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SOIL ENGINEERING INTERPRETATION FOR ROAD ALLOCATION IN SOKOTO STATE NIGERIA

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ABSTRACT

The necessity for a rational soil interpretation system for the allocation of roads and other engineering purposes, and for the collation, storage and retrieval of relevant engineering information on regional basis has been recognized for sometime. A terrain evaluation scheme suitable for engineering purposes, for example road construction, should be the one that engineers can apply and interpret. No special skills should be required for its implementation. The scheme should be compatible with all facilities that geographic information system (GIS) should offer, so that information can be stored for future use. Soil engineering interpretation for roads in this research involves the use of soil and construction material properties determined both in laboratory and in the field and modified rating tables. A terrain evaluation of the Sokoto area was conducted using remote sensing and GIS tools. Estimated soil properties significant to engineering and analytical data were put in tabular forms and interpreted using rating tables. The engineering properties of the mapping units and analytical tables were the summarized properties of soils and road construction materials. The rating tables (suitable and limiting) were used each for interpreting corresponding five selected road allocation attributes (local roads and streets, sands and gravel, shallow excavations, road fills, and top soils). The results of the interpretations were the products of the five attribute maps, which were in turn used for the production of unweighted and weighted suitability maps for road allocation. The final map showed four simulated roads and one existing road. In conclusion, it is found that the system embracing terrain evaluation using remote sensing and GIS is flexible enough to handle information at all levels and thus can be used to collate, store, retrieve at will, transform/analyze and display data accumulated during road planning, allocation and construction projects. The study shows that with the terrain evaluation and scenarios using five selected attributes relevant to road construction, road network can be planned and allocated. It is also noted that terrain evaluation for engineering purposes, use a classification similar to that widely adopted in agricultural and land use surveys.

1. INTRODUCTION

1.1 Study Area Location.

The study area is located in the north central part of Sokoto State of northwestern Nigeria. It is in the semi-arid region of the world and can be found within latitude 13^0 00'N to 13^0 10'N and longitudes 5^0 00'E to 5^0 30'E of Greenwich Meridian (figure 1). It has a surface area of 97,000 hectares.

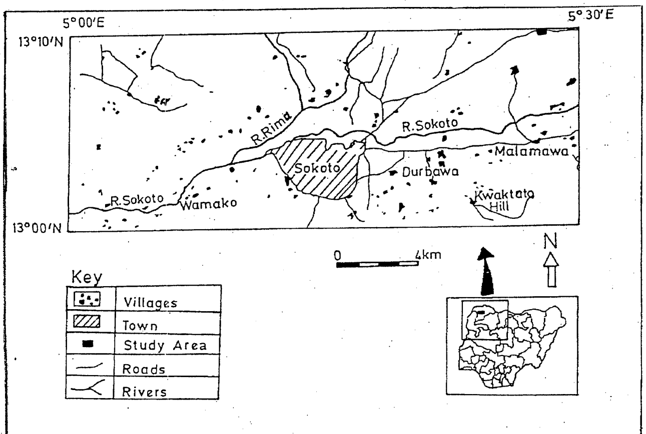


Figure 1: Location Map of the study area

1.2 General Characteristics of Study Area

The landscape is divided into three : Plateaux, Piedmont and Valleys. The soils of Sokoto area are characterized by a sandy surface layer and clayey subsoil layers. Because of the erosive nature of the climate (particularly rainfall), the soils are often liable to rill and gully erosion. The soils of the Fadamas (seasonally flooded river valleys) are generally more fertile and less prone to erosion, but flooding hazard is high on them. Generally, soils of the area can be described as coarse textured, though some medium textured soils can be found in the south-eastern part of the state. Most soils in the area are deep within the aeolian sand areas, while shallow soils can be found in the plateaux.

