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

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ABSTRACT

It was projected that the population of Enugu State will grow at approximately 300% by the year 2020. This is true considering the 3,237,298 population figure of the area in the year 1991. Accommodation problems and lowering of peoples 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 siting of residential buildings to accommodate 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, Micro soft Excel statistical software and integrated land and water information system software (ILWIS). A total of 12 land use determinants were selected as thematic data layers and basic factors influencing the choice of residential landuse. 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 Arcview software overlay model builder. The operation yielded a layer of preferred residential landuse options in a map form. Three areas of varying suitabilities resulted from this operation, and includes areas suitable for residential landuse-options, and occupies 10% of the study area. Others are areas of low suitability (60%) and areas unsuitable for residential landuse, which occupies 30%.

KEYWORDS: population, residential, land capability, mapping accommodation.

INTRODUCTION

Population explosion in developing world has generated acute accommodation problems and low standard of living.

It is necessary to make effective use of the available lands especially in developing countries, where land tenure system and population impose land scarcity. Enugu State being, the area under study is within the heart of Ibo community of Nigeria, where land is scarce due to over population and land tenure system (Dutra and Hober, 1998). Population in Enugu State of Nigeria was projected to increase at about 300% by the year 2020. This is evident considering the attained 3,237,298 population figure of Enugu State in 1991. Going by this bad State of affairs, there is an urgent need to locate areas on most sustainable basis for the establishment of residential buildings to accommodate the teeming population. Geographic Information Systems (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 residential setup 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 such as physical (Geological and topography), economic, social and political factors (Chapin, 1965).

According to Arthur and Irwin (1982), residential buildings should be located in an area of flat or gentle slope. Other factors to be considered include flood plain, surface and ground water resource, soil factor and geostructural instabilities. The acceptable site should have a distance margin of at least 1000m from the flood plain zone. Residential building should be in an area of abundant water resource, Gauley and Kroine, (2002).

Materials and Methods
Description of Study area

The study area is located between latitudes 6° 16' N and 6° 31'N and longitude 7° 20' E and 7° 41' E covering an areal extent of about 630km^3 (fig 1)

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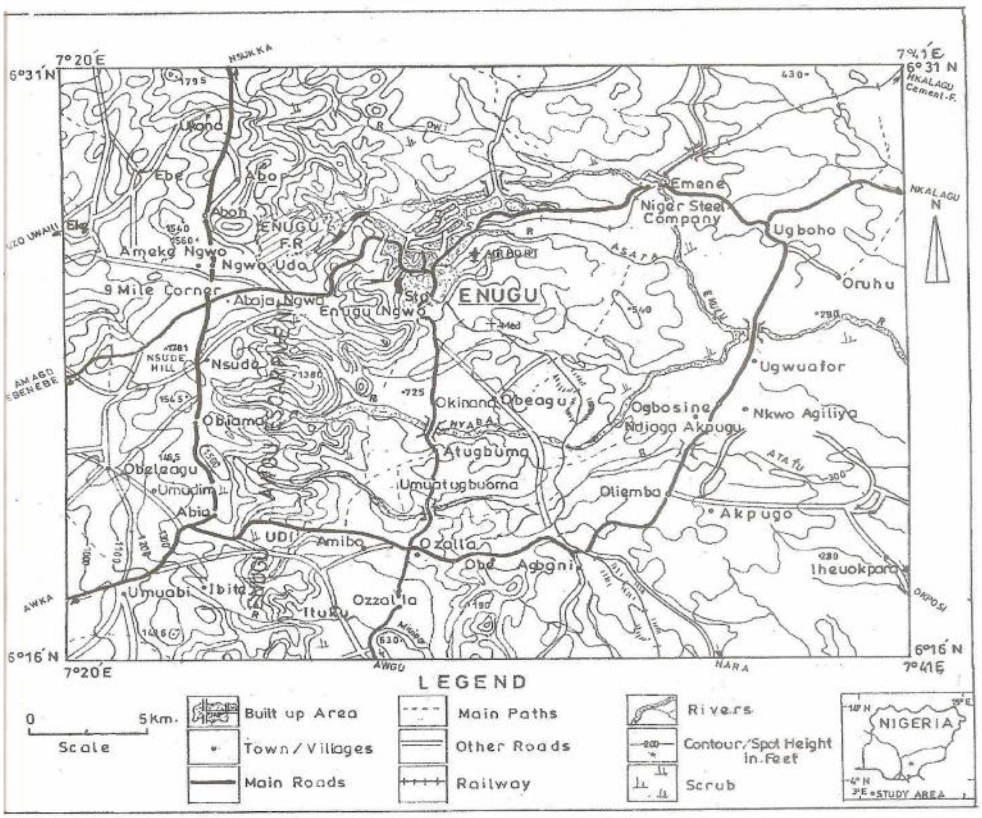

