academicJournals

Vol. 9(6), pp. 117-122, 30 March, 2014
DOI: 10.5897/IJPS2013.4069
Article Number: FA9972843989
ISSN 1992 - 1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Geophysical investigation of the effects of sewage in the soil at university of Nigeria, Nsukka, Enugu State, Nigeria

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Received 11 November, 2013; Accepted 21 March, 2014

Geophysical investigation was carried out to detect the spread of sewage effluent and to locate the sources and delineate migration paths and the extent of leachate plume. The study was to find out the geological formations that are the most conductive layers in the sewage site for the free flow of the contaminants. Soil tests showed that hydraulic conductivity, bulk density and water retention were variable in sewage soil, but consistent in soil unaffected by sewage. In sewage soil, maize crops performance, organic matter, total nitrogen exchangeability, cations exchange capacity and sodium were significantly enhanced than in non-sewage soil. In sewage soil, electrical conductivity (EC), zinc (Zn), lead (Pb), copper (Cu), Cadmium (Cd), salt concentration and other saline properties, total faecal coliform and microbial activities were high. Twelve vertical electrical soundings (VES) points with Omega Terrameter were used in the Schlumberger Array configuration which the geoelectrical section from the resistivity data revealed seven subsurface layers. Three low resistivity zones were detected as correspondent zones to the plumes. The comparative evaluation of the 3-D stack model of the resistivity of layers with respect to depth suggested that these three low resistivity layers were contaminated, especially as the depth to water table is more than 100m. The flow direction of the contaminant plume is northwest to southwest as indicated by stack model of the low resistivity layers. Generally, the contaminant plume is a threat to ecosystem and a great health problem to people living around the sewage site.

Key words: Delineate, contamination, leachate, sewage effluent, saline, ecosystem.

INTRODUCTION

The sewage site at University of Nigeria, Nsukka is accessible through numerous routes within the campus, e.g. from Nnamdi Azikiwe new Library through Eni-Njoku street, Murtala Mohammed Way and Louis Mbanefo street. The UNN campus is situated on the hills of Obukpa town and Agu-ihe of Nsukka Local

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Government Area in Enugu State, Nigeria.

Geophysical investigation was carried out with the aid of Omega Terrameter by the Department of Geology, UNN using Schlumberger Array configuration to detect the spread of sewage effluent; and also to locate and delineate the migration pathways and the extent of the leachate plume. The sewage site is envisaged as a potential source of groundwater contaminants in the campus and its environs. The soil tests were carried out at the Soil Science Unit and Department of Zoology, UNN.

The generation of the sewage effluent increased recently due to increase in the students population, and thus could be a possible source of contaminants to groundwater. The sewage effluent could be waste water generated mainly from toilets, bathrooms and laundry activities. The major sources of the waste water could be from students hostels, staff quarters, offices, medical centre, classrooms, banks, restaurants, primary and secondary schools in the campus.

Geologically, the sewage site is located on Ajali Sandstone which underlies Nsukka Formation. Ajali Sandstone within Nsukka and its environs is a sandstone unit with medium to coarse grained, moderately to poorly sorted, friable, whitish in colour with iron stains and clay lenses due to the overlying Nsukka Formation. The Nsukka Formation has sandstone, clayey shale and ironstone units (Oguamah, 1999). Ironstone is the prominent outcrop at the site.

The most outstanding threat to groundwater quality in the study area is the improper, unscientific, unacceptable and inadequate disposal, treatment and management of the sewage effluent generated. It is good to study the sewage disposal manipulations and handling from the oxidation ponds sewage systems. Due to the slow flow pattern of groundwater, the effluent plume spreads slowly as a contaminant (Montgomery, 2005), and thus the natural flow of groundwater disperses the sewage effluent as a plume of contamination. Thus, the study is to investigate the sewage effects in soil due to its indiscriminate wide spread on the soil surface for agricultural purposes.