1.3 Planning and Allocation of Roads

The necessity for a rational soil interpretation system for the allocation of roads and other engineering purposes, and for collation, storage and retrieval of relevant engineering information on regional basis has been recognized for some time. In planning and allocation of roads, railways, pipelines and canals, it is necessary to identify specific problem areas and to locate source of natural construction materials over long distances. This could be done by production of soil engineering maps by use of remote sensing techniques. This could be done by production of soil or detailed information for road allocation /planning and also for location of construction materials. It is therefore, important to document the information on the distribution of soils in an area and their properties including groundwater conditions before any reasonable and economic allocation and design can be developed for road routes.

During a road route allocation stage, existing soil (figure 2) and geological maps of the area are often used for trying to avoid swampy sections and to utilize borrowed sources. The soil properties are obtained from the field measurements and laboratory tests before the final analysis for road allocation is made.

Since the soils and geotechnical data required in the road allocation work are usually very large in quantity, geographic information system (GIS) is used for data analysis, and these have been proved as effective for decision making in road projects. (Turner, 1988; Oshima et al., 1986; Berry, 1986).

Soil engineering interpretation for road allocation should be in a scheme that can be easily applied and interpreted by road engineers and planners. No special skill should be required for its implementation. The scheme should be compatible with all facilities that the GIS should afford, so that information may be stored for future uses.

Soil engineering interpretation for this study involves the use of soil and construction materials properties determined both in the laboratory and in the field (spatial and non-spatial database) and the modified rating tables (rule base) which were used for production of attribute suitability maps.

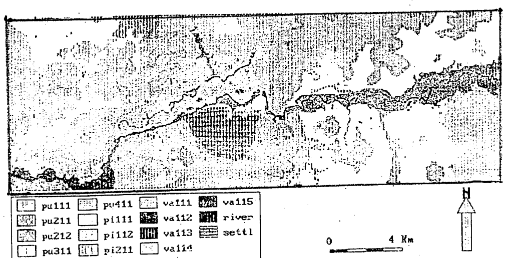


Figure 2. SOIL MAP OF THE STUDY AREA SOKOTO, NIGERIA

pu. 111 = Tread, pu. 211 = Escarpment, pu. 212 = Talus, Pu. 311 = slope-facet Complax, pu. 411 = Hill-val Complex, pi. 111 = upper slope, pi. 112 = lower slope, pi. 211 = slope-vale Complex, Va. 111 = Levee, Va 112 = overflow mantle, va 113 = Basin Complex, va 114 = Channel Complex, va 115 = Flat.

2. METHODOLOGY

2.1 General

The methodology used in this study is basically the application of remote sensing and GIS to terrain evaluation of Sokoto area. The choice of this method for soils and engineering properties of this area for road allocation is significant because of the sparse vegetation cover, typical of Nigerian savanna zone. This factor greatly increases reflectivity from soil and rock, thus, enhancing a quick study of the emmitance and reflectance characteristics of the soils and rocks.

2.2 Interpretation Criteria

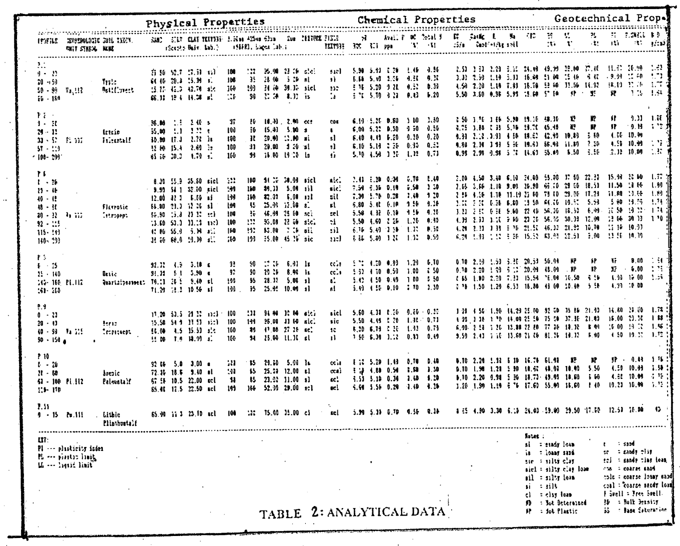
The soil properties significant to engineering (Table 1) and analytical data (Table 2) were interpreted using rating tables. Tables 1 and 2 are summarized properties of the soils and road construction materials. The rating tables were used each for interpreting corresponding five selected road construction attributes (USDA-SCS, 1971) for the study i.e. local roads and streets (LRS), road fills (RF), sands and gravel (SG), shallow excavation (SE) and topsoil (TS).

