GLOBAL JOURNAL OF GEOLOGICAL SCIENCES VOL, 9, NO.1, 2011 1-9

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CHARACTERIZATION OF TERRAIN AND BIOTITE GNEISS-DERIVED LATERITIC SOILS OF ILORIN, NIGERIA, FOR USE IN LANDFILL BARRIERS

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(Received 8 April 2010; Revision Accepted 18 February 2010)

ABSTRACT

A total land mass of $3.63 \times 10^6 m^2$ and the biotite gneiss-derived lateritic soil over it around Ilorin, Nigeria were investigated for the purpose for locating appropriate site for the disposal of municipal solid wastes. The study shows that the investigated terrain is not only underlain by fresh Basement rock that is competent enough to provide support for the containment facility but has environmental characteristics such as safe distances from water supply wells, highways, inhabited areas, source(s) of expected waste generators and availability of soils which can be used as barriers and final cover materials. The results of twenty-eight (28) vertical electrical soundings (VES) and five (5) handdug wells over the site revealed that the average thickness of the overburden is 17m; thickness of the lateritic layer is 7.8m on the average while the groundwater table is encountered at depth of 5.3m. The geotechnical assessment of the soil samples revealed that the specific gravity values range from 2.50 - 2.73; the percentage of fines range from 20% - 67%; liquid limits range from 21.64%-46.53% and the plasticity index values range from 13.47% - 25.95%. The maximum dry density values of the soil obtained using the standard Proctor energy of compaction range from $1.72 t/m^3$ -$1.97 t/m^3$; while those obtained using modified Proctor energy range from $1.78 t/m^3$ – $2.07 t/m^3$. The highest coefficient of permeability values (6.03×10^{-9}m/s) for all soil samples, which is close to the recommendation of 1×10^{-9}m/s by several previous researchers, who obtained their results by using the lower compaction energy. All the characteristics compared favourably well with those suggested by regulatory agencies and several investigators. Consequently, this study confirms the suitability of the soils and for the construction of landfill facility.

KEYWORDS: Municipal Solid Waste, Barrier, co-efficient of permeability, Landfill

INTRODUCTION

This study sets out to investigate the geological, hydrogeological and geotechnical characteristics of an area around Ilorin, Southwestern Nigeria. These characteristics were examined to evaluate the suitability of the area as a sanitary landfill site for the disposal of municipal solid waste (MSW) generated within Ilorin and environs. The environmental and health hazards associated with various waste disposal methods are well known (Ige, 2003; Fred and Anne, 2005). In the U.S.A, 75% of unengineered landfills pollute adjacent water body with leachate. This is because deposited waste undergoes degradation through chemical reaction (Bell, 1999) thereby contaminating usable surface and subsurface water supplies. In addition, the leachated produce forms complexes with the sesquioxides of lateritic soil thereby weakening their in-situ geotechnical properties (Orlov and Yeroschicheva, 1967).

However, an engineered sanitary landfill is a relatively safer and cost effective waste disposal technique that encourages healthy relationship between man and his environment (Amost *et al,* 1972; Frempong, 1999). There is a need to critically assess the important characteristics of site(s) and the anticipated impacts of the waste when deposited there on. These include the potential for precipitated surface water to infiltrate the waste and generate leachate which could be transmitted through the underlying bottom soil/rocks into the underground water.

As a result of this perceived need to deposit waste in an engineered sanitary landfill, with minimum environmental and health risk at reduced cost, in highly commercialized and industrialized cities such as Ilorin, Nigeria, the authors opted to study the suitability of this site at the southwestern corner of the capital city. The result hopefully will not only provide assistance to government on land use planning and environmental pollution control strategy but will also generate data bank for prospective scientists.

REQUIRED ENVIRONMENTAL AND GEOTECHNICAL CRITERIA FOR LANDFILLS

A sanitary landfill is expected to meet several location and geotechnical criteria, and be acceptable to the public. Therefore importance of contributions from several fields of studies such as economics, toxicology, biology, chemistry, planning, engineering, climatology, agriculture, archaeology, architecture, social sciences and more importantly geology have been recommended (Bell, 1999; Ogunsanwo and Mands,1999). The criteria for the selection of a sanitary landfill site have been reported by several researchers (Allen and McCarthy,1991; Daniel,1993; Lolos *et al.;*1997; Zuquette *et al.;*1994; Bell,1999; Ogunsanwo,1996, Montogomery ,2000; AL-yaqout and Townsend, 2001; Dorn and Tantiwanit, 2001; Onipede and Bolaji, 2004; Herwig *et al.,* 2005; Kurian and Palanivelu, 2005; Mohamedzien *et al.;* 2005; USEPA, 2005; Yilmaz and Atmaca, 2006).

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Recommendations on the geotechnical requirements of soils have also been reported (e.g ÖNORM S 2074, 1990; Daniel, 1993; Bagchi; 1994, Benson *et al;* 1994, Rowe *et al;* 1995; Knitter *et al;* 1996; Ogunsanwo 1996; Kabir and Taha, 2006, and Ige, 2009). Their recommendations indicated that geologic, hydrogeologic (including environmental impact) and geotechnical characteristics of potential sites are the important factors. See tables 1 and 2 for the list of some of the required environmental and geotechnical parameters with several recommendations and the findings of this study.