GEOLOGY

The Benue Trough is a northeast-southwest trending sedimentary basin which consists of up to 5000 m of cretaceous sediments, contiguous with the rift basins of Niger, Chad and Sudan Republic (Akande, 2004) and extending to over 1000 kms from the Niger Delta to Lake Chad.

The sedimentary rocks of the Lower Benue Trough are the hosts of various igneous rocks (Obiora and Umeji, 2004). The main lithostratigraphic units that underlie the study area are the Ajali Sandstone and Nsukka Formation within the Lower Benue Trough. The Ajali Sandstone is of Maestrichtian Age and consists of white, medium to coarse grained sandstone and friable sands. It marks the height of regression that ended the Nkporo deposition cycle and the stratigraphic position of Ajali Sandstone between two paralic sequences of the underlying Mamu Formation and overlying Nsukka Formation indicates a continental origin. This could be due to the evidence of tidal origin showed with the development of herringborne cross stratification, bimodal-bipolar, paleocurrent pattern, suspension deposit on forest laminae and mixed bedding. Ajali Sandstone is the main aquiferous unit within the campus. Ajali Sandstone is most often stained red, and thus overlain by thick red soil due to weathering.

Nsukka Formation is of the Upper Maestrichtian to Danian Age, known as Upper Coal Measure. It consists of less sands and less coal seams than Mamu Formation which has up to five coal seams. It is deposited under paralic conditions in a strand- plain marsh within shallow marine environment and occasional fluvial incursion. Nsukka Formation is divided into sandstone unit, especially at its boundary with Ajali Sandstone; clay and ironstone units at its upper contact with Imo Shale. The outcrop of the sandstone unit of Nsukka Formation exists at the opposite Green House, about 1.5 kms from University gate to Owerre-Ezu Orba, near UBA and Oceanic Bank. It is an old quarry site and also weathered with elevation of about 450 m and about 4 m thick. There is another outcrop at Hilltop Odenigwe with elevation of about 480 m and about 5.5 m thick.

RESULTS AND DISCUSSION OF THE ANALYSIS OF THE PHYSICAL CHARACTERISTICS OF THE SOIL ENVIRONMENT

The physical characteristics of the soil environment within the sewage site are classified into two, namely soil at the sewage disposal area and the soil within the non-sewage disposal area. The two categories of soils are derived from the Nsukka Formation (that is, False Bedded Sandstone). It is deep and excessively drained. Soil within the sewage disposal area is very dark reddish brown to reddish brown, while non-sewage disposal area has dark reddish brown to red in colour.

The soil colour variations within the sewage disposal site could be attributed to the existence of sludge and sewage effluent. This is because of the presence of organic matter in the soil, especially for a very long time without oxygenated environment, but with contaminated water as moisture occupying the soil- pore spaces it always changes the clayey-shale soil-colour from light grey to dark grey or dark brown with pungent smell, unless the accumulation of either salts or iron oxide in the soil modify and alter the decomposition processes that affect the colour and odour.

Table 1 helps to classify the soil with respect to some physical properties, especially after the disposal of sludge and sewage effluent. The texture or physical size analysis indicated mainly sand and loamy-sand on the top soil, but the subsoil has sandy loam. However, the coarse texture in all soils could be due to the existence of Nsukka Formation (that is, False Bedded Sandstone) that is dominance in the area. Clay content ranged from about 6 to 18%, but increased with depth in sewage soil and has no known trend in non-sewage soil. Thus, clay content is low as well as silt content which ranged from about 1 to 10%. The low contents of clay and silt indicate the degree of weathering and leaching which the soil has undergone. The low contents of clay and silt could also

Table 1. Comparative evaluation of some physical characteristics of sewage and non-sewage soil-types.

