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Water Pollution Sources for Hand-Dug Wells (HDW) in the Ancient City of Bauchi Metropolis, Nigeria

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Abstract- This study pursued a recommendation to search for the sources of water pollution in the hand dug wells (HDW) from Hardo ward a high density residential area in the ancient traditional city of Bauchi metropolis, Nigeria. Secondary data on pollution by Coli form concentration in water from HDW in Hardo ward was used as the dependent variable (Y) while primary data was collected on four parameters as potential sources of water pollution: the depth of the well; type of well; setback distances between HDW and pit latrines, setback distances between HDW and unlined water drainage channels served as independent variables (IV) = X1, X2, X3 and X4 respectively. The data were subjected to both standard and hierarchical/sequential multiple regression analysis (MRA) using the SPSS 20.0 software to determine the significant sources of water pollution in the study area. The results were presented in coefficients tables, and figures. The standard multiple regression showed a highly significant positive correlation at R2 = 0.758 (adjusted R2 0.693) implying that the level of pollution in the HWD is directly affected by the combined effect of the four independent variables. However, when each independent variable was controlled, in the hierarchical multiple regressions, the model indicated only distance from pit latrine (X2) had a significant impact on water pollution by Coliform and with the highest correlation. The study recommended the use of community boreholes for water supply in the area and educating the residents on the need for proper treatment of water before drinking, as well as measures to achieve standards of construction and the setback standards of locations of HDWs from all the pollution sources in general.

Index Terms- sources of water pollution; Hand dug wells; Coli form pollution; Ancient Traditional city

I. INTRODUCTION

The study area is Hardo Ward, a high density, low income residential area located within the ancient traditional city of Bauchi Metropolis in the north east Nigeria. Hardo Ward has about 42.47 hectares of land occupied by about 15,736 populations (NPC, 2006 in [1]). The area is mostly inhabited by the native people and hand dug wells (HDW) are the most common sources of water for drinking and domestic purposes and most of the houses use a pit latrine for sewage disposal. The area is an organic settlement where the layout is unplanned and the houses are not built to modern design standards. Furthermore, the area is lacking in adequate portable water supply, paved/lined surface water drainage channels and solid waste disposal facilities. In the study area most of the HWD are poorly constructed (Figure 1) and many are very shallow in depth and also are located close to pit latrines (Table 1).

The quality of water for drinking or any domestic use is of a great concern to public health. Poor water quality can cause a disease outbreak, which contributes to the rates of ill health conditions of any community. However, water quality in a HDW is both a factor of natural and human interaction. Adediji & Ajibade [2] showed the effect on refuse dump sites, toilets and soak away with the water quality of HDW. Many studies [3; 4; 5] have also cited the need to monitor groundwater quality including water from HDW. Furthermore, a study by [6] concluded that water from HDW in Hardo ward, is unsafe for drinking due to pollution and recommended a further research to determine the sources of the pollution. This study therefore is to determine the sources of water pollution in Hardo ward the study area.


(a) Protected well (b) Semi Protected well (c) Unprotected well

Figure 1: Hand dug wells in Hardo ward.

Sources of water pollution in hand dug wells (HDW)

The quality of groundwater is a function of either natural or human factors or an interaction of both. These factors can determine the groundwater quality [7]. Although, groundwater aquifers are sources of quality water due to the purifying effect of the soil layers [7], however, water from an HDW is very liable to several sources of pollution due to human activities. In Nigeria, many studies [8; 9; 10 11 and 12] have revealed the pollution of water wells by the sources of human activities such as poor management of waste; location of water wells near pit latrines and soak-away system, or near unlined drainage channels. Amadi et al., [13] concluded from a study that human activities are the most possible source of water contamination by heavy metals properties in the water from hand dug wells near Kaduna refinery and petrochemical company in Kaduna town, Nigeria. In many developing countries the disposal of solid wastes into open dump sites creates pollution of groundwater by contamination through leachate [14]; and in the southwest Nigeria, [15] has established the contamination of wells sited close to solid wastes dump sites. Similarly, [16; 17 and 18] have also observed the pollution effects of refuse dump sites, pit latrines and soak away systems on the water quality from HWD. Ariziki [19] and [20] variously observed from their studies in Samaru village of Zaria metropolis, Nigeria that polluted water from HDW were due to poor standards of distance, separation between the location of such wells and land uses and also poor construction standards of the wells. Iguisi et al. (2001) in [21] have routed the sources of water pollutants to the high decomposing solid wastes dump sites in various locations of human activities within the catchment area of the Kubanni river dam in Zaria, Nigeria.