Fig 1: Topographical map of Enugu and Environs (After Iloeje, 1981)

It is also located within the rainforest-belt of Nigeria and has annual rainfall of about 1100mm a year, (Iloeje 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 watershed 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.

Table 1: Generalized Sedimentary Sequence in southeastern Nigeria

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 and 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.

(After, Reyment, 1965)

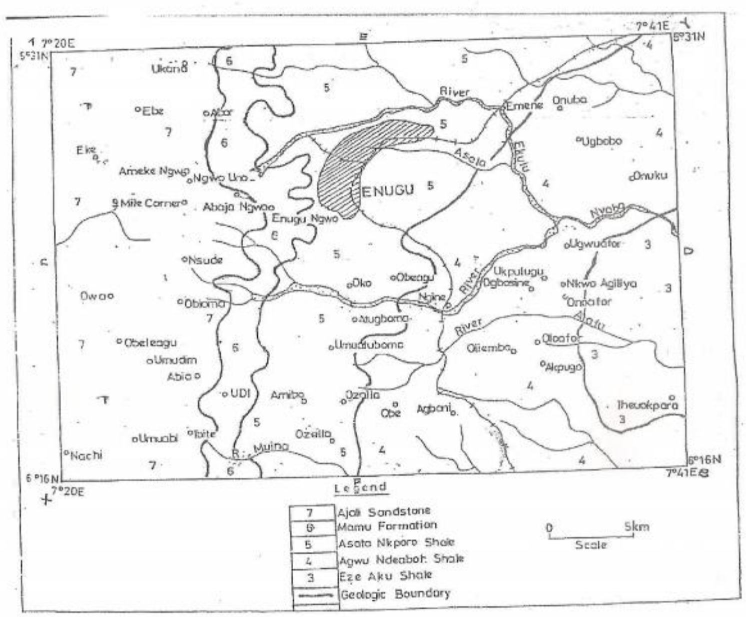

Fig 2: Geologic Map of the Study Area (Reyment, 1965)

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 ferralithic, forralithic, hydromorphic and lithosoils (fig 3).

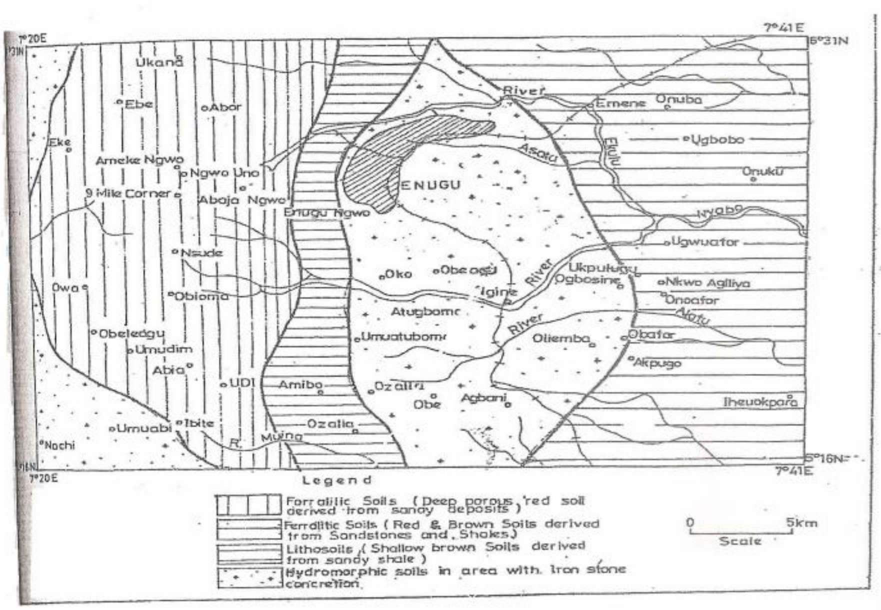

Fig 3: Soil Map of the Study Area (Ofomata, 1985)

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 soil auger. They were placed in polythene bags, and transported to laboratory for analysis. Random sampling method was adopted through which 6 (six) soil samples representing the entire soil types of the area were selected. The selected 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) used for digitization and georeferencing. Other equipments used include Geographic Information System (GPS eterex 76) used for measuring cordinate and elevation, Microsoft Excel statistical software used for data organization and computation., Arc view 3.2a academic, used for overlaying, information importation into GIS environment, digitization and georeferencing. 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.

