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Full Length Research Paper

Geo-environmental/ecological management study and audit scheme of Alakiri Field, Niger Delta

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Ten (10) water boreholes for water level monitoring and sub-soil analysis were carried out in the Alakiri Field, Niger Delta, Nigeria. The positions of the boreholes were chosen on the basis of grid sampling to reflect a good representation of the entire Alakiri field. Boring of the drill holes to 20 m each was carried out with the use of a light cable percussion rig. Stratigraphic synopses of the boreholes display considerable variations and heterogeneity in the soil types, indicating that the soils were deposited under varying energy environmental conditions of river (fluviatile) and tidal channel (marine) activities. Grain size analysis results show a range of well graded (poorly sorted) aquiferous sands with very little fines (1.60 to 3.10% finer than No.200 sieve) to uniformly graded (well sorted) clayey sands, sandy and silty clays with moderate to very high fines or silt/clay fractions (17.41 to 94.60% passing 0.075 mm sieve). Permeability tests of the samples vary from low of 6.40 x 10^{-3} to 7.82 x 10^{-3} cm/s for the silty clayey mud to sandy clay, to fairly high of 7.20 x 10^{-1} to 1.01 cm/s for the clayey sand to sand. Coefficient of permeability increases with increasing size of voids, which in turn increases with increasing grain size. Soil consistency results show a low plasticity range (2.35 to 13.40%), with the predominantly sandy soils being non-plastic. The low value of plasticity indices of the plastic soils is an indication of low water retaining capacity. The soils fall within the soil classification groups of SC, SW, CL, OL and PT under the Unified Soil Classification System (U.S.C) scheme. Resulting from almost saturated state of the soils, water boreholes sited in the area, for domestic and industrial utilization will have to go considerable depths (over 200 m) to obtain uncontaminated water in case of pollution and because of the prevalent saline water.

Key words: Environmental assessment, ecological management, soils, geotechnical engineering, Niger Delta.

INTRODUCTION

To date, the assessment of the qualitative and quantitative status of groundwater is based exclusively on hydrogeological parameters (Steube et al., 2009). Reliable ecological criteria and the design of appropriate indices/ development of applicable assessment schemes are very necessary (Danielopol et al., 2003). Evaluation of the hydrological and subsoil analysis of the study area is very desirable, especially with the intensive oil and gas exploration activities that have been going on for the past three decades.

Alakiri Field which lies on the mangrove swamp environment of the Nigerian coastline in the Niger Delta area is ecologically sensitive. The dense network of rivers and creeks in the area ensures that within the saltwater mangrove swamps, there are small islands with limited area with low ground elevation and shallow depth to groundwater. The water table is also permanently at or near the ground surface. This is mainly influenced in the same way as surface waters hence the prevailing hydrostatic relationship between the ground and surface water in the area which tends to be hydrodynamic. Therefore, assessment of subsoil characteristics, water level determination and hydro-geological investigations become imperative. The impact of recharge and discharge as a

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measure of the aquifer vulnerability and its temporal dynamics, the contaminant degradation and *in-situ* biodegradation rates and detection of effects by short-term contaminant impacts (if any) can only be corrected through regular geo-environmental monitoring.

In this study therefore, the saturated state of the soils and water boreholes was assessed for domestic and industrial utilization to obtain uncontaminated water in case of pollution and the prevalent of saline water encroachment.

The study area

The study area (Alakiri Field) lies on the mangrove swamp environment running parallel to the Nigerian coastline in the Niger Delta area. The area is sandwiched between the outer barrier island complex and the older sands of the Benin Formation, in a belt which reaches widths of between 30 and 40 km at the delta flanks and across the delta. This mangrove swamp zone crisscrossed by a network of dynamic rivers and creeks and has evolved primarily through the process of repeated bifurcation of the River Niger and its distributaries. The frequent flooding with freshwater from rainfall and/or saltwater at high tide has resulted in dense vegetation typical of a brackish environment. The decaying vegetable remains, mixing with deposit of silts and clays to form a swampy landmass.

