



RESEARCH ARTICLE

**APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN INDUSTRIAL LAND
CAPABILITY INDEX MAPPING OF A DEVELOPING COUNTRY. A CASE STUDY OF ENUGU
AREA, SOUTH-EASTERN NIGERIA**

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ABSTRACT

It was projected that the population of Enugu area will grow at approximately 300% by the year 2020. The information is further strengthened by the projected 3,237,298 population figure of the area. This implies that there is the expectation of overpopulation of the area in future. Unemployment and lowering of people's standard of living are always associated with over population. It therefore, becomes necessary to map out areas on a sustainable basis and most suitable for the sighting of industries to employ the teeming population. Land capability index mapping using Geographic Information System (GIS) principles was used for this study. The study was undertaken using Arc View 3.2a academic, Excel statistical soft-ware and auto card software of GIS. A total of 12 land use determinants were selected as thematic data layers and basic factors influencing the choice of industrial land use. Soil characteristics and geology were integrated into the thematic maps to facilitate the weighting of the basic determinants. The thematic layers were weighted on a scale of 0%-100% and 0-2 inclusive, using the criteria obtained from field work and laboratory investigation. The thematic layers were subjected to overlay using arc view soft ware overlay model builder. The operation yielded a layer of preferred industrial land use options in a map form. 3 areas of varying suitabilities (Area 7,8 and 9) resulted from this operation. Area 7 occupies 10% of the study area suitable for industrial land use options; area 8 occupies 70% and has low suitability for industrial land use while area 9 occupies 20% of the land unit unsuitable for industrial land use.

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INTRODUCTION

Population explosion in developing world has generated acute unemployment and low standard of living. There is the need to establish industries to employ the teeming population. It is necessary to make effective use of the available lands especially in developing countries where land tenure and population impose land scarcity. Enugu, the area under study is within the heart of Ibo community of southeastern Nigeria, where land is scarce due to over population and land tenure system (Dutra and Hober, 1998). Unemployment in Enugu area of Nigeria was projected to increase at about 300% by the year 2020. This is further strengthened by the projected 3237298 population figure of Enugu state of Nigeria. Going by this bad state of a affairs, there is an urgent need to locate areas on most sustainable basis for the establishment of industries to employ the teeming population.

Geographic Information System (GIS) is one of the best approaches for this type of project, since its application has been widely acclaimed to facilitate efficient decision making and planning (Holland and Smith, 2003). GIS consists of a set of computerized tools and procedures that can be used to effectively store, retrieve overlay correlate, manipulate, analyse , display and disseminate land related information (Kang 2002). Pearce and Turner (1990), observed that unplanned land development has resulted in severe environmental damage and declining quality of life for many people. Dimitri and Crynine (2003), observed that the development of any land area for industrial set up requires detailed geological and engineering studies as to ascertain the capability of the land for the purpose. Landuse planning is accomplished through the use of a variety of factors. These factors can be divided into four categories as physical (Geological and topography), economic, social and political factors (Chapin 1965). According to Arthur and Irwin, (1982),

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industrial buildings should be located in an area that will minimize the negative impacts on the natural environment. Other factors to be considered include slope, flood plain, surface and ground water resource, and soil factor and geostuctural instabilities

MATERIALS AND METHODS

Description of Study area

The study area is located between latitudes $6^{\circ} 16' N$ and $6^{\circ} 31' N$ and longitude $7^{\circ} 20' E$ and $7^{\circ} 41' E$ covering an area extent of about 630km^3 Fig 1. It is also located within the rainforest-belt of Nigeria and has annual rainfall of about 1100mm a year, (Iloje 1981). The most striking feature within the study area is Enugu –Awgu escarpment. The escarpment was formed by the resistant sandstones of Mamu Formation. Drainage system is controlled by the escarpment, which forms the most important water shed separating the cross river drainage system to the east from a network of streams flowing west towards Anambra drainage basin (Ofomata, 1985). Egboka, (1993) described the drainage basin as dentritic. Geologically, the study area lies in Anambra basin of South-eastern Nigeria. The basin is of cretaceous to tertiary age (Reyment, 1965, Murat, 1972). Five formations underlie the area namely Ezeaku Formation (Turonian), Awgu Ndiabo shale (Santonian) Nkporo Formation (Campanian – Maastrichtian) Mamu Formation (middle Maastrichtian) and Ajali sandstone (late Maastrichtian). The stratigraphic succession and geology of the area is shown in Table 1 and Fig 2.

