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A Simplified Model Study for Geo-Environmental Impact Assessment at an Oilfield Location in Southern Nigeria

[1]P.O. Youdeowei and [2]H.O. Nwankwoala

[1]Institute of Geosciences and Space Technology (IGST),
Rivers State University, Port Harcourt, Nigeria
[2]Department of Geology, Faculty of Science, University of Port Harcourt, Nigeria

Abstract: A presentation is made in this paper of a concise study of geo-environmental impact assessment of a site using an oilfield location in southern Nigeria as a case study. The purpose is to highlight the essential processes in the physical environmental impact evaluation of a site prone to crude oil contamination. At the study site, clastic deposits of fine sand overlie the area up to 10m in depth. These strata possess high porosity but are of low permeability with pores that are not interconnected. Furthermore, the site is characterized as flat-lying so that groundwater elevation and head loss is small; this implies slow groundwater movement and long residence time of possible assimilated effluents.

Key words: Simplified model study · Geo-environmental impact assessment · Oilfield site · Southern Nigeria

INTRODUCTION

The EIA aims to evaluate a proposed action, defining and quantifying its possible environmental impacts and finding means to mitigate them [1, 2]. Geo-environmental modeling is useful for advance planning and proactive environmental planning, including situations where the permitting process has outpaced the availability of critical environmental data. Resulting data can be shown to be pragmatic and robust, less subject to interpretation than some other assumptions [3]. Heterogeneities in the subsurface environment usually complicate the application of standard models of groundwater behaviour. Groundwater studies are by definition complicated by the largely hidden nature of the resource and its host media. Hydrogeological descriptions, should, nonetheless include a simplified conceptual description/model of the groundwater system. This should ideally include a three-dimensional or a box model sketch that illustrates the volume and direction of water flux through the system (i.e. the system dynamics). Components that are typically included in such a model include information on groundwater flow directions. The amount of detail to be included in such a conceptual model and its scale should be determined by the focus and scale of the development and its possible impacts.

Atala community, an oilfield location situated between longitude 6°15’ to 6° 20’ E and latitude 4° 30’ to 4° 35’ N in Bayelsa state, southern Nigeria served as the site utilized for this geo-environmental model study. The aim of the study was to highlight a simplified model of physical environmental impact assessment which delineates the key hydrogeological parameters and procedure as a forerunner to clean-up and remediation activities.

Geomorphology and Geology of the Study Area: The area lies within the mangrove swamp as part of the vegetated tidal flat of the Niger Delta sandwiched between the outer barrier island complex and the older sands of the Benin Formation. It is traversed by a dense network of watercourses and channels, which are linked, to the tidal areas of the coastal zone. The swamp belt and associated areas have a tidal capacity of about 3,000 times the freshwater influx during each tidal cycle [4]. Soils from this zone consist mainly of dark grey to black, soft mud of silt and clay with some fine sand, which supports the tall mangroves. In other places these soils are translated into peaty- clays (Chikoko), which can carry only the stunted species of the mangrove trees. Towards the sea, the soil is made up of clay, silt and sand of varying texture with high organic matter content.

Corresponding Author: H.O. Nwankwoala, Department of Geology, Faculty of Science, University of Port Harcourt, Nigeria.
E-mail: nwankwoala_ho@yahoo.com.