Surface runoff is another factor of water pollution in shallow wells. According to Strahler & Strahler [22], storm water from rainfall can transport contaminants from the atmosphere and from the land surfaces into groundwater aquifers. Similarly, [23; 24; 25] have observed water pollution incidences from surface runoff. Pollutants are also transported through surface runoff into hand-dug wells through percolation, where water wells have no concrete wall casing, especially where the mouth of the well is not sufficiently raised above the ground surface as in Figure 1c.

Studies have also shown that the depth of HWD is another important factor of groundwater pollution because of the natural filtration process of water by the soil layers and its purifying effects on groundwater quality. However, the depth has minimal pollution reduction effect on hand dug wells when water table or flood plains are at shallow aquifer. A study by [26] found that the longer polluted water passes through the soil layers the cleaner it becomes. Iserman [27] and [28] observed that shallow wells at depths less than 15 meters are very liable to contamination. Similarly, [29] studied faecal contamination from 24 wells in Abeokuta Town Nigeria and discovered an increasing water quality as the depth of the wells increases. Agbede & Akpen [30] studied water quality from 10 wells in Makurdi Town, Nigeria and found that the flood plains were shallow between 1.82 and 7.43 meters deep and all the water samples were polluted either with faecal bacteria or non-faecal bacteria. In other studies, [31] and [32] revealed in Ilorin city, Nigeria that effluents from slaughtering slab houses increases groundwater pollution within the immediate vicinity, but the level of concentrations in the parameters of water pollution decrease with depth of water table and depth of the wells.

The type of construction standard is also a factor of water quality from HDW. A standard constructed water well should have a concrete side wall from the bottom extending above the ground surface to a height 0.5-1.0 meter and also have a good cover, as shown in Figure 1a. These are necessary protections to prevent ground water leachate into the wells and also to prevent any contaminant being deposited into the water wells by agents such as the surface water runoff or wind erosion and any human activities. Therefore, based on the construction standard [34] has classified water wells into three categories: Protected (P) and Unprotected (UP) as wells with the complete presence of protection and wells with the total absence of protection respectively, while Semi-Protected (SP) as wells with incomplete protection (Figure 1).

The standard of location and distance separation setback of a well and possible sources of pollution also affects water quality in HDW. A water well is to be located at the highest elevation possible on the site to achieve optimum surface drainage. Generally, a well located downhill of pollution source has a greater risk of contamination than a well located uphill of pollution sources. In addition, it is required that hand dug wells should be located away from drainage systems, surface water ponds, a pit latrine, a septic tank and soak away systems to prevent pollution. A minimum of 15 to 30 meters distance setback between an HDW and all potential sources of contamination is the benchmark standard set by the Nigerian Standard of Drinking Water Quality [35]. Similarly, [36] recommends that a well should be at least 15.24m and 30.5m away from a septic tank and a septic system drain field. The major purpose of the setback isolation distances is to protect water wells from pathogen contamination by ensuring sufficient time for the pathogen attenuation. Therefore, hand dug wells should be located on the highest gradient while maintaining the setback standard isolation distance from any sources of contamination. This implies that both the location and the setback standards will normally act collectively to maintain the safety of water from HDW for drinking and other domestic purposes.

