PJN
ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
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OPEN ACCESS Pakistan Journal of Nutrition

ISSN 1680-5194
DOI: 10.3923/pjn.2018.596.608

Research Article
Influence of Environmental Factors on the Physico-Chemical and Bacteriological Quality of Well and Borehole Water in Rural Communities of Udenu Lga of Enugu State, Nigeria

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Abstract

Background and Objective: The influence of environmental factors on well and borehole water quality in rural communities in Nigeria was investigated in this study. The objectives were to characterize/contrast the pollutants, determine the influence of environmental factors on the water quality and highlight the health implications of the findings. **Methodology:** Water samples were collected from ten boreholes and ten hand-dug wells in ten rural communities. Fifteen physico-chemical and bacteriological water quality parameters including: pH, Temperature, Electrical conductivity, Turbidity, Nitrate, Iron, Total dissolved solids, Sulphate, Alkalinity, Total hardness, Chloride, Calcium, Magnesium, Total coliform count and *E. coli* were analyzed. **Results:** The results of the analysis were reported based on the WHO standard. The analysis showed borehole samples exhibit higher concentration of natural pollutants while well samples exhibit higher concentration of anthropogenic pollutants. Principal Component Analysis (PCA) reduced the fourteen environmental variables influencing the water quality to five underlining components which explained 84.5% of the data matrix leaving 15.5% to other variables not used in the study. The extracted components included extent of source water protection, mineral properties of rocks and influence of vegetal cover. **Conclusion:** It is concluded that to avoid contamination, regulatory authorities should closely monitor well/borehole development in the area.

Key words: Environmental factors, health implication, Nigeria, rural communities, well water quality, hand-dug well, water related diseases

Received: July 21, 2017 Accepted: July 28, 2018 Published: October 15, 2018

Citation: Obeta Michael Chukwuma and Mamah Kingsley Ifeanyichukwu, 2018. Influence of environmental factors on the physico-chemical and bacteriological quality of well and borehole water in rural communities of udenu lga of Enugu State, Nigeria . Pak. J. Nutr., 17: 596-608.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Environmental factors alter the levels of minerals and dissolved organic substances in well/borehole water and by so doing impair its quality[1]. In fact, Ajayi and Adesina[2] noted that environmental factors play decisive roles in determining the quality of water and other elements on which man and other living creatures subsist on, on the earth planet. Environmental factors which influence well and borehole water quality are known to fall into two broad categories, namely, natural and anthropogenic.

The natural environmental factors include, among others, the atmosphere, plants, terrestrial surfaces and the hydrosphere in their natural states, while human or anthropogenic environmental factors result mainly from man's carelessness, ignorance, negligence and/or from legitimate human activities in his immediate or remote surroundings[3]. Water contamination resulting from natural environmental factors, such as carbonate rocks and seepage, is difficult, if not impossible, to control[4]. In contrast, contamination resulting from human-induced environmental factors can be avoided and controlled through strategies such as close monitoring by regulatory agencies, legislations, sanctions etc[5] Causes of such contamination range from improper disposal of household wastes, through over application of manure/chemical fertilizers, oil spillage to the mishandling of wastes at industrial sites.

Groundwater is sourced mainly through wells across the globe to meet the domestic, agricultural and industrial water needs of man[6]. Groundwater is frequently influenced by naturally-occurring environmental factors[7]. Adelana *et al.*[8] opined that groundwater can easily be contaminated by natural substances in the environment such as, geology, topography and climate. They noted that the chemistry of groundwater is largely the chemistry of the rocks in which it resides. Olobaniyi and Owoyemi[1] also noted that certain metals within the rock strata can be reached by groundwater (which itself is chemically potent solvent) into the reservoir and cause the quality of water to deteriorate.

Anthropogenic activities also constitute major sources of well water contamination[9]. Hart[10] and McMahon[11], discovered that storm runoff and effluent discharges laden with particle pollutants and garbage in landfill gain access to ground aquifers and contaminate the water. Ishaya and Abaje[12] also found that improper disposal of household wastes, over application of manure/chemical fertilizers, oil spillage and mishandling of wastes at industrial sites lead to the contamination of wells/borehole water.

Currently, there is growing concern for the quality of wells and borehole water in rural communities of Nigeria. This is evident in the study of Oguntoke *et al.*[13], Raji and Ibrahim[14], Adejo *et al.*[15], Eni *et al.*[16], Okoro *et al.*[17] and Isikwue *et al.*[18]. Oguntoke *et al.*[13] and Raji and Ibrahim[14], noted that the quality of groundwater has continued to degrade in different countries due to natural and human factors. Ashbolt[19] stated that impaired water accounts for over 1.7 million deaths worldwide every year (i.e., 3.1% of all deaths) and 3.7% of all Disability-Adjusted Life Years (DALYs). Cech[20] is of the opinion that 1.1 billion people were still using water from unimproved sources in sub-Sahara Africa and 42% of the population is still without potable water supply.

In Nigeria, the high prevalence of water borne diseases such as cholera, diarrhea, dysentery, hepatitis, etc. especially, in rural areas, was attributed to the consumption of contaminated water[14]. Yusuff *et al.*[21] demonstrated the prevalence of common waterborne diseases in some parts of Nigeria, typhoid cases ranked highest among the water related diseases recorded between 2002 and 2008 in Nigeria, followed by cholera, hepatitis and dracunculiasis.

The rural communities of Udenu LGA, our study area are endowed with abundant groundwater resources (Ofomata[22] which they use for various purposes, washing of clothes, bathing, cooking, drinking, building, or construction, industrial activities and other socio-economic activities such as car wash, laundry services etc. The quality status of the well/borehole water which the people ingest and use for varied purposes are not known. Also there is little or no information on the extent to which the water is influenced by natural and man-related factors especially in the rural areas. These require a lot of research study to improve our understanding of the current realities and enhance planning activities in the area.