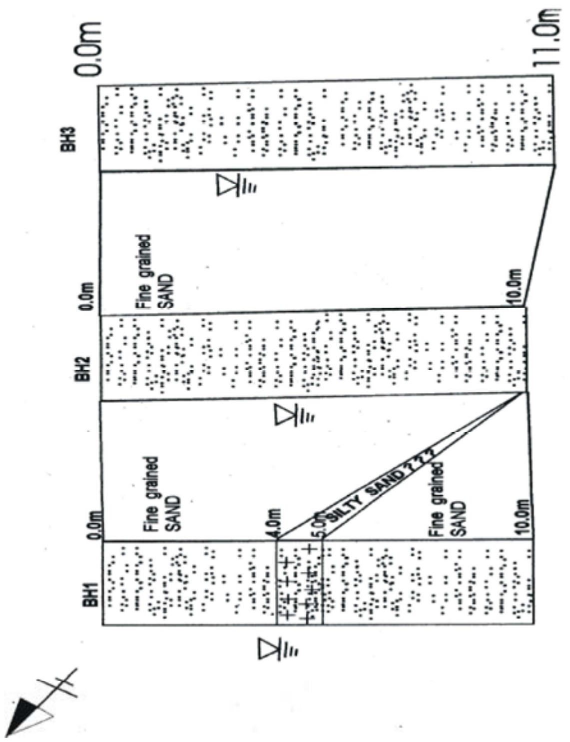


Fig. 1: Lithostratigraphic Correlation of Boreholes Drilled at Atala Field

Topographic surveys of the onshore area of the mud coast reveal heights of 0.15 - 0.90 meters above sea level and with tidal ranges of 0.45m.

Methods of Study

Data Collection/Laboratory Analysis: Three (3) water wells were bored at the project site to obtain baseline water quality data, water level monitoring and sub-soil analysis for infiltration characteristics. The boreholes were drilled with the use of a light cable percussion rig to depths of 10m for boreholes 1 and 2 and 11m for borehole 3 (Figures 1, 2 & 3). This drill type permits more accurate determination of groundwater levels and sampling of groundwater for quality analysis. The water levels in the boreholes at low tide were 4.0m, 4.5m and 3.5m for boreholes 1, 2 and 3, respectively. The wells were screened and cased with P. V.C. plastic pipes, gravel packed, cement based and capped to prevent well collapse and groundwater contamination. The physical properties of the soil samples recovered from the boreholes were examined to obtain parameters used as indices of the infiltration capacity of the soils at the site.

Laboratory tests were carried out on representative soils samples in accordance with British Standards (B.S) 1377, [5a] which are equivalent to the ASTM [5b] Standards. The tests were grain size distribution analysis, permeability (using the constant head permeameter) and Atterberg (consistency) limits. These tests were conducted to enable the evaluation of the gradation, hydraulic conductivity (coefficient of permeability) and consistency (water absorbing. and adsorbing ability) properties of the soil samples, as well as their classification. The results are summarized in Table 1.

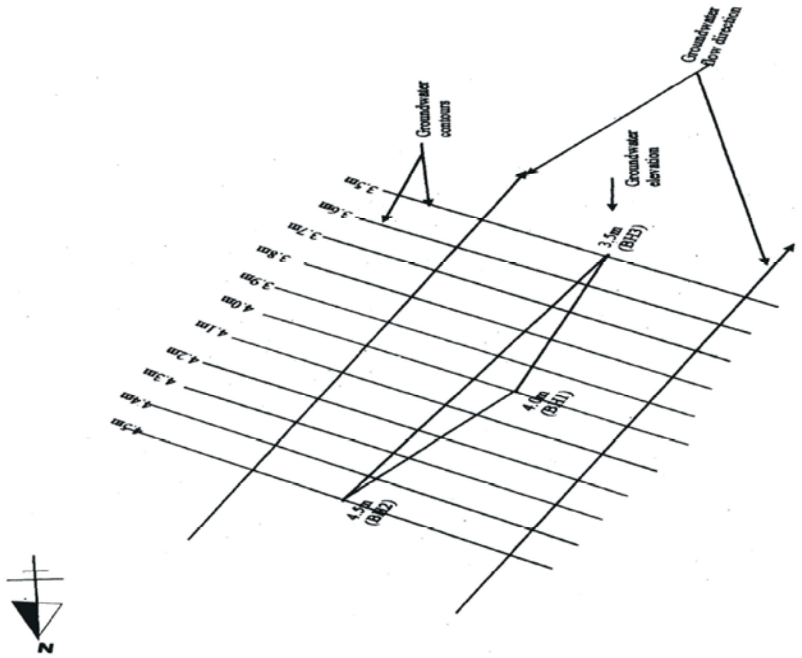


Fig. 2: Estimate of Groundwater Flow Direction at Atala Field [8]

