International Journal of Chemical, Material and Environmental Research 2017, 4 (3): 123-130

Research article

INTERNATIONAL JOURNAL OF CHEMICAL, MATERIAL AND ENVIRONMENTAL RESEARCH

An International Open Free Access, Peer Reviewed Research Journal

ISSN 2410-5945
2017, Vol. 4, No. 3: pg. 123-130

Quality Assessment of Borehole Water within Orji Mechanic Village Using Pollution and Contamination Models

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(Received: October 16, 2017; Accepted: November 01, 2017)

Abstract

Modeling of the physicochemical properties of borehole water in the evacuated sections of Orji mechanic village was carried out to determine the suitability of the groundwater in this area for human consumption. Physicochemical quality parameters in water which includes: colour, pH, electrical conductivity, total dissolved solids (TDS), alkalinity, nitrate, nitrite, phosphate, sulphate, chlorine, nickel, lead, cadmium, chromium, silver, manganese, zinc, copper and iron were determined at five sampling points in the area. Results showed that the pH of the water samples at all the sampling points were acidic, averaging 5.72, and below the SON standard for drinking water. Although the pollution load indices (PLI) at all the sampling sites indicated no pollution, nitrites, nitrates and phosphates gave contamination factors ranging from considerable to very high contamination by these compounds at most of the sampling sites. Positive correlations were observed between pH/ PO_4^{3-}, pH/Fe, NO_3^-/ PO_4^{3-}, NO_3^-/Cd, NO_3^-/Co, PO_4^{3-}/Fe, Cl^-/Mn, Cl^-/Co, Cr/Fe and Ag/Fe, indicating similar source of contamination. The water quality index (WQI) obtained for the borehole water in the area was 153.53, suggesting that the water is of poor quality.

Keywords: Borehole water, nitrite, nitrate, phosphate, contamination factor, water quality index

1. Introduction

One of the most outstanding source of environmental pollution considered almost as widespread as crude oil in Nigeria today is the indiscriminate disposal of used engine oil in the environment [1]. Frequent use of petroleum-based products such as gasoline, diesel, fuel oil and lubricating oil especially in mechanic workshops results in widespread and unavoidable release of these products into the environment [2]. It is the usual practice in most mechanic workshops to dispose used or spent engine oils resulting from automobile servicing within their surroundings. Apart from the disposal of spent engine oil within most mechanic workshops, further contamination could result from mishandling. Waste or used engine oil is usually drained from automobile and generator engines during servicing and maintenance works [3].

Many researchers have carried out studies on the level of contamination within and around automobile workshops [4-8]. In the analysis of heavy metal contamination in soil and water at automobile junk markets in Obosi and Nnewi, Anambra, South Eastern Nigeria [9], data obtained revealed that trace metal concentrations were all above the background levels with nickel in excess of international standard. Heavy metal enrichment was in the order Ni > Fe >> Zn > Cu > Mn > Pb > Cr. Results obtained from groundwater in the area showed that Ni, Fe, Cu and Mn were in excess, when compared with World

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Published online at www.ijcmer.org

Health Organization (WHO) drinking water standards. Pollution load index (PLI) and contamination factor (C_f) indicated that the soils around the automobile junk markets were at various levels of contamination with heavy metals, ranging from slight to severe pollution. They concluded that water around the auto mobile junk markets were not fit to be used domestically. Another study on the impact of auto mechanic workshops on soil and groundwater in Ibadan metropolis over a period of two months [10] showed that daily activities at auto mechanic workshops significantly increased the levels of heavy metals in the soil within the area and reduced the quality of the groundwater.

The former Orji mechanic village, Owerri was the home of more than two hundred automobile workshops scattered all over the area. The artisans in the business of auto repairs often dump or spill auto mechanic waste on every available space within their workshops. These wastes contain a mixture of different chemicals including heavy metals due to wearing of engine parts [11-13]. The significance of heavy metals in the environment is increasingly becoming an issue of global concern especially as soil constitutes an essential part of rural and urban environment [14-15]. In July 2016, the Imo State government relocated automobile mechanics and other artisans within Orji mechanic village after more than 30 years of occupation of the area. Recently, government agencies have started erecting residential buildings within the evacuated sections of the mechanic workshops. It is important to note that the area was not only occupied by automobile mechanics, but in addition metal scrap dealers. Electronic waste recycling was also visible in the area before the evacuation. There is therefore urgent need to assess the environmental impact of auto mechanic activities on groundwater quality in this area.

