International Journal of Environmental Studies and Safety Research
ISSN: 2536-7277 (Print): 2536-7285 (Online)
Volume 6, Number 3, September 2021

SPATIAL DISTRIBUTION OF CHROMIUM IN SOILS AND SHALLOW GROUNDWATER FROM A DUMPSITE IN A DELTAIC ENVIRONMENT

[1]Abah Evangeline Olohi, [2]Ngah, Sabastine Amauche & [2]Akuro, Ephraim Gobo
[1]Federal University of Health Sciences, Otukpo, Benue State
[2]Institute of Geosciences and Environmental Mgt., Rivers State University, Port Harcourt
Email: evandicta@gmail.com

ABSTRACT

The Nigerian Niger Delta is one of the world's largest wetlands and has witnessed tremendous development and population growth in recent years. Increased urbanization coupled with poor implementation of waste management best practices has resulted in proliferation of waste dumps in communities, thus increasing the vulnerability of shallow groundwater to contamination by heavy metals contained in the leachates. This study evaluated concentration of Ni in soils and shallow groundwater around the Eneka Dumpsite in Obio Akpor Local Government Area of Rivers State and modeled the migration of Ni through the vadose zone into the shallow groundwater using existing numerical codes in Groundwater Modelling System (GMS) over a 40-year period. It was concluded that, due to the flatness of the terrain, and high humidity, contamination of the top-soil around dumpsites is in all directions, with maximum lateral spread of 120m and follows the orientation of the waste dump. However, when contaminants get into groundwater, they get entrained and migrate in the direction of groundwater flow. The simulation results compared to observed data were satisfactory. It is recommended that persons living in vicinity of dumpsites or where dumpsites have been removed refrain from exploiting shallow groundwater for drinking or cooking purposes. Also, governments especially in the Niger Delta need to prioritize frequent waste removal from communities and properly dispose them in properly engineered sites since the overlying clays may be too thin to adequately protect the shallow groundwater.

Keywords: Groundwater, Contamination, Nickel, Dumpsites

INTRODUCTION

The Niger Delta environment is characterized by high rainfall, frequent flooding and high water-table almost all year round. Increasing population growth and expansion of urban areas especially in Port Harcourt and its environs and the attendant increase in waste generation and multiplication of indiscriminate waste dumpsites in settlements with the increased demand for groundwater to meet the needs of the population is cause for concern as vulnerable aquifers may pose health problems. Open dumps and landfills are common in Nigerian cities. This is the situation in the Niger Delta which has witnessed tremendous urbanization and population growth in recent years. An example is Port Harcourt city and its environs where increased urbanization has resulted in persons living in close proximity to dumpsites. Groundwater contamination has therefore become cause for public concern as some aquifers have suffered risks of contamination from leachate generated from landfills, agricultural practices such as use of pesticides, herbicides, fertilizers, also from oil spills and other toxic liquids which were actually introduced on the soil surface.

Usually, groundwater is protected by an excellent filtration system which includes soil, clay, rocks and organic matter, but in the situation where this system is overloaded or by-passed, groundwater quality may become degraded. The extent and seriousness of groundwater quality degradation depend on the geohydrologic setting, nature of contaminants, climate of the area and the interplay of physico-chemical processes that operate in the subsurface environment (Ngah and Abam, 2006). Wastes introduced at the soil surface often find their way into groundwater through the vadose zone (Bear and Cheng, 2010). Leachate from domestic wastes may contain, among other contaminants, heavy metals such as Ni, Cr, Cd, Pb etc. Heavy metals are generally unaffected during degradation of organic wastes and have toxic effects in living organisms when certain concentrations are exceeded. Heavy metal concentration in soils is influenced by anthropogenic activities intricately linked with urbanization and population growth and associated with geochemical and biological cycles (Lund, 1990).

The heavy metal of interest for this study is Chromium which may be present in domestic waste from steel products, cans, paints and various synthetic materials. Cr(VI) is the dominant form of Cr found in contaminated sites. It is found in shallow aquifers where aerobic conditions exist. It can be transported by surface run-off or leached as pH increases (Scragg, 2006). Chromium is associated with allergic dermatitis in humans (Smith *et al*, 1995), diarrhea, Stomach bleeding, liver and kidney damage, cramps, mutagenesis and cancer (Lenntech, 2015). Many studies have been carried out on contamination of groundwater from dumpsites but there is no documentation of spatial spread of Cr contaminants in a dumpsite vicinity in the Niger Delta. This study attempts to fill that gap by modeling spread of chromium using the Eneka dumpsite as case study.

