academicJournals

Vol. 11(6), pp. 331-338, June 2017
DOI: 10.5897/AJEST2015.2042
Article Number: CD305C364371
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Impacts of bacterial pollution on hand-dug well water quality in Enugu, Enugu State, Nigeria

Onuigbo A. C.[1]*, Onyia C. E.[1], Nwosu I. G[2]. and Oyeagu U[3].

[1]South-East Zonal Biotechnology Centre, University of Nigeria, Nsukka, Enugu State, Nigeria.
[2]Department of Geography, University of Nigeria, Nsukka, Enugu State, Nigeria.
[3]Department of Microbiology, University of Nigeria, Nsukka, Enugu State, Nigeria.

Received 10 November, 2015; Accepted11 February, 2016

This study investigated the effect of bacterial pollution on ground water quality in Enugu urban areas. During the study, samples were collected from ten (10) hand-dug wells (W_1-W_{10}c). Five (5) hand dug wells out of ten (10) were used as control. All samples were taken according to methods described by Federal Ministry of Water Resources (2004). Membrane filtration (MF) method was used to enumerate total coliforms (TC), fecal coliforms (FC) and *Escherichia coli*. Biological oxygen demand, dissolve oxygen, chemical oxygen demand, temperature and pH were also determined. Data were statistically analyzed for mean and standard deviation and the results showed that TC, FC and *E. coli* were influenced by distance and season of the year in all the wells. Their values decreased with increasing distance to pollution sources. Statistical analysis shows that significant difference ($p < 0.05$) was observed with changes in distance and seasons. The results of BOD, DO, COD, temperature and pH show that no significant difference ($p > 0.05$) was observed at different distances and seasons of the year. The values of temperature, DO and pH were within the permissible limit. Presence of bacterial in all the wells was strongly influenced by proximity to the pollution sources. Based on the findings, the research recommends that standard treatment should be given to water from the wells before consumption. The result of this study will be of great importance to the general public, as well as the environmental and health planning unit of government.

Key words: Groundwater, bacterial, pollution, siting distance, season.

INTRODUCTION

When water drains into rivers, lakes and ground water, it carries microbial pollutants as it moves through a watershed. Microbial pollution of water has been a growing crisis in environmental and public health and this has not been fully addressed through scientific research and risk assessment (Joan et al., 1998). Ground water has been historically assumed to be safe without treatment to kill microorganisms. It was assumed that passage through soil would filter out pathogens. Diseases such as cholera, typhoid, dysentery and hepatitis have been linked to drinking water contaminated by human waste (Eubank et al., 1995). This phenomenon has proved to be the greatest threat worldwide and accounted for 70-80% of health problem in the developing world. However, majority of waterborne diseases have resulted from use of untreated ground

*Corresponding author. E-mail: afamonuigbo@yahoo.com. Tel: +2348060306812 or +2347053939255.

water that has become contaminated (Joan et al., 1998). Increase in bacterial pollution of ground water quality has been attributed to pollution from septic tank dug near bore holes and wells (Chitanand et al., 2008). Despite the fact that ground water is one of the major sources of water supply for majority of Nigeria, there is no integrated ground water quality monitoring scheme in Nigeria (Adebola et al., 2013). Hence, there must be a critical need for an integrated, national initiative on the microbial quality of water and on risk assessment as related to public health (Joan et al., 1998). This according to them is that water quality problem-solving should address entire watershed and aquifers.

There are several studies that confirmed microbial pollution of ground water quality in Nigeria. Nola et al. (1998) identified indicators of fecal contamination such as *Pseudomona aeruginosa, Aeromonas hydrophila* in spring and well water. Also, in another study by Potgieter et al. (2006), total coliforms (TC), fecal coliforms (FC), fecal entercocci and *Clostridium perfringens* identified exceeded recommended guidelines limit. The results of ground water quality analysis carried out in Abeokuta, Nigeria showed that ground water is grossly polluted with microorganisms and heavy metals (Joan et al., 1998). The results of physiochemical analysis of ground water quality (Osibanjo, 1994), as cited in Nubi and Ajuonu (2011), showed that total solid and total hardness exceeded allowable limit. Similar results were obtained at solid waste dumpsites in 9 locations in Enugu (Chima et al., 2009). Study revealed that more than 65% of the population in the study area use water from ground water with little or no treatment. Also in Enugu, blood samples of 240 people, comprising children, pregnant women and nursing mothers and men in this area, had increase heavy metals bioaccumulation. And this was linked to water consumption (Ibeto and Okoye, 2010).

