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Abstract : Enugu, the area under study is experiencing a high rate of population growth. Problems of housing, on employment, waste disposals and the general lowering of standard of living are always associated with over-population. It has therefore become necessary to map out areas of residential, industrial and waste disposal land use for future utilization. Land capability index mapping using geographic information system(GIS) is one of the appropriate tools for solving these impending problems. Land capability index mapping of Enugu environs in composite form has been undertaken using Arc view 3.2 academic, excel statistical software and GIS Authcard software. A total of 12 land use determinants have been selected as the thematic data layers and the basic factors influencing the choice of waste, residential and industrial land use. These themes which are in map form are slope, water table, surface and subsurface water conditions, elevation, geology, soil, drainage and geo-structural stability(fault, erosion, landslide and flooding). These maps have been scanned, geo-referenced , digitized and polygonized using authcard drawing capacities to convert them to vector formats and later exported to arc view software environment for analysis. The thematic layers were weighted using the criteria obtained from fieldwork, laboratory and literature surveys. The thematic layers were further subjected to overlays using the arcview software overlay model builder. The operation yields layers showing areas of preferred waste disposal, residential and industrial landuse options in a map form. Three different maps of land use options(waste, industrial and residence) were produced. Areas of varying suitability were isolated, 3 each for waste, residence and industry, indicating suitable, low suitability and unsuitable areas respectively. The three land use maps were superimposed to obtain a single one appropriate for purposes of urban environmental planning.

Introduction

It is necessary to make effective use of the available lands especially in developing countries where land tenure and over population impose land scarcity. Waste disposal, residential and industrial landuse options were selected for the study. Mapping of landuse for a particular use is the aspect of landuse planning which ensures maximum and safe utilization of land. The purpose of landuse planning is to make the best, most sensible, practical, safe and efficient use of each parcel of land especially in developing world where land is scarce due to over population and land tenure system (Dutra and Hober, 1998). Enugu , the area under study is within the heart of Ibo community of South-eastern Nigeria where land tenure system and over population is worldly known . Unemployment, residential and waste disposal problems are always associated with over 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 analyze display and disseminate land related information (Kang, 2002). Pearce and Turner (1990), observed that unplanned development has resulted in severe environmental damage and declining quality of life for many people. Dimitri and Krynine (2003) observed that the development of any land area both for industrial, residential and waste disposals 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 (Geology and topography), economic, social and political factors (Chapin, 1965).

Materials and Methods

Description of Study Area

The study area is located between latitudes 6º16' N and 6º31' N and Longititude 7º20' E and 7º41' E covering an areal extent of about 630km² (Fig-1) annual rainfall of about 1100mm a year, (Iloeje 1981).

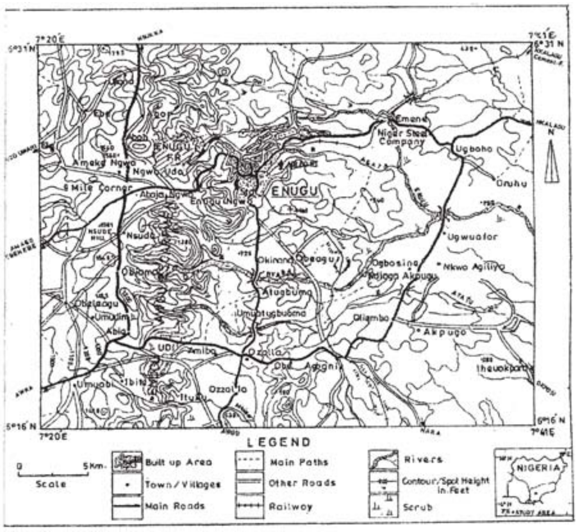

Figure-1 : Topographic Map of the Study Area

The most stricking feature within the study area is Enugu -Awgu , cuesta formed by the resistant sandstones of Mamu Formation. Drainage system is controlled by the escarpment as the Enugu-Awgu escarpment forms the most important water shed separating the cross river drainage system to the east from a net work of streams flowing west wards towards the Anambra drainage basin (Ofomata, 1985).

Egboka, (1993), described the drainage system as dendritic. Geologically, the study area lies in the 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). While Ezeaku Formation is the oldest in the area, Ajali Formation is the youngest. The stratigraphic succession and geology of the area is shown in table I and fig.-2.