Map units / Land properties		Pu. 111	Pu. 211	Pu. 212	Pu.311	Pu. 411	Pl. 111	Pl. 112	Pl. 211	Va.111	Va. 112	Va. 113	Va.114	Va.115	Va. 211
Depth to bedrock (cm)		15	45	60	40	60	>150	>150	>150	>150	>150	>150	>150	>150	>150
Shrink-swell		Low-Mod.	Low	Low	Low	Low	Low	Low	Low-Mod	High	High	High	High	High	Moderate
Engineering soil class	Unified	SC-CL	SC	SM-SC	SM - SC	SC	SP or SM	SP-SM	SM-SC	CL	CL	ML-CL	ML	CL	SC
	AASHTO	A - 6	A-2-6	A-2-4	A-2-4	A-2-6	A-2-4	A-1	A-2-4	A-7	A-7	A-6	A-4	A-6	A-2-4
Texture	USDA	Gr.scl	Gr.scl	Gr.sl	Gr.sl	Gr.scl	Cos-sl	Cosls-sl	ls-sl	sicl-cl	sicl-sic	cl-sl	sil-sic	sicl-sic	sil-sl
Slope (%)		2.5 - 4	10 - 15	5 - 6	8	12 - 18	2 - 3	2 - 2.8	3 - 4	3 - 5	1 - 2	2 - 3	3 - 4	4 - 5	2 - 4
Layer thickness (cm)		40	45	60	40	60	200	250	275	200	180	160	180	200	150
Stoniness Fraction >7.5cm (%)		90	85 - 90	80 - 90	95	75	None	None	None	15	None	None	None	None	20-40
Depth to water table (cm)		>150	>150	>150	>150	>150	>150	>150	>150	>150	<150	<150	<150	<150	<140
Soil drainage		SW.Exc dr	Well dr	Well dr	SW.Exc.dr	SW.Exc.dr	Well dr	SW.Exc.dr	Well dr	MW.dr	Imp.dr	Imp.dr	Poorly dr	Imp.dr	Imp. dr
Flooding *		None	None	None	None	None	None	None	None	Frequent	Frequent	Frequent	Frequent	Frequent	Frequent
Salinity (mmhos/cm)		0.65	0.65	0.6-0.65	0.6-0.7	0.6-0.75	0.5-0.9	0.65-1.20	0.7-1.2	2.0-6.2	2.5-5.5	2.5-5.5	2.5-5.5	2.5-5.5	2.0-6.20
Consistency (moist)		Friable	Firm	V.fri.	friable	V.friable	Friable	Friable	Friable	Friable	Firm	V.firm	V.firm	Firm	V.firm
Soil reaction (pH)		5.9	5.8	5.70	5.90	5.70	5.7-6.4	5.4-5.7	5.4-5.7	5.5-7.5	5.9-6.7	5.9-6.7	5.9-6.7	5.9-6.5	5.6-6.5
Bulk density (50 - 150cm) depth		-	-	-	-	-	1.9-1.8	1.56-1.76	1.7	1.70-1.74	1.64-1.77	1.7	1.65	1.77	1.6-1.75

KEY:
SW Exc. w dr --- somewhat excessively well drained
Gr.scl --- gravelly sandy clay loam
cos.ls-sl --- coarse loamy sand to sandy loam
SC-CL --- clay sand to clay with low plasticity
SM-SC --- silty sand to clay sand
SP --- poorly graded sand
ML --- silt with low compressibility

