed to provide adequate safe drinking water infrastructure to cope with the growing population. For instance, less than 10% of the households in Nigeria have access to pipe-borne water [3]. This condition is of course a reflection of the harsh economic and poor governance realities in sub-Saharan African countries. Thus the scarcity of municipal or centrally distributed safe drinking water is largely intractable in these countries ([4], [5], giving rise to isolated private drinking water supply arrangements among many households. These arrangements are systems of collecting/harvesting rainwater, fetching/drawing surface water and abstracting ground water.

Rainwater is limited by its seasonal and erratic nature. As the surface water sources are becoming increasingly polluted by both human activities and possibly climate change effects [6], recourse to groundwater for drinking water continues to increase. Hence, the water borehole is speedily becoming a veritable alternative to municipal or centralized drinking water supply system in the developing countries [7], [8].

Water boreholes or wells, fitted with either hand or motorized pumps, are popular means of delivery of drinking water to households in Nigeria. Most property owners in the country now consider the water borehole a necessity [9]. Government agencies, international donor agencies, non-governmental organizations [NGOs], philanthropic/charitable organizations and well-to-do individuals are providing boreholes across Nigeria in a bid to bridge the gap of safe drinking water supplies. However, the sinking and operation of water boreholes are not regulated. Consequently many boreholes are sunk indiscriminately [10], [11], in close proximity to each other[12], within and around living residences , and many in poor sanitary environment (e.g. fig.1 and fig.2).

Figure 1 Household drinking water borehole sited in close proximity with the gutter and septic tank in the study area (both buildings have septic tanks by their sides), wellhead is directly under the overhead tank.

Figure 2 Site environment of drinking water borehole in the study area.

Experts are worried that the indiscriminate siting of drinking water boreholes portends environmental danger: could trigger geological dysfunctions capable of initiating earth tremors or even quakes[13]. Another important concern is the risk of water contamination, especially microbial water quality. While the environmental effect could be futuristic or remote, contamination of many drinking water boreholes in Nigeria is an ongoing reality, exacerbating waterborne disease incidences.

Many seem, erroneously, to believe that borehole water supplies are free from pathogenic microorganisms due to the perceived natural filtering ability of the underground environment and tendency of microorganisms to be deactivated during their travel over earth structures before reaching the aquifer. What, therefore, seems to matter to many drinking water borehole operators, is the delivery of a “reasonable quantity” of water whose quality is perhaps measured by only apperance i.e. visual level of clarity (turbidity). In Nigeria, the installation and operation of the majority of the drinking water boreholes are virtually not monitored by anybody, even the government agencies. Nevertheless, attempts have been made by researchers to assess the microbial water quality of water supplied from drinking water boreholes across communities in Nigeria [7], [14].

Many of the microbial water-quality-assessment studies on water boreholes found that some water boreholes produce unsafe drinking water due to high load of pathogens [15]. However, these assessments tend to provide data on only water samples, without detailed information on the effects of the biophysical environment of the borehole on water contamination. Consequently the outcomes of these studies most likely serve as an awareness creation resource, about the safety or otherwise of drinking borehole water for human consumption. Since many of the boreholes could be contaminated from the poor environment under which they operate, these research outcomes tend to leave both knowledge and practical gaps in data required for proper management of drinking water boreholes for water safety or guarding of public health. The practical gap arises because it would be obviously easier to persuade borehole operators to improve borehole water environment than to ask them to close down due to some perceived quality issues by a researcher. It seems apparent then that in the absence of alternative sources of drinking water supplies, closure of water boreholes based on the outcome of microbial assessment studies is not an easy option, especially when the adverse health effect of water contamination may not be immediate or visible. Addressing these gaps, this study aims to investigate, using a logistic regression model, the effects of site environmental conditions on microbial contamination of drinking water boreholes. The specific objectives of the study include the following:

1. Assess the microbial contamination status of selected drinking water boreholes in the study area using coliform organisms as the indicator organism.
2. Identify, and determine the measures of, the site environmental conditions of the selected boreholes
3. Determine the effect of site environmental conditions on the microbial contamination of drinking water boreholes using a logistic regression model.