Table-1 : Generalized Sedimentary Sequence in South Eastern Nigeria (Reyment 1965)

AGE	FORMATION	LITHOLOGY
Maastrichtian 6.5 - 6.8 myrs	Ajalli Formation	Friable Sandstone with cross bedding
	Mamu Formation	Alternating Sequence of sandstone clay stone and shale with coal seams.
Campanian 78-82 myrs	Nkporo/Enugu Shale	Dark grey shale with clayey shale with clay lenses.
Sanonian 78-82 myrs	Awgu Formation	Bluish grey shale with clay lenses.
Turonian 82-92 myrs	Ezeaku Formation	Blackshale with clay and limestone lenses.

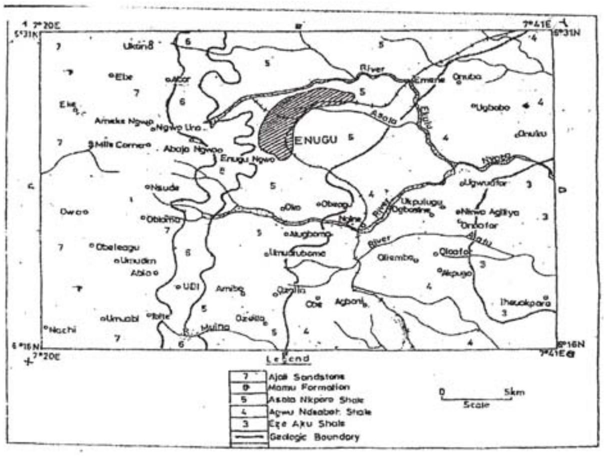

Figure-2 : Geological Map of the Study Area

The hydrogeology of the area indicates that the major water bearing unit is Ajalli 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 aquifers 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.

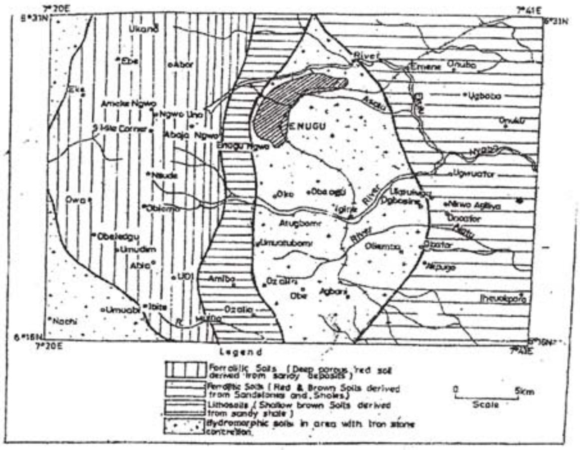

Figure-3 : Soil Map of the Study Area

soils were derived from Enugu shale and Ajalli 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).

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 meters 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 equipments. Atterberg limits, using Cassagrande apparatus), particle size distribution, using British electric shaker machine, porosity and permeability using permeameter, consolidation settlement using consolidometer, shear strength, using triaxial shear box and finally compressive strength. Analysis were done using ASTM D, 4318-98(2000) and ASTM, 1988 standard specifications. All analytical procedures are shown in (Robert, 2001).

12 (Twelve) thematic maps of the landuse determinants within Enugu area obtained from different sources were employed in the work. 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), arcview 3.2a academic, Geographic Positioning System (GPS, eterex 76), excel statistical software, autocard software 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; They were then saved in different layers for GIS analysis. Field and laboratory studies were further carried out to complement and update the details in the thematic maps and also helped in taking decision during the rating processes.

Results and Discussion

The average results of laboratory, filed and literature studies are shown in table-2. The table is a reference guide in the rating of the basic determinants of landuse factors. From the table, while the forralithic soil is poorly graded the hydromorphic and ferralithic soil are well graded. Forralithic soil and lithosoil tilt towards Sandyclay 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 Jude, (1957). The result shows that while the clay fraction of hydromorphic soil is 13%, that of ferralithic soil is 13.5%. From these, 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. This was obtained using the relation according to Robert (2001):

Activity of Clay (A) = PI/ Clay fraction ....(1) and

Liquidity of Clay (LI) = w – PL/PI ....(2)

Where PI is plasticity Index, w natural moisture content and PL is Plastic Limit. The result of this calculation indicates that the two soils hydromorphic and ferralithic soils are expansive and weak, therefore unsuitable for residential and industrial buildings, (Robert , 2001). Permeability and porosity result show that while permeability and porosity of hydromorphic soil measured 1.97×10^{-2} cm/sec and 0.31, that of ferralithic soil measured 1.89×10^{-2} cm/sec and 0.30, while lithosoil has 1.70×10^{-2} and 0.30. The Forralithic and hydromorphic soils has 1.70×10^{-2} and 0.30.