Water sources in the study area: In our study area there is a near total dependence on water from hand dug wells and boreholes in most communities due to absence of surface drainage. The absence of surface drainage in many of the communities according to Ofomata[22] is, due to the fact that the underlying sandstones are highly permeable and pervious. Thus the groundwater resource endowment of the area is high and this is massively exploited to meet the community water needs. During the dry season when there is no more rain water to be harvested and the distant seasonal streams dry up, every one turns to either hand-dug wells, boreholes or to water vendors. These sources of water supply exist in all the autonomous communities within the local government area. In fact, it is correct to say that well usage is ubiquitous in the study area as wells and boreholes are routinely dug to access water.

Unfortunately well sinking and use is not regulated by state agencies and the level of risks to which users are exposed to remain unknown. Also, the state is yet to come out with policies to safeguard the health of the well water users and/or tackle the challenges of well water contamination in the area. To intervene in this direction, there is the need for an in-depth understanding of the well water quality status and of the natural and anthropogenic factors influencing the well water chemistry of the areas which is currently lacking. This is necessary both for planning purposes and to verify the concerns of the people about the deteriorating quality of water they consume.

Empirical review: Studies on the quality of water consumed in rural communities in Nigeria by scholars like[23,24] in Igbora and Uyo, Southern Nigeria and found that the quality of water from hand-dug wells were polluted by human activities and therefore, unsuitable for human consumption. Similarly, the study of Adediji and Ajibade[9] confirmed the unsuitability of well water for human consumption in Ede area of southwest Nigeria. They identified human activities as likely sources of pollutants to the groundwater.

Maxwell *et al.*[25] examined the spatial distribution of iron across rural communities of Benue State and attributed the variations in iron concentration to the geology of the study area. Omoboriowo *et al.*[26] observe that the groundwater in Arochukwu area of Afikpo Basin, were generally soft, free from saltwater intrusion and low with iron constituents. Awoyemi *et al.*[27] established that the groundwater problems in Majidun-Ilaje rural community of Ikorodu west LGA of Lagos State was due to the pollution of groundwater by pollutants from natural.

Weli and Ogbonna[28] examined the relationship between water quality parameters and water borne diseases. They identified the major contaminants in the well water samples and posited that the prevalent water borne diseases in the area may probably be due to the consumption of the degraded well water. Uzoije *et al.*[29] ascertain the chemical constituents of deep and shallow aquifer waters in the rural areas of Nsukka and the contributions of household, industrial and agricultural pollutants to its impaired quality. Similarly, Onunkwo *et al.*[30] investigated the water quality status of shallow and deep aquifers wells from the rural communities of Nsukka and discovered that while the aquifers are highly polluted by iron, the shallow aquifers are polluted by human activities. Majuru *et al.*[31] discovered that wells, in many, poor, rural and backward communities are not typically cased from the surface down into the smaller hole with a casing that are of the same diameter as the holes. The annular space between the large hole and the smaller casing is not filled with bentonite clay, concrete or other sealant materials. This creates a permeable seal from the surface to the next confining layer and permits contaminants to travel downwards along the side walls of the casing into the aquifer.

Groundwater typically contains more minerals in solution than surface water which may require treatment to soften the water by removing minerals like arsenic, iron, manganese[32] and isolate and determine the concentration levels of the minerals contained in such water and the problem(s) resulting from such minerals[33]. This is even more necessary in rural communities, like our study area, where residents may lack information on how their land use patterns and living conditions pose dangers to their well water sources. Unfortunately, studies which accomplish these objectives in our study area are currently lacking. Against this background, this study is designed to close the gap in knowledge.

MATERIALS AND METHODS

Study area: The study area is Udenu local Government Area of Enugu State, Nigeria. Obollo-Afor is the administrative headquarter of the Local Government Area. The study area lies approximately at latitudes 6°48^{1}N and 6°58^{1}N and Longitudes 7°26^{1}E and 7°40^{1}E. It covers an area of 248 km^2. It is bounded to the Northwest by Kogi State, Northeast by Benue State, to the West by Igbo-Eze North LGA, to the East by Isi-uzo LGA and to the South by Nsukka LGA. (Fig. 1). The study area is underlain by the following geologic formations, the Ajalli Sandstone and the Mamu Formation. The Mamu Formation[34] is the oldest outcrop in the study area. It outcrops further east of Nsukka, around Obollo-Afor to Obollo-Eke area. Only deep boreholes of up to 220-250 m at Obollo-Afor encounter the Mamu. The lithology is made up of sandstone, shales, sandy shales and coal[35]. The study area consists of two topographic features: The high elevated areas and the lowland areas. Udenu LGA is mainly drained by the Ebonyi River. It flows through communities such as Obollo-Etiti and Obollo-Eke. The rest of the areas are drained by springs. This was also acknowledged by Eze[36] that the Ebonyi River is the dominant hydrological feature of the area. The climate of Udenu LGA falls under the same climate of Enugu state, Nigeria. It is a tropical wet and dry (Aw) climate type according to Koppen's classification system. According to the 2006 population census, Udenu LGA has a total population of 178,687 and an area of 248 km^2 with 88,381 males and 90,306 females[37].