II. MATERIALS AND METHODS

2.1 The Study Area

The study area is Afikpo North Local Government Area [L.G.A] of Ebonyi State, Nigeria. The area experiences tropical climate with approximately six months of dry season (November – April) and six months of rainy season (May to October). It is located on latitude 6 degrees, north and longitude 8 degrees, east. The population of Afikpo North L.G.A, based on the last (2006) Nigeria National Census is about 157,000 people [16]. The topography of the area consists of a series of low-lying hills and valleys. Afikpo North L.G.A is clustered settlement due to topography. The land use is predominantly subsistent farming and animal husbandry. Commercial, civic and micro-industrial activities also abound in the area, creating a peri-urban lifestyle. Over 50% of the population currently relies on water boreholes for supply of drinking water. Water boreholes are sited close or within living residences. Technical records of the boreholes are typically not available.

2.2 Assessment of Microbial Water Contamination Status

Microbial water contamination status was determined from 110 drinking water boreholes sampled fortnightly over a six-month period (July – December 2021). Ten boreholes each were sampled from 11 communities spread across Afikpo North Local Government Area of Ebonyi State, Nigeria. The boreholes were randomly selected from high-density areas, which included Akanu Ibiam Federal Polytechnic Unwana, Unwana Town, Amuro, Mgbom, Eke Market, Ndibe, Ukpa, Government College Environs, Ngodo, Amachi and Amaizu.

Samples were analysed for presence or absence of coliform organisms. In this study, coliform organisms were chosen as indicator of microbial contamination of drinking water because they are organisms that survive in vegetation, soil and gastro–intestinal tracks of warm-blooded animals and water. Coliform organisms are associated with waterborne diseases [17], and are transmitted to humans from drinking water via a fecal-oral route. Water sampling and detection of microbial pathogen were done using standard laboratory procedures [18]. Boreholes recorded as positive to coliform organisms were those that tested positive for at least three occasions throughout the sampling period.

2.3 Assessment of Borehole Site Environment Status

The environmental conditions of the drinking water site environment were identified as: 1) general sanitary conditions, 2) distance of the borehole from the nearest septic tank, 3) location of pump head, and 4) type of pump. The general sanitary condition was measured numerically (with scores ranging between 0 and 10) using the sanitary inspector's checklist [19] in Appendix 1' table A1. Distance of borehole from the nearest septic tank was measured in metres (m) using a tape rule. The location of pump was coded as zero (0) for pump located in an open space and one (1) for pump located in a fenced/confined space. The type of pump was coded as zero (0) for hand pump and one (1) for motorized pump.

2.4 Application of Logistic Regression Model Analysis

In this study, an empirical model was based on the assumption of a non-linear relationship between the microbial water contamination of water boreholes and the borehole site environment. Thus, a logistic regression model analysis was performed to ascertain the effects of the sanitary inspector's score, distance of borehole from septic tank, location of borehole and type of pump on the likelihood of the sampled drinking water boreholes to be microbial contaminated. The model was applied using the presence of coliform organisms (PreColi) - the indicator of microbial water contamination- as the outcome variable. The outcome variable was measured on a dichotomous scale, categorized as one(1) for presence of coliform organisms and zero(0) for absence of coliform organisms in the water sample. The explanatory variables were the indicators of borehole site environment condition, which include the sanitary inspector's scores (SaScore), distance of borehole from septic tank (DiSept), location of pump (LoPump) and type of Pump (TyPump). The explanatory variables were measured as explained in the previous section. The data generated were analysed with the aid of IBM SPSS Statistics 20 software.

A generalized multiple logistic regression model can be stated as:

$$log[p/1-p] = a + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n$$

(1)

Where: p is the probability of an event occurring; *[p/(1-p)]* is the odds of the event occurring, x_1, x_2, x_3 ... x_n are explanatory variables; and a, b_1, b_2, b_3,b_n are numerical constants.

For the current study, the logistic regression model was stated as:

$$log[p/1-p] = a + b_1s + b_2d + b_3l + b_4t$$

(2)

Where: $\boldsymbol{p}$ is the probability of a borehole to be microbial contaminated, $\boldsymbol{s}$ is the sanitary inspector's score, $\boldsymbol{d}$ is the distance of borehole from septic tank, $\boldsymbol{l}$ is the location of the pump (whether within a fenced /confined space or open), and $\boldsymbol{t}$ is type of the pump (whether hand pump or motorized pump).

III. RESULTS AND DISCUSSION

3.1 Descriptive Statistics Results

Fig. 3 shows the presence of coliform organisms in the water samples. The table indicates that 30% of the drinking water boreholes tested positive to coliform organisms. This presents a risky scenario because the guideline value for coliform organisms recommended by both [19] and [20] is zero which means negative detection. This result agrees with [15] and suggests poor sanitary or operation conditions of most boreholes in the study area and other communities in Nigeria.