The increase in water pollution in Enugu and attendant shortage of water supply (Onuigbo and Madu, 2013; Onuigbo et al., 2013; Chima et al., 2009; Utomi et al., 2012 and Ezenwaji, 2008) has continued to grow unabated. Water supply shortages in Enugu urban area is attributed to poor quality of water supply and increase in population density which place high demand on ground water supply. In Enugu, soak away pits are usually located close to hand dug wells where access to water is guaranteed. Ground water from hand dug wells is the major source of water supply in the study area. Enugu and its surrounding areas are known to have abundance source of underground water resources. Ground water resources abound in Enugu, 9th mile Ngwo, Ajali Owa in Ezeagu and Oji river axis all in Enugu state. Numerous industries such as Nigeria brewery, Guinness, cocoa-cola, paints and plastic industries attracted to these areas were majorly because of availability of ground water resources. The increase in number of industrial location, population density and various socio-economic activities which place high demand on water in this area make aquiferous zone vulnerable to contamination.

Digging of hand dug well in every household in Enugu urban has become a general practice. Water from wells constitutes a major source of microbial pollution. Bacteria such as *Vibrio cholera, Salmonella typhi, Salmonella paratyphi, Shigella* spp., *Enterotoxigenic Escherichia coli, Salmonella* spp., *Campylobacter* spp. are able to travel unrestricted through the subsoil (Sugden, 2006). If time taken for microorganisms to be transferred from soak away pit to the zone of water table is long, the microorganisms will die off before getting to water point and will no longer be health threat. In ground water, some viruses are known to survive for up to 150 days; *E. coli* indicator bacteria, survive for up to 42 days while some *salmonella spp* have been shown to persist for up to 42 days (ARGOSS, 1991). The further water containing bacterial loads has to travel to the zone of aquifer, the more complex its path, the lesser the organisms it will hold. Longer distance and time allow for higher numbers of microorganisms to die off naturally. When contaminants move through soil and fractured rock, they generally follow the flow of the groundwater. Therefore, it is important to always take the groundwater flow pattern into consideration when siting a well.

This study was conducted to assess the impacts of soak away pits on hand dug wells in relation to siting distance and season in Enugu urban area. The results of this work will provide basic information and source of the scientific knowledge on hand dug wells water in Enugu and other similar water where little or no information is available for effective management and sustainability. It will also help to form baseline data for users of hand dug wells water; help researchers and stake holders in water resources to prevent future deterioration of hand dug well water quality, and for future study.

MATERIALS AND METHODS

Study area

Enugu urban is located within latitude 06°21'N and 06°30'N and longitude 07°26'E and 07°37'N. It is situated at the foot of Udi escarpment and covers an approximate area of 145 sq km. Enugu is commonly referred to as coal city (Newcastle of Nigeria) because of abundant of coal deposit in the area. It is also known as civil service and educationally base city; though industrial and commercial activities are now dominating in major parts of the area. Enugu urban area drains by rivers such as Asata, Ekulu, Akwata, Ogbete, Emene and its tributaries; and they are captured by Nyaba River and drain into Cross River basin. Dry and rainy seasons occur between November to March and April to October, respectively. It lies in transitional-savanna region; and this is derived from prolonged cultivation. The population of Enugu urban according to 2006 National Population Census was 722, 644, (National Population Commission), (NPC, 2007). Using 2.8% annual rate of increase, the populations' projections of people that consume water in the sample areas is about 679, 043.