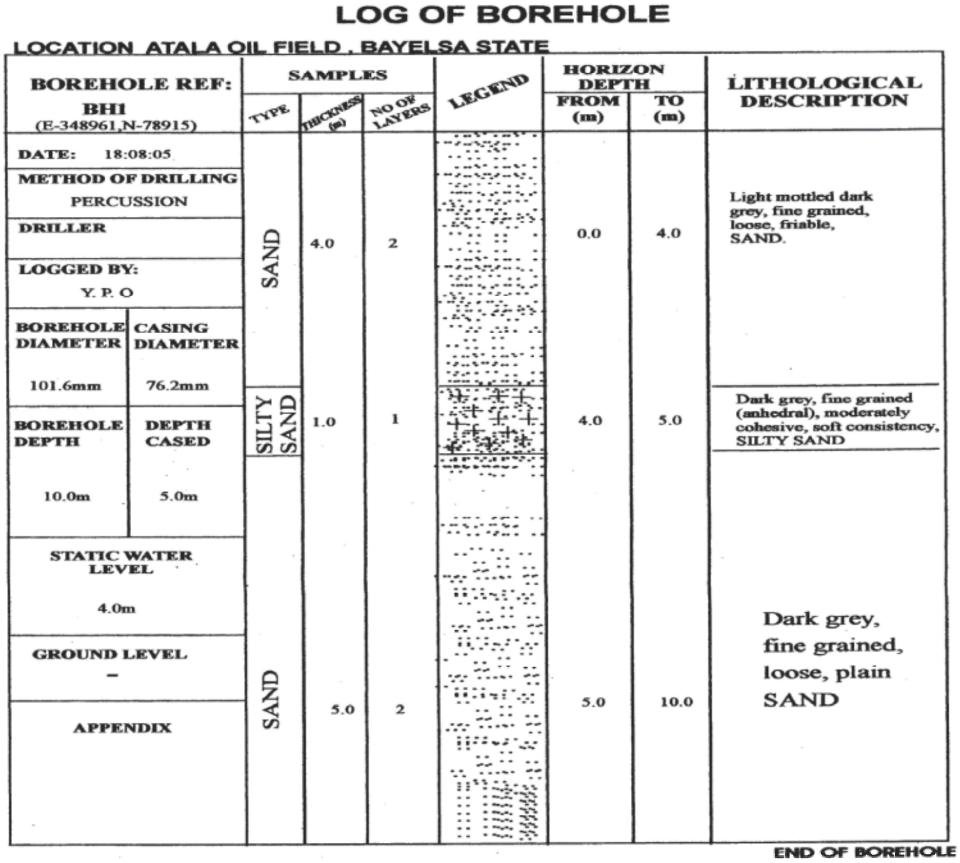


Fig. 3: Log of BH 1 for Atala Oilfield, Bayelsa State

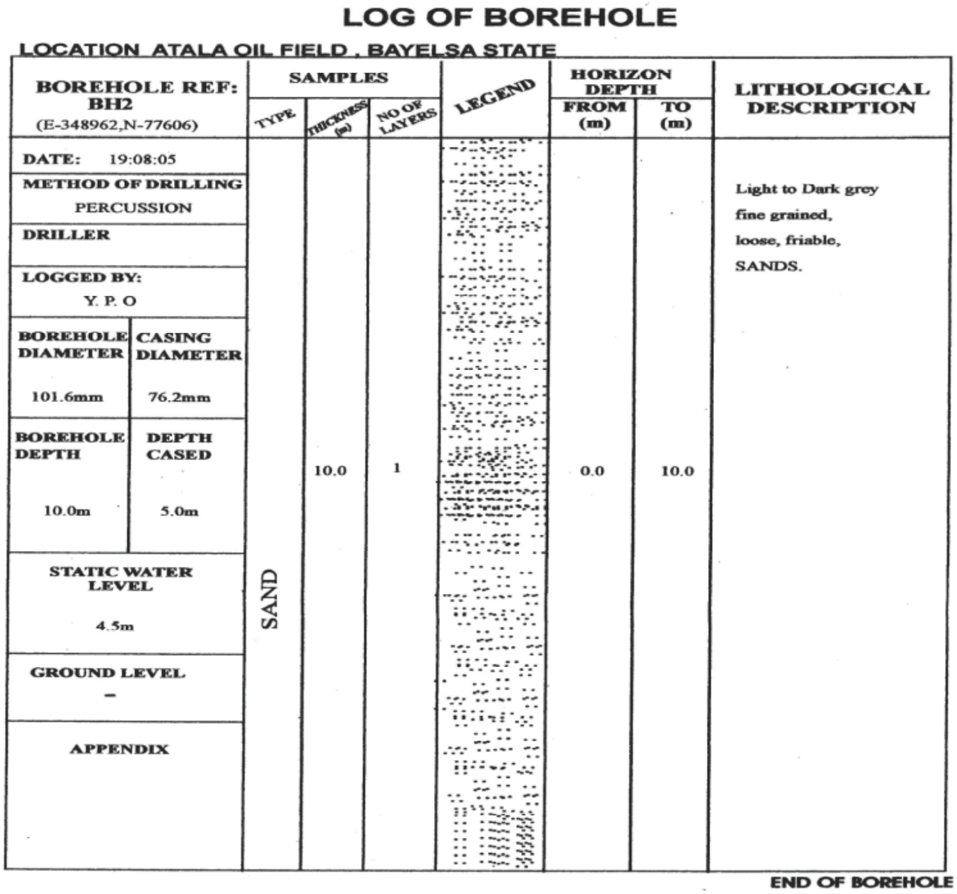
Table 1: Summary of Laboratory Soil Test Results (Atala Field)