This study would therefore assess the physicochemical properties of groundwater within the evacuated sections of Orji mechanic village. The contamination and pollution index models of the data obtained would be used to determine the suitability of the groundwater in this area for human consumption.

2. Materials and Methods

2.1. Study Area

The Orji mechanic village was situated in Orji, Owerri North Local Government Area of Imo State. It was occupied by auto mechanics in 1987. Geographically, the area falls between coordinates of latitude 5.24-5.27 ^{0}N and longitude 7.04-7.06 ^{0}E with an area of 0.41 km^2 and lying on an area of flat agricultural land converted to mechanic workshops and residential homes. The geology of the area consists of plain soil which is about 0.05-2.0 mm in size. This type of soil has good drainage making it fast drying. The major activity in the site was basically repairs and maintenance of automobile vehicles.

2.2. Sample Collection

The sampling design used for this study was based on the need to spread sampling sites over the entire study area. The borehole water samples were collected at five different sampling points marked A-E (Figure 1). The coordinates of sample collection points are shown in Table 1.

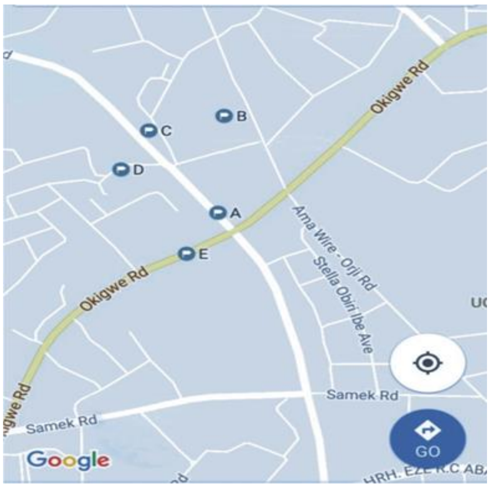

Figure 1. Map Showing Study Area and Sampling Points

Figure 2. On-going Projects at a Section of the Former Mechanic Village

Table 1. Coordinates of Sampling Points

Sampling Points	Coordinates	
	Longitude	**Latitude**
A	N 5^0 30.9183'	E 7^0 2.6596'
B	N 5^0 31.1236'	E 7^0 2.6597'
C	N 5^0 31.8900'	E 7^0 2.5523'
D	N 5^0 30.9992'	E 7^0 2.4213'
E	N 5^0 30.8349'	E 7^0 2.6216'

Three water samples were collected from each sampling point. The water samples were collected using sterile plastic bottles before been transferred to the laboratory for analysis. The mean values of the parameters at the five points were determined and used for data computation.

2.3. Physicochemical Analysis of Borehole Water Samples

Borehole water samples were analyzed for the following: colour, pH, electrical conductivity (EC), total dissolved solids (TDS), alkalinity, nitrate, nitrite, phosphate, sulphate, chlorine, nickel, lead, cadmium, chromium, silver, manganese, zinc, copper and iron. The physical properties of the borehole water samples which include colour, pH, EC and TDS were determined in situ.

2.4. Instrumentation

Checker plus pH meter by HANNA Instruments was used for the pH determination. EC and TDS were determined using Groline TDS/EC meter by HANNA Instruments. Water colour and anion determination were done using Multiparameter bench photometer HI 82300 by HANNA Instruments. Heavy metals were determined using GBC Scientific SensAA Dual Atomic Absorption Spectrophotometer.

2.5. Data Analysis

The data obtained were subjected to contamination and pollution index models. The models used were: C_f, PLI, Spearman's correlation coefficient and water quality index (WQI).

3. Results and Discussion

3.1. Physicochemical Properties of Water Samples

The results of the physicochemical analysis of borehole water samples in the studied area are presented in Table 2. Colour largely determines the appearance, taste and general drinkability of water. The colour of the water samples at all the sampling points were below the permissible limit of 15 PCU set by Standard Organization of Nigeria (SON) and as such have good appearance. The pH of the water samples at all the sampling points fell below the permissible level of 6.5-8.5 as recommended by SON. The values obtained ranged from 5.48-6.07, indicating that the water in the study area is acidic.

