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Investigation of Possible Groundwater Contamination from Septic System Siting in Port Harcourt, Nigeria

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Abstract
The purpose of this study was to investigate the effect of siting of septic systems on the quality of groundwater in the immediate vicinity. Water samples were collected randomly from twenty (20) boreholes located less than 30m from septic systems in Port Harcourt, Nigeria to determine their physico-chemical qualities and microbiological characteristics. Standard analytical techniques were employed in the investigation. Five (5) boreholes at distances ranging from 60m to 100m from the nearest septic system were sampled for analyses as controls. The water temperature, dissolved oxygen, turbidity and total dissolved solid values were within the World Health Organisation (WHO) standards. The pH of water from all the boreholes including the controls were lower than the WHO standards. The values of the physico-chemical parameters obtained for water samples from boreholes located less than 30m were similar to the values obtained from control boreholes. These physico-chemical parameters were invariably not a function of the location of the borehole in relation to septic system. The total coliform bacteria concentration ranged from 130 MPN index/100ml to 172 MPN index/100ml while the faecal coliform distribution ranged from 14 MPN index/100ml to 36 MPN index/100ml. Going by WHO standards on total and faecal coliforms, the studied boreholes and controls are all polluted. However, total Coliform and faecal coliform are found in all the control boreholes. The presence of these coliforms in borehole located close to septic systems cannot be specifically said to have come from the septic system.
Keywords: Borehole, septic system, advection, dispersion, diffusion, coliform, contamination.

Introduction

Water is a natural resource and is essential to sustain life. Accessibility and availability of fresh clean water does not only play a crucial role in economic development and social welfare, but also it is an essential element in health. Groundwater is one of the world's most abundant and vulnerable natural resources. Groundwater is particularly important as it accounts for about 88% of man's safe drinking water (Kumar, 2004). In Nigeria, a lot of people depend on ground water for drinking, domestic, industrial and even agricultural uses.

A borehole is a hydraulic structure which when properly designed and constructed, permits the economic withdrawal of water from an aquifer. Potable water is described as odourless, colourless, tasteless and free from pathogens. Generally, groundwater is a clean source of water. However, contamination of this groundwater makes the water unsuitable for domestic use like drinking and washing. One of the common sources of groundwater contamination is private septic system. In many instances septic tanks and soak-away pits are closer to boreholes than the World Health Organisation (WHO) and United Nations Children Fund (UNICEF) standard safe distance of 30m-40m. Besides, boreholes are drilled to depths shallower than UNICEF standard of 100m-150m. This scenario makes groundwater vulnerable, particularly by leachates, to contamination from septic systems. Widespread groundwater contamination however, has occurred in many rural areas utilizing on-site wells and septic tank systems. This is because of effluent which is discharged onto the subsurface by soakaways as this often percolates into the same aquifer tapped by wells for domestic water supply (Banda *et al*., 2014). According to Ehirim and Ebeniro (2013), Port Harcourt has unconsolidated moderately porous and permeable sands with lenticular clays and shales at depth of up to 50m. Sandy textured soils generally exhibit rapid permeability. This suggests that these soils will drain rapidly. The fine textured soils - those that contain clays exhibit very limited capacity to transmit liquid. The depth to the water table ranges between 3 to 15m, depending on the time of the year while a percolation rate of 15mm/hour has been reported for the Port Harcourt Area (Ehirim and Ebeniro, 2013).

Contamination of Groundwater by Septic Systems

Safe drinking water remains inaccessible for about 1.1 billion people in the world and the hourly toll from biological contamination of drinking water is about 400 deaths of children below the age five (Gadgil, 1998). Subsurface sewage disposal systems are the largest sources of wastewater to the ground, and are the most frequently reported causes of groundwater contamination (Miller, 1980). More than 80% of Nigerian urban dwellers rely on septic systems to treat and dispose of sanitary waste that includes wastewater from kitchens, clothes washing machines, and bathrooms. A typical household septic system consists of a septic tank and a soakaway pit (Figure 1). The septic pit is often a rectangular concrete lined pit. Wastewater flows into the septic tank, where it is held for a period of time to allow suspended solids to separate out before flowing into the soakaway pit. Wastewater flows out of the soakaway pit through the gravel, and into the surrounding soil. As the wastewater effluent percolates down through the soil, chemical and biological processes remove some of the contaminants before they reach groundwater.