Percentage					Percentage				
					(A) Sewage disposal area and soil-type				
Soil classification	**Depth (cm)**	**Sand**	**Clay**	**Silt**	**Bulk density (g/cm^3)**	**Micro porosity**	**Macro porosity**	**Ratio of micro/macro porosity**	**Percent of total porosity**
Sand	0-15	90	8	4	1.56	23	25	2:4	45
Loamy sand	15-36	87	7	7	0.82	39	8	5:1	47
Sandy loam	36-55	90	8	2	1.58	32	10	3:1	43
Sandy loam	55-105	80	18	2	1.55	35	12	5:4	40
Sandy loam	105-160	78	18	4	1.56	30	14	5:3	39
	Mean	85	12	4	1.41	32	14	-	43
					(B) Non-sewage Disposal area and soil-type				
Loamy soil	0-14	84	6	10	1.45	24	27	4:5	51
Sandy loam	14-37	82	14	4	1.48	24	26	4:5	50
Sandy loam	37-76	78	12	10	1.50	31	14	2:1	45
Sandy loam	76-90	76	18	6	1.53	24	16	3:2	40
Sandy loam	90-160	78	16	6	1.64	26	19	3:2	45
	Mean	80	13	7	1.52	26	20	-	46

be attributable to high detachability and transportability of these lighter materials (Obi and Ebo, 1995). Sand content was about 80% mean in non-sewage soil, and about 85% mean in sewage soil; but sewage soil may have sand content up to 90% due to easy dispersion of clay and silt fractions that were clearly washed away. The importance of clay dispersibility is a measure of soil structural integrity and implication of water infiltration and retention (Curtin et al., 1994).

For bulk density, the soil of sewage disposal area has a range from 0.82 to 1.58 g/cm^3, but for non- sewage disposal area, the soil has a range from 1.45 to 1.64 g/cm^3. The low bulk density in sewage soil could be due to the accumulation of humified sewage materials. Generally, organic matter has very low bulk density and hence the most likely cause of the low bulk density of the soil in the sewage disposal area. It was observed that there is an inconsistent pattern of bulk density with depth in sewage soil, but consistent pattern in non-sewage soil. This is because, sewage soil has discontinuity of soil profile due to the presence of humified sewage material layers. The density of the primary particles in sewage soil structures may be responsible for the low and high bulk density values variation. Generally, there was no positive improvement in bulk density and total porosity in both soil-types due to large application of sludge and sewage effluent over a long period of time, but short-time low application of sewage effluent to soil can yield positive improvement in the soil bulk density and porosity.

The high ratio of micro to macro porosity in sewage soil may make for aeration build-up and toxicity in plant roots and microorganisms. Pagliai and DeNobili (1993) observed that adequate proportion of micro and macro porosity was necessary for the existence of continuous air diffusion pathways in the soil.

In Table 2, the sludge and sewage effluent soil has a range of 0.39-0.49 volumetric water content at saturation. The highest volumetric water content at saturation of 0.49 could be due to the water adsorption capacity of organic matter. About 70% water retained in sewage soil at 60cm tension was more than 50% of water held in non-sewage soil. The actual amount of water retained in the sludge and sewage effluent soil was contributed by the amount of organic materials and the dominance of micro-pores. The non-homogeneous continuity of the sewage soil could be contributed to high water retention capacity.

At the same depth of soil profile of both sewage soil and non-sewage soil, the saturated hydraulic conductivity is variable and consistent in sewage and non-sewage soils respectively. It is as low as 4.21 cm/h in sewage soil against 7.10 cm/h in non-sewage soil. The permeability class ranged from moderate to rapid for sewage soil and rapid to very rapid for non-sewage soil. The long-term application of sludge and sewage effluent could reduce soil hydraulic conductivity due to the formation of biological materials within the crust. It could also be due to the accumulation of solids filtered from the effluent and/or the collapse of soil structure because of dissolution of organic matter. The same observation was made by Lieffering and McLay (1996) because they observed that long-term application of organic waste such as sludge and sewage effluent significantly reduce

Table 2. Volumetric water content retention characteristics at saturation and 60cm tension, hydraulic conductivity and dispersion ratio of the sludge and sewage effluent and non-sludge and sewage effluent soils.