Table 2. Mean Values of the Physical and Chemical Properties of Borehole Water Samples

Sampling Points	Physical properties and anions									
	Colour (PCU)	**pH**	**Conductivity (μS/cm)**	**TDS (mg/L)**	**Alkalinity (mg/L)**	**NO_2^- (mg/L)**	**NO_3^- (mg/L)**	**PO_4^{3-} (mg/L)**	**SO_4^{2-} (mg/L)**	**Cl^- (mg/L)**
A	10	6.07	100	60	ND	1.0*	37.40	ND	ND	0.01
B	1	5.51	290	174	ND	1.0*	53.13*	0.30*	ND	0.13
C	3	5.78	70	42	5	ND	29.32	0.70*	ND	0.02
D	0	5.57	60	36	25	ND	47.56	0.20*	ND	0.09
E	0	5.68	100	60	10	ND	85.82*	0.50*	ND	0.06
SON	**15**	**6.5-8.5**	**1000**	**500**	**200**	**0.2**	**50**	**0.03**	**100.0**	**250**

ND - Not Detected, * - values greater than SON standards

pH value has a marked effect on the taste of the water and also indicated possible corrosion problems resulting from dissolution of metals such as copper, zinc and cadmium in water [16]. Conductivity is an indicator of total dissolved solid (TDS) and ionic concentrations in the water. The conductivity and TDS in the investigated samples were all below the permissible limit of 1000 μS/cm and 500 mg/L, respectively set by SON. However, water from sampling point B gave the highest TDS value of 174 mg/L. High values of TDS in ground water are generally not harmful to human beings, but may not be good for persons suffering from kidney diseases [17].

Alkalinity of water is a measure of its acid-neutralising capacity. It acts as a buffer; protecting the water and its life forms from sudden shifts in pH. It also measures the aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known. However, the alkalinity concentrations in the investigated borehole water samples were below the permissible limit of 200 mg/L by SON. The alkalinity was generally low averaging 8 mg/L in the samples studied. Alkalinity was not detected in sampling points A and B. The low alkalinity indicated that the borehole water samples are susceptible to changes in pH as observed in the pH measurements obtained in this study.

Nitrite and nitrate are common in groundwater (borehole) samples, particularly in areas of intensive agricultural activity, or where pit latrines are used [18]. Severe toxic effects are possible such as blue baby syndrome in infants [19] and reduction in the oxygen-carrying ability of blood in pregnant women [20]. Nitrite concentrations in samples A and B were the same and very high (1.0 mg/L), compared to the set limit by SON (0.2 mg/L). Nitrate concentrations were highest in sample E (85.82 mg/L) followed by sample B (53.13 mg/L) and both were above the limit of 50 mg/L by SON, indicating possible pollution at these points. These suggested that borehole water at sampling points A, B and E is not fit for consumption by new born babies and pregnant mothers.

The phosphate level obtained in this study ranged from 0.00 in sample A to 0.70 mg/L in sample C averaging 0.33 mg/L which was about ten times higher than the safe limit set by SON (0.03 mg/L). Phosphates are not toxic to humans unless when present in very high levels. Extremely high levels of phosphates could lead to digestive problems. Sulphate is particularly common in mining areas. High sulphate concentration can cause diarrhea, particularly in users not accustomed to drinking water with high sulphate concentrations. In this study, sulphate was not detected in all the samples analyzed. Chloride may cause nausea and vomiting at very high concentrations. Chloride levels in the samples ranged from 0.01-0.13 mg/L and were below the permissible limit of 250 mg/L by SON.

3.2. Heavy Metal Concentrations in Water Samples

The mean values of heavy metals in borehole water samples from the various sampling points are presented in Table 3.

Table 3. Mean Values of Concentration of Heavy Metal in Borehole Water Samples

Sampling Points	Heavy Metal Concentrations (μg/L)									
	Ni	**Pb**	**Cd**	**Cr**	**Ag**	**Mn**	**Co**	**Zn**	**Cu**	**Fe**
A	ND	ND	ND	0.07	0.27	ND	0.01	ND	ND	0.15
B	ND	ND	0.05	0.01	ND	0.12	ND	ND	ND	ND
C	ND	ND	0.05	0.05	0.04	0.02	0.01	ND	ND	ND
D	ND	ND	ND	0.06	0.02	ND	0.17	ND	ND	0.12
E	ND	ND	0.01	0.04	ND	ND	0.07	ND	ND	0.05
SON (μg/L)	**20**	**10**	**3**	**50**	**100**	**200**	**50**	**3000**	**1000**	**300**

ND - Not Detected

Nickel, lead, zinc and copper were generally not detected in the investigated samples. However, all metals detected were not significant and below the permissible limit set by SON. These suggested that the borehole water samples from the evacuated section of the Orji mechanic village is not yet contaminated by toxic heavy metals.