Water samples were collected from twenty (20) different locations in ten sampled communities. Two (2) groundwater samples were collected from each of the sampled community

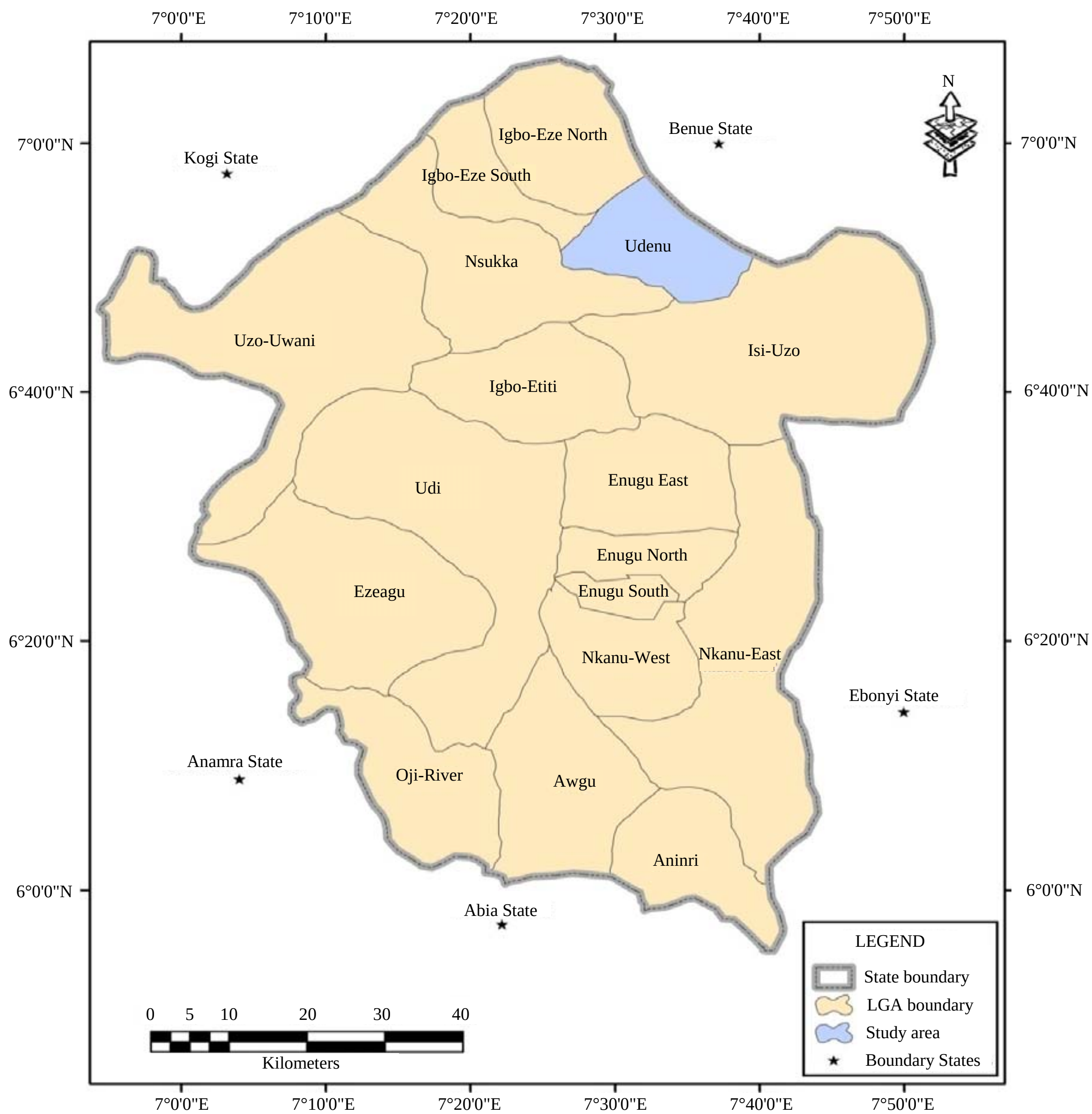

Fig.1: Enugu state showing (UDENU) LGA

(one from hand-dug well and one from borehole). The reason for two samples per community is to get a fair representation of water sources that serves the people in the rural communities that make up the LGA. The water was collected from boreholes and hand-dug shallow wells. The borehole and hand-dug well water samples were taken once in the month of August, 2016, when the boreholes and hand-dug wells must have experienced rise in water table. All water samples were collected in sterilized rubber bottles following standard procedure. Sterilized bottles were labeled before sampling and all samples were taken immediately to the laboratory for analysis. Two different bottles were used for the collections from each of the location. One was for the physico-chemical analysis while the other was for bacteriological analysis. Also, the samples for microbial analysis were preserved in Ice block in a cooler and sent immediately to the laboratory for analysis. The aim was to slow down the rate of any biochemical reaction. Samples were analyzed for pH, Temperature, Electrical conductivity, Calcium, Magnesium, Iron, Hardness, Turbidity, Alkalinity, Sulphate, Chloride, Nitrate, Total dissolved solids, Total coliform, *Escherichia coli*. Other information like environmental factors used in this study (Table 1) were selected based on the observed characteristic of the sampled hand-dug well and borehole environments, opinions from field survey and consultation with experts.