TABLE 1: REQUIRED ENVIRONMENTAL CRITERIA- RECOMMENDATIONS AND FINDINGS OF PRESENT STUDY

PARAMETERS	SITE CHARACTERISTICS	RECOMMENDATIONS
LAKE	NA	≥ 60m (Nathanson, 2000) ≥ 300m (Keller, 1976; Bagchi, 1994; Dorn and Tantiwanit, 2006; USEPA, 2005
TOPOGRAPHY	2^0-7^0	≤ 15^0 (Gallas *et al,* 2008); Zuquette *et al,* 1994) Flat area (Bagchi,1994; Montgomery, 2000; Dorn and Tantiwanit, 2006
FLOWING STREAM	154m	≥125m (WRSC, 1993) >90m (Bagchi, 1994) ≥150 (WB, 2004) 90m (Yilmaz and Atmaca, 2006).
DEPTH TO WATER TABLE	DRY SEASON : ND WET SEASON : 5.3m	≥3.0(Frempong, 1999) >2.6m(Dimitra et al., 2001) >6.0m(Zuquette et al., 2001) >1.5m(Nathanson, 2000;WB, 2004)
WATER SUPPLY WELL	NA	≥635m(Bhardway and Singh, 1997); ≥500(WB, 2004) ≥800m(Bell,1999);365m(Dimitra *et al*,2006)
DEPTH TO BASEMENT ROCK	18.0m	≥1.2m(Yilmaz and Atmaca, 2006); 3.3m(WRSC, 1993) >5m(Zuguette et al.,1994)

KEY: *NA= Not Available*, ND= Not Determine

TABLE 2: REQUIRED GEOTECHNICAL CRITERIA- RECOMMENDATIONS AND FINDINGS OF PRESENT STUDY

PARAMETERS	AUTHOR(S)	RECOMMENDATIONS	RESULTS
GRAIN SIZE ANALYSES	Oeltzschner (1992) Bagchi (1994) ONORMS 2074 (1990) ONORMS 2074 (1990) Daniel (1993b), Rowe et al 1995	Clay fraction <20% Largest Grain Size ≤63mm Silt/clay fraction ≥15% Largest grain size <25mm, %Gravel <30, % fine ≥30	%Clay: 30%-70% %Gravel: 0%-7% %Fine: 39%-82%
ATTERBERG (CONSISTENCY) LIMITS	Daniel (1993b); Rowe et al(1995) Seymour & Peacock (1994) Oeltzschner (1992)	LL ≥30%, IP≥15% LL ≥30%, IP≥10% LL ≥30%, IP≥15% LL ≥25%, IP≥15% LL ≥30%, IP≥15% Inorganic Clay of low – medium plasticity(CL-CI) and Ac of <1.25	Liquid Limit: 31.6% - 68.4% Plasticity index: 13.9% - 44.4% Ac: 0.27 - 0.63
MOISTURE CONTENT-DENSITY RELATIONSHIPS	ÖNORMS 2074 (1990) Kabir and Taha (2006)	MDD ≥ 1.71t/m^3 MDD ≥ 1.74t/m^3	SP: 1.49t/m^3- 1.93t/m^3 MP: 1.79t/m^3- 2.07t/m^3
COEFFICIENT OF PERMEABILITY (*k*)	Murphy and Garwell (1998) Mark (2002) Joyce (2003) Fred and Anne (2005)	≤1x10^{-9}m/s ≤1x10^{-9}m/s ≤1x10^{-9}m/s ≤1x10^{-8}m/s ≤1x10^{-9}m/s	SP: 3.47x10^{-9}m/s to 9.15x 10^{-10}m/s MP: 8.49x10^{-10}m/s to 9.60x 10^{-11}m/s

KEY: SP= Standard Proctor LL= Liquid Limit
MP= Modified Proctor IP= Index of Plasticity
Ac= Activity of clay Gs= Specific Gravity

SITE LOCATION AND CHARACTERISTICS

The investigated site is bounded by longitudes 4^0 15'E and 4^0 45'E and latitudes 8^0 15'N and 8^0 45'N. It is located near Gamo, approximately 4km south of Ilorin, the capital city of Kwara State, Nigeria (Fig. 1). The site is 195m off Ilorin – Lokoja highway. It covers a land mass of $3.63x10^6m^2$ and is easily accessible during the dry and wet seasons. It is characterized by a rainy season (April-October) and a pronounced dry spell from November – March. The annual rainfall which is 1200mm per annum is characteristically torrential, resulting in both sheet and gully erosion in several locations. The area is well drained by a NW-SE direction ephemeral stream which is located about 141m south of the site. The monthly temperatures range between 26^0C to 30^0C with highest occurring in the dry season (FAAN, Ilorin, 2006). The vegetation is dominated by few shrubs and grasses. This has encouraged human activities dominated by such plantations as maize, yam tuber, cassava etc.