Sample selection

Enugu urban area is made of three local government areas namely,

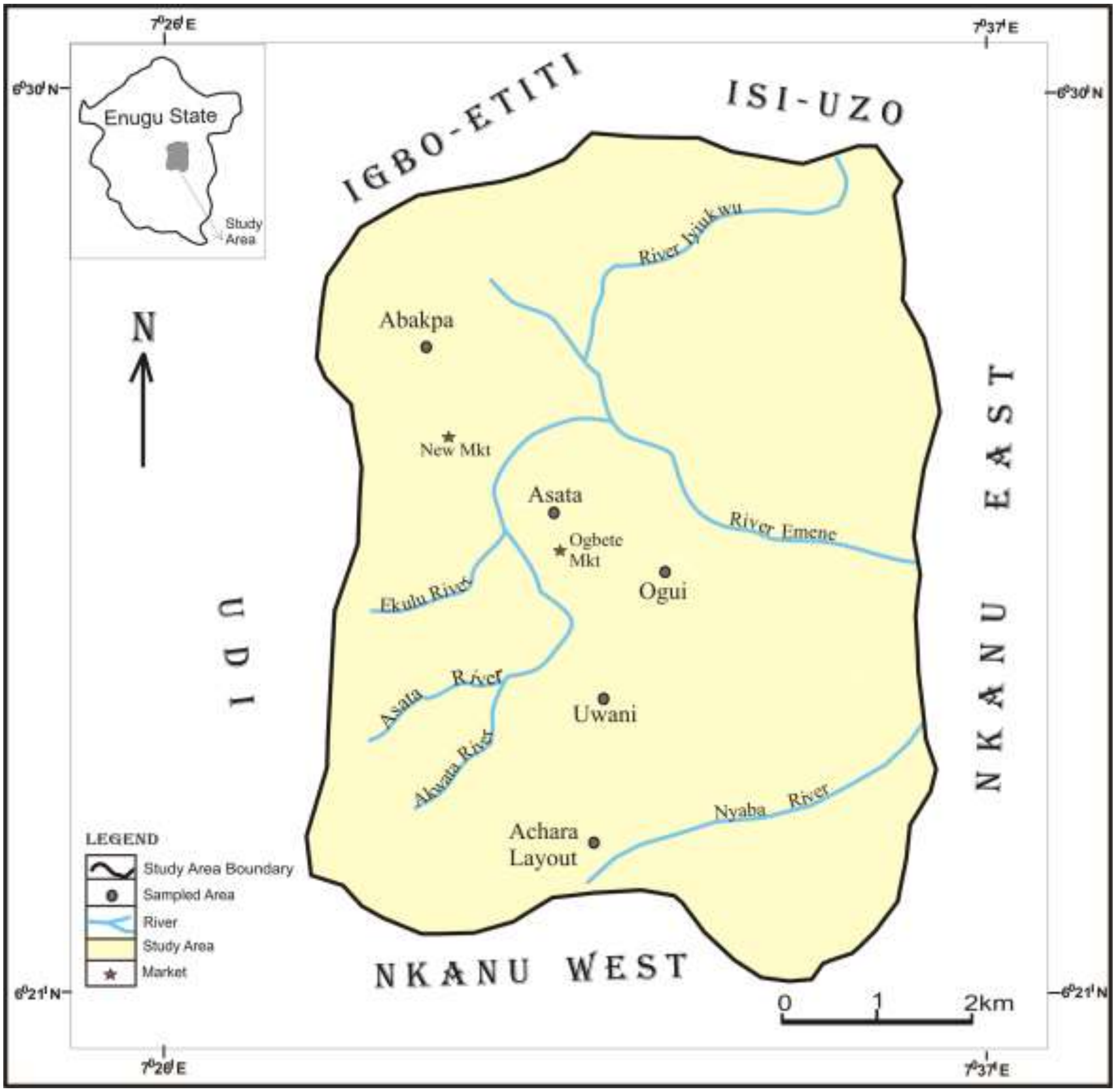

Figure 1. Map of Enugu urban showing sample area (Adapted from Map of Enugu Urban: Ministry of Land and survey, Enugu, 2015).

Enugu East, Enugu North and Enugu South. Five (5) sample areas were randomly selected for the study (Figure 1). Two sample areas were selected from two local government areas, while one area was selected from one local government area. The sample areas are Asata, Ogui (Enugu North), Uwani, Achara Layout (Enugu South) and Abakpa in Enugu East. The choice of selecting the areas was because more than 80% of water supply in the area is source from ground water sources (hand-dug wells). A total of ten (10) hand-dug wells were selected for the study. Two hand dug wells were selected from each of the five sample areas. Five (5) hand-dug wells dug within 30 m away from soak away pits were selected, while five (5) wells dug more than 30 m away from pollution sources were selected as control. The choice of distance was based on the standard distance for digging of soak away pit away from hand dug wells as described by Aguwamba (2001). The standard distance according to him shows that soak away pit should be dug 30 m away from hand dug well or borehole, 15 m for any surface waters meant for domestic uses and 3 m for dwelling or property lines. Also, the Sphere Project (2011), recommended 30 m as a minimum standard for the lateral distance between on-site sanitation systems and water sources. This was used to determine the influence of distance of siting soak away pits and bacterial pollution of hand dug wells in Enugu urban.

Sample collection

Samples were taken from 10 hand-dug wells whose depth varied from 30 to 50 m (98-164 ft) during rainy (June and July) and dry seasons (January and February). This was used to determine seasonal variations of bacterial pollution during the two seasons. They were taken in the morning before users start drawing water from the wells. This was to avoid contamination from other sources and also to make sure that water drawn in the previous day was

Table 1. Distribution of indicators organisms (100 ml) in samples collected during rainy and dry seasons.

Well	Distance (meter)	Rainy season			Dry season			Mean	
		Total coliform count	Fecal coliform	*E. coli*	Total coliform count	Fecal coliform	*E. coli*	Rainy season	Dry season
W_1	26	210	105	70	78	50	15	128.3	47.6
W_2	28	113	83	64	59	47	25	86.6	43.7
W_3	29	100	75	57	47	11	9	77.3	22.3
W_4	22	221	120	108	82	59	31	150	57.3
W_5	29	105	78	42	100	31	12	75	47.7
W_6c	72	55	35	30	2	Nil	Nil	40	0.7
W_7c	63	67	50	45	2	1	0.5	54	1.2
W_8c	85	40	23	12	Nil	Nil	Nil	25	0.0
W_9c	48	60	55	50	3	2	1	55	2
W_{10}c	45	88	65	58	12	4	2.5	70	6.2
WHO		3/100 ml	0/100 ml	0/100 ml	3/100 ml	0/100 ml	0/100 ml	-	-

W_1 - W_{10}c = Well samples (W_6c - W_{10}c = wells used as control).

replenished in the wells. A total of twenty (20) samples were taken in all; two (2) samples from each well. Ten (10) samples were used to determine bacterial loads, while ten (10) samples were used for physicochemical characteristics of hand dug well water quality. Samples for bacterial analysis were collected with white bottles that were sterilized in an autoclave at 121°C for 15 min (Sharma, 2009), while samples for physicochemical analysis were collected in clean sterile screw capped polypropylene bottles.