Table 1: Natural and anthropogenic environmental factors used in the study

Categories	Name of Factors	Description of the factors
Natural		
1	Host Rock	Different types of minerals exist naturally in some rocks. Iron and magnesium, for instance, exist widely in most rocks in Nigeria
2	Soil	Soil nature and characteristic influence the extent of pollutant concentrations in groundwater Coarse material like sand and gravel transmit dissolved pollutants more rapidly than finer materials like clay and silt[38]
3	Topography (natural flow paths)	Runoff along natural flow paths usually moisturize the environment, dissolve organic matter and significantly increase the susceptibility of wells and boreholes in such areas to contamination[39]
4	Natural hazards	Natural hazards, particularly, soil erosion and flooding increase the likelihood of entry of contaminant (debris and discharges)into nearby wells or boreholes[36]
5	Vegetal cover	Hand-dug wells and boreholes developed in forested areas are susceptible to contamination by leaves, insects and decayed organic matter which can easily be carried into the Groundwater by rain percolating through the soils
Anthropogenic		
6	Waste from households	Common household items such as paints thinner, cleaning materials, batteries, cans, household chemicals etc pose a threat to well/borehole water
7	Wastes from Farms and industries	Domestic and industrial wastes pose threats to groundwater because they can easily be carried into groundwater by rain percolating through the soils[25]
8	Presence of chemical fertilizers	Pesticides, fungicides and fertilizers may be transmitted downwards into the saturation zone (aquifer) and this has been reported to be responsible for groundwater pollution in many areas[40]
9	Presence of failing septic tanks.	Seepage from septic tanks is typically a major source of groundwater contamination[41]
10	Nature of well or borehole development	Hand-dug wells and boreholes constructed manually generally have higher risk of contamination than those developed mechanically
11	Nature of well/borehole cap	Hand-dug wells/boreholes that are typically capped with either a well cap or seal keep insects, impurities, small animals from accessing the well water
12	Nature of water collector	The quality of containers used in drawing water from hand-dug well increases the risk of groundwater contamination
13	Presence of Animals	Animals loitering around groundwater disposes faecal materials at the month of hand-dug wells/boreholes. Some even fall into hand-dug wells not properly covered
14	Fencing	Unfenced hand-dug wells/boreholes have higher risk of being accessed by impurities than the fenced hand-dug well/boreholes

Source: Authors' field study, (2016)

Environmental factors used in the analysis: Environmental factors used in this analysis fall into two broad categories, natural and anthropogenic. All the relevant factors that were suspected to interactively impact on well and borehole water quality were and built into the investigation. Such factors included soil type, host rock, topography, natural hazards, vegetative cover, wastes from household, waste from farms and industries, presence of chemical fertilizers, presence failing septic tanks, nature of well or borehole development, nature of well or borehole cap, nature of water collector, presence of animals and fencing.

Table 1 presents a summary of the factors.

The selected environmental factors were quantified on a calibration scale of 1-8 within a 20 m radius. For instance the distances of wells/boreholes to the influencing factor(s) 3, 4, 5, 6, 7, 8, 9 and 14 in Table 1 determined the scores that was awarded to the factors. The awarded scores ranged from 1, 2, 4, 6 and 8, respectively. The criteria adopted for assigning scores is based on the assumption that the closer a source of water is to the factors (shown in Table 1), the more prone the source is to contamination. Other factors like, Nos 10 and 12 were scored based on the nature and type of materials used in groundwater environment, including the nature/type of well cap development. Number 2 was scored based on the characteristics of soil. Scores were awarded based on type of soil and permeability rates. Soil nature and characteristic influence the extent of pollutant concentrations in groundwater. Coarse material like sand and gravel transmit dissolve pollutants more rapidly than finer materials like clay and silt[38].

RESULTS AND DISCUSSIONS

Results of the hand-dug well and borehole water quality: Tables 2, presents the results of the analyzed water samples from the boreholes and hand-dug well water studied.

The pH values for boreholes range from 5.2-6.7, temperatures range from 25.4-28.6°C, Electrical conductivity (EC) ranges between 16-43 µS cm^{-1}, turbidity ranges from 0.22-2.6 NTU, TDS ranges from 28-63 mg L^{-1} while Chloride

Table 2: Characteristics of borehole and hand-dug well water samples

Codes	pH	Temp.	Ec	Turbidity	Calcium	Magnesium	Iron	Chloride	Nitrate	TDS	Alkalinity	Sulphate	Hardness	Total coliform	*E. coli*
BH1	5.9*	26.5*	23.0	0.22	1.60	1.36	0.20	5.3	0.6	41.0	10.0	6.4	7.3	0.47	0.0
BH2	6.2*	25.5*	28.0	0.34	1.50	0.84	0.32*	5.6	1.8	56.0	12.0	7.3	6.2	0.75	0.0
BH3	5.6*	27.5*	28.5	1.2	1.87	0.33	0.23	4.6	1.76	28.0	19.0	2.6	6.8	0.65	0.0
BH4	6.5	26.5*	38.5	1.3	2.40	0.93	0.31*	3.7	0.0	38.0	14.0	3.7	7.4	0.01	0.0
BH5	6.4*	25.8*	16.0	2.6	1.30	0.31	1.30*	3.2	2.3	63.0	8.0	6.2	8.3	0.91	0.0
BH6	6.3*	26.6*	23.0	2.3	1.60	0.67	1.41*	20.1	3.1	52.0	10.0	8.6	7.8	2.87	0.0
BH7	6.6	28.6*	26.0	2.3	1.52	0.22	0.43*	9.8	0.39	49.5	11.0	2.4	7.9	0.66	0.0
BH8	6.1*	25.4*	43.0	1.4	1.30	0.32	0.35*	17.8	2.28	49.3	19.0	4.6	8.5	2.06	0.0
BH9	5.2*	28.4*	37.0	1.0	1.60	0.40	0.33*	4.5	1.4	38.0	8.0	4.1	10.0	0.78	0.0
BH10	6.7	27.3*	33.0	1.2	1.90	1.54	0.14*	8.5	3.4	40.1	11.0	5.6	11.2	0.68	0.0
HDW1	7.1	27.0*	64.3	3.5	6.30	1.40	1.10*	3.5	2.7	120.0	10.1	10.0	40.0	6.00	1.3*
HDW2	6.8	25.5*	334	6.7*	5.40	4.10	0.20	7.0	3.7	140.0	11.2	8.0	28.0	4.00	0.9*
HDW3	6.5	27.4*	77.4	1.6	4.10	4.80	0.90*	6.0	1.8	100.0	8.2	7.0	34.2	3.00	0.8*
HDW4	6.4*	26.2*	167	2.4	3.60	3.70	0.50*	5.9	2.4	110.0	7.6	6.0	30.0	5.00	0.2*
HDW5	6.1*	27.6*	128.2	2.9	1.60	3.90	0.60*	5.1	5.3	200.0	6.5	6.4	18.0	2.00	0.5*
HDW6	6.7	26.1*	220	3.2	3.10	4.50	0.10	8.4	9.4	180.0	10.0	7.4	33.6	5.00	0.8*
HDW7	6.2*	28.0*	262.4	5.0	3.80	1.80	0.20	11.5	5.8	170.0	14.0	5.8	26.1	4.00	1.8*
HDW8	7.2	24.4	123	2.6	4.30	2.60	0.20	9.3	11.2*	150.0	15.0	6.8	24.0	7.00	1.2*
HDW9	6.7	26.5*	77.0	4.5	8.00	2.40	0.30	8.5	2.8	140.0	7.0	0.0	20.0	3.00	0.6*
HDW10	7.6	25.3*	147	3.5	7.00	3.20	0.20	10.1	6.5	170.0	12.0	8.6	31.4	6.00	1.0*
Mean	6.44	26.6	94.8	2.5	3.20	1.90	0.50	7.9	3.4	96.7	11.2	5.9	18.3	2.70	0.45
WHO (2011)	6.5-8.50	25.0	1000	5.0	75-200.00	50.00	0.30	-	10.0	500.0	80-120.0	250.0	500.0	10.00	0.00