The site which has an average altitude range from 23m above mean sea level in the lowlying areas to 41m (msl) for the high rise area is decorated on the eastern part with Inselbergs of north-south trending quartzschist ridge

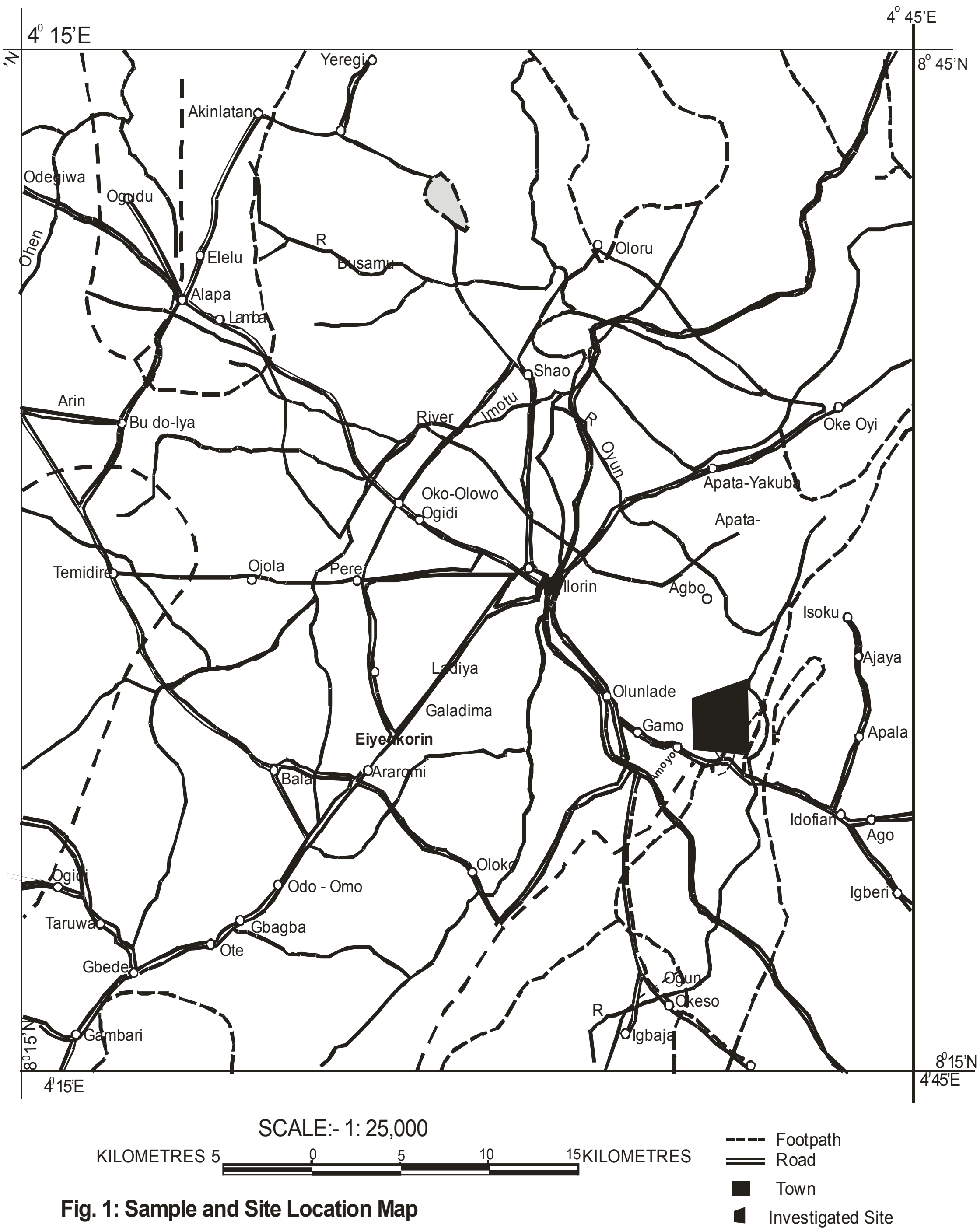

Fig. 1: Sample and Site Location Map

GEOLOGICAL SETTING

The city of Ilorin and the environ is underlain by rocks of Precambrian age. These include the migmatites, granites and the gneisses (Oluyide *et al;* 1998*)*. Outcrops of granite, biotite gneiss and biotite granite with characteristics cross-cutting pegmatite intrusions are common in the northern corner of the study area, while quartz and quartzschist are the predominant in the southern direction. They generally have westward direction and northeastern – southwestern trend. The main geological formation underlying the investigated site is the biotite gneiss with rock- head range between 10m in the south and 25m in the north. This rock type is stable and strong enough to sustain the weight of the waste containment facility. The contact of this lithology with other rock types is obscured by vegetated lateritic cover. Alao (1983), reported that the lateritic soil of the study area consist of three (3) layers; a basal lateritic clay, lateritic gravel and the lateritic crust.