Results and Discussion

The results of Laboratory, field and literature studies are shown in table 2

Table 2: Summary of Laboratory, Field and Literature Studies

Soil Rock Type	Liquid Limit %	Plastic Limit %	Plasticity Index %	Dry Density DD Kg/m^3	Consolidation Values	OMC %	Compressive Strength N/M^2	Shear Strength N/M^2	Cohesions 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^{-2} Cm/s & 0.31	38
Ferralithic 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	Ferralithic 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 +						8.6		276.67	24		25
Mamu FM+ Fractured , expansive, low shear strength			3.16-37.9	1.77-2.55							
Enugu Shale + Expansive and weak.	56.60	21.00	35.60			24.5					
Ezeaku FM+ Solution cavities	50.8	39.47	11.33	1.53							
Lithosoil:					e 0.892 cv 1.23					1.70 x 10-2 Cm & 0.30	

Literature
+ Information

Table 2 is a reference guide in taking a decision in the rating of the basic determinants of landuse factors. From the table, while the forralithic soil is poorly graded, the hydromorphic and ferralithic soils are well graded. Forralithic and lithosoil tilt towards sandy clay, while that of ferralithic 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 feralithic soil is 13.5%. From these, and employing the relation Activity of Clay (A) = PL/ p1 ……(1)

$$\text{Liquidity of Clay L1} = \frac{w - pL}{P1} \ldots\ldots \quad (2)$$

where p1 is Plasticity Index w, natural moisture content and PL is plastic limit. The activity indices of ferralithic 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 ferralithic soils are expansive and weak and therefore unsuitable for industrial buildings (Robert et al. 2001). Permeability and porosity result shows that while permeability and porosity of hydromorphic soil measured 1.97 x 10^{-2} cm/sec and 0.31 that of ferralithic soil measured 1.89 x 10^{-2} cm/sec and .30. The forralithic and hydromorphic soils have 1.92 x 10^{-2}, .31 and 1.97 x 10^{-2}, .31. The laboratory investigations of Atterberg limits employing ASTMD. 4318-98 (2000) standard methods show that forralithic 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%, ferralithic soil has liquid limit 39.84%, plastic limit 14.70% and plasticity index 25.14, while lithosoil 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 ferralithic 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 calculated as 0.92, while the coefficient of volume settlement/ consolidation (cv) gave 1.12. For ferralithic and forralithic soils, the void ratio (e) and coefficient of volume settlement/ consolidation (Cv) are 0.934, 1.3 and 0.94, 0.63. From these results, the settlement readjustment of forralithic soil is smaller indicating soil best suited for residential buildings (Ola, 1981). The shear strength of the soils were calculated using the relation according to Chapin (1965).

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

Where τ is Shear Strength, C = Cohesion, δn = effective stress on soil and θ = Frictional angle based on total stress analysis. Employing equation 3 and parameters C and tan θ from graph of shear versus normal stress, the shear strength for hydromorphic, forralithic, ferralithic and lithosoils are 85.56KN/m^2, 96.09 KN/m^2, 87.82KN/m^3 and 88.36KN/m^3 respectively. The shear strength of hydromorphic and ferralithic soils are lower than forralithic and lithosoils, also the angle of internal friction is high for forralithic soils indicating a high shear strength (Aria 2003). Hydromorphic and ferralithic soils show high cohesion. There is likelihood of shear failure when subjected to load like residential buildings since saturated clays fail if subjected to stress (Braja, 1988). The result of compressive strength shows that forralithic soil has compressive strength of 9.10KN/m^2 with test load of 14.43KN/m^2, ferralithic soil 2.10KN/m^2 test load 20.16 KN/m^2

