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Investigation of the Possible Impact of Seismic Explosive Energy Sources on the Turbidity of Groundwater in Sagbama, Niger Delta, Nigeria

A. J. C. Madu[1], C. L. Eze[2], I. E. Otuokere[3,*]

[1]Department of Geology, Michael Okpara University of Agriculture, Umudike, Nigeria
[2]Institute of Geosciences and Space Technology, Rivers State University of Science and Technology, Portharcout, Nigeria
[3]Department of Chemistry, Michael Okpara University of Agriculture, Umudike, Nigeria

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Abstract

Explosives contamination of groundwater has been a major environmental challenge. The possible impact of seismic explosive energy sources on the turbidity of groundwater in Sagbama, Niger Delta, Nigeria was investigated using 2,4,6-trinitrololuene (TNT) energy source. The energy source was the high explosive dynamite 2,4,6-trinitrololuene (TNT) and 6 m electric detonators loaded in 5 hole pattern source array. The eleven upholes used in this study were drilled to 60 m depth using the rotary method and flushed continuously for 20 min to enhance stability. The turbidity values were determined using a turbidimeter. A control sample was taken from the borehole stations by sampling a day before detonation of dynamite. Subsequently, sampling was carried out a day after dynamite detonation and then, on a fourth-nightly basis. The average turbidity value of the control (sample water before detonation) was 3.76 NTU. After dynamite detonation, the average measured turbidity values ranged from 2.91 to 3.80 NTU. The highest recorded average value of 3.80 NTU was obtained on day-57 after dynamite detonation. Thereafter, the average turbidity value remained fluctuated. The lowest average value of 2.91 NTU was recorded on day-99. These variations from the control are not significant enough for dynamite to be said to have impacted on the turbidity value of the ground water. The control and test results values are both within World Health Organization guidelines for drinking-water quality limit of 5 NTU. Similar daily variations have been observed in areas where there was no dynamite detonation.

Keywords: Explosives, contamination, 2,4,6-trinitrololuene, turbidity, groundwater, uphole

1. Introduction

Explosion can be defined as the sudden release of energy. This energy may be obtained from nuclear or chemical reactions. Most explosives are composed of nitrogen compounds. The compounds oxidize to form small molecules such as H_2O, N_2 and CO_2 [1]. Based on susceptibility to initiation, explosives can be classified as primary or secondary [1]. Primary explosives are highly susceptible to explode and they can be used to initiate secondary explosives [1]. Contamination of groundwater by explosion has been a major environmental challenge. The transportation of 2,4-dinitrotoluene (2,4-DNT) and 2,6-dinitrotoluene (2,6-DNT) have been evaluated [2]. Explosive contamination of ground water and soil were reported in Belgium after World War 1 ammunition destruction. It was reported that the groundwater was contaminated with lead,

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* Corresponding author:
ifeanyiotuokere@gmail.com

arsenic, copper and nitroaromatics [3]. The production and detonation of explosives at the Werk Tanne ammunition site in Claudthal Zellerfeld, Germany caused a major pollution in that area [4]. It was reported that the site was polluted with polycyclic aromatic hydrocarbons (PAHs) and heavy metals [4]. Agricultural and rangelands around Partex plant in the U.S was reported to be contaminated with Royal Demolition eXplosive (RDX), trinitrotoluene (TNT) and 1,3,5,7-tetranitro-1,3,5,7-tetrazocane (HMX). This contamination was concentrated 10 m just below the soil surface [5]. In Cambodia, Southeast Asia, contamination due to mortar bombs, rocket-propeller, artillery shells, cluster bombs, rifle grenades and aircraft bombs were reported [6]. Explosives may enter the environment during the process of production, storage, usage or disposal, resulting in the contamination of groundwater. The contaminated groundwater may affect organisms in the environment [7, 8]. The rate and extent of transport and transformation of the explosive compounds are governed by the solubility, vapour pressure, Henry’s law constant, soil properties, pH and weather conditions [3]. Explosive compounds have the tendency to generate toxic effects. The effect of TNT explosion on mice, rats and dogs showed that it causes adverse health effect, including genotoxic and carcinogenic effects [9].