FIELD AND LABORATORY INVESTIGATIONS

Subsurface exploration was undertaken, using five test pits (Fig. 2), to unravel the nature, sequence and distribution of soil /bed rock, determine the groundwater conditions, and to recover soil samples over the site for geotechnical tests in the laboratory. The test pits were dug to water (>5.3m) while samples for laboratory analyses were recovered from various depths between 0.87m to 2.8m. From the soil samples recovered, the engineering properties were determined in accordance with the British standard (BSI 1377, 1990): Such properties included the grain size distribution, plasticity characteristics (Atterberg limits), natural moisture content,compaction and coefficient of permeability.

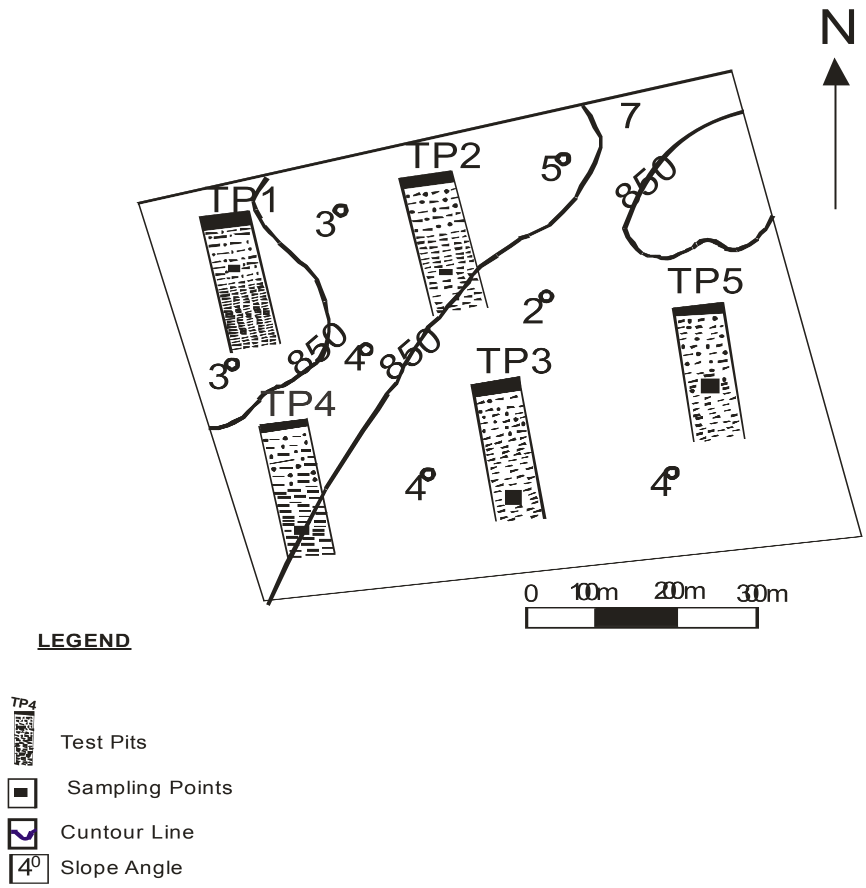

Fig.2: Map of the investigated site showing test pits and slope angles.

SITE EVALUATION

Engineering characteristics

Information from the test pits revealed that superficial soil cover is shallow and made up of admixtures of humus and plant rootless up to a total of 0.8m including the crust. This is underlain by lateritic zone of average thickness of 7.8m over the weathered rock (Fig.3).

Specific gravity values range from 2.50 to 2.73 and the largest grain size is 2.65mm. This is very small compared to the level of 63mm suggested by ÖNORM S 2074 (1990) and between 30mm-50mm recommended by Daniel (1993). The grading curves over the site are shown in figure 4. The curves showed that the soil samples can be compacted (Bagchi, 1994). The percentage content of fine soil (clay and silt) ranges from 20% to 67%. These values are much higher than the 15% proposed by several investigators (e.g. ÖNORM S 2074 (1990); Daniel, 1993; Benson *et al, 1994;* Rowe *et al, 1995).* The highest percentage of gravel from the studied sample is 7%.

Atterberg (consistency) limits tests show that the liquid limit (LL) ranges from 21.64 to 46.33%. The plasticity indices (PI) range from 13.47 to 25.95%. Other characteristics of the soil are presented in Table 3. From the Casagrande Plasticity Chart (Fig. 5), the soils are generally classified as inorganic clay of low plasticity (CL) indicating a kaolinitic - type clay soil (Withlow, 1998). These are found to be suitable for the construction of the capping and the base of a sanitary landfill. The maximum dry density (MDD) was also evaluated using both standard and modified Proctor compaction energies. The results obtained (Table 4) were found to be higher than 1.7t/m^3 and 1.6t/m^3 recommended by ONORM S 2074 (1990) and Kabir and Taha (2006). Hence, they are suitable for use as landfill barrier materials. Also falling head permeability test was carried out on the soil samples recovered from the test pits. The coefficient of permeability (k) values range from 3.47 x 10^{-9} to 6.03 x 10^{-10} m/s for standard compaction energy and 2.03 x10^{-9} to 9.34 x10^{-11} m/s for modified compaction energy. These results show that the soils have *k*-values less than 1 x 10^{-9} m/s recommended by several investigators (e.g. ONORM S 2074, 1990; Oeltschner, 1992; Daniel 1993; Rowe *et al,* 1995). The availability of such suitable materials locally could contribute significantly to reduction in facility construction cost by minimizing the cost of haulage and mining of borrow materials.