Hydromorphic soil 2.176 KN test load 56.0 KN/m^2, while lithosoil has 3.24KN/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 2KN/ m^2 and 7KN/m^2 is weak, while those above these values are strong. Based on this, forralithic soil is stronger. The moisture-density curve indicates optimum moisture content of 11.02% and maximum dry density of 1.51kg/m^3 for ferralithic soil, that of hydromorphic soil has 13.01 and 1.52kg/m^3 while forralithic soil has 14.0 and 1.90kg/m^3. Forralithic soil satisfied conditions for accommodating heavy residential buildings (Terzaghi and Peck, 1967). The lower dry density and higher moisture content of the hydromorphic and ferralithic 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 forralithic soil is classified as Ml-cl (silt / sand, poorly graded) hydromorphic soil Sp-cl (silty caly and poorly graded), ferralithic soil is Sw-cl (silty caly and well graded) while lithosoil is silty and poorly graded. The above results are relevant guides in rating of landuse determinants.

Twelve (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 over lay operation as shown in table 3. The percentage influence which adds up to 100% signifies the degree of importance of the theme to the land determinant factor.

TABLE 3: ORGANIZATION OF THEMATIC DATA LAYERS FOR RESIDENTIAL LANDUSE

INPUT THEME	PERCENTAGE INFLUENCE	INPUT FIELD	INPUT LABEL	SCALE VALUE	REMARKS
SLOPE THEME 1 (LAYER 1)	5%	1 2 3 4	0-9 9-19 > 19	2 1 0 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	Deep soil is good for foundation.
GEOLOGY THEME 4 (LAYER 4)	12%	1 2 3 4 5	Ajalli fm Mamu Asata/ Enugu Shale Awgu-Ndi Abo Shale Ezeaku	2 1 1 1 1	Fractured rocks lead to instability of foundations, Asata Nkporo/ Enugu shale Awgu Ndi Abo have low strength from literature.
DRAINAGE THEME 5 (LAYER 5)	12%	1 2 3	Moderate Moderate Well Drained	1 1 2	Wet lands could lead to instability of foundations.
SOIL CLASS THEME 6 (LAYER 6)	15%	1 2 3 4	Sandy (Forralithic) Clayey sand (Hydromorphic) Silty Sand (Lithosoil) Sandy Clay (Ferralithic)	2 1 0 1	Soil strength depends on class. This is based on Engineering classification of soils.
SURFACE WATER THEME 7 (LAYER 7)	5%	1 2	High Availability Low Availability	2 1	Important sources of water supply. Surface water is scarce in the Western segment.
DEPTH TO WATER TABLE THEME 8 (LAYER 8)	8%	1 2 3	Very Shallow Shallow Deep	1 2 1	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)	4%	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 results in environmental devastation and hazard GIS Buffer ≥ 1000m (1km).
FAULT THEME 12 (LAYER 12)	8%	 1 2	BUFFERED ACTIVE NON ACTIVE	 0 0	Promote instability and failure in slopes and buildings especially when fault plane slopes in the direction of buildings.
TOTAL	100%				

The table is a computer statement where scale values were selected based on the results of laboratory and field studies, of table 2 and 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 procedure of overlay operation is shown in fig 4, while the resulting suitability map is shown in fig 5.