Sample collection from hand dug well was done according to guidelines outlined by Federal Ministry of Water Resources, (2004). A capped sterile bottle covered with a sterile handkerchief was used, with a piece of string, and a clean weight attached to the sample bottle. A 50 m length of clean string was rolled around a stick and tied to the sample bottle. The sample bottle was lowered down, and was not allowed to touch the sides of the well. The bottle was completely immersed in water and submerged below the water, without hitting the bottom or disturbing any sediment. The string was unwind immediately the bottle was filled up. For bacterial analysis, some water was discarded to provide for air space and it was then capped with stopper. All samples were properly labeled with marker, and they had information on i.) sample site/well, ii.) date of sample collection, iii.) time of sample collection and iv.) purpose of sample collection. Samples were put in ice packed plastic boxes. The boxes protected samples from sunlight, prevented breakage of sample bottles. Samples were transported to Water Quality Laboratory and analyses were done within two hours of samples collection.

Sample analysis

Samples were subjected to bacterial analysis at Water Quality Laboratory, Federal Ministry of Water Resources, Enugu. Chemicals and reagents used were of analytical grade. Membrane filtration (MF) method was used to enumerate total coliform, fecal coliform and *E. coli*, and they were expressed in Cfu/100 ml (Sharma, 2009). The types of bacterial were determined by serial dilution and plating of samples on differential culture media. The isolates were identified and characterized accordingly. Temperature and pH were determined *in situ* using a portable pH digital meter. Biological oxygen demand (BOD), chemical oxygen demand (COD) and dissolved oxygen (DO) were analyzed using digital titrator.

Statistical analysis

Data were analyzed for mean and standard deviation. Difference in parameter was tested for statistical difference at $p< 0.05$ using student's t-test. All the analyses were done using the statistical package service solution (SPSS) version 21 (SPSS Inc., Chicago Il., USA). Values were compared with water quality standard set by World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ).

RESULTS AND DISCUSSION

The results of bacterial analysis of sample collected from ten (10) hand-dug wells (W_1-W_{10}) are shown in Table 1. The results showed that water sample from W_1 dug at a distance of 26 m away from soak away pit recorded values of 210/100 ml (TC), 105/100 ml (FC) and 70/100 ml (*E. coli*). The values were lower than result of sample collected from W_4 dug at a decreased distance of 22 m. The results showed that TC, FC and *E. coli* have values of 221/100, 120/100 and 108/100 ml, respectively. These have shown that distance and season were the determining factors of bacterial pollution of ground water quality (Table 1).

Also, the results of sample from W_2, W_3 and W_5 have similar lower values because of increasing distance. The least values of 57/100 ml (*E. coli*) were obtained at W_3 at a distance of 29 m. The values were lower than values of 108/100 ml of *E. coli* obtained at W_4 at a distance of 22 m. The results of sample from W_3 and W_5 dug at the same distance have similar values indicating that distance from pollution sources was a determining factor of bacterial pollution of ground water quality in Enugu. The results showed that TC, FC and *E. coli* have values of 100/100, 75/100 and 57/100 ml; and 105/100, 78/100 and 42/100 ml, respectively. The highest values of TC

(88/100 ml), FC (65/100 ml) and *E. coli* (58/100 ml) obtained at control of W_{10}c showed that it was less than the lowest values of TC (100/100 ml), FC (75/100 ml) and *E. coli* (57/100 ml) obtained at W_3 dug within 29 m away from soak away pits.

This result was in accordance with earlier work done by Idika et al. (2005), Opara et al. (2011) and Chitanand et al. (2008). Their results showed that location of wells very close to soak away pits led to bacterial pollution of wells. Results obtained by Opara et al. (2011) indicated that more than 90% of wells located within 27 m away from soak away pits were microbiologically polluted. Chitanand et al. (2008), confirmed that proximity of contaminating sources determine the presence and transportation of TC into ground water. This corroborated that distance of locating soak away pits influenced bacterial pollution of hand dug wells located close to it. Table 1 shows that TC, FC and *E. coli* have increased and decreased values in W_1-W_5 dug less than 30 m away from soak away pits, and W_6c - W_{10}c (control) dug more than 30 m away from soak away pits, respectively. This indicated that the further the distance to pollution sources, the lesser the amount of bacterial pollution to hand dug wells (Adekunle et al., 2007). These results were in consistent with results obtained by Adekunle et al. (2007) in Igbora, Nigeria. Their results showed that proximity of hand dug wells to pollution sources and season of the year influenced the concentration of TC and FC.