TABLE 3: SUMMARY OF INDEX PROPERTIES OF SOIL SAMPLES

			ATTERBERG LIMITS (%)			PLOT ON PLASTICITY CHART	GRAIN SIZE DISTRIBUTION (%)					
SAMPLE SYMBOL	SAMPLING DEPTH(m)	G_s	LL	PL	PI		GRAVEL	SAND	SILT	CLAY	TOTAL FINE	AC
IG 1	0.87	2.67	21.64	8.17	13.47	CL	6	74	09	11	20	1.22
IG 2	2.17	2.61	42.21	21.40	20.81	CL	1	63	13	23	36	0.90
IG 3	1.90	2.50	37.53	12.91	24.69	CL	1	32	30	37	67	0.66
IG 4	2.80	2.73	46.33	20.38	25.95	CL	3	36	20	41	61	0.63
IG 5	1.41	2.57	34.77	12.24	22.53	CL	1	54	32	13	45	1.73

KEY: LL= Liquid Limit
PL=Plastic Limit
CL= Inorganic clay of low plasticity
PI=Index of plasticity
Ac=Activity of Clay
Gs= Specific Gravity

TABLE 4: RESULTS OF COMPACTION AND COEFFICIENT OF PERMEABLITY TESTS (*k*)

			WATER CONTENT-DENSITY RELATIONSHIP					
			STANDARD PROCTOR		MODIFIED PROCTOR		COEFFICIENT OF PERMEABILITY (m/s)	
PIT NO	SAMPLE SYMBOL	SAMPLE DEPTH (m)	MDD (t/m^3)	OMC (%)	MDD (t/m^3)	OMC (%)	STANDARD PROCTOR	MODIFIED PROCTOR
1.	IG 1	0.87	1.97	12.3	2.07	10.8	3.37X 10^{-9}	9.24X 10^{-11}
2.	IG 2	2.17	1.82	14.4	1.89	11.2	3.15X 10^{-9}	2.03X10^{-9}
3.	IG 3	1.90	1.74	16.9	1.91	13.0	6.03X 10^{-9}	8.83X10^{-11}
4.	IG 4	2.82	1.72	16.0	1.78	12.7	1.97X 10^{-9}	1.29X10^{-10}
5.	IG 5	1.41	1.83	15.3	1.95	11.9	2.55X 10^{-9}	7.98X10^{-11}