				Grain Size Distribution (Percent passing sieves)				Atterberg Limits				Classifi-cation
Bore-hole No.	Sample No.	Depth (m)	Soil Nomen-clature	No. 4 (4.75mm)	No. 10 (2.00mm)	No.40 (0.42mm)	No.200 (0.075mm)	LL (%)	PL (%)	PI (%)	Perme-ability (cm/sec.)	Unified Soil Classifi-cation System (U.S.C.)
BH1	BH1 (1m)	1.0	Sand	100	100	96.0	0.5	-	-	NP	$7.84x10^{-1}$	SP
	BH1 (4m)	4.0	Silty Sand	100	100	93.0	13.9	-	-	NP	$8.76x10^{-1}$	SM
	BH1 (10m)	10.0	Sand	100	100	95.1	0.3	-	-	NP	$8.78x10^{-1}$	SP
BH2	BH2 (1m)	1.0	Sand	100	100	99.6	0.4	-	-	NP	$8.75x10^{-1}$	SP
	BH2 (10m)	10.0	Sand	100	100	100	0.0	-	-	NP	$8.80x10^{-1}$	SP
BH3	BH3 (1m)	1.0	Sand	100	100	98.1	0.1	-	-	NP	$8.82x10^{-1}$	SP
	BH3 (11m)	11.0	Sand	100	100	97.4	0.0	-	-	NP	$8.76x10^{-1}$	SP

* NP= Non-Plastic.

RESULTS AND DISCUSSION

Lithologic profiles of the soils from each of the three (3) boreholes drilled are detailed in the borehole logs. The lithostratigraphic correlation is also shown in Figure 4. The predominant soil type at the site in all three boreholes consist of light to dark grey, fine grained, loose, friable sands. This is interspersed in borehole 1 (BH1) by a dark grey, fine grained (anhedral), moderately cohesive, soft consistency, silty sand of about 1.0m in thickness. Grain size analysis involved dry sieving on field obtained samples. Results of the grain size analysis show from the data and uniform gradation curves a range of poorly graded sands and gravelly sands with little or no fines (0.00 to 13.90%) passing 0.075mm sieve. The fine grained nature of the sands means that fluid flow through them may be slow, as the number of particles per unit area is relatively small and void spaces are fewer. The sands therefore have relatively low permeabilities on account of their fine grains.



LOG OF BOREHOLE

LOCATION ATALA OIL FIELD , BAYELSA STATE

BOREHOLE REF: BH2 (E-348962,N-77606)		SAMPLES			LEGEND	HORIZON DEPTH		LITHOLOGICAL DESCRIPTION
		TYPE	THICKNESS (m)	NO OF LAYERS		FROM (m)	TO (m)	
DATE: 19:08:05		SAND	10.0	1		0.0	10.0	Light to Dark grey fine grained, loose, friable, SANDS.
METHOD OF DRILLING PERCUSSION								
DRILLER								
LOGGED BY: Y. P. O								
BOREHOLE DIAMETER 101.6mm	CASING DIAMETER 76.2mm							
BOREHOLE DEPTH 10.0m	DEPTH CASED 5.0m							
STATIC WATER LEVEL 4.5m								
GROUND LEVEL –								
APPENDIX								