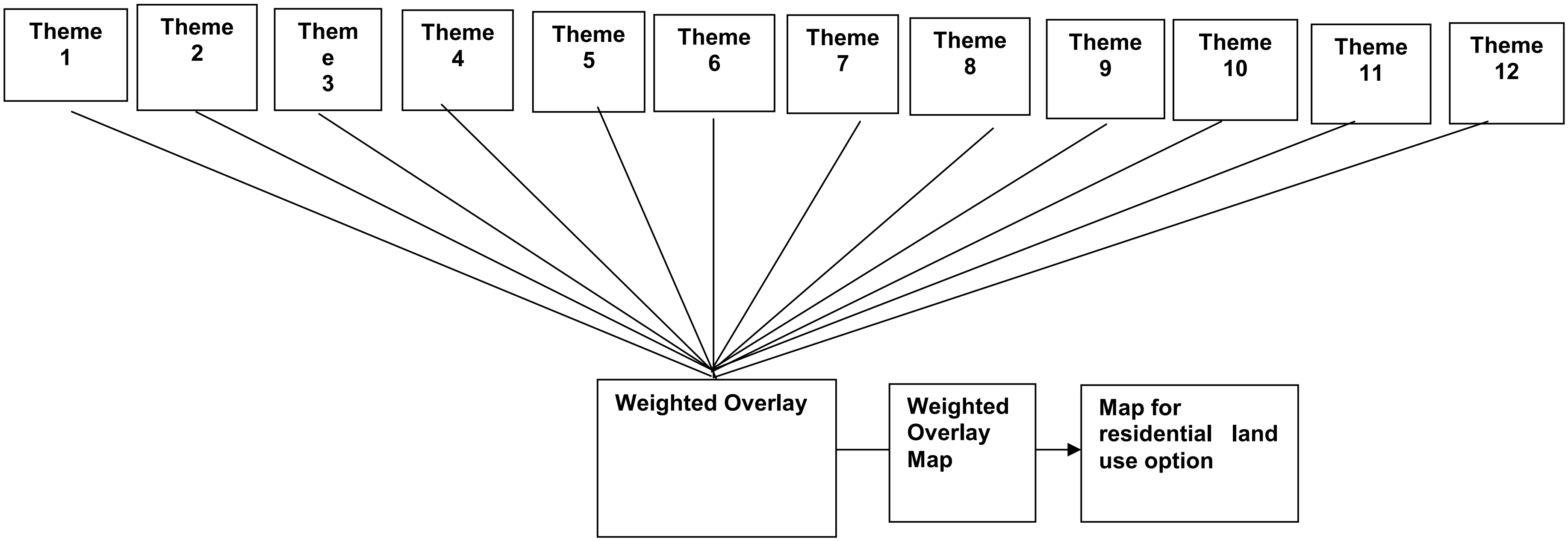

Fig 4: Overlay Model for Residential LandUse

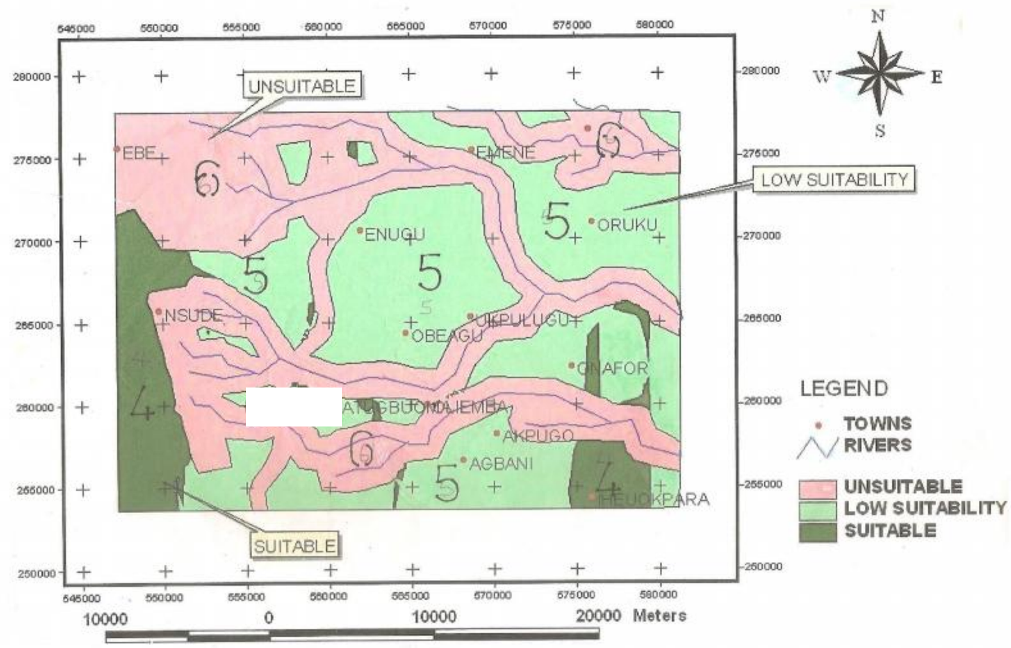

Fig 5: Weighted Overlay map for Residential Landuse

The map shows designated locations of varying suitabilities numbered as 4, 5 and 6 respectively. Location 4 occupies 10% of the study area suitable for residential landuse, location 5 occupies 60% being the largest and has low suitability for residential landuse, while location 6 occupies 30% of the entire land unsuitable for residential landuse,

EVALUATION AND CONCLUSION

The study shows that high proportion of Enugu State land unit has low suitability for residential 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 residential landuse options. Comparison of comparism of the results of the study against the existing landuse clearly exposed the limitations of the present landuse of the area.

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