KEY: MDD= Maximum Dry Density
OMC= Optimum Moisture Content

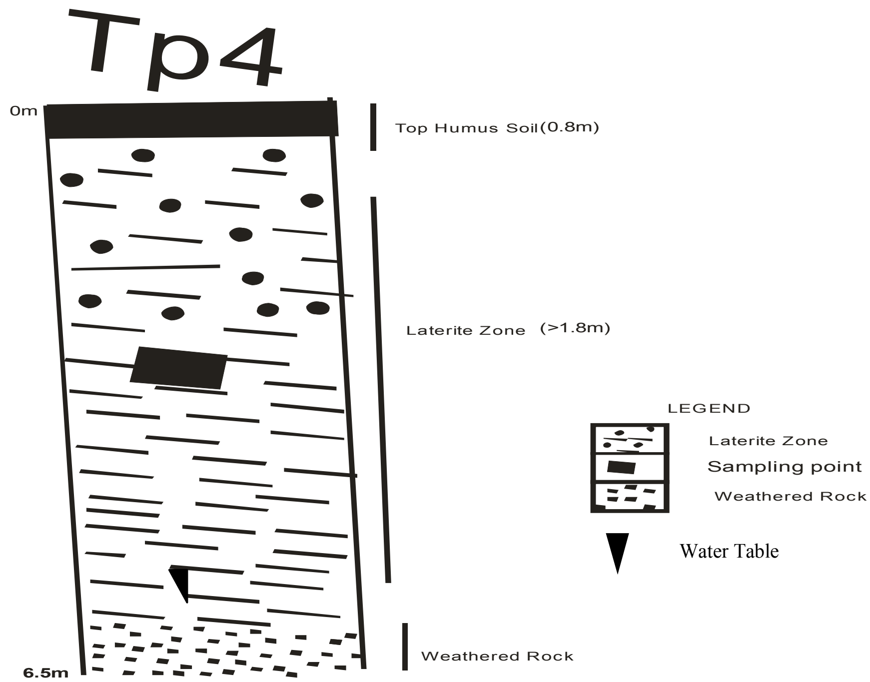

Fig.3 : Typical Soil Profile over the Investigated Area

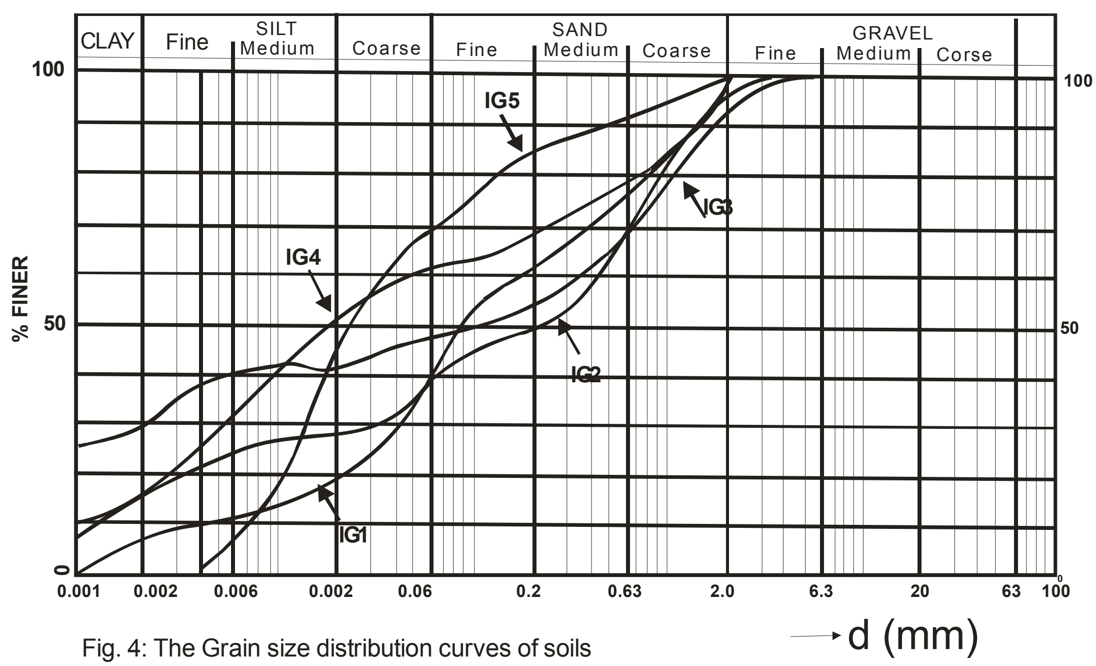

Fig. 4: The Grain size distribution curves of soils

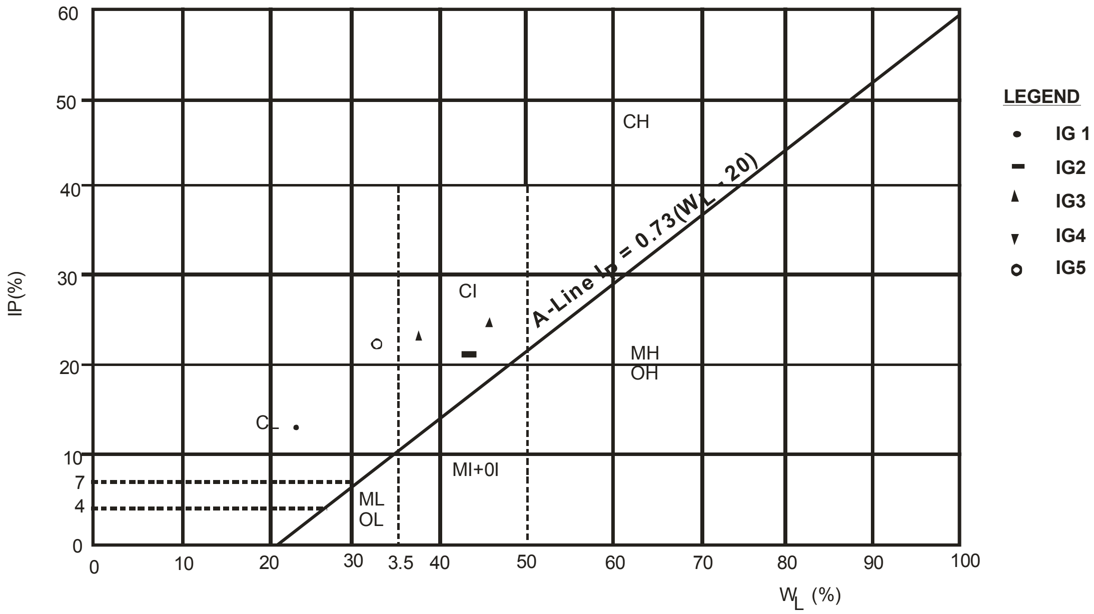

Fig.5 : Casagrande's Plasticity Chart of the Soil Samples

Hydrogeological characteristics and Environmental Impact Assessment

Hydrogeological data were compiled from field observations and records of test pits. Evidences from geophysical studies show that perched aquifers existed at depths varying from 5.2m to 6.5m. Fractures were intercepted at depths ranging from 40m to 45m, and the frequency of fracturing reduces with increase in depth of probing. The groundwater table, which was monitored over ten months spanning through the two climatic conditions, was intercepted only at one of the wells (Fig. 2) during the wet season at depth of 5.3m. This characteristic is well compared with the existing hydrologic requirement and therefore makes the site suitable for the development of sanitary landfill (WRSC Team, 1993; Zuquette *et al.,* 1994; Frempong, 1999; Nathanson, 2000; Dorn and Tantiwanit, 2001 and Dimitra *et al.,* 2006).