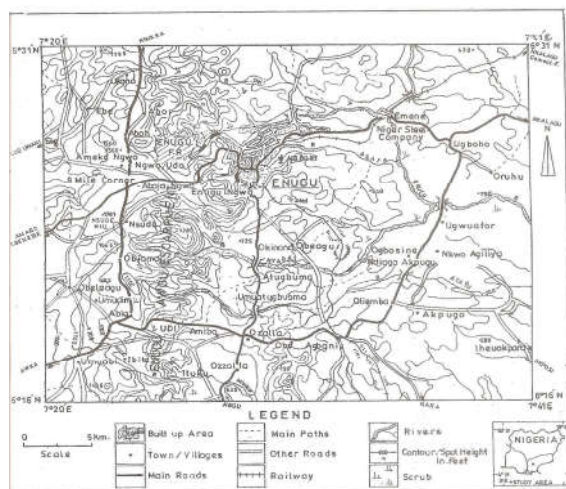


Fig 1: Topographical map of Enugu and Environs

The hydrogeology of the area indicates that the major water bearing unit is Ajali sandstone that underlies areas to the west with deep static water table of about 30m to 40m (Nwankwor *et al.*, 1988). Egboka, (1993) observed the occurrence of aquifer within Mamu Formation, while aquitards occur within Nkporo Formation / Enugu shale. These aquitards are fractured and are tapped by hand dug wells that show high coliform counts (Ezeanyim, 1988). The main soil types in the area are ferrallithic, forrallithic, hydromorphic and lithosoils Fig 3.

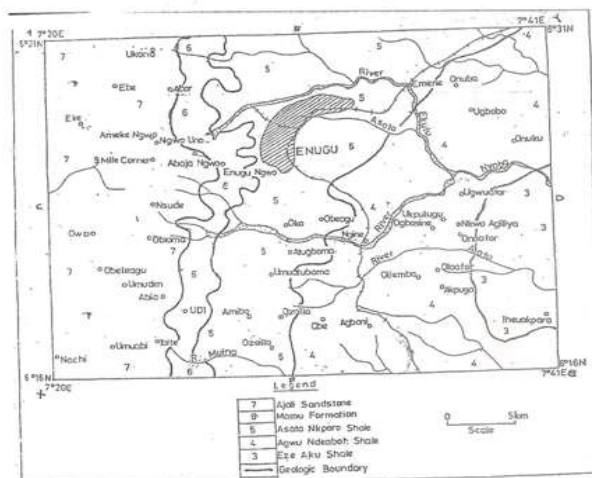


Fig 2: Geologic Map of the Study Area

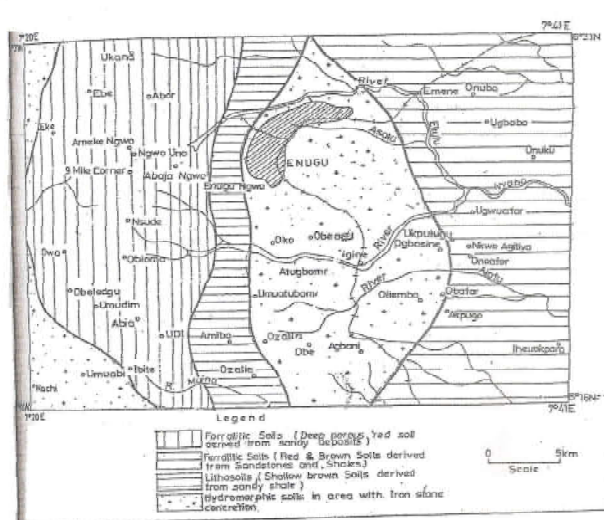


Fig 3: Soil Map of the Study Area

These soils were derived from Enugu shale and Ajali sandstone (Ogbukagu, 1976). The soils derived from Enugu shale are expansive and have hydraulic conductivity values of about 10^{-5} m/s (Egboka and Onyebueke, 1999) making them poor construction materials.