Intra-swamp deltas form as complexes of islands and mudflats in the widest parts of the larger channels. Mangrove tidal flats soils are polygenetic, consisting of cross-stratified fine to coarse sand and organic - rich clays with abundant drifted debris, which were deposited during the Pliestocene epoch. The predominant vegetation in the area is the hylophytic red mangrove species, *Rhizophora racemosa.*

METHODOLOGY

Drilling technique and soil sampling

Drilling of ten (10) water boreholes for water level monitoring and sub-soil analysis was carried out onsite (positions of water wells are shown on the location map and the groundwater level contour map). Their positions were chosen on the basis of grid sampling to reflect a good representation of the entire Alakiri Field. Boring of the drill holes to 20 m each was carried out with the use of a light cable percussion rig of the Pilcon Wayfarer type. Percussion rig drilling method permits more accurate determination of groundwater levels, more accurate sampling of groundwater for quality analysis, and more accurate sampling of the cuttings as brought up with the bailer. Furthermore, the equilibrium water level in the well is an accurate measure of the pressure head in the aquifer at the bottom of the hole.

This drilling technique entails the boring of a vertical hole by repeatedly dropping a heavy, cylindrical chisel-type drill bit combined with a bailer. This loosened up the soil material and drilling is periodically interrupted to remove the soil samples. The length of the combined tool is about 1.5 m and was suspended from a wire cable, which was strung over a pulley at the top of a near-vertical mast erected over the hole. The bottom of the bailer consisted of a flat valve which was open when the bailer was lowered into the hole and closed when the bailer was pulled up, bringing out drill cuttings with it. The boreholes were logged on site and soil samples recovered at intervals where lithologic changes occurred for laboratory analysis of textural characteristics, classification and infiltration properties.

The wells were screened (0.5 mm slot) at the aquifer depth, gravel packed (3/8" gravel size), cased, and capped with PVC plastic pipes (3" diameter). Their bases were also cemented. These were all done to prevent well collapse and groundwater contamination within the borehole sites as per casing and/or sealing of the wells may result in the direct ingress of contaminated surface water into groundwater. Soil samples recovered from the boreholes were subjected to both visual examinations and laboratory tests. Laboratory tests carried out on representative soil samples in accordance with B.S 1377 (1990) Standard.

RESULTS AND DISCUSSION

Soil stratigraphy

Stratigraphic sections of the ten boreholes drilled are detailed in the log sheets (Figure 1). The stratigraphic synopses of the boreholes display considerable variations and heterogeneity in the soil types. This is an indication that the soils were deposited under varying energy environmental conditions of river (fluviatile) and tidal channel (marine) activities. The sandy lenticular sediments represent the high energy environmental deposits of river and tidal channel processes. The inter-bedded silty, clayey sediments were deposited in the low energy environment.

The most commonly occurring soil type as revealed by the loss of the drill holes are the light to dark grey, very fine grained, organic silty clays. They are prominent in the fossiliferous (woody plant remains) muddy form as peaty silty clayey mud (clayey shale) also locally known as *Chikoko mud.* This latter soil type represents a marker bed, as it occurs consistently across the area. In some places, it is the superficial, overlying soil with thickness up to 5 m, in other places, it lies about 1 m below the dredge spoils to depths of about 8 m. It is however absent in BH4 and BH10. Clastic sequences of coarse sand (2 to 6 m thick) interpose the various strata and occur at end of some of the boreholes. These are the aquiferous layers. The boreholes are also ineter-stratified with other detrital deposits such as sandy clay, clayey sand, gravelly silty clay, and sandy silty clay which vary in thickness, grain size, relative density and consistency, but with minor colour alterations (light to dark grey and light to dark brown).