AASHTO ----- American Association of State Highways and Transport Officials
UNIFIED ----- Unified Soil Classification System
USDA ----- United State Department of Agriculture

TABLE 1 : ENGINEERING PROPERTIES OF GEOPEDOLOGIC UNITS


Physical Properties | Chemical Properties | Geotechnical Properties

PROFILE | GEOPEDOLOGIC UNIT SYMBOL | SOIL TAXON. NAME | SAND | SILT | CLAY | TEXTURE (Soil Lab.)

KEY:
PI --- plasticity index
PL --- plastic limit
LL --- liquid limit

TABLE 2: ANALYTICAL DATA

Interpretation data in terms of suitability or limitation for specific engineering soil uses were obtained using rating tables for each of the five attributes already selected. The criteria adopted in the interpretation of the engineering properties for road allocation include the following:

- The limitation classes of severe, moderate and slight used conventionally in some rating tables were converted into suitability classes of poor, moderate and good in conformity with the suitability classification of FAO (1977). This was done to make the suitability evaluation uniform and easy for computer coding.
- There were three suitability classes for the interpretation, and these are: 1 = good, 2 = moderate and 3 = poor.
- The soil limitation classes are indicated by: 1 = slight, 2 = moderate and 3 = severe. Slight means soil properties generally favourable for the rated use or, limitations that are minor and that can easily be overcome; moderate means soil properties that are unfavourable, but can be overcome or modified by specific planning and design; severe means soil properties that are so

unfavourable and so difficult to correct, overcome, almost impossible to remove or very costly to remove as to require major soil reclamation and specific design.
In order to combine both suitability and limitation for the interpretation of the five selected attributes, 1 = good = slight, 2 = moderate for the two classes and 3 = poor = severe.

2.3 Interpretation of the Attributes' Engineering Properties

The attributes (LRS, RF, SG, SE & TS) engineering properties were interpreted manually using tables 1 and 2 to come up with the final current land evaluations for each of the mapping units of the five attributes selected for the road allocation. An example of these current land evaluations is as in table 3.

The outcome of the interpretation of the engineering properties of the attributes are the production of five suitability tables. An example of suitability rating tables is given in table 4. The suitability tables were put into the database, and by using the ILWIS - GIS mapping facilities, five suitability maps, one per attribute considered as relevant for road allocation were produced.

Map units / Land properties		Pu. 111 Lim R.f	Pu. 211 Lim R.f	Pu. 212 Lim R.f	Pu.311 Lim R.f	Pu. 411 Lim R.f	Pi. 111 Lim R.f	Pi. 112 Lim R.f	Pi. 211 Lim R.f	Va.111 Lim R.f	Va. 112 Lim R.f	Va. 113 Lim R.f	Va.1 Lim R.f	Va.115 Lim R.f	Va. 211 Lim R.f
Depth to bedrock (cm)		P Rk	P Rk	M Rk	P Rk	M Rk	G -	G -	G -	G -	G -	G -	G -	G -	G -
Shrink-swell		G -	G -	G -	G -	G -	G -	G -	G -	P SS	P SS	P SS	P SS	P SS	M SS
Engineering soil class	Unified	M LS	G -	G -	G -	G -	G -	G -	G -	M LS	M LS	P LS	P LS	M LS	G -
	AASHTO	M LS	G -	G -	G -	G -	G -	G -	G -	M LS	M LS	M LS	M LS	M LS	G -
Slope (%)		G -	M Sl	G -	M Sl	P Sl	G	G -	G -	G -	G -	G -	G -	G -	G -
Layer thickness (cm)		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stoniness Fraction >7.5cm (%)		P St	P St	P St	P St	P St	G -	G -	G -	G -	G -	G -	G -	G -	M St
Depth to water table (cm)		G -	G -	G -	G -	G -	G -	G -	G -	G -	M Wt	M Wt	M Wt	M Wt	M Wt
Soil drainage		G -	G -	G -	G -	G -	G -	G -	G -	G -	M Sd	M Sd	P Sd	M Sd	M Sd
Flooding		G -	G -	G -	G -	G -	G -	G -	G -	P Fl	P Fl	P Fl	P Fl	P Fl	P Fl
Salinity (mmhos/cm)		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Consistency (moist)		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Soil reaction (pH)		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Final Current L.E. class		P Rk & St	P Rk & St	P St	P Rk & St	P Sl & St	G -	G -	G -	P SS & Fl	P SS Fl	P SS,LS & Fl	P SS,LS Fl	P SS & Fl	P Fl