The Study Area

Eneka town is located in Obio Akpor Local Government area of Rivers State. Eneka Area had a population of 7,607 persons by 2006 census (NBS, 2006) but has witnessed tremendous population growth and urbanization since then. The Eneka dumpsite, where this study was carried out is situated in Eneka, along Eneka-Igwuruta Road on 282888.25mE and 540948.49mN UTM Zone 32N and covers an area of over 29000 square metres.

Figure 1: Maps of Nigeria and Rivers State showing Obio Akpor Local Government Area

The dumpsite has been partly engineered and is utilized by the Shell Petroleum Development Company for the deposition of non-hazardous domestic wastes generated from their kitchens and offices, operational and residential locations and wastes generated from estate management activities. The nearest building to the dumpsite is located about 50m away from the perimeter fence of the dumpsite

Figure 2: Image Clarity Map of a section of Eneka Town Showing the dumpsite Area.

The area is essentially warm and humid all year round. Relative humidity ranges from 75-99% and annual average rainfall exceeds 2800mm with peaks in July and September. Although, there are two seasons (wet and dry), measurable precipitation occurs in all the months of the year. The area experiences lengthy and heavy rainy seasons and very short dry seasons. Only the months of December and January qualify as dry season months (ESIA, 2015) and (Gobo, 1990). Annual rainfall varies from 500mm at the coast to 300mm (Nwankwoala and Ngah, 2014). The main aquifer system in the Niger Delta region comprises of two stratigraphic units namely Alluvium occurring close to the shore area and the Benin Formation which forms the main aquifer system. A separate member of the Benin Formation is recognized in the Port Harcourt area. This is the Afam clay member, which is interpreted to be an ancient valley fill formed in Miocene sediments (Short, and Stauble, 1967). The study area is typically underlain by the Afam clay. Recharge is mainly from rainfall while discharge is through run-offs, surface seepages, submarine discharge into the oceans and abstraction through boreholes (Reijers, 2011).

General Physico-chemical Character of Soils at the Dumpsite. Fifteen soil samples were collected from three locations using a manual one-meter hand auger. Five soil samples (Plate 1) were taken from each location at depth intervals of 25cm from the surface to one meter depth.

Plate 1: Soil samples taken at 25cm depth intervals from location 2

The sampling locations were measured with the handheld GPS device and readings recorded in the field notebook. Index tests were conducted on the samples to assist in soil classification. Soil colour was determined using the Munsell soil colour charts with reference to the combination in the Munsell system of time, value and chrome. Soil moisture and texture were examined by feel and visual observation. The soil samples were wrapped in polythene bags to prevent moisture loss and preserve integrity of sample, properly labeled and stored in ice-cooled chest box before transporting to the laboratory for further analysis. The top soil is composed of organic stiff clay material. Total organic Content (TOC) in the topsoil at 0-25cm depth measured about 5600mg/l, at depth of 50cm TOC was about 4000mg/l and at 100cm depth, 1800mg/l. this reflects progressive decrease of TOC with depth. Soil pH at the surface ranged from 4.53 at site 2 which is SW to the dumpsite to 6.2 at location 3 NE to the dumpsite. Results of soil acidity of soil at sample point 2 showed downward increase within the top 100cm, with pH values of 4.53 at the top, 4.39 at 50cm depth and 4.22 at 100cm depth. Results of Ni concentration with depth is displayed in table 1

Table 1: Concentration of Cr in Soil Samples

sample point	Location	depth (cm)	Cr (mg/kg)
1	283109.9	0-25	88.3
	540867.7	50-75	84.35
		100	81.1
2	283218.5	0-25	82.22
	540718.7	50-75	85.25
		100	80.3
3	283021 540694	0-25	123.46
		50-75	120.67
		100	90.24
DPR target value (2002)			100

General Physico-chemical Character of the Groundwater

The water table lies well above the clay-sand contact with static water levels ranging from 1.2 m to 2.11m below ground surface. Groundwater flow is in NE-SW direction with hydraulic gradient of 0.029. This was calculated from the existing monitoring boreholes using the triangulation method.