*Values that exceed WHO[42] Standard, -No guideline value, BH: Borehole, HDW: Hand-dug well, Source: Authors' Field study, 2016

Table 3: Statistical summary of borehole water parameters in the area

Parameters	Units	Mean	Min	Max	SD	No of Locations with values exceeding the WHO[42] standard
pH	-	6.15*	5.20	6.70	0.46	7
Temperature	°C	26.81*	25.40	28.60	1.12	10
Electrical conductivity	μS cm^{-1}	29.60	16.00	43.00	8.25	Nil
Turbidity	(NTU)	1.37	0.22	2.60	0.80	Nil
Calcium	mg L^{-1}	1.66	1.30	2.40	0.32	Nil
Magnesium	mg L^{-1}	0.59	0.22	1.54	0.41	Nil
Iron	mg L^{-1}	0.50*	0.14	1.41	0.45	9
Chloride	mg L^{-1}	8.31	3.20	20.10	5.99	Nil
Nitrate	mg L^{-1}	1.70	0.00	3.40	1.12	Nil
Total dissolved solids	mg L^{-1}	45.49	28.00	63.00	10.31	Nil
Alkalinity	mg L^{-1}	12.20	8.00	19.00	3.99	Nil
Sulphate	mg L^{-1}	5.15	2.40	8.60	2.02	Nil
Hardness	mg L^{-1}	8.14	6.20	11.20	1.48	Nil
Coliform	CFU/100 mL	0.98	0.01	2.87	0.83	Nil
Escherichia coli	CFU/100 mL	0.00	0.00	0.00	0.00	Nil

*Mean values that exceeded WHO[42], Source: Authors' Field study, 2016

Table 4: Statistical summary of hand-dug well water parameters

Parameters	Units	Mean	Min	Max	SD	No of Locations with values exceeding the WHO[42] Standard
pH	-	6.73	6.1	7.6	0.46	3
Temperature	°C	26.40*	24.4	28.0	1.13	9
Electrical conductivity	μS cm^{-1}	160.03	64.3	334.0	88.08	Nil
Turbidity	(NTU)	3.59*	1.6	6.7	1.47	1
Calcium	mg L^{-1}	4.72	1.6	8.0	1.94	Nil
Magnesium	mg L^{-1}	3.24	1.4	4.8	1.15	Nil
Iron	mg L^{-1}	0.43*	0.1	1.1	0.34	4
Chloride	mg L^{-1}	7.53	3.5	11.5	2.46	Nil
Nitrate	mg L^{-1}	5.16	1.8	11.2	3.15	1
Total dissolved solids	mg L^{-1}	148.00	100.0	200.0	32.24	Nil
Alkalinity	mg L^{-1}	10.16	6.5	15.0	2.91	Nil
Sulphate	mg L^{-1}	7.30	5.8	10.0	2.64	Nil
Hardness	mg L^{-1}	28.53	18.0	40.0	6.75	Nil
Coliform	CFU/100 mL	4.50	2.0	7.0	1.58	Nil
Escherichia coli	CFU/100 mL	0.91*	0.2	1.8	0.45	10

*Mean values that exceeded who[42], Source: Authors' Field study, 2016

returned values that range from 3.2-20.1 mg L^{-1}. The values for Nitrate range from 0-3.4 mg L^{-1}, Sulphate ranges from 2.4-8.6 mg L^{-1}, Alkalinity ranges from 8-19 mg L^{-1}, Hardness ranges from 6.2-11.2 mg L^{-1} while Total coliform counts range from 0.01-2.87 CFU/100 mL. *E. coli* ranges from 0-0 CFU/100 mL. Iron ranges from 0.14-1.41 mg L^{-1}, Calcium ranges from 1.3-2.4 mg L^{-1} and Magnesium ranges from 0.22-1.54 mg L^{-1}.

Conversely, the pH values for hand-dug wells range from 6.1-7.6, temperatures range from 24.4-28°C, Electrical conductivity (EC) ranges between 64.3-334 μS cm^{-1}, turbidity ranges from 1.6-6.7 NTU, TDS ranges from 100-200 mg L^{-1} while Chloride returned values that ranges from 3.5-11.5 mg L^{-1}. The values for Nitrate range from 1.8-11.2 mg L^{-1}, Sulphate ranges from 5.8-10 mg L^{-1}., Alkalinity ranges from 6.5-15 mg L^{-1}, Hardness ranges from 18-40 mg L^{-1} while Total coliform counts range from 2-7 CFU/100 mL. *E. coli* ranges from 0.2-1.8 CFU/100 mL. Iron ranges from 0.1-1.1 mg L^{-1}, Calcium ranges from 1.6-8 mg L^{-1} and Magnesium ranges from 1.4-4.8 mg L^{-1}.