TABLE 3. INTERPRETATION OF ENGINEERING PROPERTIES FOR LOCAL ROADS AND STREETS

KEYS for Land Evaluation classes
G --- Good
M --- Moderate
P --- Poor
L.E class --- Land Evaluation class
LS --- Low strength
SS --- Shrink-Swell
Sl --- slope
Rk --- rock
Fl --- flooding

St --- stoniness
Wt --- wetness
Sd --- soil drainage
Lim --- degree of limitation
R.f --- restrictive features

Notes :
AASHTO---American Association of State Highways and Transport Officia.
Unified--Unified Soil Classification System
USDA ----United State Department of Agriculture

Feature PROPERTY		Degree of Soil Suitability Good (g)	Fair (f)	Poor (p)	Restrictive (Res. Feat.)
Depth to Bedrock		>150	100-150	<100	Depth to rock
Shrink Swell		Low	Moderate	High (V.High)	Shrink Swell
Engineering Soil Class	UNIFIED	GW,GP SW, SP, GC, SM,SC	SL,CL With PI< 0.15	CL with PI>15% CH, MH, OL OH, Pt	Low Strength
	AASHTO	0 - 4	8-May < 8		
Slope (%)		<15	15 - 25	>25	Slope
Layer Thickness (cm)		>150	75 - 150	<75	Thin layer
Stontness (wt. %)		<6.25	62.5 - 125	<125	Layer stones
Depth to Water table (cm)		>90	30 - 90	<30	Wetness
Soil drainage		Exc - to M.W.dr	somewhat poorly drained	poorly drained and very poorly drained	Poor drainage

TABLE 4. SOIL SUITABILITY RATING FOR ROAD FILLS

2.4 Suitability Classification and Mapping

The system (ILWIS - GIS) used the final current land evaluation (LE) column in the suitability tables to match each corresponding mapping unit in the soil map (figure 2) to produce good, moderate and poor suitability units. These attribute suitability maps were used as inputs in the land suitability analysis for road allocation by overlaying the five suitability maps using ILWIS - GIS facilities for the final road allocation map.

3. RESULTS AND DISCUSSIONS

The results of the land evaluation, interpretation of the attributes' engineering properties and ILWIS - GIS processes were the production of five interpreted attribute tables leading to the final current land evaluations (LE), the five suitability maps and the final road allocation maps.

3.1 Local Road and Street

The local road and street suitability map showed only good and poor units. Within the three landscapes of the study area (Plateau, Piedmont and Valley), the LRS map indicated that all piedmont landscape units are good for road allocation, while the plateaux and valley are poorly suited.

3.2 Road Fills

The road fills attribute map showed the same trend as the local roads and streets map, rating all units in the piedmont as good and those of the valleys and plateaux as poor. This rating was according to the interpretation table for the road fills.

3.3 Sands and Gravel

The attribute map of sands and gravel showed three classes of units rated as good in the upper slope of piedmont, moderate in the lower slope and poor for the slope-vales complex of the valleys and plateaux. This means that sands and gravel sourcing is better done in the upper slope of the piedmont than at any other part of the study area.

3.4 Shallow Excavations

Shallow excavation attribute map indicated only moderate suitability at the upper and lower slopes of the piedmont and poor at the slope vale complex of the piedmont, valleys and the plateaux.