Table-2 : Summary of Laboratory, Filed and Literature Data

Soil/ Rock Type	Liquid Limit %	Plastic Limit %	Plasticity Index %	Dry Density DD kg/m^3	Consolidation Values	OMC%	Comprehensive strength IM/M^2	Shear Strength N/M^2	Cohesion N/M^2	Permeability porosity	Angle of Internal Frictione
Forralithic Soil Poorly graded Silty Sand	26.06	19.75	6.31	1.90	eO.94 cv 0.63	14.0	9.10	96.09	13	1.92 × 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 1.3	11.02	2.10	87.82	30	Ferralithic 1.89 × 10^2 cm/s & 0.30	30
Hydromorphic Soil Well graded Clayey silt Clay fraction 13%	43.35	16.89	26.46	1.52	e 0.92 cv 1.12	13.01	2.176	85.56	31		30
Ajalli 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 × 10^{-2} Cm/s & 0.30	

Literature +Information

The forralithic and hydromorphic soils have higher porosity and permeability, and are not best suited for waste disposal landuse (Chenglin and Evett, 2000). The laboratory investigations of Atterberg limits employing ASTM D. 4318-98(2000) standard methods show that forralithic soil has liquid limit 26.06%, Plastic Limit 19.75%, Plasticity Index 6.31%. 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 and coefficient of volume settlement / consolidation 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 and industrial buildings (Ola, 1981). The shear strength of the soils were calculated using the relation according to (Chapin 1965).

$$\tau = C + \delta n \tan \theta \quad \text{................(3)}$$

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, 96.09KN/m^2, 87.82KN/m^3 and 88.36 KN/m^3 respectively. The shear strength of hydromorphic and ferralithic soils are lower than forralithic andlithosoils, 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 industrial buildings , since saturated clays fail if subjected to vibration, (Braja, 1988). The result of compressive strength shows that forralithic soil has compressive strength of 9.1 OKN/m^2 with test load of 14.43KN/m^2, ferralithic soil 2.10 KN/m^2 test load 20.16 KN/m^2. Hydromorphic soil 2.176KN/m^2 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 (OMC) of 11.02% and maximum dry density (MDD) of 1.51kg/m^3, that of hydromorphic soil has 13.01 and 1.52 kg/m^3, while that of forralithic soil is 14.0 and 1.90kg/m^3. Forralithic soil satisfied conditions for accommodating heavy buildings (Tersaghi 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 and using Unified Soil Classification System (USCS) shows that Forallithic soil is classified as ML-CL (Clay = Silt and poorly graded), Hydromorphic soil Sp-cl (Silty clay and well graded), ferralithic soil is Sw-cl (Silty clay and well graded) while lithosoil is silty clay 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/ landslide map, fault map and escarpment map. These maps are the thematic data layers for GIS operation. The thematic layers were organized into a geographic input data form for the 3 land uses in readiness for overlay procedure see tables 3, 4 and 5. The tables are computer statement. The scale values were selected based on laboratory and field studies and are the capability ratings assigned to each environmental factor based on a scale of 0-2 inclusive as to make up three classes of suitable (2), low suitability (1) and unsuitable (0). Input label are the determinants of the theme. The theme is added up to 100%. The higher the percentage of the themes, the more relevant its application to the land use in question, and likewise the input label which shows the number of polygons contained in thematic maps.

Overlay Procedure : The themes were overlaid together starting from theme I to 12 for each landuse option as shown in figs 4, 6 and 8 using a model builder of arch view