Taken together the values returned for many of the parameters as shown in Table 2 are in line with the WHO[42] standard of drinking water supplies, the major exceptions are for temperature, iron for both the hand-dug well and borehole water samples. The values returned for *E. coli* for the hand-dug well samples were generally above the WHO[42] standards indicating that the hand-dug wells are largely polluted and unfit for human consumption.

Variations between the quality status of hand-dug well and borehole samples: Information on the variations between the quality status of hand-dug well and borehole samples in the study area are summarized in Table 3 and 4. Table 3 presents the statistical summary of the analyzed hydro-chemical and bacteriological parameters for borehole water in the study area.

As shown in Table 3, seven out of the ten sampled borehole sites showed low values of pH which are clear signs of acidity as confirmed by Kura *et al.*[43]. The sites with low pH values as shown in Table 2, are BH1 and BH2 (Amalla), BH3 (Umundu), BH5 and BH6 (Imilike-Uno), BH8 (Ezimo-Uno), BH9 (Orba-Uno). These communities are found in the upper section of the study area which is characterized by low HCO_3 and high Fe content. The low pH values of the water samples in affected communities may have resulted due to the rock type and runoff waterways that moisturize the area and increase the dissolved organic carbon (DOC), which will eventually lead to a decrease in pH. This is similar to the findings of Kura *et al.*[43]. Also, the dissolution of rocks that are of acid origin is a frequently reported cause of low pH in water.

The temperatures recorded in the ten sampling locations, of the study area, were well above the WHO recommended limits (25°C) for drinking water quality. Changes in temperature, as noted earlier, affect living organisms. The rates of biological and chemical reactions depend to a large extent on temperature. The high temperatures recorded in the different communities of the study area were reported to have resulted from geothermal gradient which is the rate of increasing temperature with respect to increasing depth in the earth's interior[44]. The geothermal gradient varies with location and is typically measured by determining the bottom open-hole temperature after borehole drilling. The depth of the sampled boreholes were found to be very high (mean depth = 168.3 m). As EPA[45] noted, there is a positive correlation between borehole depths in many regions with borehole water temperature. This suggests that temperature is largely controlled by depths.

As shown in Table 3, the mean values of iron were above the WHO[42] standard for drinking water supplies. In fact, in all the sample stations (except BH1) recorded values for this parameter were above the WHO permissible limit of 0.3 mg L^{-1} for human use. Iron exists naturally in rivers, lakes and underground water[46]. Ezeigbo[46] and Kura *et al.*[43] added that iron may also be released to water from natural deposits, industrial wastes, refining of iron ores and corrosion of iron containing metals. When the groundwater with higher concentration of iron is abstracted, it quickly oxidizes to ferric state in the form of insoluble ferric hydroxide, a brown substance. Field investigations revealed that the observed high iron loads in the water samples could not have come from industrial effluents refining ores. Ezeigbo[46] also established that iron is a very common element that is found in many rocks and soils of the study area and these must have been the source of this pollutant in the samples.

Table 4 presents the statistical summary of the values of analyzed hydro-chemical and bacteriological parameters for hand-dug well water samples in the study area.

As shown in Table 4 the mean values of Temperature, *E. coli* and Fe^{2+} exceeded the WHO[42] standard for drinking water supplies. From Table 4, it was revealed that pH values were lower than the recommended minimum in three locations, temperature values were above in 9 locations, Turbidity in one location, Fe^{2+} in 4 locations and *E. coli* in all the 10 sampled locations. Iron in the hand-dug well water samples, as observed earlier, were reported to have been released from natural deposits, as other possible sources (industrial wastes, refining of iron ores and corrosion of iron containing metals) were completely absent in the observed hand-dug well environments. This again indicates that the most probable environmental sources of the pollutant (Fe^{2+}) is the rocks and soils of the study area in which iron is a very common element[46,30].

Turbidity, as shown in Table 4, returned a high value in HDW 3 which is clearly above the WHO[42] standard for drinking water. Turbidity is a measure of transparency (clarity) or the cloudiness of water due to fine suspended colloidal particles of clay or silt, waste effluents or microorganisms contained in water. The recorded values for turbidity for the entire sampled hand-dug well are low except HDW 2 as summarized in Table 4. Turbidity in water samples often result from clay, silt and finely divided soluble inorganic and organic matter[44]. So this high load of turbidity in HDW 2 could be attributed to parent rock mineralogy as the hand-dug well is developed in an area rich in fine particles of clay or silt[47].

Values of pH which were lower than the WHO[42] standard were observed in three hand-dug well samples. As noted in the borehole samples earlier described, pH values of a water sample measures its hydrogen ion concentration and indicates whether the sample is acidic, neutral or basic[45]. The observed scenarios were attributed to the shallowness of the hand dug wells and probable dissolution of some rocks that are of acid origin.

Nitrate showed a relatively high value which was above the WHO[42] standard in one (HDW 8) sample location. Water with a high nitrate concentration can cause blood disease known as methemoglobinemia (blue baby syndrome) in bottle fed infants WHO[42].Nitrate shows the effects of organic pollution in water samples. It is the oxidation of ammonium to nitrite followed by the oxidation of nitrite to nitrate by group of organisms in the environment. High nitrate concentrations have been recorded in similar groundwater studies in shallow hand-dug well[48,49,30].