The widespread use of DNT in manufacturing munitions, polyurethane foams, and other chemical products has contributed to extensive soil and groundwater contamination [10]. Recent research has shown that explosives contaminated groundwater can be rapidly degraded using zero-valent iron, and that the use of in situ permeable reactive barriers (PRBs) has very good potential for reducing the costs associated with groundwater cleanup at TNT- and RDX-impacted sites [11]. Explosives used in the destruction of casting during construction have been implicated as sources of NO_3^- contamination in groundwater [12]. Residual concentrations of the most commonly used explosives 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) have been identified in soil and groundwater at military training ranges in Finland [13]. The manufacture; load, assembly and pack (LAP); demilitarization; washout operations; and open burn/open detonation (OB/OD) of ordnance and explosives has resulted in contamination of soils with munitions residues [14].

In the light of groundwater contamination by explosive, we hereby report the possible effect of seismic energy sources on the turbidity of groundwater in Sagbama (SG), Niger Delta, Nigeria.

2. Materials and Methods

2.1. Study Area

This study was carried out in Oil Mining Lease (OML) X_2, Niger Delta, Nigeria. The vegetation of the area is generally dominated by dense rain forest. The total area covered by this study is about 771.26 km^2.

2.2. Uphole Drilling

The uphole was drilled to 60 m depth using the rotary method and flushed continuously for 20 min to enhance stability. Each hole was cased with perforated 6 inch PVC pipe. The uphole lithology was sampled every 5 m or at the change in lithology. The grain size analysis was accomplished using the sieve method for the sands. The result of the sieve analysis was used to calculate the particle size and percentage passing with the aim of estimating the porosity and permeability of the soil. No size analysis was carried out for the silt and clay. The source and receiver line number were used for the identification of the uphole locations while the coordinates was verified using a handheld Global Positioning System (GPS) set. The Meridian Platinum GPS was used after calibrations. The elevations of the uphole points were determined using the same instrument (Table 1).

Table 1. Sagbama Monitoring Boreholes Showing Location x-y Coordinates and Elevation

Uphole No.	Uphole location	Easting	Northing	Elevation (Z)
SG1	2030/4070	397450.42	133107.70	18.70
SG2	270/4070	397850.88	129103.76	19.80
SG3	2110/4070	397450.72	125101.30	16.20
SG4	1950/4070	397451.30	121100.00	28.10
SG5	1790/4070	397450.50	117100.30	32.80
SG6	2430/4230	401451.50	133101.60	18.14
SG7	2270/4230	401450.82	129100.90	18.50
SG8	2110/4230	401452.74	125102.84	26.70
SG9	1950/4230	401450.50	121600.80	27.20
SG10	1790/4230	401448.80	117100.50	31.80
SG11	2430/4390	405450.82	133101.18	39.60

2.3. Explosive Detonation

The energy source was the high explosive dynamite (TNT) and 6 m Electric Detonators loaded in 5 hole pattern source array. In dry areas, the holes were thumped to a depth of 4 m while in flooded/marshy terrain they were flushed to a depth of 6 m. Each pattern hole was loaded with 0.4 kg/L seismic, electric detonators (1 shot point = 5x0.4 kg/L caps for five hole pattern). A total amount of 84207 kg dynamite was detonated in 41, 949 source point in an area of 549.73 square kilometers of Sagbama area.

2.4. Water Sampling and Analysis

The groundwater was sampled from 11 upholes in Sagbama. The sample locations were geo-referenced using the survey coordinates of eastings and northings. The elevation of each sample location was determined by measurement of the z-component of the coordinates. The water samples were taken from the boreholes at a depth of 12 m to 15 m (Table 1).Water samples were collected and analyzed from each uphole before the commencement of dynamite detonation. The water samples were collected using small bottles with a rope. The results of the analysis before the commencement of dynamite detonation served as control. The water was subsequently sampled fortnightly, that is 14 days for an interval of 2 months after the seismic acquisition process has been completed. The results obtained from the analysis of the samples during and after acquisition were compared with the results obtained before detonation and also with standard values.

2.5. Measurement of Turbidity and Permeability

The turbidity was determined the same day the samples were taken by the use of Hach 2100AN Laboratory Turbidimeter. A standard formazine solution was placed on the turbidimeter in path of rays and the scale was brought to 9 NTU. The water sample was taken in a test and placed in a turbidimeter. The readings were recorded. The coefficient of permeability was determined by constant head permeameter using 4 inch (102 mm) Laboratory Asphalt permeameter. Soil sample was placed in the cylinder. A measurement was taken between the two tapings in the cylinder connected to the manometers. Water from the reservoir was allowed to flow through the sample at a constant rate. As soon as the water began to flow, the stop clock reading began. Water flowing through the sample was collected with the measuring cylinder. The differences of heads from the manometers were measured. The time was recorded using the stop clock. This was repeated for two other samples. Coefficient of permeability (K) was calculated using Darcy's Law (Equation 1).

$$K = \frac{QL}{A \; x \; tH} \qquad 1$$

where Q is the quantity of water passing through sample during time t (cm^3/sec), A is the cross-sectional area of sample (cm^2), L is the length of sample (cm) and H is the difference of head (cm).