Table 2: On-site Groundwater Physico-Chemical Analysis Results

Borehole	Location	T (^{oC})	TDS (ppm)	E c	$_{p}$H
1	540968.5mN, 283008.0mE	27.7	13.6	19.6	6.2
2	540832.0mN, 282965.0mE	29.2	39	26	4.36
3	540848.0mN, 283078.0mE	27.3	13.4	19.9	6.1
Well	540812.0N, 282950.0E	28.8	38	23	5.1

Table 3: Concentration of Cr in Water Samples

Borehole	Location	Cr (mg/l)
1	540968.5mN, 283008.0mE	0.13
2	540832.0mN, 282965.0mE	0.58
3	540848.0mN, 283078.0mE	0.59
Well	540812.0N, 282950.0E	0.48
WHO Guideline Value		0.05

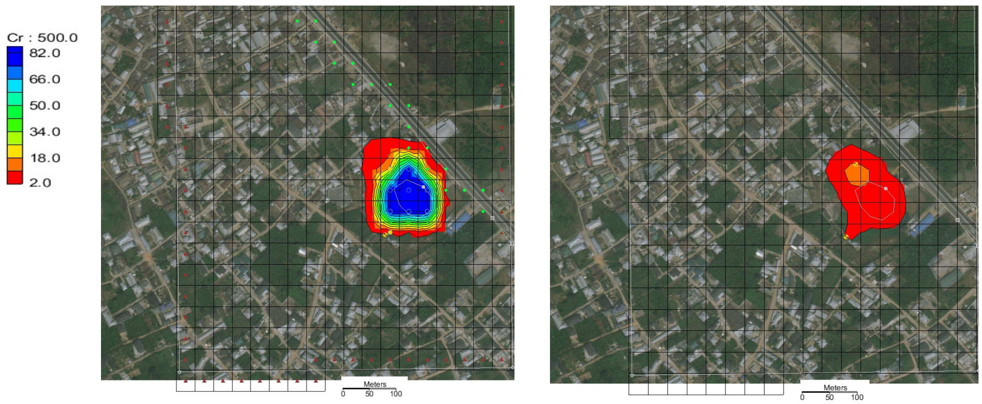
Spatial Distribution of Cr

For the purpose of this research, two numerical models were run in Groundwater Modeling System (GMS): the GIS module was used to map and locate the dumpsite, boreholes and sampling points; MODFLOW was used to solve for the distribution of hydraulic head within the model domain. The time of travel of groundwater through a system depends on the spatial and temporal gradient of hydraulic head, porosity and hydraulic conductivity of the system (Seyed and Sa'ari, 2011). MODFLOW solves for the distribution of hydraulic head within the model domain. The formula used to predict flow is

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial x}\left(K_{yy}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial x}\left(K_{zz}\frac{\partial h}{\partial x}\right)-W=S\frac{\partial h}{\partial t} \quad (1)$$

providing the basis for the calculation of velocity components; Then MT3DMS was used to simulate transport of contaminants. The Term 'Transport' is an abbreviation that describes the movement, storage and changes in concentration of dissolved chemical species as consequences of chemical reactions and interphase transfers (Bear and Cheng, 2010). The steady state flow solution computed by MODFLOW was used to construct MT3DMS simulations using the conceptual model approach. The simulations modeled transport due to Advection,dispersion, sorption and decay. One stress period was used for simplification with the assumption that that source concentration was constant for modeled period and all Ni concentration values obtained from the laboratory were generated by the dumpsite. The length of the stress period was 40 years. By default, MT3DMS outputs a solution at every time step resulting in a large output file, to reduce this, the output was changed to write a solution every year. The MT3DMS packages used were Advection, Dispersion, Source/sink mixing, Transport and Chemical reaction packages.

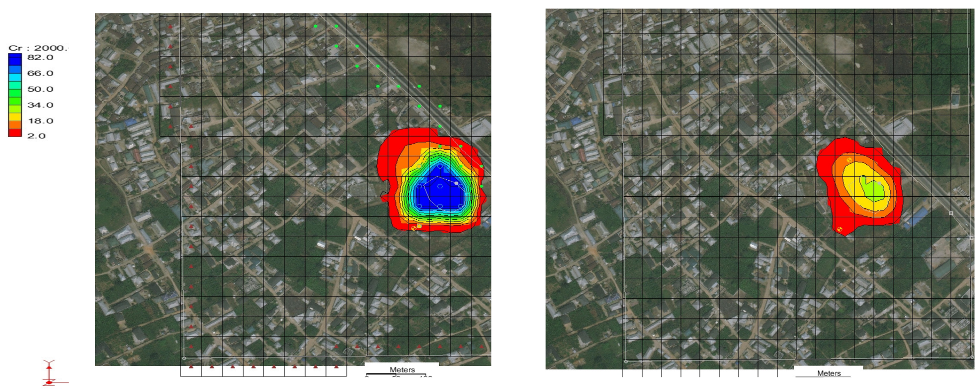
The simulations were built and results of the analysis are displayed below.