II. METHODOLOGY OF THE STUDY

Previous data on the Coli form concentrations in water from HDW in Hardo ward by [6] were used as the dependent variable (DV), while the primary data collected on four parameters, namely: the depth of the well; construction standard of HDW i.e. Type of well or construction category (protected, semi-protected and unprotected); setback distances between HDW and pit latrines, setback distances between HDW and unlined waste water drainage channels were used as the independent variables (IV), represented by X1, X2, X3, and X4, respectively. The data were subjected to both standard and hierarchical multiple regression analysis (HMRA) model using SPSS 20.0 software. The MRA model was used to determine the interrelationships between the IV as sources of pollution and pollution by coil form in HDW as the DV.

Data on conditions of Hand dug wells (HDW) in Hardo ward

The data collected through field survey on the conditions of hand dug wells in hardo ward are presented below:

(i) Construction standards of HDW: The data on construction standards of HDW in the study area revealed that the majority (70%) of HDW is semi-protected while another

(25%) are unprotected and only 1 well (5%) is protected (Table 1 and Figure 1).

(ii) Setback distances: The data on the setback distance between the locations of HDW from pit latrines (in Table 1) show a range of 4.20 to 8.50 meters with a mean of 6.05 meters. The setback distances between HDW and unpaved surface water drainages also range from 0.50 to 8 meters with a mean 3.65 meters. The setback in the study area is all well below 15 meters, the minimum separation distance to protect water wells from pathogens of coli form contamination from pit latrines and also polluted waste water runoff from unpaved drainages in the study area.

(iii) Depth of HDW: The depth of HDW in the study area (in Table 1) showed a range from 3.05 to 5.33 meters with a mean of 3.62 meters. This also showed that all the sampled HDW in the study is below the 15 meters, minimum recommended depth of quality water.

Table 1: Parameters of water pollution sources from Hand Dug Wells in the study area.

Samples HDW	*Pollution Level [DV=Y]	Depth of HWD (m) [IV=X1]	Type of HDW [IV=X2]	Distance from Pit Latrine [IV=X3]	Distance from Drainage [IV=X4]	Position Longitude ^{o}E	Position Latitude ^{o}N
HDW1	35	3.810	SP	4.4	2	9.84111	10.31510
HDW2	17	3.048	SP	6.2	3	9.84122	10.31536
HDW3	95	4.572	SP	4.2	2	9.84148	10.31348
HDW4	21	3.048	SP	5.0	0.5	9.84275	10.31316
HDW5	82	3.810	SP	4.2	1	9.84219	10.31541
HDW6	22	3.810	SP	7.1	5.5	9.84117	10.31533
HDW7	71	3.048	SP	4.4	6	9.84165	10.31536
HDW8	42	3.048	UP	6.2	8	9.84129	10.31532
HDW9	18	3.048	SP	7.6	4.5	9.83861	10.31644
HDW10	65	5.334	SP	4.6	5	9.83629	10.31701
HDW11	42	3.048	SP	5.4	2	9.83904	10.31644
HDW12	61	3.810	SP	5.1	3	9.84102	10.31549
HDW13	4	4.572	P	8.4	5	9.84121	10.31721
HDW14	56	3.048	UP	5.3	3.5	9.84128	10.31655
HDW15	9	3.048	UP	8.5	6	9.84114	10.31642
HDW16	12	3.810	SP	8.1	7	9.84100	10.31527
HDW17	34	3.048	UP	6.5	3	9.84108	10.31551
HDW18	7	3.810	SP	7.1	3	9.84123	10.31541
HDW19	28	3.048	UP	6.7	2	9.83970	10.31810
HDW20	16	4.572	SP	6.1	1	9.84155	10.31642
MEAN	36.85	3.6195		6.05	3.65		

Source: *Isah, et al. (2015) and Field survey, (2014)

III. DATA ANALYSIS AND RESULTS

1. Standard multiple regression analysis (SMRA) was carried out based on the four characteristics of each of the twenty (20) HDW in Hardo ward. The depth of the well; type of well; distance from pit latrine; and the distance from the unlined drainage channel were analysed as the independent variables labelled X1, X2, X3, and X4, respectively. This is to establish their relationship with the level of pollution in the well (dependent variable labelled Y). Tables 2a and 2b give the results of the correlation between the level of pollution (Y) and the four independent variables (X1- X4) simultaneously expressed as:

$$Y = a + b1\ X1 + b2\ X2 + b3\ X3 + b4\ X4. \quad *$$

[Equation 1]

Where: Y = level of pollution, a= constant, b= regression coefficients,

X1 = the depth of well, X2=type of well (protected, semi-protected and unprotected), X3 =distance from pit latrine, and X4 = distance from unlined drainage channel [37 and 38].