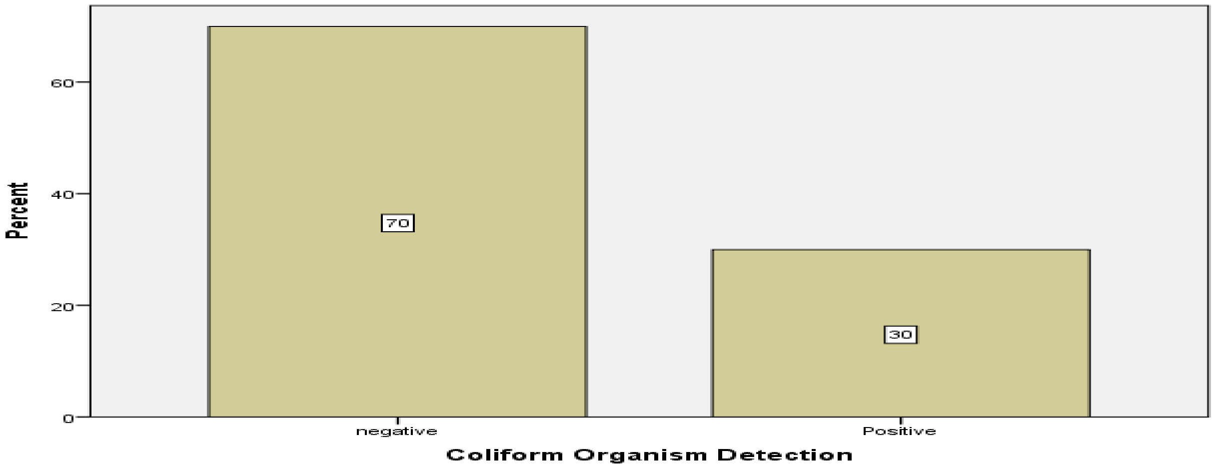

Figure 3 Presence of Coliform Organisms in Water Samples

Table 1 shows the sanitary inspector's scores, which indicate the sanitary conditions of the boreholes. The table suggests that over 40% of the boreholes scored between 6 and 10. These scores represent a high to very high risk of water contamination [19].

Table I Sanitary Inspector's Scores

Scores		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	5	4.5	4.5	4.5
	3	17	15.5	15.5	20.0
	4	18	16.4	16.4	36.4
	5	22	20.0	20.0	56.4
	6	7	6.4	6.4	62.7
	7	10	9.1	9.1	71.8
	8	13	11.8	11.8	83.6
	9	11	10.0	10.0	93.6
	10	7	6.4	6.4	100.0
	Total	110	100.0	100.0	

Table 2 presents a summary of the distance of borehole from the septic tank. The mean distance is about 11m indicating that most boreholes in the study area are below the safe distance of 15m (50 feet) from septic tank to drinking water boreholes recommended by most researchers to prevent microbial contamination of water [21]. This can be the case in places where the installation and operation of water boreholes/well are not regulated.

Table 2 Distance of Borehole from Septic Tank

	N	Minimum	Maximum	Mean	Std. Deviation
Distance from Septic Tank	110	3.00	19.00	10.8636	3.89890
Valid N (listwise)	110				

Fig. 4 shows the proportions of the two types of pumps - motorized pump and the hand pump- for drinking water boreholes in the study area. Motorized pumps are employed in 58.18% of the boreholes while 41.82% use hand pumps. Motorized pumps are typically used in boreholes provided by private owners while boreholes fitted with hand pumps are mostly pumps donated by government agencies, politicians, International organizations, etc.

Figure 4 Type of Pump

Fig. 5 shows the proportion of the location of pump heads. Pump heads sited within a fenced/confined area were 56.36% of the total sample while 43.64% of the pumps heads were located in the open area. Most of the boreholes sited in fenced area are privately owned while most of the boreholes located in an open area are community owned and their pump type is mostly the hand pump. Government agencies, politicians and other donors typically provide community drinking water boreholes.