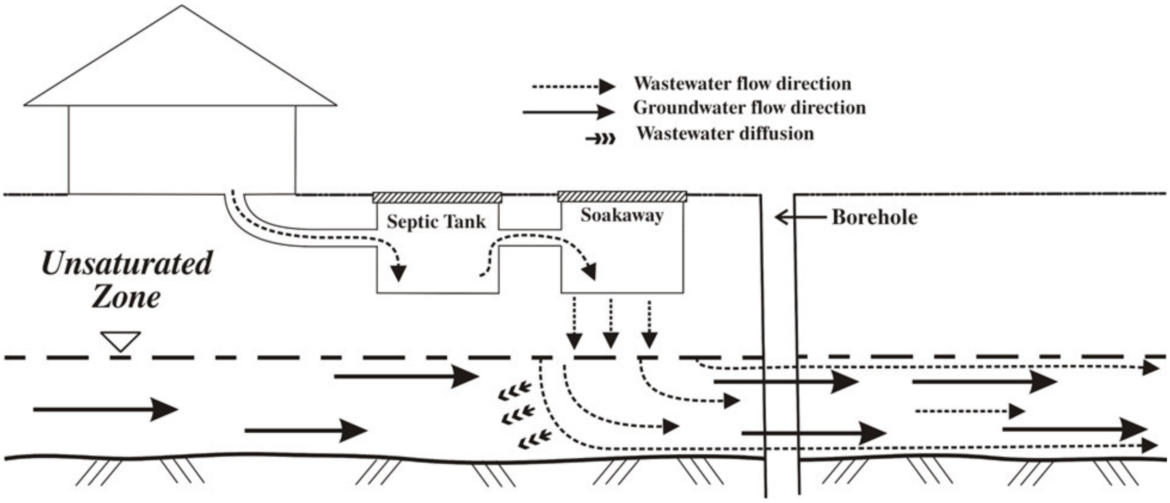

Figure 1: Wastewater Flow in a Typical Septic System

Eventually septic system effluent reaches groundwater, where it impacts water quality. Septic waste discharged to coarse-textured soils proceeds vertically through the unsaturated zone and into groundwater. Approximate times for septic effluent to pass through the unsaturated zone to groundwater range from a few hours to a few days, depending on the volume of effluent and the distance to ground water (Robertson *et al*., 1991; Robertson, 1994; Robertson and Cherry, 1995). The rate of migration also depends on the lithology, porosity and permeability of the underlying soil formation. Effluent migration has been monitored, both vertically and laterally, using variations in concentrations of these constituents (Waller *et al*., 1987).

Domestic septic tank effluent typically contains elevated concentrations of chloride, sulphate, nitrite plus nitrate, ammonia, organic nitrogen, total nitrogen, total phosphate, faecal coliform and faecal streptococci bacteria, and total organic carbon (Canter and Knox, 1985). About 70% of the waste contains germs and pathogens which pose real threat of contamination and diseases and is therefore very dangerous to human life (Robert, 1994). Septic tanks have been found to fail and leak profusely, causing environmental damage (Phiri *et al*., 2006). The types and numbers of pathogens in sewage will differ depending on the incidence of disease and carrier states in the contributing human and animal populations and the seasonality of infections. All of these constituents, however, are commonly found in groundwater. As a result, unless elevated concentrations are present, one cannot confidently determine whether a system has been affected by sewage (Alley, 1985). Besides, septic tanks store wastes for a period during which it undergoes pre-treatment. Groundwater in Port Harcourt has been reported to be contaminated with unacceptable levels of aerobic bacteria. Ogbonna, *et al.,* (2006) reported that faecal coliform *E, coli* and *faecal Klebsiella* were found in almost all the boreholes studied in the area.