Results for standard multiple regression analysis (SMRA):

In the model summary (Table 2a) the coefficient of determination or R2 of 0.758 is high, however the adjusted R^2 = is 0.693, is used due to small samples of N<50 [39]. This means that 69.3% of the level of pollution in the HDW is explained by these four independent variables (depth of, well, the type of well, distance from Pit latrine and distance from the unlined drainage channel.

Table 2a: Standard Multiple Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.871a	0.758	0.693	14.756	0.758	11.739	4a	15	0.000

a. Predictors: (Constant), Depth of Well, Type of Well, Distance from Pit latrine, Distance from unlined Drainage
b. Dependent Variable: Pollution

The R^2 value is positive, indicating a direct relationship where an increase in variable X, leads to an increase in variable Y. The strength of the relationship is further indicated by the significance, F Change (4.15) = 11.739 in Table 2b where the p value is 0.000, which is less than 0.5 (therefore: $p < 0.5$). Thus the model has given a strong positive relationship between the level of pollution and the combination of the four independent variables.

Table 2b: ANOVAa

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10224.319	4	2556.080	11.739	. 000b
	Residual	3266.231	15	217.749		
	Total	13490.550	19			

a. Dependent Variable: Pollution. . Predictors: (Constant), DistDrain, Depth, DistPit, Type of well

2. Hierarchical or Sequential Multiple Regression Analysis (HMRA):

The data were further subjected to hierarchical/sequential multiple regression analysis (HMRA) in order to determine the interrelationship between each of the independent variable with the dependent variable. Therefore, there were four iterations of the model, in each round one of the independent variable (Xn) was controlled. The analyses were conducted to ensure that there was no violation of the three prerequisite assumptions of normality, linearity, multicolinearity and homoscedasticity.

a. Results of HMRA 1:

Table 3a is the result of the analysis of the HWD level of pollution (Y) as it relates to three other independent variables, while controlling the depth of the well (X1). The depth of the well (X1) was entered at Step 1, explaining 1.4% of the variance in pollution (Y). After entry of the type of well [X2], distance from pit latrine [X3], and distance from drainage [X4] at Step 2, the total variance explained by the model as a whole was 69.3% (adjusted R2), F (4, 15) = 11.739, $p < 0.001$. The three control measures explained an additional 72% of the variance in pollution, after controlling for the depth of the wells, R2 change = 0.719, F change (3, 15) = 14.842, $p < 0.001$. In the final model the depth of well measures was statistically not significant with a beta value (beta =0. 198, $p > 0.05$).

Table 3a: HMRA Model Summary 1

Model	R	R Square	Adjusted R Square	Std. Error of Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.198a	0.039	-0.014	26.835	0.039	0.734	1a	18	0.403
2	0.871b	0.758	0.693	14.756	0.719	14.842	3b	15	0.000

b. Results of HMRA 2: Table 4a presents the result of the analysis of the HWD level of pollution (Y) as it relates to three other independent variables, while controlling the type of well (X2). Hierarchical multiple regression was carried out to assess the ability of the type of well variables to predict the level of pollution in the wells after controlling for the influences of the other independent variables. The type of well (X2) was entered at Step 1, explaining 5.1% of the variance in pollution (Y). After entry of the depth [X1], distance from pit latrine [X3], and distance from drainage [X4] at Step 2, the total variance explained by the model as a whole was 69.3% (adjusted R^2), F (4, 15) 11.739, $p < 0.001$. The three control measures explained an additional 75.3% of the variance in pollution, after controlling for the type of well, R^2 change = 0.753, F change (3, 15) = 15.560, $p < 0.001$. In the final model the type of well measures were statistically not significant with beta value (beta = 0.66, $p > 0.05$).