2.6. Soil Porosity Determination

The soil was placed into a mould of volume (V_T) = 1000 cm^3. The weights of the sample and mould (M_t) were determined. The sample was dried in an oven at temperature 105^{0}C and re-weights (M_s). The weight of water M_w, weight of solid M_s, volume of voids V_v was determined based on Equations 2 and 3, respectively.

$$V_v = V_T - V_s \qquad 2$$

$$V_s = \frac{M_s}{G_s yw} \qquad 3$$

where G_s is the specific gravity of solid, yw is the density of water; G_s is taken as 2.66 and yw is 1 g/cm^3. From Equations 2 and 3, the porosity values were calculated from Equation 4.

$$Porosity \ (\varphi) = \frac{V_V}{V_T} x100\% \qquad 4$$

3. Results and Discussions

Borehole water turbidity analysis results in Sagbama area is shown in Table 2. The turbidity averages over the sampled period is shown in Figure 1. Sagbama area borehole lithologic log is presented in Figure 2, while sieve analysis and grain size distribution curve (13 m depth) of Sagbama area is presented in Table 3.

Table 2. Borehole Water Turbidity (NTU) Analysis Results in Sagbama Area

Day	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8	SG9	SG10	SG11	Mean
0.00	2.55	4.46	2.53	3.41	5.01	4.00	4.00	4.30	4.00	4.00	3.13	3.76
1.00	2.34	4.54	2.98	3.21	4.86	4.00	4.00	4.40	4.00	4.00	2.56	3.72
15.00	2.34	4.34	2.70	3.44	4.50	4.00	4.00	4.01	4.00	4.00	3.34	3.70
29.00	2.44	3.54	3.00	3.45	4.34	4.00	4.00	3.56	4.00	4.00	3.45	3.62
43.00	2.23	4.43	3.10	2.54	4.33	4.00	4.00	3.34	4.00	4.00	3.23	3.56
57.00	3.10	4.54	3.12	3.34	4.12	4.00	2.00	3.23	5.00	6.00	3.32	3.80
71.00	2.23	4.43	3.02	3.45	4.01	4.00	2.00	3.16	4.00	4.00	2.35	3.33
85.00	2.31	4.43	2.98	3.32	4.02	5.00	4.00	3.23	5.00	2.00	3.22	3.59
99.00	1.98	3.43	2.79	3.31	4.10	2.00	5.00	3.10	2.00	2.00	2.33	2.91
113.00	2.73	3.43	3.10	3.32	4.33	2.00	5.00	3.41	4.00	4.00	3.32	3.51