The results of samples collected during rainy season recorded higher values than results of samples collected during dry season. The mean values of W_1-W_5 during rainy season decreased from 128.3, 86.6, 77.3, 150 and 75; to 47.6, 43.7, 22.3, 57.3 and 47.7 during dry season respectively. The same decreasing values were observed in the control (W_6c-W_{10}c). The increase in values of bacterial pollution of ground water quality during rainy season was similar and in line with research work done by Awe et al. (2012) and Adekunle et al. (2007). Their work confirmed increase in bacterial pollution during rainy season than dry season. Increase rainfall resulted to increase in water table and this act as a good medium of microbial transfer from soak away pits to hand dug wells close to it. Also, increase use of water for servicing of toilets during rainy season when compare to dry season was also observed during the study.

All these resulted to increase in bacterial pollution of wells during rainy season as was proved by Hill et al. (2006). Decreasing values of 221/100 to 82/100 ml (TC) was recorded from sample collected from W_4 during rainy and dry seasons, respectively, at the same distance of 22 m. The values of TC from W_3 and W_5 at the same distance of 29 m decreased from 100/100 to 47/100 ml and from 105/100 to 100/100 ml in the rainy and dry seasons, respectively. The decreasing values have shown that bacterial pollution of ground water quality was higher during the rainy season than the dry season. The results were consistent and similar to earlier work done by Adekunle et al. (2007) in Igbora, Oyo state, Nigeria.

The results of bacterial analysis showed that W_8c and W_6c were free from microorganisms during dry season. The two wells met the standard requirement of 3/100 (TC), 0/100 (FC) and 0/100 ml (*E. coli*) set by NSDWQ and WHO for drinking, irrigation and commercial activities. W_8c and W_6c in the control showed that there were negligible values of TC, FC and *E. coli* and FC and *E. coli* during dry season, respectively. Interestingly, the two wells were safe from bacterial pollution and this qualified them to be used for domestic, agricultural and commercial activities during dry season only. The values of TC and *E. coli* from the two wells (W_8c and W_6c) were in contrast with the values obtained by Onuigbo and Madu (2013) in surface water of Emene River in Enugu. Results of W_1-W_5, and W_7c, W_9c, and W_{10}c in all the seasons exceeded the maximum allowable limit. Their values were similar and in accordance with values of TC and *E. coli* obtained by Onuigbo and Madu (2013) in Enugu, Nigeria.

The results of physicochemical analysis of water sample collected from W_1-W_{10}c during the study are shown in Table 2. The results showed that the values of temperature, pH and dissolved oxygen which ranged between 10±0.55 to 30±2.67°C, 6.5±0.12 to 8.5±0.25 and 3±1.11 to 8±2.55, respectively, were within the maximum allowable limit as recommended by NSDWQ and WHO. The values of temperature, pH, DO and COD have shown that the physicochemical quality of ground water in the study area was not influence by distance to pollution sources and season of the year. Statistical analysis showed that no significant difference ($p>0.05$) was observed at distance and season of the year. Therefore, the use of distance and season of the year as determinant factors of physiochemical pollution of ground water was not reliable. The results of temperature and pH obtained from this study were similar and consistent with the results obtained by Adefemi (2003) and Ipinmoroti and Oshodi (1993) in Ado Ekiti and Akure, Nigeria, respectively. It was only BOD that has substantial increase in W_1 and $W_{4;}$ and this may be attributed to other factors not factored in the study.

The values of BOD in W_1-W_5, and W_7c, W_9c and W_{10}c exceeded maximum permissible limit of 10 mg/l during rainy season. It was only values obtained at W_5 (10±0.67), and values obtained in control of W_6c (10±0.32 and 8±2.11), W_7c (10±1.10) and W_8c (8±0.21 and 8±0.01) during dry season, rainy and dry season, dry season and rainy and dry seasons, respectively that fell within the standard limit. This revealed that there was no significance difference ($p>0.05$) in values of variables irrespective of season of the year and distance to pollution sources. The values of chemical oxygen demand also confirmed that distance to pollution sources and season of the year did not influence the pattern of physiochemical pollution of 10 hand dug wells used in this study. The values which ranged between

Table 2. Mean spatial variation of physiochemical analysis of water samples.