END OF BOREHOLE

Fig. 4: Log of BH 2 for Atala Oilfied, Bayelsa State

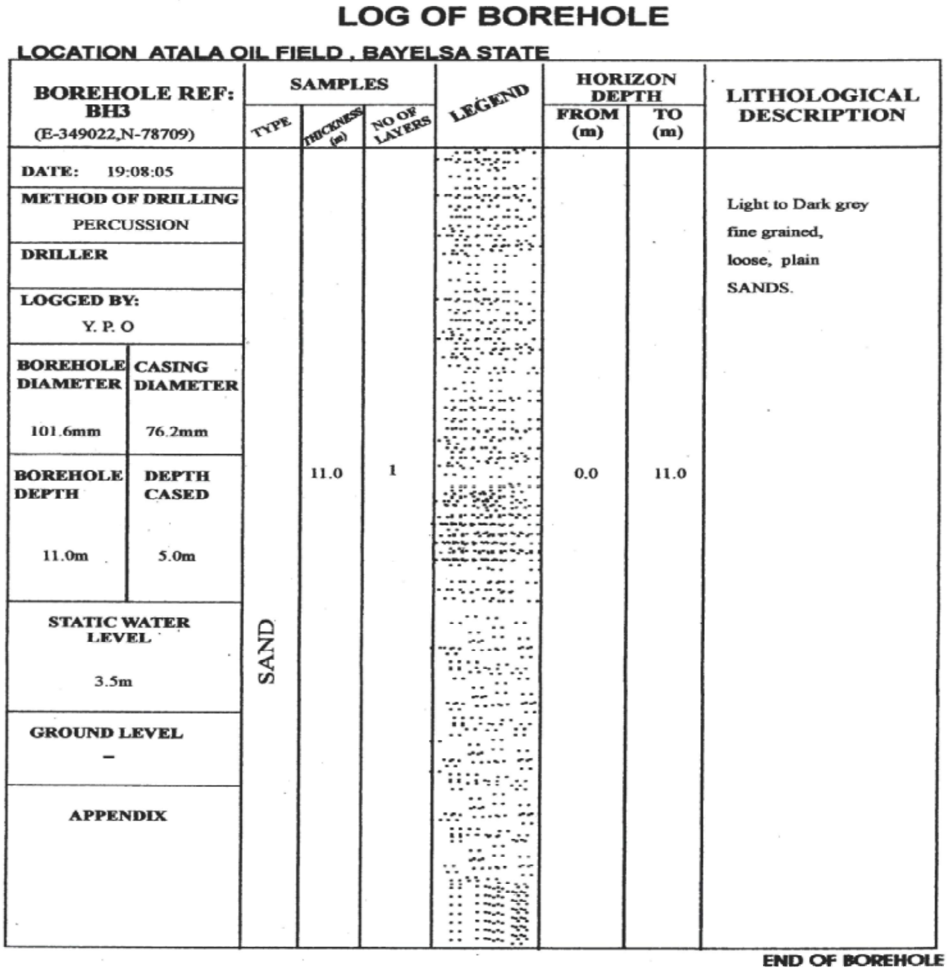
Atterberg limits (also known as consistency limits) expresses the water absorbing and adsorbing ability of fine grained, cohesive soil, with the plasticity index indicating the range of water content, through which the soil remains plastic.

The soils at the study site were determined to be non-plastic and fall within the soil classification group of SP and SM under the unified soil classification system (U.S.C) scheme (Table I).

The values obtained from the permeability test of the samples are relatively low as expected for these fine grained, sandy soils and range from 7.84 x I0^{-1} cm/s to 8.82 x I0^{-1} cm/s (Table I). The ability of these sediments to hold and transmit water is determined by their porosity and permeability. Coefficient of permeability increases with increase in voids sizes, which in turn increases with increasing grain size. The larger grains permit more fluid motion as a result of high permeability than the finer ones. Permeability depends on soil density, degree of saturation, viscosity of fluid and soil particle size [6].