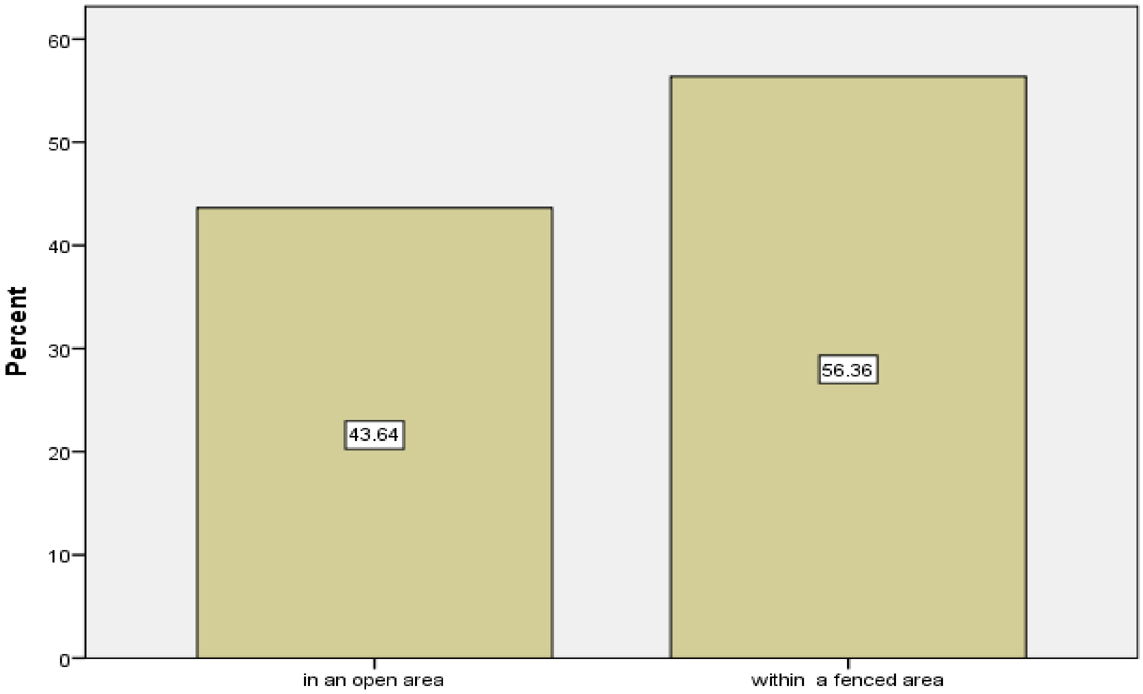

Figure 5 Location of Pump Head

3.2 Logistic Regression Model Results

The baseline model is depicted in table 3. It is a model that has only the outcome variable- the proportion of coliform organisms detected in the borehole water samples. According to this table the model with just the constant is a statistically significant predictor of the outcome (*p*<.001). However, it is only accurate 70% of the time.

Table 3 The Baseline Model

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-.847	.208	16.584	1	.000	.429

Table 4 is the omnibus test used to test whether the complete model is significant (i.e., that general sanitary condition, distance of borehole from septic tank, type of pump and location of pump jointly have a significant effect on the contamination of a drinking water borehole). The result of the omnibus test indicate that the chi-square is highly significant (*chi-square = 65.960, df = 4, p<.000*). The model containing the explanatory variables explained more of the variance in the outcome and is therefore an improvement over the baseline model.

Table 4 Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	65.950	4	.000
	Block	65.950	4	.000
	Model	65.950	4	.000

Table 5 presents the model summary. The Nagelkerke's R^2 suggests that the model explains about 64% of the variation in the presence of coliform organisms in water samples.

Table 5 Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	68.440[a]	.451	.639

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table 6 shows the Hosmer and Lemeshow Test. The result of this test suggest that the model is a good fit to the data as *p=0.965*(>*.05*).

Table 6 Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.430	8	.965

Table 7 shows the classification table for the logistic regression model. This table indicates that by including all the explanatory variables, the prediction of the model outcome improved from 70% to 87.3%.

Table 7 Classification Table

Observed			Predicted		
			Coliform Organism Detection		Percentage Correct
			negative	Positive	
Step 1	Coliform Detection	negative	70	7	90.9
		Positive	7	26	78.8
	Overall Percentage				87.3

a. The cut value is .500

Table 8 presents the explanatory variables, which are the sanitary inspector's score [Sanscore], the distance of borehole from septic tank [DisBH], the type of pump [TyPump], and the location of pump head [Locpum] in the equation for the complete model. From the results presented in table 9, the logistic regression model for predicting the probability of a borehole in the study area to be microbial contaminated given the identified environmental factors can be written as:

$$log[p/1-p] = -6.315 + 0.955s - 0.128d + 0.656l + 0.593t \tag{3}$$

Where: $\boldsymbol{p}$ is the probability of a borehole to be microbial contaminated, $\boldsymbol{s}$ is the sanitary inspector's score, **d** is the distance of borehole from septic tank, $\boldsymbol{l}$ is the location of the pump (whether within a fenced /confined space or open), and $\boldsymbol{t}$ is type of the pump (whether hand pump or motorized).