Well	Distance (m)	Rainy Season					Dry Season				
		Temperature (°C)	pH	BOD (mg/l)	DO (mg/l)	COD (mg/l)	Temperature (°C)	pH	BOD (mg/l)	DO (mg/l)	COD (mg/l)
W_1	26	21±0.12	6.7±1.01	80±0.78	5±0.22	58±1.01	27±1.02	6.7±0.34	50±1.23	7±1.20	42±2.34
W_2	28	25.8±0.2	7.2±0.11	29±0.32	6±0.55	40±0.45	21±1.12	6.5±0.12	20±0.41	8±0.54	38±0.21
W_3	29	16±1.26	7.8±1.82	22±1.75	3±1.11	37±0.33	23.5±0.2	6.9±0.24	19±0.01	5±0.22	29±0.23
W_4	22	28±2.05	6.6±1.27	95±2.08	6±0.02	60±2.21	20±2.10	7.5±2.11	34±1.07	7±2.3	53±0.12
W_5	29	23±2.34	8.5±0.25	12±1.22	4±2.20	30±0.10	23±0.55	6.8±2.22	10±0.67	6±0.12	27±0.21
W_6c	72	13±0.45	6.9±0.56	10±0.32	4±1.02	25±2.11	15±0.15	7.4±0.10	8±2.11	6±1.22	28±0.05
W_7c	63	20±2.12	7.4±2.05	12±0.55	5±1.12	28±0.21	22±1.11	6.5±0.05	10±1.10	8±1.01	24±0.01
W_8c	85	11±0.07	7.5±0.28	8±0.21	8±2.55	27±2.22	10±0.55	7±2.70	8±0.01	7±0.10	37±2.11
W_9c	48	21±0.87	6.8±0.05	30±1.70	6±0.37	40±0.78	23±0.71	7.7±0.34	21±0.45	7±1.21	27±2.10
$W_{10}c$	45	30±2.67	6.7±2.30	31±0.03	3.4±0.71	48±1.10	22±2.01	6.5±2.29	101±3.40	6±0.75	25±2.77
NSDWQ		30	6.5-8.5	10	<8	20	30	6.5-8.5	10	<8	20
WHO		30	6.5-9.2	10	<10	20	30	6.5-9.2	10	<10	20

25±2.11 and 60±2.21 as it is in Table 2, exceeded the allowable limit in all the seasons.

Spatial distribution of bacterial in the ten hand dug wells (W_1-$W_{10}c$) used in the study showed that there was strong presence of bacterial in all the wells (Table 3). The table shows more concentration of bacterial in the wells dug within 30 m (W_1-W_5) away from soak away pits than those dug 30 m (W_6c-$W_{10}c$) away from pollution sources. The results are confirmation of influence of distance to bacterial pollution of hand dug wells in Enugu urban area. It was only *E. coli* that was found in all the wells, *Salmonella thyphi* and *Vibrio* cholera were found in all the wells except W_6c, W_7c and $W_{10}c$ respectively. *Klebsiella aerogenes, Micrococcus luteus, Enterobacter aerogenes* and *Shigella flexneri* were only present in three wells. The presence of *E. coli* in all the wells was an indication of fecal pollution by soak away pits. The results revealed that waters from wells used in this study were not safe for domestic and commercial uses and this calls for treatment before it will be used for domestic, agricultural and commercial purposes. The presence of bacterial in water from wells used for various purposes in the study area was an indication of possible outbreak of cholera, dysentery, typhoid and yellow fever, if consumption of water from hand dug wells was not discontinued. These diseases according to Jahata et al. (2009), have continued to be major cause of human mortality and morbidity. The presence of bacteria indicate contamination of hand dug well water with fecal waste that may contain other harmful or disease causing organisms, such as viruses, parasites. Drinking water contaminated with these organisms will cause stomach and intestinal illness including diarrhea and nausea, and even lead to death. These effects may be more severe and possibly life threatening for babies, children, the elderly or people with immune deficiencies or other illnesses. Waterborne diseases are caused by pathogenic microorganisms that are transmitted in contaminated fresh water. Infection generally results during bathing, washing, drinking, in the preparation of food, or the consumption of foods that are infected.

Conclusion

The results of this work showed that distance and season of the year strongly influenced the bacterial pollution of hand-dug well water quality used for socio-economic activities in Enugu urban area. Distance and season are two determinant factors of bacterial pollution of hand dug wells by soak away pits in the area. Statistical analysis showed that significant difference ($p<0.05$) was observed at distance and seasons of the year. Results showed that water samples collected from hand dug wells have increased values of TC, FC

Table 3. Spatial distribution of bacterial species in wells used for the study.