From the analysis of water samples taken from all the hand-dug wells in the study area, *Escherichia coli* was recorded in all the hand-dug wells sampled which is an indication of faecal pollutant. The communities where it was recorded are: Obollo-Eke, Obollo-Etiti, Ogboduaba, Imilike-Agu

Table 5: Factor loading after varimax rotation Eigen value, variability and cumulative% of each of the extracted components of environmental variables

	Components				
Variables	1	2	3	4	5
Nature of water collector	0.889	-0.029	-0.041	0.171	-0.069
Fencing	0.888	-0.004	0.014	-0.036	0.078
Nature of well/borehole development	0.877	-0.164	0.175	0.309	-0.036
Nature of well/borehole cap	0.848	-0.096	0.137	0.394	-0.025
Presence of animal	0.692	0.179	0.132	0.048	0.520
Rock	-0.179	0.882	0.079	-0.044	0.203
Natural hazards	0.063	0.801	0.022	0.066	-0.433
Soil type	-0.534	0.590	0.154	-0.036	0.503
Topography	0.178	0.495	0.313	0.415	0.219
Vegetation cover	-0.105	0.041	0.922	0.108	0.037
Farm wastes	0.399	0.170	0.777	-0.074	0.150
Septic/latrine	0.310	-0.156	-0.186	0.867	0.046
Household wastes	0.146	0.335	0.343	0.754	-0.215
Fertilizer	0.053	-0.010	0.088	-0.043	0.947
Eigen values	4.825	2.916	1.816	1.198	1.079
Variance%	34.464	20.828	12.971	8.555	7.704
Cumulative%	34.464	55.292	68.263	76.818	84.522

Source: Authors' Field study and computation, 2016

and Ezimo-Agu. The presence of the Escherichia coli in the hand-dug well water samples is a clear indication of contamination of water supplies. *E. coli* indicates faecal contamination of drinking water which can cause some types of clinical syndromes namely, urinary tract infection, diarrhea or gastroenteritis, pyogenic infection and septicaemia[45]. The presence of this pollutant was attributed to the unhygienic conditions around hand-dug well environments which favour the growth of microorganisms. Although a clinical report supporting this finding could not be obtained, the findings are however consistent with the study of Owuna[50] and Isikwue *et al.*[18].

Principal component analysis of the environmental factors affecting borehole and well water quality in the study area: To further strengthen our analysis on the factors influencing borehole and well water quality in our study area, we applied PCA to the 14 natural and anthropogenic factors earlier identified and described in Table 1. PCA is the most widely used technique among the families of multivariate statistical analysis[43]. It is a technique which identifies patterns in data and then presents them based on their similarities and differences. The main aim of PCA is to summarize a multivariate dataset by reducing the statistical noise in the data, exposing the outlier and then arranging the components in descending order (from the largest contributor to the least) as accurately as possible with as few principal components as possible[43]. Normally the first few PCs will interpret the variables with the highest variance in the case of large differences in variance.

Only components with eigenvalues greater than 1 was considered to be very important source of variance in the data set, the highest priority ascribed to the component that has the highest eigenvalue[51]. As such, any component that displays an eigenvalue greater than 1.00 is believed to be responsible for a greater amount of variation than is contributed by one variable. Thus a component with such a characteristic is responsible for a significant amount of variance and deserves to be retained. This is because the higher the eigenvalue of a component, the greater the contribution of that particular component to the variability of the environmental variables in the area. Also, for the interpretation of the factors that are of high significance without changing the variance, factor rotation using varimax, which is the most popular rotation technique[51] was employed. Thus, the 14 variables identified and used in our analysis were reduced to five principal components (Table 5). This is because each of the observed variables contributes one unit of variance to the total variation in the data set. The threshold significant loading used in this study is 0.7 and above. A threshold value of 0.7 and above, signifies a stronger degree of association of a variable[52].

The PCA result consists of five components that cumulatively account for 84.5% of the total variance in the data matrix. The first component which normally accounts for the most significant process explains 34.4% of the total variance with an eigenvalue of 4.8. The component has high loadings on: Nature of water collector, fencing, nature of hand-dug well/borehole development and nature of hand-dug well/borehole cap. This component shows the influence of poor source water protection in the study area.

Component 2 accounts for 20.8% of the total variance with an eigenvalue of 2.9. It consists of high loading of rock type and natural hazard. This component shows the influence of mineral properties of the rocks in the study area. Groundwater is influenced by the rock and geology that the water flows through because of various minerals being hosted underground. Also, coarse material like sand and gravel transmit dissolved pollutants more rapidly than finer materials like clay and silt[53]. The study area is characterized by two different underlying rock materials: Sandstone (prevalent in the upland area) which is porous and shale (prevalent in the lowland area) which is less porous[22].

Component 3 accounts for 12.9% of the total variance with an eigenvalue of 1.8. This component shows high loading of vegetation cover which is an evidence of the influence of vegetal and related impurities. Litters of plants fall into uncovered hand-dug wells and contaminate the hand-dug well water. Also, dissolved organic matter, significantly increase the susceptibility of hand-dug wells and boreholes in such areas to contamination which can easily be carried into the groundwater by rain percolating through the soils. Surface runoff can as well carry litters of plants into hand dug wells especially the unprotected ones.

Component 4 accounts for 8.5% of the total variance with an eigenvalue of 1.1. This component shows high loading of septic/latrine and household wastes. This is an indication of unsanitary surroundings around the water sources. Poorly constructed septic tanks and pit latrines pose major threat to groundwater quality. These septic tanks and pit latrines are most often located within a 15 m radius to the sampled groundwater. Pit latrines are dug to about 8-9 m which is the average water table of the communities in the lowland areas. The liquid effluent from a septic system or pit latrines follow the same path as the rain that percolates into the unsaturated zone. Like the rain, once the effluent reaches the water table, it flows down the hydraulic gradient, which may be roughly parallel to the slope of the land, to lower points[38]. Thus, again, the location of one's house in relation to neighbouring houses, both upslope and down slope is important. In rural communities where houses are nucleated and everybody has either a septic tank or pit latrines, effluent recycling can occur if the wells are shallow or the septic systems and pit latrines are improperly placed[38]. Deep wells are less likely to draw in septic waste. Microbial loads (*Escherichia coli*) were found in all the hand dug wells from the five different communities in the lower side of the divide. Finally, component 5 accounts for 7.7% of the total variance with an eigenvalue of 1. The component shows high loading of fertilizer. This is an indication of the influence from agricultural pollutants in the study area. In the study area of Udenu LGA, every available and unoccupied land is seen as a viable space for agriculture. Fertilizers and pesticides applied near groundwater such as areas with shallow water table have a high risk of groundwater contamination[40].