Impact Assessment and Prediction: The hydrology of the area is governed by its high precipitation rate (annual rainfall averaging 4000mm with no pronounced dry season) and the low-lying nature of the terrain. The ambient predominant network of rivers and creeks ensures that within this saltwater mangrove swamp there are small islands with limited area and normally low ground elevation. The main hydrological influences on the surface water are tidal intrusion and freshwater input from inland areas including the freshwater swamp forests. The magnitude of flow varies with tide (upstream) and downstream, the flow reverses under the influence of the tide.

The clastic overburden at the site of fine sands tends to have high porosity but is not free draining [7]. Their relatively low coefficient of permeability may help to limit the lower part of the aquifer from brackish water intrusion from the rivers and creeks adjoining the site. The existence of this overburden layer determines whether or not a pollutant will reach the aquifer from a surface spill.



LOG OF BOREHOLE

LOCATION ATALA OIL FIELD . BAYELSA STATE

BOREHOLE REF: BH3
(E-349022,N-78709)

DATE: 19:08:05

METHOD OF DRILLING: PERCUSSION

DRILLER

LOGGED BY: Y. P. O

BOREHOLE DIAMETER: 101.6mm

CASING DIAMETER: 76.2mm

BOREHOLE DEPTH: 11.0m

DEPTH CASED: 5.0m

STATIC WATER LEVEL: 3.5m

GROUND LEVEL: -

APPENDIX

SAMPLES			LEGEND	HORIZON DEPTH		LITHOLOGICAL DESCRIPTION
TYPE	THICKNESS (m)	NO OF LAYERS		FROM (m)	TO (m)	
SAND	11.0	1		0.0	11.0	Light to Dark grey fine grained, loose, plain SANDS.

END OF BOREHOLE

Fig. 5: Log of BH 3 for Atala Oilfield, Bayelsa State

Figure 5 shows the determination of groundwater flow direction as defined from the delineated groundwater contours using the method advanced by Todd [8]. Flow lines sketched perpendicular to contours show directions of movement. Groundwater moves in the direction of decreasing head, from areas of recharge to points of discharge [9]. The local groundwater migration at the site between boreholes 1, 2 and 3 as shown in Figure 2 is towards the Southwestern direction. Pollutants reaching the groundwater will migrate along these flow paths.

Environmental Management Plan (EMP): In the event of an incidental oil spill at the site, it will be necessary to carry out remediation exercises [10] which may include:

- Containment methods such as grout curtain as well as clean up and to restore affected areas by replacing excavated contaminated soil with uncontaminated soil from a clean, unpolluted site. The soil may then be stabilized mechanically (compaction) or chemically (inclusion of additives) to reduce its erosion potential. The excavated soil can be treated by incineration to remove or neutralize the hazardous materials [11].
- Design drainage whereby flow lines generally follow existing rights of way so that spill is led away to dedicated drainage treatment system in collection pits or interceptor trenches.
- Pump and treat the wells to remove the oil from the aquifer. Contaminants extracted from the groundwater are passed to treatment facilities, treated and re-injected into the wells.

CONCLUSION

The overburden lithologic strata, which overlie the aquifer, the low-lying topography coupled with the linkage of rivers and creeks and the high rainfall regime of the study area, control the occurrence and distribution of groundwater in the area. The semi-confined nature of the aquifer at the site means that the upper-most aquifer may be prone to contamination. The homogeneous uniformity of the overburden fine textured sand, especially predominant in boreholes 2 and 3 is an indication that the soils were deposited under similar energy conditions. The difference in groundwater elevations (hydraulic head) at the site is small (Fig. 2) and since groundwater flows when there is head loss caused by the hydraulic gradient (slope of the water table), it is obvious that groundwater movements will be slow. Subsequently, groundwater discharge between two points at the site will vary very little [12]. This implies that assimilated effluents into the sub-soil and possibly the aquifer will undergo long residence time. Pollutants that may reach the groundwater will tend to move laterally in a southwesterly direction. As it, moves away from the point or lines sources of pollution, the concentration of contaminants decreases due to dispersion and other attenuation effects, such as biological decomposition of organic compounds and precipitation of dissolved chemicals [13, 14].

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