Top Layer

Bottom Layer

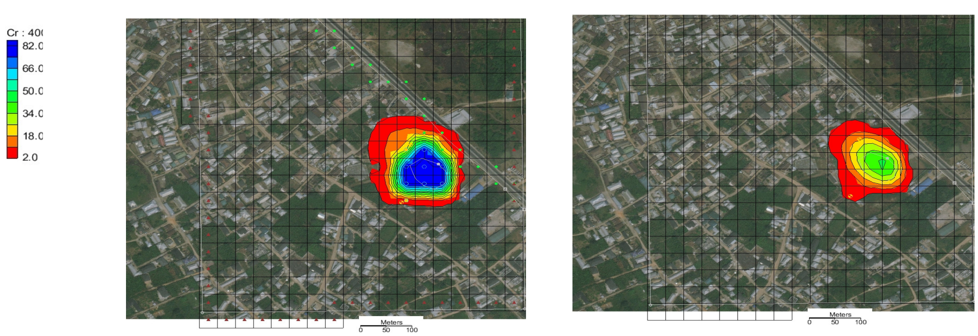
Figure 3: Cr Transport after 1 Year.



Top Layer

Bottom Layer

Figure 4: Cr Transport after 5 Years.



Top Layer

Bottom Layer

Figure 5: Cr Transport after 10 Years.

International Journal of Environmental Studies and Safety Research
ISSN: 2536-7277 (Print): 2536-7285 (Online)
Volume 6, Number 3, September 2021