3.3. Contamination and Pollution Index Models of Water Samples

3.3.1. Contamination Factor and Pollution Load Index

The C_f is an indicator used to assess the presence and intensity of anthropogenic contaminants in groundwater. The C_f was determined mathematically using Equation 1 [21].

$$C_f = \frac{C_m}{C_b} \quad 1$$

where C_m is the concentration of a particular parameter in the water and C_b is the reference concentration of that parameter. SON standards for drinking water were taken as the reference concentrations. The C_f values as specified by Hakanson [22] are given in four levels and are shown in Table 4.

Table 4. Contamination Factor Values

C_f Value	Contamination Factor
$C_f < 1$	Low contamination
$1 \leq C_f < 3$	Moderate contamination
$3 \leq C_f < 6$	Considerable contamination
$6 \leq C_f$	Very high contamination

The PLI is a potent tool that provides a simple and comparative means for assessing the level of pollution. The PLI gives a summative indication of the overall level of toxicity in a sample. The PLI value greater than 1 is polluted, less than 1 indicates no pollution whereas values equal to 1 indicates contaminant loads close to the reference concentration [23]. The pollution load index was determined mathematically using Equation 2.

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \times ... \times C_{fn})^{1/n} \quad 2$$

where n is the number of parameters considered in the study and C_{fn} is the contamination factor for each individual parameter. The C_f and PLI of the parameters detected in this study are presented in Table 5.

Table 5. Contamination Factors and Pollution Load Indexes of Detected Parameters in Borehole Water Samples

Sampling Points	Contamination Factor									PLI
	NO_2^-	NO_3^-	PO_4^{3-}	Cd	Cr	Ag	Mn	Co	Fe	
A	5.000	0.748	0.000	0.000	0.001	0.003	0.000	0.000	0.001	0.26
B	5.000	1.063	15.000	0.017	0.000	0.000	0.001	0.000	0.000	0.27
C	0.000	0.586	23.333	0.017	0.001	0.000	0.000	0.000	0.000	0.12
D	0.000	0.951	10.000	0.000	0.001	0.000	0.000	0.003	0.000	0.07
E	0.000	1.716	16.667	0.001	0.001	0.000	0.000	0.001	0.000	0.03

All sampling points showed low PLI which indicates that there is no pollution within the study area. However, the sampling points showed different degrees of contamination by individual contaminants. Sampling points A and B were considerably contaminated by nitrites. Sampling points B and E were moderately contaminated by nitrates. Nitrite has been shown to react with nitrosatable compounds in the human stomach to form N-nitroso compounds. Many of these N-nitroso compounds have been found to be carcinogenic in all studied animal species. Thus, a link between cancer risk and endogenous nitrosation as a result of high intake of nitrate and/or nitrite is possible [24-25]. All the sampling points apart from A were highly contaminated by phosphates. Acute phosphate toxicity can provoke hypocalcaemia and associated symptoms. Moderate phosphate toxicity that takes longer time to develop can lead to the deposition of calcium phosphate crystals in various tissues, including fatal cardiovascular calcification [26].

3.3.2. Correlation Coefficient

The degree of linear association between any two of the water quality parameters was measured by simple correlation coefficient (r), and values are presented in Table 6. A correlation coefficient value of 0.5 and above indicates positive correlation between the parameters. There were positive correlations between pH/ PO_4^{3-}, pH/Fe, NO_3^-/ PO_4^{3-}, NO_3^-/Cd, NO_3^-/Co, PO_4^{3-}/Fe, Cl^-/Mn, Cl^-/Co, Cr/Fe and Ag/Fe. Positive correlation equal to or higher than 0.5 indicates similar source of contamination. The contamination source from the study area points to auto-mechanic waste and agricultural activities. Other sources could be from pit latrine or decomposing human excreta which was visible in the study environment.

3.3.3. Water Quality Index

The WQI was calculated based on the suitability of borehole water for human consumption. Out of the 20 parameters analyzed, 12 important quality parameters were detected in at least one sampling point. The average of each parameter over the five sampling points was used for the calculation.