Soil textural analysis and classification

Grain size distribution analysis, permeability (using both falling and constant head permeameters) and Atterberg (Consistency) limits were carried out. The tests were carried

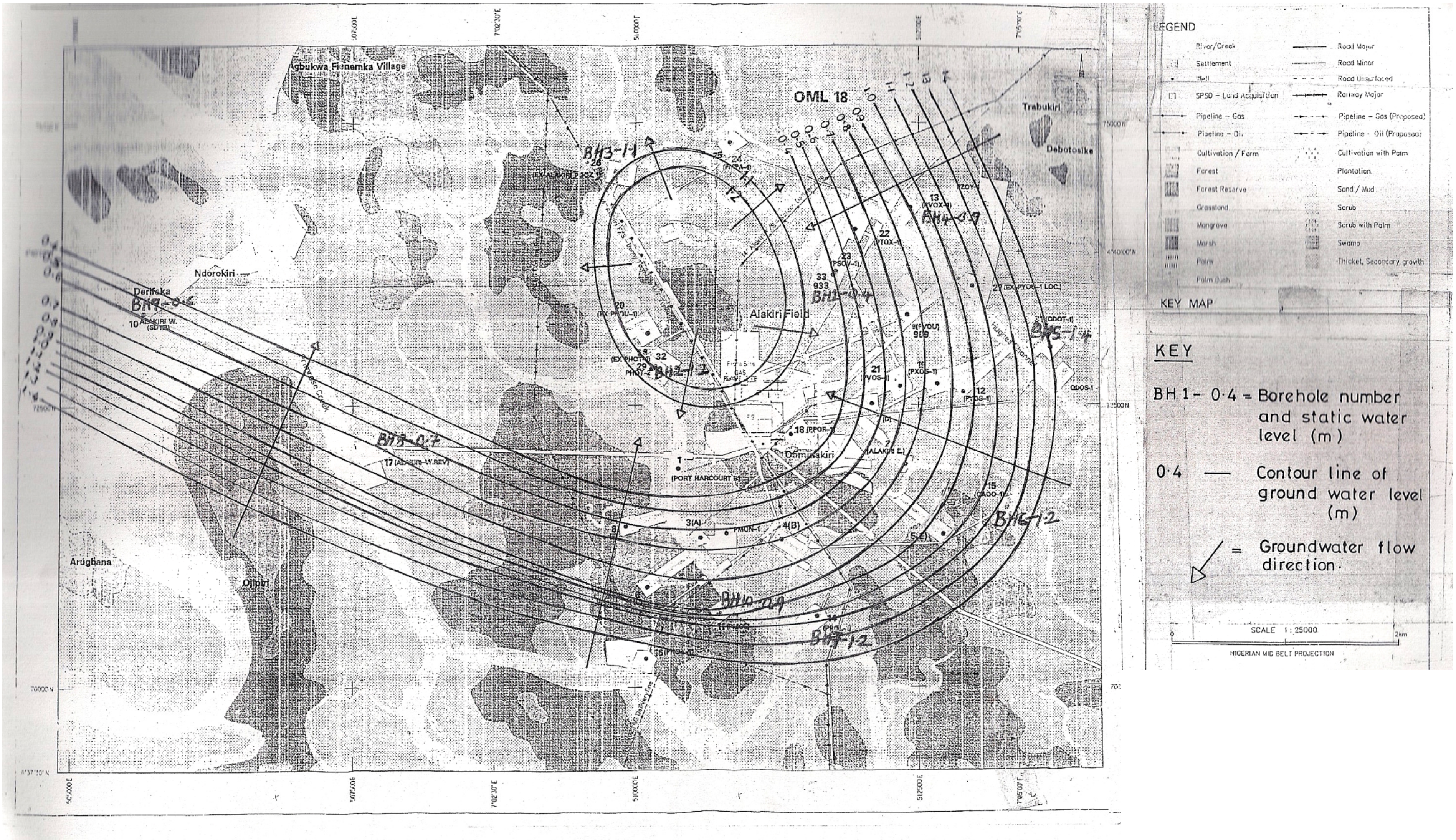

Figure 2. Groundwater level contour map of Alakiri Field.

Table 1. Summary of laboratory soil test results in the study area.