3.5 Topsoil

Topsoil attribute map showed all the classes of good, moderate and poor units in the study area. These are as follows : good in the upper slope, moderate in the lower slope and poor in slope- vale complex, valleys and plateaux.

3.6 Final Road Allocation Map

This map displays one existing and four simulated roads. The map used the options of joining important towns and industrial/farming centers to other places. The resulting road network map (figure 3) shows that road allocations in the study area and in similar terrain and climatic conditions would be better done within the piedmont locations. This is because of the seemingly low construction costs in terms of less obstacles, availability of construction materials and less interference to agricultural lands. This result was also confirmed by Zinck (1990).

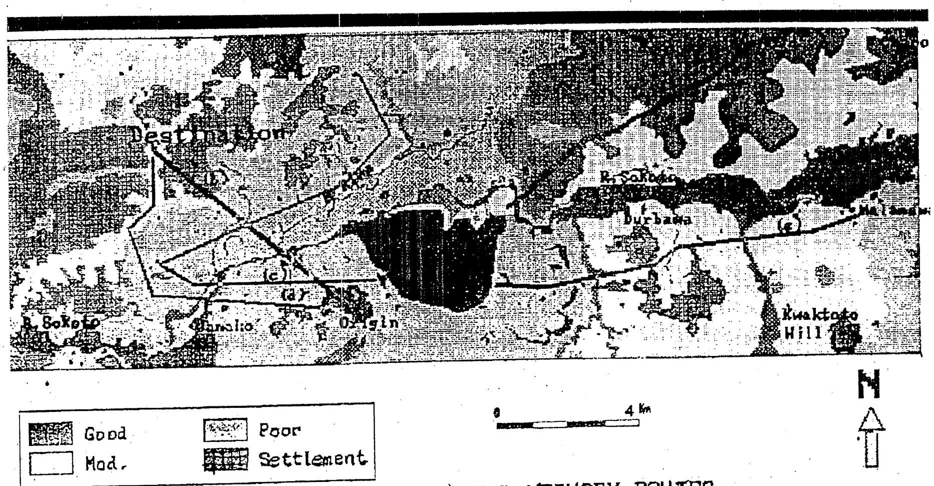


Figure 3. SELECTED NETWORK ROUTES
a = existing road, and b,c,d,e = simulated roads

The map shows that all the four new roads (simulated) have mostly good allocation units except for the one labelled "b" which is a short-distance road which did not take into account the avoidance of obstacles and others. The existing road "a" is the worst allocated road because it has poorly suited units in almost all the stretch of the road. Hence, the existing road requires upgrading by removing the obstacles to improve the road condition.

4. CONCLUSION

It is found in this study that the system embracing terrain evaluation using remote sensing and GIS is flexible enough to handle information at all levels. Thus it can be used to collate, store, retrieve at will, transform/analyse and display data accumulated during road planning, allocation and construction projects.

The study shows that with terrain evaluation and scenarios using the five selected attributes relevant to road construction, road network can be planned and allocated.

The study also shows that road allocation is better done in the piedmont than in any other landscape of the study area as shown in figure 3. This also applies to any other place with similar terrain and climatic conditions. This is true because of the suitable terrain properties of the area, and also the seemingly low construction costs in terms of less obstacles, availability of construction materials and less interference to agriculturals lands.

It is found that since terrain evaluation is based on the classification of soils and landform, it is particularly suited for use with remote sensing techniques especially that of aerial photographs.

The engineering soil properties interpretation uses a classification similar to that widely used in agricultural and land use surveys. This leads to the possibility of land development. This can help directly in getting information in the quantity of earth works associated with road construction to different geometric standards.

The engineering soil properties lead to the production of soil engineering maps showing swampy area erosion - prone sites,, shifting sands and indicating where unstable ground exists. Construction costs of roads therefore can be greatly reduced if the results obtained from this study are used.

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