Meteorological records between 2000- 2006 indicate that the maximum rainfall is observed in October with maximum evaporation experienced in February (FAAN, 2006). The investigated site has moderate to fair slope ($2^0 \le$ slope angle $\le 10^0$). Therefore the potential for run-off which may cause water–logging is limited. There exists a (parallel) northwestern- southeastern flowing stream of 2.4m wide which provides drainage for the area around the site. Other environmental impacts of such waste containment facility were studied and compared with recommendations of several environmentalists (Table 1).

CONCLUSIONS

The investigated site has desirable characteristics on the basis of environmental impact assessment and economic consideration. This is because the environmental factors that were studied have values that compared favourably well with the recommendations of many previous investigators and/or landfill regulatory agencies. These include proximity to waste generation center, accessibility at all climatic conditions, proximity to major highway, the availability of soil material as liner and final cover materials, distance from settlement and water supply wells etc. The area is generally low lying and characterized by torrential rainfall and a relatively deep water table when compared with recommended values. The site has a northwestern - southeastern flowing river which provides drainage thereby protecting the investigated site from water-logging. The closeness of waste generators (cities and villages) will also reduce the cost of haulage. The underlying geology (biotite gneiss) is expected to be stable and strong enough to prevent settlement or future failure.

The overall engineering characteristics of the soil samples recovered from test pits, irrespective of the depth of recovery, show that the soils are inorganic clays with low to medium plasticity. Generally, these types of soils possess desirable characteristics to minimize hydraulic conductivity when compacted. The index properties (liquid limit, plastic limit, percentage fine, percentage gravel, activity etc) of the soil samples satisfy the basic requirements as barrier materials for landfills. This result compares favourably well with the recommendations of several researchers. However, low percentage of clay content below recommended values was observed in TP1 and TP5 for samples recovered at depths 0.87m and 1.41m respectively. This may be improved upon by increasing the depth of excavation to a more clayey layer or by borrowing little more clayey soil samples from close sources. Also higher energy of compaction is recommended because it gives lower values of coefficient of permeability for the compacted soils.

REFERENCES

Alao, D. A., 1983. Geology and Engineering Properties of laterites from Ilorin, Nigeria. Eng. Geol. 19, p111-118.

Amost, T., Jonathan, T. and Janet. T., 1972. Ecology, Pollution and Environment. WB Sanders Company, Philadephia. p138-143.

Allen, R. A. and Maccarthy, A.J., 1991 Geological aspects of waste disposal site selection. In:

ALISTAIR. R.A. et al, 1997: Approaches to landfill site selection in Ireland. Engineering Geology and the Environment, *Marinos Koukis and Stournaras (eds).* 1569-1574
.

Al-yaqout, A. and Townsend, F., 2001. Strategy for Landfill design in arid regions. *ASCE,*.1, 2-13.

Bagchi, A., 1994. Design, Construction, and Monitoring of landfills.2nd Edition, A Wiley-Interscience Publication. U. S. A, 361p.

Bell, F. G., 1999. Geological Hazards. Their assessment, avoidance and Mitigation. E and FN Spon, London and New York, 626p.

Benson, C. H., Zhai, H. and Wang, X.,1994. Estimating hydraulic conductivity of compacted clay liners. Journal of Geotechnical Engineering. 120, (2): 336-387.

Daniel, D. E., 1993. Clay Liners. In: Geotechnical Practice for Waste Disposal (Daniel D.E eds.). Chapman Hall, London, U.K, 137-163

Dorn, M. and Tantiwanit, W., 2001. New methods for search for waste Disposal sites in the Chiang Mai- Lamphun Basin, Northern Thailand. Environmental Geology. 40, 507-517.

Dimitra. R; Francesco. S. and Salvatore. M., 2006. Pollution risk assessment based on hydrogeological data and management of solid waste landfill. www. sciencedirect.com, 10p.

FAAN - Federal Airport Authority of Nigeria (2006). Report of the Federal Ministry of Aviation, Ilorin Office.

Fred, L. and Anne, J., 2005. Flawed technology of subtitle D. Landfill Municipal Solid Waste. Http. www.gfredlee.com.64p.

Frempong. E.M. 1999. Engineerig geological assessment of a proposed waste disposal site in the coastal southwestern Ghana. Environmental Geol. Springer-verlag. vol.37 (3). p55-260.

Herwig, P; Jan. V; Mike S. R; Mathais. D; Martins. C and Brian. M., 2005. Special purpose mapping for waste disposal sites. Bull. Environmental. Eng. 64, 1-54.

Ige, O.O., 2003. Impact of cultural and Industrial waste on surface and shallow groundwater along Asa River, Ilorin metropolis, Kwara state, Nigeria. University of Ilorin, unpublished M.Sc., thesis. 108p.

Ige, O. O. 2009. Assessment of geotechnical properties of migmatite-derived residual soil from Ilorin, southwestern Nigeria, as Barrier in sanitary landfill. Continental Journal of earth science. 4, 23-33.