Contaminants are carried into aquifers through dispersion and advection (Emongor *et al*., 2005). Most of the wastewater in the septic system moves into the aquifer by dispersion due to differential concentration of the dissolved ions and advection because some of the contaminants are carried along with the moving groundwater. Bennington (2012) demonstrated that the overall contaminant is quantified by the advection-dispersion equation thus:

$$\frac{\partial u}{\partial t} = -\frac{\partial}{\partial x_i}(cv_i) + \frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial c}{\partial x_j}\right] + R_c i, j \qquad (1)$$

Where
C is the concentration of the solute
R_c is the sources or sinks
D_{ij} is the dispersion coefficient tensor
V_i is the velocity tensor
According to Premlata *et al.,* (2012), concentration values, in the presence of a source pollutant, rapidly decrease

with position near the inlet boundary. At the inlet boundary concentration changes periodically with time. In the absence of a source pollutant, concentration values rapidly increase. In both cases, concentration values are highly dependent on time. When there is a very low dispersion coefficient, the transport process becomes advective in characteristics, resulting in indefinitely high contaminant concentrations. The amount of the spreading depends on the contaminant properties and concentration gradients, and soil matrix for diffusion and mechanical mixing (dispersion). If diffusion is considered, some contaminant travels against the flow direction, i.e. contaminants may be found upstream of the contaminant source (Figure 1)

Sample Collection and Field Measurements
Water samples were collected from 20 boreholes in Port Harcourt whose distances to septic systems were less than WHO recommended safe distances. All boreholes from which water samples were collected were already cased and must have been in use for at least 10 years near the septic system. Water samples were collected from the taps. To avoid possible source contamination each tap was sterilized by a flame from cotton wool soaked in methylated spirit as the source of heat. Dry heat sterilizes by protein denaturation, oxidative damage and toxic effects of elevated levels of electrolytes. After sterilization the tap was allowed to flow for at least 60 seconds before 500ml of groundwater was collected into a sterile bottle. All samples were stored in ice-packed containers in the field and transported to the laboratory the same day to ensure that the organisms did not change in their population characteristics before laboratory analysis. The distance between each borehole and the soakaway was measured using 10 metre measuring tape. The depth of the septic system was obtained from the engineering drawings where they were available or estimated by the property owner. The homes where the necessary information could not be obtained were omitted in the study.

Samples were collected from five control boreholes with an average distance of 60m to the nearest septic system. The average value of pH, temperature, turbidity, total and faecal coliform of water from the five boreholes were used as control values.

Data Analyses
Temperature, pH, Total Dissolved Solids (TDS), Turbidity and Dissolved Oxygen (DO) are the physico-chemical parameters of groundwater that were considered to be most readily affected by domestic sewage contamination and these were studied in the boreholes. Temperature, pH, Total Dissolved Solids (TDS), were measured *in-situ* using Jenway Hand Held Meter Model 430. Turbidity, was measured using Horiba Water Quality Meter Model W-2000S/W-23XD while Dissolved Oxygen (DO) was measured *in-situ* using Jenway Model 970 MK II. All *in-situ* meters were calibrated prior to measurement.

Coliform bacteria are used as water quality indicators because coliforms may be associated with the sources of pathogens contaminating water. Faecal coliforms are a part of the total coliform group which are of faecal origin. To differentiate between the faecal coliform and the rest of the total coliform group, temperatures higher than 35°C were used during incubation. Faecal coliform have the ability to ferment carbohydrates at 44.5°C within 24 hours while the rest of the total coliform group will not (Banda *et al*., 2014).