Sampling Techniques and Analytical Methods

Soil samples were collected at Owa, Ngwo, Ugwuafor, Agbani and Enugu Township from pits dug at a depth of 5 metres using auger. They were placed in polythene bags, and transported to laboratory for analysis. Method of random sampling was adopted in which 6 (six) soil samples covering the entire soil types of the area were collected. The collected soil samples were subjected to the following analysis using specified methods and equipments: Atterberg limit tests (using Cassagrande apparatus and Hammer methods) particle size distribution (using British electric shaker machine), porosity and permeability (using falling head method and permeameter), Consolidation test was performed using consolidometer. Shear strength was carried out using triaxial shear box and finally compressive strength.

Analysis was done using ASTM D, 4318-98 (2000) and ASTM, 1988 Standard specifications. All analytical procedures are shown in (Robert, 2001) Twelve (12) thematic maps of the landuse determinants within Enugu area obtained from different sources were employed as landuse determinants. These include, slope map, elevation map, soil depth map, soil class map, geologic map, drainage map, surface water map, depth to water table map, soil erosion map, flooded/ landslide map, fault map and escarpment map. These maps are the thematic data layers for GIS operation. The equipments used for GIS analysis include integrated land and water information system (ilwis) arc view 3.2a academic, geographic positioning system (GPS eterex 76), excel statistical soft ware, autocard soft ware and geocal. The thematic maps were converted to GIS compatible format by scanning, digitization, georeferencing, projection, polygonization and conversion to common scale of 1:10,000. The thematic layers were saved in different layers in readiness for GIS analysis.

permeability and porosity of hydromorphic soil measured 1.97×10^{-2} cm/sec and 0.31 that of ferrallithic soil measured 1.89×10^{-2} cm/sec and .30. The ferrallithic and hydromorphic soils have 1.92×10^{-2} , .31 and 1.97×10^{-2} , .31. The laboratory investigations of Atterberg limits employing ASTM D, 4318-98 (2000) standard methods show that ferrallithic soil has liquid limit 26.06% plastic limit 19.75%, plasticity index 0.31%, Hydromorphic soil has liquid limit 43.35% plastic limit 16.89%, plasticity index 26.46%, ferrallithic soil has liquid limit 39.84%, plastic limit 14.70% and plasticity index 25.14, while lithosol has liquid limit 28.06%, plastic limit 20.45% and plasticity index of 7.61. The result clearly shows that the liquid limit and plasticity indices for hydromorphic and ferrallithic soils are high indicating an inherent swelling capacity of the soils (Seed *et al.*, 1962, Ola, 1981). Expansive clays are known to be problematic in building industry (Anon, 1981). The consolidation result for time deformation reading shows that for hydromorphic soil, the void ratio (e) was