S/No	Depth (cm)	Volumetric water content at saturation	Moisture (gg/L) at 60cm tension	Hydraulic conductivity (cm/h)	Dispersion ratio (percentage)	Permeability class
			(A) Sludge and sewage effluent soil			
(i)	0 –15	0.47	0.26	20.52	96	Rapid
	15 – 35	0.47	0.40	4.21	98	Moderate
	35 – 55	0.40	0.23	7.89	98	Moderately rapid
	55 –105	0.42	0.28	13.15	91	Rapid
	105 -160	0.39	0.29	19.47	80	Rapid
	Mean	0.42	0.35	13.05	93	Rapid
(ii)	0-18	0.48	0.22	20.52	97	Rapid
	18-43	0.49	0.40	4.21	98	Rapid
	43-65	0.42	2.30	7.89	98	Moderately rapid
	56-80	0.46	0.27	19.15	88	Rapid
	Mean	0.47	0.32	13.05	92	Rapid
			(B) Non sludge and sewage effluent soil			
(i)	0-14	0.51	0.25	24.72	63	Very rapid
	14-37	0.53	0.25	7.10	75	Rapid
	37-76	0.45	0.30	16.78	42	Rapid
	76-90	0.40	0.32	19.99	67	Rapid
	90-160	0.44	0.33	19.47	80	Rapid
	Mean	0.47	0.30	20.52	62	Rapid

soil permeability and the low permeability was attributable to the accumulation of solids filtered from effluent and the collapsed soil structure due to the dissolution of organic matter.

Dispersion ratio is a measure of soil's structural integrity which is used mainly to identify the soils susceptibility to slaking, crusting, infiltration and erosion capabilities during rainfall. Thus, dispersion ratio is about 98% in sewage soil and about 80% in non-sewage soil. The high dispersion ratio in sewage soil causes aggregate breakdown and subsequent clay dispersion leading to pore blockage and surface crushing. This leads to low water infiltration, high retention and very high surface soil erosion (Table 3).

The effects of exchangeable sodium on the soil are based on sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP). The saturated soil electrical conductivity (EC) is used to appraise the effect of soil salinity on plant growth. Salt concentration, total cations and osmotic pressure are used as indices of the wilting coefficient of soils. An index of the wilting coefficient of a soil is a measure of the quantity of water that the soil can supply to plants. A plant or flower wilts when it bends towards the ground because of either heat or lack of water.

The concentration values of SAR, ESP, EC, salt, total cation and osmotic pressure of sludge and sewage effluent soil are higher than that of non-sludge and sewage effluent soil. For example, the SAR values of the sewage effluent soil ranged from 0.06 to 0.13, with 0.13 been the highest value which indicates that a high percentage of exchangeable sodium has been built in the soil, but in non-sewage effluent soil SAR ranged from 0.06 to 0.10 indicating no significant exchangeable sodium (Onah, 2012). Therefore, if the non-sewage effluent disposal soil is to be considered as the baseline for comparative evaluation, it is evident that long-term application of sludge and sewage effluent greatly increase the exchangeable sodium concentration in the top soil and subsoil of the sewage soils. High SAR causes an increase in soil dispersion.

The soil salinity and the high SAR in soils causes the yields of salt sensitive crops to be restricted. Furthermore, the salts may interfere with the absorption of water by plant hair roots through reduction in the soil osmotic water potential, and thus decrease the amount of water that would be readily available for the plant roots uptake and increase in the wilting coefficient of soils. Therefore, high salt concentration in soils through heavy application of municipal effluent most often interfere with the absorption of water by soyabeans through the reduction in the soil osmotic water potential.

Table 3. Results of SAR, ESP, EC, salt concentration, total cation concentration, osmotic pressure and salinity hazards of sewage soil.