Borehole number	Analyzed soil sample	Sample depth (m)	Soil group nomenclature	Grain size distribution (Percent passing sieves)				Atterberg limits			Permeability (cm/s)	Classification
				No. 4 (4.75 mm)	No. 10 (2.00 mm)	No. 40 (0.42 mm)	No. 200 (0.075 mm)	LL (%)	PL (%)	PI (%)		Unified soil classification system (U.S.C.S)
BH1	BH (0.00)	0.00	Clayey sand	99.50	92.70	41.300	30.00	18.50	12.60	5.10	1.01×10^{0}	SC.
	BH (15.00)	15.00	Sandy clay	100	98.80	77.60	43.20	22.50	11.90	10.60	7.34×10^{-3}	CL.
BH2	BH (0.00)	0.00	Peaty mud	-	-	-	-	34.20	22.30	11.90	6.51×10^{-3}	PT.
BH3	BH (11.00)	11.00	Silty clayey mud	-	-	-	-	39.20	25.80	13.40	6.40×10^{-3}	PT.
BH4	BH (6.00)	6.00	Sandy silty clay	99.00	97.00	74.30	66.60	26.50	20.37	6.13	7.81×10^{-1}	OL.
BH5	BH (0.00)	0.00	Clayey sand	96.77	55.41	33.07	17.41	-	-	Non plastic	9.31×10^{-1}	SC.
	BH (16.00)	16.00	Sandy silty clay	99.00	97.50	34.50	20.00	20.80	17.55	3.25	8.60×10^{-1}	OL.
BH6	BH (17.00)	17.00	Clayey sand	97.20	92.40	58.40	29.10	15.00	12.65	2.35	7.20×10^{-1}	SC.
BH7	BH (20.00)	20.00	Silty clay	100	100	96.40	94.60	39.60	30.05	9.55	6.61×10^{-3}	OL.
BH8	BH (20.00)	20.00	Sand	94.40	80.60	26.70	1.60	-	-	-	8.73×10^{-1}	SW
BH9	BH (0.00)	0.00	Silty clay	100	99.60	95.30	83.80	34.00	27.50	6.50	6.80×10^{-3}	OL
	BH (3.00)	3.00	Sandy clay	99.70	96.40	70.70	46.00	18.00	14.10	3.90	7.82×10^{-3}	CL
BH10	BH (0.00)	0.00	Sand	98.70	90.70	21.40	3.10	-	-	-	7.50×10^{-1}	SW

out 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. These para-meters were also used as indices of the infiltration capa-city of the soils at the site. The results are summarized in Table 1.

Grain size patterns

Grain size analysis results obtained from the test showed a range of well graded (poorly sorted) aquiferous sands with very little fines (1.60 to 3.10% finer than No. 200 sieve) to uniformly graded (well sorted) clayey sands, sandy and silty clays with moderate to very high fines or silt/clay fractions (17.41 to 94.60% passing 0.075 mm sieve). Uni-form graded soils have relatively low densities since the number of particles per unit area is small. Infiltration of fluids through the uniformly graded fine grained soils such as the silty clay and the peaty mud will be greatly reduced due to the reduction of void spaces in them, so that they are characterized by poor drainage capacity.

Permeability

The values obtained from permeability tests of the sam-ples varied from low of 6.40×10^{-3} to 7.82×10^{-3} cm/s for the silty clayey mud to sandy clay, to fairly high of 7.20×10^{-1} to 1.01 cm/s for the clayey sand to sand. Coefficient of permeability increa-sed with increasing size of voids, which in turn increased with increasing grain size. The larger grains will permit more fluid flow as a result of high

Table 2. Static water levels for the wells.

Bore holes (wells)	Static water levels (m)
BH1 (Oil Well 33)	0.47
BH2 (Oil Well 32)	1.22
BH3 (Oil Well 26)	1.13
BH4 (Oil Well 13)	0.97
BH5 (Oil Well 31)	1.40
BH6 (Oil Well 15)	1.24
BH7 (Oil Well 14)	1.26
BH8 (Oil Well 17)	0.78
BH9 (Oil Well 10)	0.65
BH10 (Oil Well 11)	0.97

permeability than the finer ones.