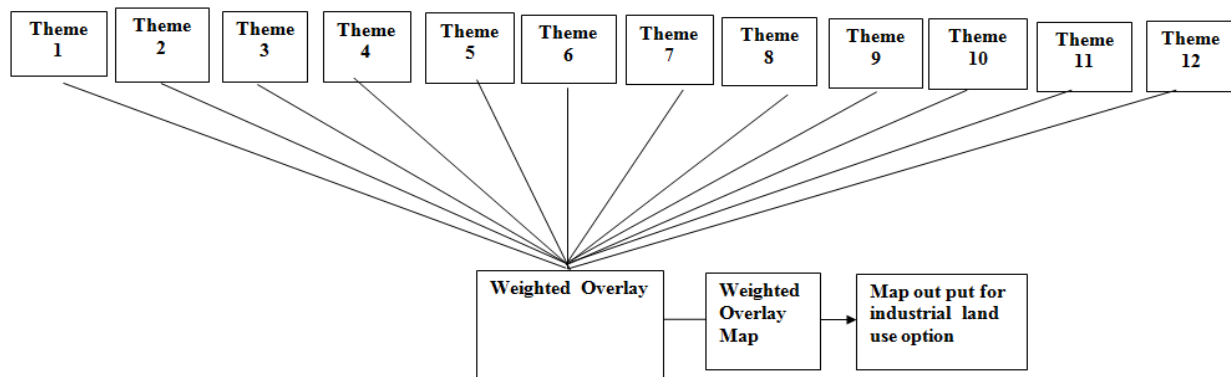


Fig 4: Overlay Model for Industrial Land Use

RESULTS AND DISCUSSION

The results of laboratory field and literature studies are shown in Table 2. The table is a reference guide in taking a decision in the rating of the basic determinants of landuse factors. From the table, while the ferrallithic soil is poorly graded, the hydromorphic and ferrallithic soils are well graded. Ferrallithic and lithosol tilt towards sandy clay while that of ferrallithic and hydromorphic soils tilt towards silty clay. Soils that tilt towards sand have high shear and compressive strength while those tilting towards silt have high attenuative power in handling waste effluents (Gauley and Krone, 1966, Krynine and Judd, 1957). The result shows that while the clay fraction of hydromorphic soil is 13%, that of ferrallithic soil is 13.5%. From these, and employing the relation Activity of clay (A) = PL/pI (1)

$$\text{Liquidity of Clay } L1 = \frac{w - pL}{pI} \dots\dots\dots(2)$$

P1

where p1 is Plasticity Index w, natural moisture content and PL is plastic limit. The activity indices of ferrallithic and hydromorphic soils were calculated to be 1.86 and 2.04, while their liquidity indices were calculated as - 0.23 and -0.40. the result of this calculation indicates that the two soils hydromorphic and ferrallithic soils are expansive and weak therefore unsuitable for industrial buildings (Robert *et al.* 2001). Permeability and porosity result show that while

Table 1. Generalized Sedimentary Sequence in southeastern Nigeria (after, Reymont, 1965)

AGE	FORMATION	LITHOLOGY
Maastrichtian 65-68 ma	Ajali Formation	Friable Sandstone with cross bedding.
Middle Maastrichtian 68-78ma	Mamu Formation	Alternating Sequence of sandstone clay stone and shale with coal seams.
Campanian 78-82 ma	Nkporo / Enugu Shale	Dark grey shale with clayey shale with clay lenses.
Santonian 78-82 ma	Awgu Formation	Bluish grey shale with clay lenses
Turonian 82-92 ma	Ezeaku Formation	Black shale with clay and limestone lenses.

calculated as 0.92, while the coefficient of volume settlement/consolidation (cv) gave 1.12. For ferrallithic and ferrallithic soils, the void ratio (ℓ) and coefficient of volume settlement/consolidation (Cv) are 0.934, 1.3 and 0.94, 0.63. From these results the settlement readjustment of ferrallithic soil is smaller indicating soil best suited for industrial buildings (Ola, 1981). The shear strength of the soils were calculated using the relation according to Chapin 1965.

$$\tau = C + \delta n \tan \theta \dots\dots\dots(3)$$

Where τ is Shear Strength, C = Cohesion, δn = effective stress on soil and θ = Frictional angle based on total stress

Table 2: Summary of Laboratory, Field and Literature

Soil Rock Type	Liquid Limit %	Plastic Limit %	Plasticity Index %	Dry Density Kg/m ³	Consolidation Values	OMC%	Compressive Strength N/M ²	Shear Strength N/M ²	Cohensions N/M ²	Permeability Porosity	Angle of Internal Friction Ø
Forralithic Soil Poorly Graded Silty Sand	26.06	19.75	6.31	1.90	e 0.94 cv 0.63	14.0	9.10	96.09	13	1.92 x 10 ⁻⁴ Cm/s & 0.31	38
Ferrallithic Soil Well graded Silty Clay Clay fraction = 13.5%	39.84	14.7	25.14	1.51	e 0.934, cv 1.12	11.02	2.10	87.82	30	Ferrallithic 1.89 x 10 ⁻² Cm/s & 0.30	30
Hydromorphic Soil Well graded Clayey silt Clay fraction = 13%	43.35	16.89	26.46	1.52		13.01	2.176	85.56	31	1.97 x 10 ⁻² cm/s & 0.31	30
Ajali sandstone + Mamu FM+ Fractured expansive, low shear strength Enugu Shale + Expansive and weak. Ezeaku FM+ Solution cavities Lithosoil:			3.16-37.9	1.77-2.55		8.6		276.67	24		25
	56.60	21.00	35.60			24.5					
	50.8	39.47	11.33	1.53	e 0.892 cv 1.23					1.70 x 10 ⁻² Cm & 0.30	