Health implications of borehole/hand-dug well water contaminations: Lower water quality has the potential of becoming a threat in drinking water if such water is consumed. The WHO guidelines for drinking water stipulated specific acceptable and safety limits for drinking water. Deviations from these limits usually have health implications due to either elevations or reductions in the level and nature of these parameters. Two main pollutants identified in the hand-dug well and borehole water samples were, iron and *E. coli*. The first comprises of conventional hand-dug well/borehole water pollutants that come primarily from the nature of host rocks of the hand-dug wells/boreholes, while the last is usually human-related, particularly unsanitary surroundings leading to contact with human feces. The health implications of the impaired water quality in the study area as revealed by our analyzed results are highlighted below.

Implications of iron: Iron is an essential element in human but excess of iron in water can be of health hazard. For example, exposure at high levels has been shown to result in vomiting, diarrhea, abdominal pain, seizures, shock, low blood glucose, liver damage, convulsions, coma and possibly death after 12-48 h of ingesting toxic level of iron[33]. It can also lead to Alzheimer type II astrocytosis, Parkinsonism, cognitive dysfunction and ataxia[16]. Death may also occur if children ingest sufficient iron to exceed the body's iron-binding capacity, the metal-binding proteins that make ionic iron availably[33]. Thus, the World Health Organization recommended that the iron content in drinking water should not be greater than 0.3 mg L^{-1} because iron in water stains plumbing fixtures, stains cloths during laundering, incrusts well screens and clogs pipes[16].

Implications of *Escherichia coli*: Organisms such as *E. coli* is known as indicator of bacteria in water. More so, the presence of *E. coli* is used as an indicator to monitor the possible presence of other more harmful microbes, such as cryptosporidium, giardia, shigella and non virus. *E. coli* in drinking water can cause the following: Urinary tract infections, meningitis, diarrhea, (one of the main cause of morbidity and mortality among children), typhoid fever, acute renal failure and haemolytic anaemia[54]. Hence, it becomes necessary to ensure that the drinking water is free from bacteriological contamination. The respondents' assessment of the burden of water related diseases in the study area is presented in Table 6.

Table 6: Respondents views of the prevalence of water related diseases in the study area

Names of health institution	Water related diseases treated in 2016	Perception on the regularity of occurrence	Most affected category	Perceptions on Trends	Response on main water source
Nwaossai hospital orba	Cholera typhoid fever, nausea, hepatitis, diarrhea	Very frequent	Children and women	Downwards (i.e., on the decrease)	Vended water/borehole
ST john's hospital, imilike agu	Typhoid fever, malaria, miscarriages cholera, trachoma, diarrhea	Frequent	Children	Stable	Wells
ST teresas hospital, obollo afor	Dysentery, malaria, liver damage, high blood pressure, hepatitis, diarrhea	Fairly frequent	Children and adults	Downwards	Vended water
Imilike uno health center	Respiratory diseases, typhoid, urinary tract infection, malaria, diarrhea	Very frequent	Children and women	Stable	Boreholes/Wells
ST john's hospital, ezimo uno	Methaemoglobiaemia, dysentery, malaria, typhoid Cholera, hepatitis, diarrhea	Frequent	Children	Stable	Vended water
Obollo eke health center	Urinary tract infection, typhoid cholera, hepatitis, Eczema,, malaria,	Seasonal	Adults and children	Downwards	Wells
ST briget hospital, ezimo agu	Malaria, cholera, schistosomiais, gastro intestinal infection, diarrhea	Very frequent	Adults and children	On the increase	Wells
Obollo etiti health center	Malaria, intestinal infection malaria, Miscarriages, hepatitis, diarrhea	Frequent	Children and women	Downwards	Wells
Amalla health center	Gastro intestinal infection, malaria, diarrhea	Fairly frequent	Children and women	Downwards	Vended water

Source: Authors' Field study, 2016

CONCLUSION AND RECOMMENDATIONS

Drinking water should be free from disease causing organisms, poisonous substances and excessive amounts of minerals and organic matter[6]. This study shows that the quality of hand-dug well and borehole water of the study area is influenced by natural and anthropogenic factors. The results of the analysis reveal that the concentration levels of some of the parameters are above the WHO guideline limit for drinking water in many of the sample locations. Pollutants such as: Fe^{2+}, temperature, turbidity, were attributed to natural factors while pH and *E. coli* were attributed to anthropogenic/natural. The results of the PCA analysis reveal that the groundwater of the area was found to be influenced by five components extracted from the PCA namely, poor hand-dug well/borehole protection, mineral properties of the rocks, influence of organic pollutants, unsanitary surroundings and agricultural activities. Based on the findings of the research, the following recommendations are necessary in order to enhance the sustainability of potable rural water supplies in the area:

- Enugu State Rural Water Supply and Sanitation Agency should ensure that wells developed and used in the area are closely monitored in order to ensure that water supplied to the rural residents is of the best possible quality that can guarantee good health and wellbeing for the water users. Hand-dug wells and boreholes that are vulnerable to contamination by environmental pollutants need to be closed. The State government in collaboration with the local government authorities should, in addition, create awareness among the water users in the rural communities on the dangers of poor sanitation/inadequate protection of wells and borehole water sources
- State government in collaboration with the local government should also encourage the rural residents to build collective waste disposal facilities and pit latrines to avoid indiscriminate disposal of wastes and/defecation in areas close to wells

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