Joyce, M. P. E., 2003. A study of the merit and effectiveness of alternate liner Systems at Illinois landfills. A research paper submitted in fulfillment of house resolution 715 State of Illinois 92nd General Assembly. 46p.

Kabir, M. H. and Taha, M. R., 2006. Sedimentary residual soils as a Hydraulic barrier in waste containment systems. 2nd International Conference on Advances in soft soil Engineering. Technology Putrajaya, Malaysia. 894-904.

Knitter, C.C., Haskell, K.G., Peterson, M. L., 1996. The use of low Plasticity silt for soil liners and covers http:www.golder.com archive. 14p.

Kurian. J., N. R. and Palanivelu. P., 2005. Open dumps to sustainable landfill. Centre for environmental studies, Anna University, Channai,India.www.serd.ait.ac.th/sidaSWM/project. 78p.

MARK, Y., 2002. Geology and Geotechnical Investigation of the proposed Canterbury regional landfill, Kate Valley, North Canterbury Transwaste Canterbury Ltd. 147p.

Mohamedzien, Y. A. M., Al-rawas. A. A., Al-aghbari. M.Y., Qatan. A. and Abdul-hamid. A., 2005. Assessment of Crushed Shales for use as compacted landfill liners. Journal of Engineering Geology, vol. 80, 271-281.

Montgomery, W. M., 2000. Environmental Geology, 5th Edition, McGraw Hill, 546p.

Murphy, R. and Garwell, E.J., 1998. Infiltration rate through landfill liners Florida centre for solid and hazardous waste management report. #97-11. http:www.floridacentre.org/publications, 106p.

Nathanson, J.A., 2000. Basic Environmental Technology. Water supply Waste Management and Pollution control. 3rd edition Prentice Hall Inc. 514p.

Oeltzschner, H., 1992. Anforderin an die Geologic, Hydrogeologie Und Geotechnik beim Bau von Deponie. In: Ogunsanwo O. (1996), Geotechnical Investigation of some soils from S.W. Nigeria for use as mineral scale in waste disposal landfills. Bulletin of IAEG, Paris, No 54, p119-123.

Ogunsanwo, O., 1996. Geotechnical investigation of some soils from Southwestern Nigeria for use as Mineral Seals in Waste Disposal landfills. Bulletin of IAEG. Paris , No 54, 119-123.

Ogunsanwo, O. and Mands. E., 1999. The role of geology in the evaluation of waste disposal sites. Journal of Mining and Geology 33, (1): 83-87.

Onipede, M. A. and Bolaji, B. O., 2004. Management and Disposal of Industrial waste in Nigeria. Nigeria Journal of Mechanical Engineers. 2, (1): 49-61.

ÖNORMS 2074, 1990. Geotechnik in Deponiebau-Erdarbeiten. Osterrichisches Normungsinstitut, Wein. In: Ogunsanwo O. (1996). Geotechnical Investigation of some soils from Southwestern Nigeria for use as mineral seal in waste disposal landfills. Bulletin of IAEG, Paris, 54, 119-123.

Oluyide. O.P., Nwajide. C.S. and Oni, A.O., 1998. The Geology of Ilorin area. Minisrty of solid Mineral and Development. GSN Bull., 42, ISSN 0367-5300, 84p.

Orlov, D. S and Yeroshicheva, N. L.., 1967. Interaction of humic acids with the cations of some metals. Soviet Soil Science. vol. 12, 1799-1806.

Rowe, R.K., R.M. Quigley, and Booker, J. R., 1995. Clayey barrier systems for waste disposal facilities, E & FN Spon, London, pp 404.

Seymour and Peacock, 1994. Quality Control of Clay Liners. In:Christensen T. H. *et al* (eds), Landfilling of waste: Barriers. E and F. N. Spon, London, 69-79.

United State Environmental Protection Agency (USEPA)., 1989. Hazardous Waste Management Systems: Permitting Requirement for land Disposal facilities. Federal registers July, 16.

United State Environmental Protection Agency (USEPA). 2005. Solid waste Disposal methods. http:www.usepa.org

Westinghouse Savannah River Company, U.S.A., 1993. Preliminary Site Selection Report for the new sanitary landfill at the Savannah River Site. Prepared for the U.S Department of Energy under contract No.:DE-AC09-89SR18035 for Savannah River Technology Centre, U.S.A; 117p.

Withlow, R., 1998. Basic Soil Mechanics. Third Edition. Longman Group Ltd. 557p.

World Bank, 2004. Guidelines for selection and construction of sanitary landfills. www.worldbank.edu.org. 39p.

Yilmaz., A. and Atmaca .E., 2006. Environmental geological assessment of a solid waste disposal site: a case study in Sivas, Turkey. J. Environmental. Geol. DOI 10. 1007/s0025-006-0241-1. Springer-Verlag. 271-281.

Zuquette, L.V., Pejon, O.J and Sineli. O., 1994. Methodology of specific engineering geological mapping for selection of sites for waste dispoal. In: Oliveira *et al* (eds). Proceedings of the 7th IAEG, Lisbon, 4, pp 2481-2489.