Table 3: Organization of thematic data layers for industrial landuse

INPUT THEME	PERCENTAGE INFLUENCE	INPUT FIELD	INPUT LABEL	SCALE VALUE	REMARKS
SLOPE THEME 1 (LAYER 1)	10%	1 2 3 4	0-9 9-19 > 19	2 1 0	Construction cost, slope is important for the stability of buildings.
ELEVATION THEME 2 (LAYER 2)	6%	1 2 3	280 -432 432-585 > 585	-	Not very important but used in the development of DEM
SOIL DEPTH THEME 3 (LAYER 3)	10%	1 2 3	Deep Deep Shallow	2 2 1	For deep foundation. and foundation stability
GEOLOGY THEME 4 (LAYER 4)	20%	1 2 3 4 5	Ajalli fm Mamu Asata/ Enugu Shale Awgu-Ndi Abo Shale Ezeaku	2 1 1 1 1	Geology is important in foundation siting. A sloppy lithology made of the alternation of shale / clay and sandstone are detrimental to foundation. Mamu FM Enugu shale Awgu Ndi Abo have these characteristics.
DRAINAGE THEME 5 (LAYER 5)	10%	1 2 3	Moderate Moderate Well Drained	1 1 2	Wet lands could lead to instability of foundations.
SOIL CLASS THEME 6 (LAYER 6)	6%	1 2 3 4 5	Sandy gravel (Forralithic) Clayey sand (Hydromorphic) Silty Sand (Lithosoil) Sandy Clay (Ferrallithic)	2 1 0 1	Soil strength depends on class. (Engineering classification).
SURFACE WATER THEME 7 (LAYER 7)	4%	1 2	High Low	2 1	Important source of water supply.
DEPTH TO WATER TABLE THEME 8 (LAYER 8)	10%	1 2 3	Very Shallow Shallow Deep	1 1 2	Could predispose ground water to contamination when shallow and expensive to exploit when deep.
EROSION THEME 9 (LAYER 9)	10%	1 2	BUFFERED ACTIVE NON ACTIVE	0 0	Creates hazards of housing and economic activity containing erosion is expensive.
ESCARPMENT THEME 10 (LAYER 10)	5%	1	Scarp Crest Dip	0 1 2	Slope problems.
FLOODED / LAND SLIDE THEME 11 (LAYER 11)	5%	1 2	BUFFERED ACTIVE NON ACTIVE	0 0	Could result in environmental devastation and hazard GIS Buffer ≥ 1000m (1km).
FAULT THEME 12 (LAYER 12)	4%	1 2	BUFFERED ACTIVE NON ACTIVE	0 0	Promote instability and failures of buildings. Buffer ≥ 1000m (1km).
TOTAL	100%				

analysis. Employing equation 3 and parameters C and $\tan \theta$ from graph of shear versus normal stress, the shear strength for hydromorphic, forrallithic, ferrallithic and lithosoils are 85.56 kN/m^2 , 96.09 kN/m^2 , 87.82 kN/m^2 and 88.36 kN/m^2 respectively. The shear strength of hydromorphic and ferrallithic soils are lower than forrallithic and lithosoils, also the angle of internal friction is high for forrallithic soils indicating a high shear strength (Aria 2003). Hydromorphic and ferrallithic soils show high cohesion there is likelihood of shear failure when subjected to load like industrial buildings since saturated clays fail if subjected to vibration (Baja, 1988). The result of compressive strength shows that