Bacteria were introduced into a fermentation tube containing media for the bacteria to thrive on. By observing gas production or the lack of gas production, it was possible to determine the probable number of bacteria originally present in the sample. The analyses were conducted on five portions of each of three serial dilutions of each water sample. The goal of the dilution scheme is to have some tubes positive with gas production and some tubes negative. The dilutions used were decided base on the purity of the water under study and experience. The test tubes were incubated at 37^{o}C for total coliform and 44.5^{o}C for faecal coliform for 24hours. The presence of coliforms is indicated by turbidity in the culture medium, by a pH change and/or by the presence of gas.

Through consideration of the relative numbers of tubes in the various dilutions which yielded positive (presence of gas) and negative (no gas) results, it was possible to make an approximate estimate of the number of coliform bacteria present in the sample. The most probable number (MNP) of organisms present was estimated by using a table of number determined statistically (Collins and Lynne, 1980). The results of the physico-chemical and microbial analyses are shown in Table 1.

BH	Distance of Borehole to Septic System *(m)*	Static Water Level *(m)*	Total Depth of Borehole	Average Depth of Septic System *(m)*	pH	Temperature (^oC)	Turbidity *(NTU)*	TDS (mg/l)	Total Coliform Bacteria $(MPN\ index/100ml)$	Faecal Coliform Bacteria $(MPN\ index/100ml)$
WHO	30m-40m	-	-		6.5– 8.5	≤ 35	< 5.0	< 600	0	0
Control (av. value)	60m	-	35	2.5	6.0	27.0	4.1	45.49	135	18
1	22.7	3.1	33.5		5.9	31.0	4.0	90.5	110	20
2	11.9	11.9	30.1		6.1	29.0	3.8	95.2	130	20
3	26.1	3.6	30.5		5.2	27.0	5.1	91.5	136	25
4	3.9	4.3	36.6		5.8	28.0	4.8	103.2	130	20
5	14.0	6.1	36.8		5.8	28.0	4.2	100.0	148	30
6	15.0	7.5	36.6		6.0	27.9	4.3	105.0	157	45
7	7.6	3.7	30.5		5.7	31.0	5.0	98.6	125	20
8	10.1	2.8	36.6	2.5	6.3	33.0	4.7	102.3	137	14
9	14.0	4.8	30.1		5.1	30.0	4.5	110.7	172	15
10	13.2	2.4	30.5		6.1	29.0	4.8	112.0	130	20
11	39.9	6.1	33.9		5.4	29.0	4.0	116.0	156	18
12	13.2	4.5	40.5		5.4	27.0	4.8	127.0	142	36
13	15.4	8.2	40.9		5.6	26.0	5.1	113.3	130	20
14	16.0	4.9	38.9		5.4	26.0	4.0	96.6	166	36
15	21.2	6.7	42.2		5.5	26.0	4.2	94.8	139	18
16	25.8	9.6	30.9		6.2	28.0	5.0	130.0	138	25
17	17.8	9.2	36.8		5.9	27.0	4.5	100.3	128	28
18	12.5	5.8	40.2		6.1	26.0	4.2	93.2	121	32
19	13.0	5.5	38.8		6.2	26.0	4.8	115.3	129	42
20	12.5	7.2	30.8		5.9	31.0	4.5	107.0	130	20

Discussions

The water from the different boreholes were all slightly acidic with slight variations in the pH value. The variations did not show any correlations with the distance of the borehole from soakaways. The acidity is also similar to the control such that this property cannot be attributed to faecal contamination but instead to the local geology and general environmental condition of the place. The temperature of the water was equally not influenced by the location of the soakaway. The turbidity values are all within the WHO limit. The boreholes located close to soakaways did not in any way show turbidity values above those located more than 40m from a soakaway. By WHO standards on total and faecal coliforms, the studied boreholes and controls are all polluted. The presence of these coliforms in borehole located close to septic systems cannot be specifically said to have come from the septic system. Moreover, the coliforms including the faecal coliforms are not necessarily of faecal origin.

Conclusions

The presence of coliforms in the water from the boreholes are levels that render them unfit for drinking. There are however no indications that this contamination are as a result of the fact that the boreholes are closer to soakaway than the recommended minimum safe distance of 30m. The contamination is from the general unhygienic condition of the environment.

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