Soil consistency

The consistency of the soils at the study site was studied by measuring the natural moisture contents, determining both the liquid and plastic limits and the plasticity indices. The results show a low plasticity range (2.35 to 13.40%), with the predominantly sandy soils being non-plastic. The low values of plasticity indices of the plastic soils is an indication of that they have a low water retaining capacity. The soils fall within the soil classification groups of SC, SW, CL, OL and PT under the Unified Soil Classification System (U.S.C) scheme. Soils with the same classification tend to have the same engineering behaviour (Krynine and Judd, 1957).

Hydrological conditions, pollution susceptibility and pathways

Several factors govern the occurrence and distribution of groundwater in the area. This includes the overburden geologic formation, the low-lying topography, the high – rainfall regime (annual average over 3000 mm), its surrounding rivers and creeks, and even the occasional canalization activities. Surface water comes from either rivers and primary freshwater flows or creeks which receive freshwater flows but are also subject to tidal influences, twice daily, pushing saltwater into the area. The area is almost totally submerged during high tides and seasonal floods giving rise to very severe drainage problems. The insufficient drainage capacity is caused by the generally flat topography and superficial clayey deposits, giving rise to a wide distribution of swamps within the area.

The dense network of rivers and creeks ensures that within the saltwater mangrove swamps, there are small islands with limited area and normally low ground elevation as well as shallow depth to groundwater. The water table is permanently at or near the ground surface and is mainly influenced in the same way as surface waters, so that the prevailing hydrostatic relationship between the ground and surface water tends to be hydrodynamic. Because of the fairly uniform nature of the terrain, gravity drainage is low and the hydraulic gradient between two points will change very little from point to point. Subsequently, both groundwater movement and surface discharge will vary only little from hour to hour. Topography is the primary control over flowing wells and there is head loss, the hydraulic gradient will cause the flow of groundwater.

From field measurements of static water levels in the boreholes (Table 2), a ground water level contour map was constructed for the study site (Figure 1). Flow lines, sketched perpendicular to contours show directions of movement (Todd, 1980; Davies and DeWeist, 1966). The velocity of groundwater, other things being equal, is greatest where the contour lines are closest together such as at the groundwater cascade between BH7 and BH10. Leachate or any pollutants introduced at a given point will migrate as pollution plumes along these flow paths. Effluents may fail to be mineralized or metabolized at significant rates in such aquatic ecosystems. Some chemicals readily dissolve in water while others have low chemical solubility. Solvents with lower density tend to float while those with heavier density than water tend to sink or migrate vertically down the aquifer. Except for small amounts of hydrocarbons that go into solution, oil does not penetrate to below the water table (oil is immiscible in water and is less dense). As oil accumulates on the water table, the oil zone spreads laterally, initially under the influence of gradients caused by gravity and latter in response mainly to capillary forces (Freeze and Cherry, 1979).

Conclusion

This study has revealed, from lithostratigraphic setting the intercalations of predominantly sand and clay formations which constitute a system of aquifers separated by aquitards. The peaty silty clay mud which overlies most parts of the terrain will exhibit a measure of transmissivity due to the presence of the thickly fibrous materials in them. However, the near-saturation state of the soil will restrict infiltration (Davies and DeWiest, 1966). Parameters that influence infiltration include soil type and cover, surface texture, limiting slope value, initial moisture content of soil, and intensity of spill. Infiltration decreases exponentially with time, and as the soil becomes saturated and as its clay particles swell. This is caused mainly by the filling of the soil pore by water.

The decline is more rapid and the final constant rate is lower for fine grained clay soils than for loose sandy soils (Freeze and Cherry, 1979). Resulting from almost saturated state of these soils and water boreholes sitting in the area, for domestic and industrial utilization, one will have to go considerable depths (over 200 m) to obtain uncontaminated water in case of pollution and because of the prevalent saltwater.

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