S/N	Bacteria	W_1	W_2	W_3	W_4	W_5	W_6c	W_7c	W_8c	W_9c	W_{10}c
1	*Escherichia coli*	+	+	+	+	+	+	+	+	+	+
2.	*Vibrio cholera*	+	+	+	+	+	+	+	+	+	-
3.	*Salmonella typhi*	+	+	+	+	+	-	-	+	+	+
4.	*Salmonella paratyphi*	+	+	+	+	+	+	-	+	-	-
5.	*Stereptococcus feacalis*	+	+	+	-	+	-	+	+	-	-
6.	*Enterococcus faecalis*	+	-	+	-	+	-	-	+	+	-
7.	*Pseudomonas aeruginosa*	+	-	-	+	+	-	-	-	+	+
8.	*Shigella flexneri*	-	+	-	+	-	+	+	-	-	+
9.	*Staphylococcus aureus*	+	+	-	+	-	-	-	-	+	+
10.	*Proteus mirabilis*	-	+	-	+	-	+	-	-	-	+
11.	*Vibrio parahaemolyticus*	+	-	-	+	-	-	+	-	+	-
12.	*Enterobacter aerogenes*	-	+	-	-	-	+	-	-	+	-
13.	*Klebsiella aerogenes*	-	-	+	+	+	-	-	-	-	-
14.	*Micrococcus luteus*	-	+	-	-	+	-	+	-	-	-
15.	*Shigella flexneri*	-	-	+	+	-	-	-	-	-	+

(+) Positive; (-) negative.

and *E. coli* at wells dug closer to soak away pits than wells dug further away from pollution sources; and during rainy season than during dry season. Contrastingly, the results of physiochemical quality of ground water were not influenced by distance to soak away pits and season of the year. Analysis showed that no significant difference ($p>0.05$) was observed in distance and season of the year. The results of this research work have shown that hand dug wells in Asata, Ogui, Uwani, Achara Layout and Abakpa areas are no longer potable for domestic consumption.

Policy implications of the study

The following recommendations if implemented will ensure that potable water is available for the residents of the study area:

1. Treatment: Water from wells in the study area should be adequately treated so as to meet NSDWQ and WHO permissible limit.
2. Alternative sources of water supply: This should be urgently provided by government, non-governmental organization and other stake holders in water resources. Alternative sources of water supply such as bore-hole, piped water should be established in flash point areas so as to curtail this ugly trend.
3. Review: There should be upward review of standard distance for digging of soak away pits away from hand dug wells since most of the wells dug 30 m away from soak away pits as recommended distance have high presence of microorganism and were confirmed to be polluted and unhealthy for domestic and other socio-economic uses. Data obtained from the review should be used to set new specification and standards for siting of soak away pits away from hand dug well water resources in a localized areas.
4. Awareness: This should be created in the areas to inform users of water abstracted from hand dug wells on the increased bacterial pollution of well waters used in the area. Users of ground water should be alerted on the lurking dangers of continued use of water from hand dug wells in the study area. This should be done through women organizations, town hall meeting, focused group discussion, posters, hand bills, public and private schools, hospitals and market places.
5. Geology: Ground water flow and the structure of underlying rocks should be thoroughly investigated before selecting site for digging of hand dug wells and soak away pits in Enugu. The configuration and structure of geological formation of Enugu urban area should be investigated so as to spot out areas with aquifer formations. Areas with abundance ground water resources should be mapped out and detailed geologic studies carried out and local specification used in area with localized rock and soil structure. This is due to the fact that the structure of underlying rocks are determining factors of direction of ground water flow, the medium of transport of microorganisms. Some bacteria and virus have potentials to travel unrestricted under the subsoil. Better assessment of ground water flow condition will enable identification of dominant contaminants sources.
6. Structural modification of hand-dug wells: Wall of the hand-dug wells where ground water seeps into the well should be protected with minute sized stones. The stones will help to trap and sieve out microorganisms from entering into well water.
7. Specifications and guidelines: Land developers such as engineers, surveyors, architects, estate managers,

quantity surveyors and allied workers should be given specifications and guidelines. This will enable them to build houses and its components that will be in conformity with local, regional and international regulations on standard distance of siting of soak away pits away from ground and surface water resources, dwelling places, recreational centers and property lines in all its ramification.

8. Enactment of enabling laws: Enabling laws should be made by legislatures to prevent outbreak of disease that emerge from water pollution and to protect people's life and fragile environmental resources. It will also help to enhance water resources utilization and management, promote and protect urban and regional town planning functionality and ecological and aesthetic functions of the environment.

9. Routine inspection and law enforcement: Sanitary inspection officers should be employed to carry out routine inspection of housing and housing patterns that are built in violation of environmental and building standards. Housing patterns that are not in compliance with standards should be redesigned in order to comply with the standards. Health challenges associated with consumption of ground waters that are polluted with bacterial invasion will be reduced. Also they should enforce laws and regulations, prosecute law violators so that hygienic and sanitary conditions of dwellers will be optimally enhanced.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the anonymous reviewers for their efforts in correcting this paper. Also, technical support from staff of the South-East Zonal Biotechnology Centre, University of Nigeria, Nsukka, Enugu State is appreciated.

REFERENCES

Adebola AA, Adedayo OB Abiola OO (2013). Pollution studies on groundwater contamination: Water quality of Abeokuta, Ogun State, South West, Nigeria. J. Environ. Earth Sci. 3(5):161-166.