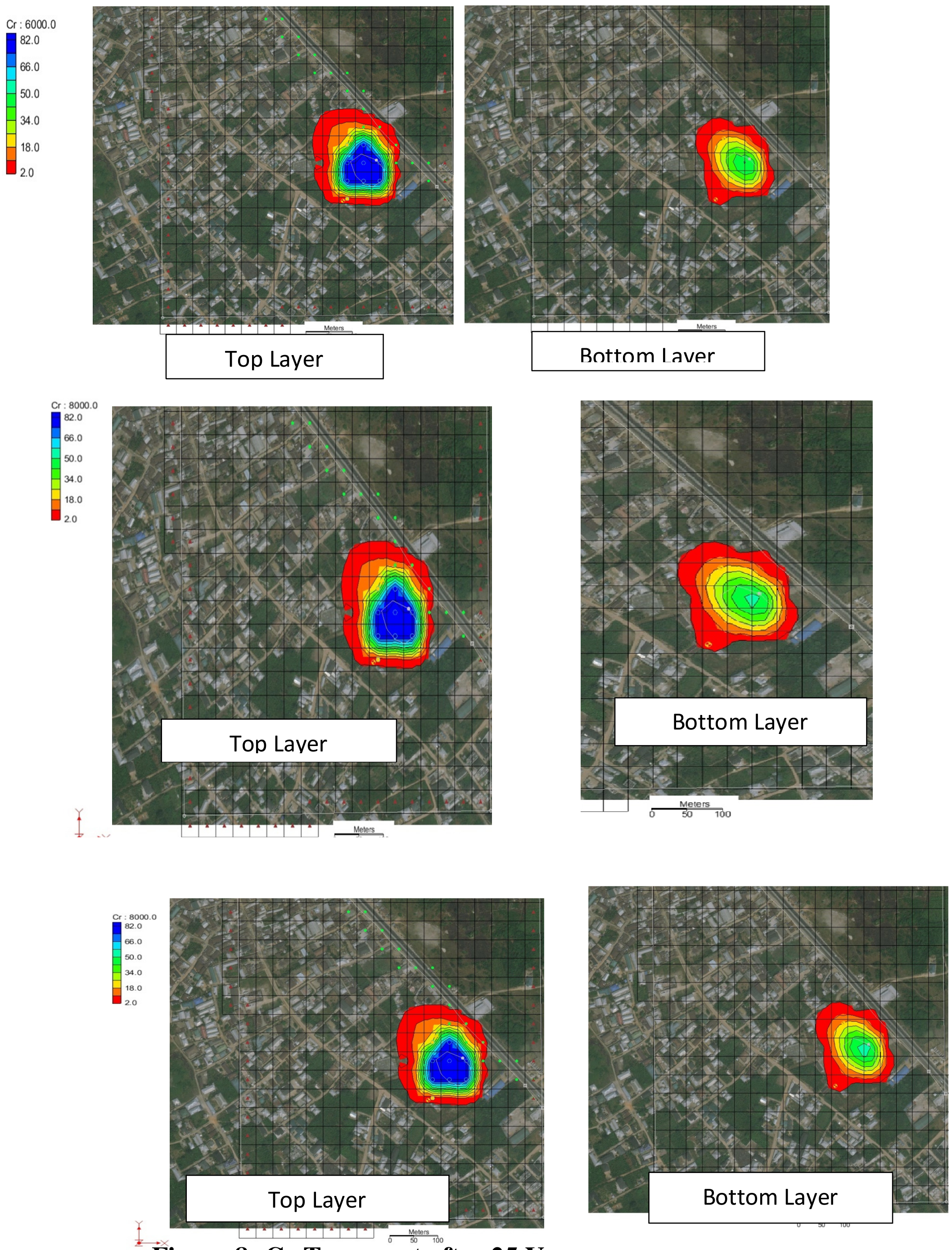


Figure 8: Cr Transport after 25 Years.

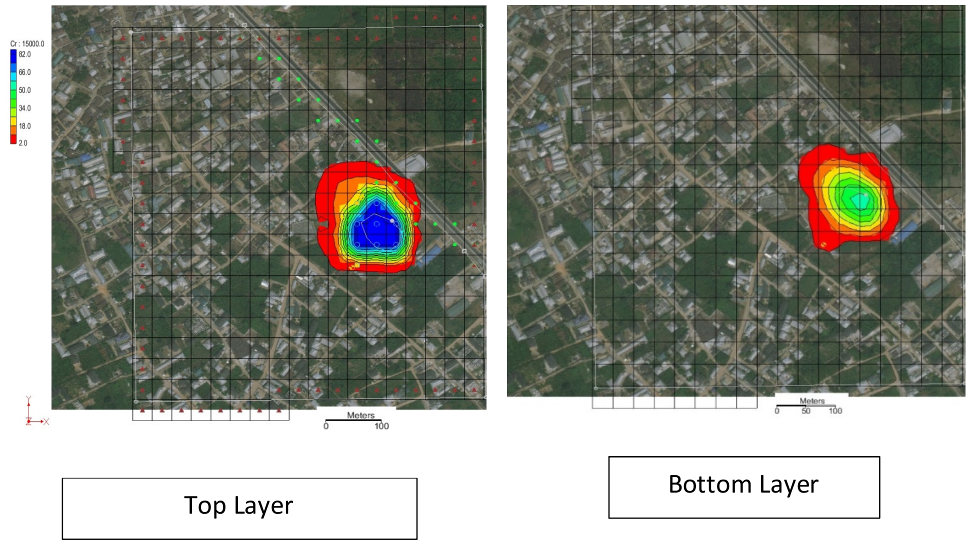


Figure 9: Cr Transport after 40 Years.

For the purpose of simplification, it is assumed that constant concentration of chromium is discharged to the surroundings from the dump. The value for chromium concentration inputted in the model was 88mg/kg. linear sorption was assumed. Figure 3 shows migration of Chromium from the dump after a year. It can be seen that it reaches the lower layer in the first 500days although greatly localized below the dump and in very low concentration. The top layers in the model results show that migration of contaminants at near surface of the vadose zone is not controlled by groundwater flow direction but by the orientation of the waste dump and presence of drainage channels, in this case, the man-made drain close to the dump. Thus there seems to be a slightly greaater spread of contaminants in the NE diection, although there is observed three-dimensional spread.