Table 6. Correlation Coefficient Matrix between Water Quality Parameters in the Borehole Water Samples

	pH	**NO_2^-**	**NO_3^-**	**PO_4^{3-}**	**Cl^-**	**Cd**	**Cr**	**Ag**	**Mn**	**Co**	**Fe**
pH	1.000	–	-0.396	***0.930***	-1.000	-1.000	–	0.141	-0.806	–	***0.747***
NO_2^-		1.000	–	–	–	–	–	–	–	–	–
NO_3^-			1.000	***1.000***	-1.000	***1.000***	-0.999	-1.000	-0.998	***1.000***	-0.996
PO_4^{3-}				1.000	0.052	–	-1.000	-1.000	-1.000	-1.000	*1.000*
Cl^-					1.000	–	-0.714	-1.000	***0.994***	***0.513***	0.023
Cd						1.000	–	-0.389	-0.721	-0.284	-0.892
Cr							1.000	0.372	-0.729	0.284	***0.816***
Ag								1.000	-0.336	-0.316	***0.517***
Mn									1.000	-0.474	-0.582
Co										1.000	0.415
Fe											1.000

Three steps were followed for WQI computation. In the first step, each of the 12 parameters was assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes (Table 7). The maximum weight of 5 was assigned to the parameters; nitrate, nitrite, phosphate, cadmium and chromium due to their major importance in water quality assessment. Chloride which was given the minimum weight of 1 impacts basically on the taste of water. In the second step, the relative weight (W_i) was computed following Equation 3.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (3)$$

where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale (q_i) for each parameter was assigned by dividing its concentration in each water sample by its respective standard (SON) and the result multiplied by 100.

$$q_i = \frac{C_i}{S_i} \times 100 \quad (4)$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in mg/L, and S_i is the SON drinking water quality standard.

To compute the WQI, the SI was determined for each chemical parameter (Equation 5), which is then used to determine the WQI using Equation 6.

$$SI_i = W_i \times q_i \quad (5)$$

$$WQI = \sum SI_i \quad (6)$$

SI_i is the subindex of ith parameter, q_i is the rating based on concentration of ith parameter and n is the number of parameters.

Table 7. WQI Computation of Borehole Water in the Study Area

Parameters	**S_i**	**w_i**	**W_i**	**C_i (mean values)**	**q_i**	***SI***
pH	7.5	4	0.0816	5.72	72.25	5.90
TDS	500	4	0.0816	74.40	14.88	1.21
NO_2^-	0.2	5	0.1020	0.40	200	20.40
NO_3^-	50	5	0.1020	50.65	101.30	10.32
PO_4^{3-}	0.03	5	0.1020	0.34	1133.33	115.60
Cl^-	250	1	0.0204	0.06	0.02	0.00
Cd	3	5	0.1020	0.02	0.67	0.07
Cr	50	5	0.1020	0.05	0.10	0.01
Ag	100	4	0.0816	0.07	0.07	0.01
Mn	200	4	0.0816	0.03	0.02	0.00
Co	50	4	0.0816	0.05	0.10	0.01
Fe	300	3	0.0612	0.06	0.03	0.00
		Σw_i = 49				
WQI = 153.53						

The WQI in the present study was calculated from the mean physicochemical parameters of the borehole water samples. The computed WQI values were classified into five types [20] and are shown in Table 8.

Table 8. Water Quality Index Values

C_f Value	Water Quality
WQI < 50	Excellent water quality
50 < WQI ≤ 100	Good water quality
100 < WQI ≤ 200	Poor water quality
200 < WQI ≤ 300	Very poor water quality
WQI > 300	Unsuitable for drinking

The WQI obtained for the borehole water from the evacuated section of the Orji mechanic village was 153.53 suggesting that the water is of poor quality.

4. Conclusions

The pH of the borehole water samples from the studied section of the Orji mechanic village were found to be acid and below the recommended pH for drinking water by WHO. The major chemical pollutants in the water samples were nitrites, nitrates and phosphates, with average concentrations at the sampling points higher than the WHO standard. Though toxic heavy metals were detected in the water samples, their concentrations were well below the recommendations by WHO. Even with low concentrations of these toxic heavy metals as observed, regular consumption of the borehole water from this area will have long term health effects due to metal bioaccumulation in the human systems. WQI model for the physicochemical properties of water samples from the sampling points showed that borehole water from this area is of poor quality. Treatment of the water in this area before consumption is recommended.

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