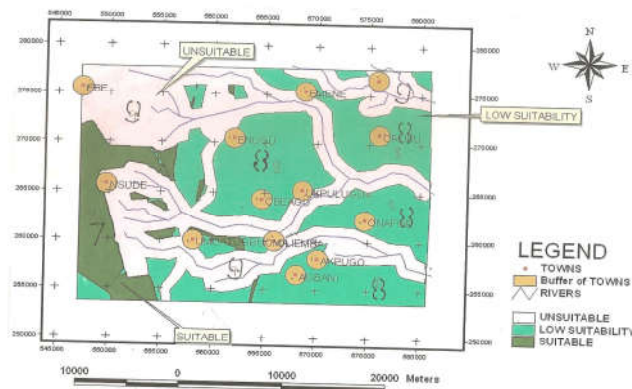


Fig 5: Weighted Overlay map for Industrial Landuse

forrallithic soil has compressive strength of 9.10 kN/m^2 with test load of 14.43 kN/m^2 , ferrallithic soil 2.10 kN/m^2 test load 20.16 kN/m^2 . Hydromorphic soil 2.176 kN test load 56.0 kN/m^2 , while lithosoil has 3.24 kN/m^2 with test load of 21.34 kN/m^2 . Earlier, Terzaghi and Peck (1967) observed that any rock or soil mass with compressive strength between 2 kN/m^2 and 7 kN/m^2 is weak, while those above these values are strong. Based on this, forrallithic soil is stronger. The moisture-density curve indicates optimum moisture content of 11.02% and maximum dry density of 1.51 kg/m^3 for ferrallithic soil, that of hydromorphic soil has 13.01 and 1.52 kg/m^3 while forrallithic soil has 14.0 and 1.90 kg/m^3 . Forrallithic soil satisfied conditions for accommodating heavy industrial buildings (Terzaghi and Peck, 1967). The lower dry density and higher moisture content of the hydromorphic and ferrallithic soils indicated higher affinity for water which makes them expansive and weak (Aria, 2003). The result of soils engineering classification, employing grain size and Atterberg limit result using unified soil classification system (USCS) shows that forrallithic soil is classified as MI-cl (silt / sand, poorly graded) hydromorphic soil Sp-cl (silty clay and poorly graded), ferrallithic soil is Sw-cl (silty clay and well graded) while lithosoil is silty and poorly graded. The above results are relevant guides in rating of landuse determinants.

12 thematic maps of the landuse determinants obtained from different sources were employed for GIS operation. These include slope map, elevation map, soil depth map, soil class map, geology map, drainage map, surface water map, depth to water table map, erosion map, flooded / land slide map, fault map and escarpment map. These maps are the thematic data layers for GIS operation. The thematic layers were organized as input data necessary for overlay operation. Table 3. The

percentage influence which adds up to 100% signifies the degree of importance of the theme to the land determinant factor. The table is a computer statement where scale values were selected based on the results of laboratory and field studies, of fig 2 are the capability ratings assigned to each environmental factor based on a scale of 0-2 inclusive making up three classes of suitable (2), low suitability (1) and unsuitability (0). The result of overlay operation fig 4 yielded a layer of industrial landuse map fig 5. The map shows various areas of suitabilities designated areas 7, 8 and 9 respectively. Area 7 occupies 10% of the study area suitable for industrial landuse, area 8 occupies 70% and has low suitability for industrial landuse, while area 9 occupies 20% of the entire area unsuitable for industrial landuse.

Evaluation and Conclusion

The study shows that high proportion of Enugu land unit has low suitability for industrial land uses. The few areas that are suitable are located within the western segments and to a small extent the east. Some of the available lands are unsuitable due to fault, erosion, landslide flooding and to some extent the scarp face of the escarpment. Areas to the west, south west and south east are highly favoured for industrial landuse options. Comparison of the results of the study against the existing landuse clearly exposed to limitations of the landuse of the area. Adherence to this research would minimize the occurrence of material hazards, hence the quality of lives of the greater number of Enugu residents would be raised in the most cost effective manner possible.

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