About 5 years from introduction of Chromium contaminant, the top layer exhibits an increased lateral spread, contaminant can be found in soil 70-80m from the dump (Figure 4). The concentration in the lower layer increases and a 3-dimensional spread can be observed with dominant direction in the SW direction which is the groundwater flow direction. There is increased conentration below the dump. About 10 years from onset of contaminant introduction, Spead in the top layer remains about the same but there is increased spread with increased concentration in the bottom layer. Traces can also be recoerded in water samples in the borehole as it has spread to soils surrounding the two boreholes included in the model. There is no difference in spread and concentration in the top layer by 20 years, however there is increased concentration in the SW direction. Lateral spread is about 100m from the source of ccontamination. By 25 years, the picture looks exactly the same as at 20 years, however, heavy abstraction of groundwater in neighboring areas might influence migration of plume.

CONCLUSIONS

The inclusion of unsaturated flow in Groundwater modeling is important for obtaining physically realistic results. The focus of this research was to examine fate and transport of Chromium from the Eneka dumpsite. The present research confirms that the soil in the near proximity of the dumpsite is contaminated with Cr though contamination is still marginally within DPR permissible limits all groundwater samples contained Cr above WHO maximum permissible limits for groundwater. Migration of Cr through the soil was encouraged by the acidity of soil and shallow groundwater. The Model matches perfectly the field observations; therefore, GMS is a very effective tool for modeling groundwater and making future projections pertaining to water contamination from different sources and Geologic settings. Results obtained from the Model showed that contamination of the surface resulting from dumpsites is in all directions from the source, however, when it meets with groundwater, it moves in the general direction of groundwater flow, if the dumpsite architecture remains unchanged, lateral migration in the top layer attains maximum spread in about 25 years. The effects of open waste dumps persist long after the dumpsite is closed or engineered.

RECOMMENDATION

1. Governments at all levels should take solid waste removal from communities to properly engineered dumpsites and recycling facilities seriously as lack of this service promotes proliferation of open dumpsites.
2. Persons living in vicinity of dumpsites or in areas where dumpsites have been closed or moved should be discouraged from using water from the shallow unconfined aquifer but encouraged to exploit deep for drinking purposes and other domestic needs.
3. Boreholes should be sited at least 200m away from dumpsites as increased abstraction may affect migration of plume.

REFERENCES

Bear, J. and Cheng A. H-D (2010). Modeling Groundwater Flow and Contaminant Transport. Pp341 – 381. Downloaded from http://Springer.com/978-1-4020-6681-8.

Das. K.K., Das S.N., & Dhundasi. S.A. (2008). . Impacts of Urban Growth on Surface Water and Groundwater Quality (Proceedings of IUGG 99 Symposium HS5, Birmingham, July 1999). *IAHS Publ*. 259, 429 – 430.

Dunnick, J.K., Elwell, M.R., Radovsky, A.E., Benson, J.M., Hahn, F.F., Nikula, K.J., Ebarr, B., and Hobbs, C.H. (1995). Comparative Carcinogenic Effects of Nickel Subsulfide, Nickel Oxide, or Nickel Sulfate Hexahydrate Chronic Exposures in the Lung. *Cancer Res*, 55, 5251–*5256*.

ESIA Water Project (2015). Environmental and Social Impact Assessmentfor Port Harcourt and Obio/ Akpor Water and sanitation Project. Ministry of Water Resources and Rural Development. Rivers State.

Gobo, A.E. (1990). Rainfall data analysis as an aid for designs for maximum drainage and flood control works in Port Harcourt. *J. of Discovery and Innovations African Academy of Science. Nairobi, Kenya.* 2 (4), 25-31.

NBS (National Bureau of Statistics). (2006). National Bureau of Statistics official Gazette (FGP 71/52007/2500), National and State provisional totals, 2006 census.

Ngah, S.A and Abam, T.K.S (2006). Groundwater Contamination Pathways in Unengineered Waste Dumps. *Afr. J. Environ. Pollut. Health* 5(1), 23-34.

Nwankoala, H.O. and Ngah, S.A. (2014). Groundwater Resources of the Niger Delta: Quality Implications and Management Considerations. *International Journal of Water Resources and Environmental Engineering.* 6(5) 155-163.

Reijers, T.J.A. (2011). Stratigraphy and sedimentology of the Niger Delta. *Geologos* 17(3), 142.

Short, K.C. and Stauble, A.J. (1967). Outline of the Geology of Niger Delta. *Am. Ass. Petroleum Geologists Bull.* 51, 761 – 779.