Table 9 Variables in the equation for the complete model

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Sanscore	.955	.182	27.582	1	.000	2.598	1.819	3.710
	DisBH	-.128	.084	2.303	1	.129	.880	.746	1.038
	TyPumo(1)	.656	.668	.963	1	.326	1.927	.520	7.143
	Locpump(1)	.593	.679	.764	1	.382	1.810	.478	6.849
	Constant	-6.315	1.797	12.351	1	.000	.002		

a. Variable(s) entered on step 1: Sanscore, DisBH, TyPumo, Locpump.

Table 9 suggests that the sanitary condition has a significant effect on the microbial contamination of drinking water boreholes. Taken individually, the distance of borehole from septic, or type of pump (hand or motorized), location of borehole (in open area or fenced/confine area) does not have significant effect on the microbial contamination of drinking water boreholes. However, increasing the distance between the borehole and septic tank reduces the chances of the borehole to be microbial contaminated. This is in consonance with the suggestion of researchers that a water borehole should be located at distance of a least 15m (50 feet) from the septic tank [21].

IV. CONCLUSION AND RECOMMENDATIONS

A logistic regression was performed to ascertain the effects of immediate site environmental conditions, namely sanitary conditions, distance of borehole from septic tank, type of pump and location of pump on the likelihood that a drinking water borehole can be microbial contaminated. The logistic regression model was statistically significant, $\chi 2$ (4) = 65.950, p < .0005. The model explained 63.9% (Nagelkerke R^2) of the variance in microbial contamination and correctly classified 83.7% of cases. The logistic regression model indicates that the sanitary condition (captured) by the sanitary inspector's score has the overall significant effect on the microbial contamination of drinking water boreholes (*Wald* =27.582, *df =1, p<.000*). Boreholes fitted with motorized pump are about 1.93 times more likely to be microbial contaminated when compared with those with hand pump. Similarly, boreholes located in the open environment are1.81 times likely to be microbial contaminated compared to those located in the confined environment. Increasing the distance between the drinking borehole and the septic tank was associated with a reduction in the likelihood of microbial contamination of a drinking water borehole. The following are the recommendations:

1. The use of a simple sanitary inspector's checklist to monitor proper operation of drinking water boreholes should be enforced by government agencies.
2. The Agencies should create awareness and ensure water boreholes are sited at least 15 m from septic tank to prevent fecal contamination. This is currently not the practice in Nigeria.
3. Pumps heads should be adequately protected to prevent access to animals, run-off and unauthorized persons.

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APPENDIX A

Table A1 Sanitary Inspector's checklist for drinking water boreholes

S/no	Description
i	Type of Borehole Pump (tick as appropriate) : Motorized pump/Hand pump
ii	Location of Borehole head (tick as appropriate) : Within a fenced Area/In open area
iii	Borehole label :
iv	
	Assessor's Name------------------------------------- Signature------------------------ Date--------------
	Status

	Biophysical Environment Condition	*(Tick)*
1	Is there latrine/Septic tank within 10 meter of the borehole?	Yes/No
2	Is the nearest latrine/Septic tank on higher ground than the borehole?	Yes/No
3	Is there any other source of pollution (eg animal excrete, surface water, rubbish) w ith 10 m of the borehole?	Yes/No
4	Is the drainage poor, causing stagnant water within 2m of the borehole?	Yes/No
5	Is the borehole drainage channel faulty? Is it broken, permitting ponding; does it need cleaning?	Yes/No
6	Is the fencing around the bore inadequate, allowing animals in or is there no fencing?	Yes/No
7	Is the concrete floor less than 1m wide all round the borehole?	Yes/No
8	Is there any ponding on the concrete floor around the borehole	Yes/No
9	Are there any cracks in the concrete floor around the borehole, which could permit water to enter the borehole catchment?	Yes/No
10	Is the borehole loose at the point of attachment to the base so that water could enter the casing?	Yes/No

Status Analysis	
Maximum Score of Yes =10	
Number of Yes	Risk of Microbial Contamination
9-10	Very High
6.-8	High
3-5	Intermediate
0-2	Low

Source: Adapted from WHO (2004)

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