S/No	Depth (cm)	SAR	ESP	EC (µ/cm)	Salt conc. (mg/L)	Total cations conc. (mg/L)	Osmotic pressure (atm)	Salinity hazards
					(A)	Sludge and sewage effluent soil		
(i)	0-15	0.13	2.0	1.04	665.60	10.40	0.37	Yields of many crops, especially sensitive crops may be restricted.
	15-35	0.12	2.25	3.15	2016.00	31.40	1.13	,,
	35-55	0.09	2.00	0.38	243.00	3.80	0.14	,,
	55 -105	0.09	2.00	0.21	134.00	2.10	0.08	Salinity effects negligible
	105-160	0.07	1.50	0.18	115.20	1.18	0.07	Salinity effects negligible
	Mean	0.10	2.00	0.99	634.88	9.92	0.36	Salinity effects negligible
(ii)	0-18	0.10	2.00	1.16	742.40	11.60	0.42	Salinity effects negligible
	18-43	0.13	2.22	3.05	1925.00	30.60	1.10	Salinity effects negligible
	43-65	0.09	2.25	0.40	256.00	4.00	0.14	Salinity effects negligible
	65-80	0.10	2.00	0.21	134.00	2.10	0.08	Salinity effects negligible
	80-150	0.06	1.50	0.20	128.00	2.00	0.07	Salinity effects negligible
	Mean	0.01	2.00	1.00	642.56	10.06	0.36	Salinity effects negligible
					(B) Non – sludge and sewage effluent soil			
	0 – 14	0.08	1.50	0.09	57.60	0.90	0.03	Salinity effects negligible
	14 – 37	0.10	1.80	0.06	38.40	0.60	0.02	Salinity effects negligible
	37 – 76	0.08	1.76	0.03	19.20	0.30	0.01	Salinity effects negligible
	76 – 90	0.07	1.50	0.02	12.80	0.20	0.01	Salinity effects negligible
	90 – 160	0.06	1.50	0.02	12.80	0.20	0.01	Salinity effects negligible
	Mean	0.08	1.62	0.04	28.16	0.44	0.20	Salinity effects negligible
	Waste water	1.89	1209.60	18.90	0.68	Yields of very sensitive crops may be restricted	Yields of very sensitive crops may be restricted	Salinity effects negligible

CONCLUSION

The spread and migration pathways of sludge and sewage effluent in soil physical environment has variable and consistent hydraulic conductivity, bulk density and water retention in sewage soil zone and in soil unaffected by sewage respectively. From the geophysical study, the low resistivity zones are correspondent zones to the plumes. The 3-D stack model of the resistivity of layers with respect to depth suggest that the three low resistivity layers were contaminated. The study of flow direction of the sludge and sewage effluent is NW to SW as indicated by stack model of the low resistivity layers.

The permeability of the sludge and sewage effluent into the soil is moderate to rapid for sewage soil, but rapid to very rapid for non-sewage soil. Therefore, long application of sludge and sewage effluent reduce soil hydraulic conductivity. This is because of the dissolution and accumulation of solid particles filtered from the sewage effluent and organic matter.

Dispersion ratio which measures soil structural integrity helps to identify the susceptibility of the soil to slaking, infiltration and erosion. It is about 98 percent in sewage soil and about 80 percent in non-sewage soil. The high value of dispersion ratio in sewage soil causes clay dispersion that blocks the soil pores leading to surface crushing, low water infiltration and high surface erosion. Salt concentration, total cations and osmotic pressure in soil are the qualities applied as measures of the wilting coefficient that determines the quantity of water the soil can supply to plants. Both SAR and ESP are higher (0.06-0.13 and 1.50-2.25) in sludge and sewage effluent soil than (0.06-0.10 and 1.50-1.80) in non-sludge and sewage effluent soil. The implication is that there is no significant exchangeable sodium in non-sewage soil, but long-term application of sludge and sewage effluent can increase the exchangeable sodium concentration in topsoil and subsoil. Therefore, to improve and enhance the natural condition of the soil within the sewage disposal site, there must be scientific and sanitary approaches in handling the wastes to reduce the accumulation of both SAR and ESP.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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