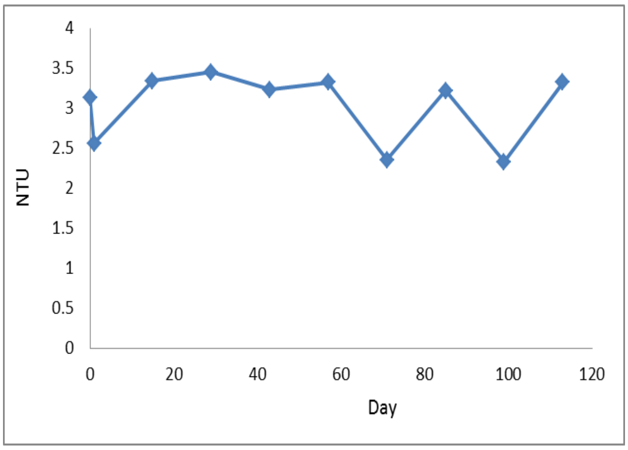

Figure 1. Turbidity Averages (NTU) over the Sampled Period in Sagbama Area

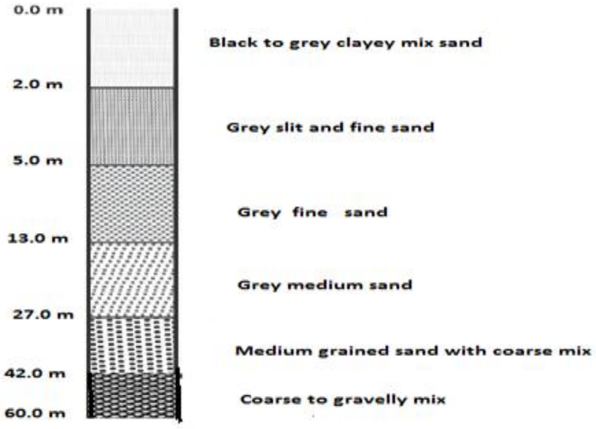

Figure 2. Lithology of a Typical Borehole in Sagbama Area

Table 3. Grain Size and Coefficient of Permeability

Sample Number	Depth (m)	Grain Size Distribution (Percent Passing Sieves) (mm)							Coefficient of Permeability (cm/s)
		0.08	0.15	0.30	0.60	1.18	2.36	5.00	
SG 1	3.00	0.00	8.00	38.00	85.00	94.00	99.00	100.00	2.02
SG 2	3.00	7.00	8.00	38.00	70.00	91.00	95.00	100.00	2.02
SG 3	7.00	7.00	8.00	39.00	77.00	95.00	96.00	100.00	2.09
SG 4	7.00	3.00	7.00	41.00	86.00	94.00	99.00	100.00	2.46
SG 5	10.00	3.00	4.00	27.00	83.00	93.00	99.00	100.00	2.02
SG 6	10.00	7.00	8.00	39.00	77.00	95.00	96.00	100.00	2.09
SG 7	13.00	3.00	7.00	39.00	85.00	94.00	97.00	100.00	2.02
SG 8	15.00	7.00	8.00	38.00	78.00	94.00	97.00	100.00	2.09
SG 9	15.00	3.00	7.00	40.00	85.00	95.00	99.00	100.00	2.46
SG 10	15.00	7.00	10.00	39.00	88.00	92.00	99.00	100.00	1.78
SG 11	20.00	2.00	6.00	38.00	86.00	95.00	99.00	100.00	2.02

The average turbidity value of the control (sample water before detonation) was 3.76 NTU. After dynamite detonation, the average measured turbidity values ranged from 2.91 to 3.80 NTU. The highest recorded average value of 3.80 NTU was obtained on day-57 after dynamite detonation. Thereafter the average turbidity value fluctuated with time. The lowest average value of 2.91 NTU was recorded on day-99. In our previous publication on seismic explosive energy sources and the possible impact on groundwater quality in the Niger Delta Area of Nigeria [15], it was discovered that after 10 days, the use of dynamite as seismic energy source did not impact the groundwater quality in the Niger Delta Area of Nigeria. Results after 100 days of dynamite detonation also showed that the variations from the control are not significant enough for dynamite to be said to have impacted on the turbidity value of the groundwater. These variations from the control are not significant enough for dynamite to be said to have impacted on the turbidity value of the groundwater. The control and test results values are both within World Health Organization guidelines for drinking-water quality limit of 5 NTU [19]. Similar daily variations have been observed in areas where there was no dynamite detonation [16].

The representative lithology of Sagbama area (Figure 2) as revealed by the borehole logging consists of 0-2 m clayey sand, 2-5 m silty and fine sand, 5- 13 m medium sand, 13-27 m medium to coarse sand, 27-60 m medium to coarse sands and gravelly mix. These litho-types are mainly non-plastics also categorized as cohensionless sands. The presence of silty sands at 4 to 5 m depths could be an obstruction to infiltration of contaminants from dynamite detonation. Sieve analysis results from Sagbama (Table 3) showed 0-7 % passing for grain size 0.08 mm, 4-10 % passing for 0.15 mm grain size, 27-40 % passing for grain size 0.03 mm, 70-88 % passing for grain size 0.6 mm, 91-95 % passing for grain size 1.18, 96-99 % passing for grain size 2.36 mm and 100 % passing for grain size 5.00 mm. The coefficient of permeability, K, at depths of 3-20 m (Table 3) were in the range 1.78-2.46 cm/sec. Permeability is the ability of a soil or rock type to conduct or discharge water (and effluents) under a hydraulic gradient. It depends on soil density, degree of saturation, rainfall and duration of rainfall [17, 18]. Coefficient of permeability of unconsolidated sand is affected by the fluid viscosity, grain size, grain sorting, grain shape and packing [17].

4. Conclusions

Dynamite detonation did not affect the turbidity of the groundwater in Sagbama, Niger delta, Nigeria. The control and test results are both within the World Health Organization guidelines for drinking-water quality limit of 5 NTU. Similar daily variations have been observed in areas where there was no dynamite detonation. The litho-types are mainly non-plastics also categorized as cohensionless sands. The presence of silty sands could be an obstruction to infiltration of contaminants from dynamite detonation.

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