Adefemi SO (2003). Physicochemical and microbiological assessment of ground water from Ijan-Ekiti South Western Nigeria. SWISS J. Appl. Sci. 2(5):13-21.

Adekunle IM, Adetunji MT, Gbadebo AM, Banjoko OB (2007). Assessment of ground water quality in rural settlement in Southwest Nigeria. Intl. J. Environ. Res. Public Health 4(4):307-318.

Aguwamba JC (2001). Waste Engineering and Management Tools. Immaculate Publication Ltd, Enugu, P 270.

ARGOSS (1991). The Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation. British Geological Survey.

Awe S, Madueke SN Olonila OT (2012). Bacterial examination of spring water in different location in Enugu Metropolis, Enugu State, Nigeria. Nat. Sci. 10(9):176-179.

Chima GN, Ogbonna CE, Nwankwo U (2009). Effects of urban wastes on the quality of Asata River in Enugu, South Eastern Nigeria. Global J. Environ. Sci. 8(1):31-39.

Chitanand MP, Gyananath G, Lade HS (2008). Bacterial assessment of ground water: A case study of Nanded city. J. Environ. Biol. 29(3):315-318.

Eubank W, Carpenter JD, Maltsberger BA (1995). Bacteria in drinking water. Department of Health, Ohio State University pp. 441-449.

Ezeigbo HI, Ezeanyim BN (2006). Environmental pollution from coal mining activities in Enugu area. Mines Water Environ. 12:53-62.

Ezenwaji EE (2008). Investigation into water supply shortages in squatter settlements of Enugu Urban Area, Nigeria. Nig. J. Geogr. Environ. 1:12-20.

Federal Ministry of Water Resources (2004). Drinking water quality surveillance in rural area: Water sampling and testing. Minna Regional Laboratory.

Hill DD, Owens WE Tchounwou PB (2006). The impact of rainfall on fecal Coliforms bacteria in Bayou Dorcheat (North Louisiana). Int. J. Environ. Res. Public Health 3(1):114-117.

Ibeto CN Okoye COB (2010). High levels of heavy metals in blood of urbanPopulation in Nigeria. Res. J. Environ. Sci. 4(4):371-382.

Idika N, Odugbemi TO, Ekanem EE (2005), An evaluation of bacteriological quality of water consumed by inhabitants of some rural areas of Lagos State, Nigeria. J. Health Biomed. Sci. 4(1):61-66.

Ipinmoroti KO, Oshodi A (1993). Determination of trace metals in fish, associated waters and soil from fish ponds. Dis. Innov. 5(2):135-138.

Jahata BL, Prasai T, Singh A, Yami KD (2009). Assessment of drinking water in Madhyapur-Thumi and study of antibiotics sensitivities against bacterial isolates. Nepal J. Sci. Technol. 10:162-172.

Joan BR, Ronal MA, Charles PG (1998). Microbial Pollutants in our nation's water. Environ. Public Health Issues pp. 1-15.

National Population Commission (NPC) (2007). National Population Commission, Enugu.

Nola M, Njine T, Monkiedje FVS, Djuikom E, Tailliez R (1998). Bacteriological of spring and well water in Younde, Cameroun. *Sante*, 8(5):330-336.

Nubi OA, Ajuonu N (2011). Impacts of industrial effluent and dumpsite leachate discharges on the quality of ground water in Oyo State, Nigeria. J. Biodiv. Environ. Sci. 1(3):13-18.

Onuigbo AC, Madu IA (2013). Assessment of impacts of effluent discharge on the quality of Emene River, Enugu, Nigeria. NY Sci. J. 6(8):34-42.

Onuigbo AC, Madu IA, Ikejiofor IG (2013). Management and disposal of industrial effluent on surface waters in Enugu. Proceeding of the Nigeria Association of Hydrological Sciences. C.C. Mbajiorgu (Eds) 5:72-78.

Opara AU, Nnodim J, Okorochi E, Nwanjo HU (2011). Microbial and physico-chemical qualities of water sources in a pig-rearing rural community, Southeastern Nigeria. Int. Sci. Res. J. 3:25-28.

Osibanjo O (1994). Present water quality status in Nigeria. Federal Environmental Protection, Lagos.

Potgieter N, Mudau LS, Maluleke FR (2006). Microbiological quality of ground water sources used by rural communities in Limpopo Province, South Africa. Water Sci. Technol. 54(11-12):371-377.

Sphere Project (2011). Minimum standards in water supply, sanitation and hygiene promotion. In: Humanitarian Charter and Minimum Standards in Disaster Response. Geneva: The Sphere Project. Sugden S (2006). The microbial contamination of water supplies. Well Factsheet.

Utomi AU, Odo BI, Okoro AU, Egboka NE (2012). An investigation into the use of electrical restivity in aquifer contamination study: A case study. Near Surface Geoscience, France-the 18th European meeting of environmental and engineering geophysics of the near surface geosciences division of EAGE, Paris, 3-5 Sept.