Table 4a: HMRA Model Summary 2

Model	R	R Square	Adjusted R Square	Std. Error of Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.066a	0.004	-0.051	27.316	0.004	0.080	1a	18	0.781
2	0.871b	0.758	0.693	14.756	0.753	15.560	3a	15	0.000

c. Results of HMRA 3: Table 5a presents the result of the analysis of the HWD level of pollution (Y) as it relates to three other independent variables, while controlling the distance from pit latrine (X3). Hierarchical multiple regression was carried out to assess the ability of distance from pit latrine variable to predict the level of pollution in the wells after controlling for the influences of the other independent variables. The distance from pit (X3) was entered at Step 1, explaining 65% of the variance in pollution (Y). After entry of the depth [X1], type of well [X2], and distance from drainage channel [X4] at Step 2, the total variance explained by the model as a whole was 69.3% (adjusted R2), F (4, 15) = 11.739, $p < 0.001$. The three control measures explained an additional 89% of the variance in pollution, after controlling for the distance from pit latrine, R2 change = 0.0.089, F change (3, 15) = 1.841, $p > 0.05$. In the final model the distance from pit were statistically significant with beta value (beta = -0.818, $p < 0.001$).

Table 5a: HMRA Model Summary 3

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.818a	0.669	0.650	15.757	0.669	36.336	1a	18	0.000
2	0.871b	0.758	0.693	14.756	0.089	1.841	3b	15	0.183

d. HMRA 4: Table 6a shows the result of the analysis of the HWD level of pollution (Y) as it relates to three other independent variables, while controlling the distance from drainage channel (X4). Hierarchical multiple regression was carried out to assess the ability of distance from drainage variable to predict the level of pollution in the wells after controlling for the influences of the other independent variables. The analysis was conducted ensuring that there was no violation of the three prerequisite assumptions as discussed earlier. The Distance from drainage (X4) was entered at Step 1, explaining 2.5% of the variance in pollution (Y). After entry of the depth [X1], type of well [X2] and distance from pit latrine [X3] at Step 2, the total variance explained by the model as a whole was 69.3% (adjusted R2), F (4, 15) = 11.739, $p < 0.001$. The three control measures explained an additional 72.9% of the variance in pollution, after controlling for the Distance from drainage channel, R2 change = 0.729, F change (3, 15) = 15.062, $p < 0.001$. In the final model the distance from drainage channel measures were statistically not significant with a beta value (beta = -0.169, $p > 0.05$).

Table 6a: Table 3a: HMRA Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R. Square Change	F Change	df1	df2	Sig. F Change
1	0.169a	0.029	-0.025	26.983	0.029	0.529	1a	18	0.476
2	0.871b	0.758	0.693	14.756	0.729	15.062	3b	15	0.000

IV. DISCUSSIONS OF RESULTS

Results of the standard multiple linear regression analysis imply that all the independent variables acting collectively as the sources of water pollution contribute up to 69.3% of the Coli form contamination in the hand dug wells. The results of the hierarchical multiple regression have asserted that the independent variable of distance from pit latrine [X3] is the major source (about 65%) of the Coli form pollution of water in the wells and it also showed a statistical significant at P=0.001 while the other 3 independent variables: depth [X1], type of well [X2], and distance from the drainage channel [X4] are statistically insignificant.

V. CONCLUSION

Based on the findings of the study, it is concluded that pit latrines are the major source of water pollution in HDW from Hardo ward. This stressed the need of upholding the minimum 15 meter setbacks distance between HDWs and pit latrines. This is however difficult to achieve because of both the high population density and smaller plot sizes in the study area [6]. However, portable water supply can be achieved through the provision of either bore holes or the construction of standard wells in the study area and public education on the potential hazards of drinking polluted water from the HDWs.

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