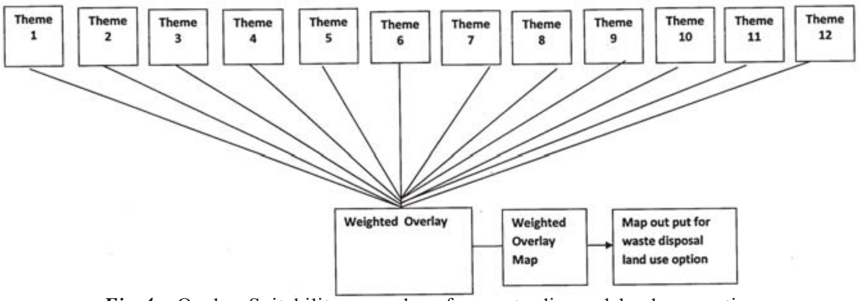

Fig-4 : Ovelay Suitability procedure for waste disposal land use option

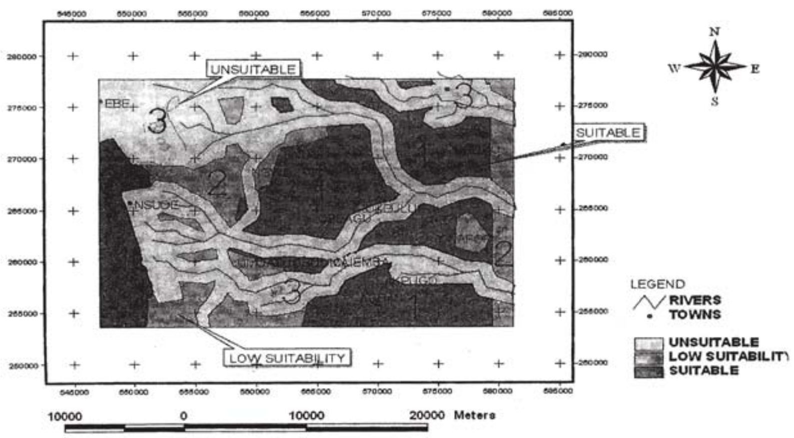

Fig-5 : Suitability Map for Waste disposal landuse

The result of fig. 4 operation yielded a layer of waste disposal landuse map fig. 5. The map shows various areas of suitabilities designated areas, 1 (Suitable), 2 (low suitability) and 3 (unsuitable), representing 60% and 20 % of the entire area under study.

In the same way, the result of fig. *6* operation yielded a layer of residential landuse map fig 7. The map shows various areas of suitabilities 4, 5 and 6 respectively . Area 4 occupies 10% of the land unit suitable for residence. Area 5 occupies zones of low suitability for residential landuse and occupies 60% of the land unit, while area *6* is unsuitable for residential landuse.

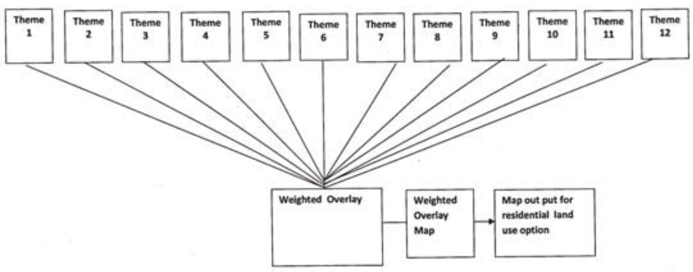

Fig-6 : Overlay Procedure for Residential landuse option

The overlay procedure for industrial landuse map is shown in fig 8 and the resulting map is shown in fig 9. The map shows various areas of suitability designated areas 7, 8 and 9 respectively. Area 7 which occupies 10% of the study is suitable for industrial landuse, while areas 8 and 9 are low and unsuitable for industrial landuses and occupy 70% and 20% of the study area.

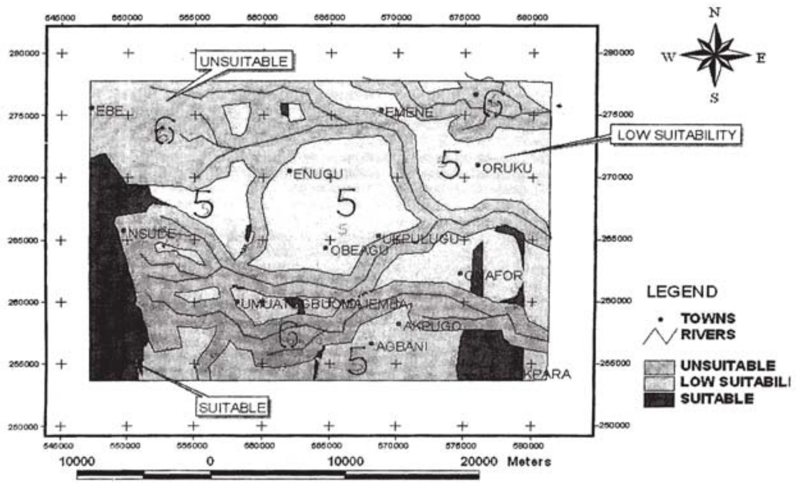

Fig-7 : Suitability Map for Residential Landuse

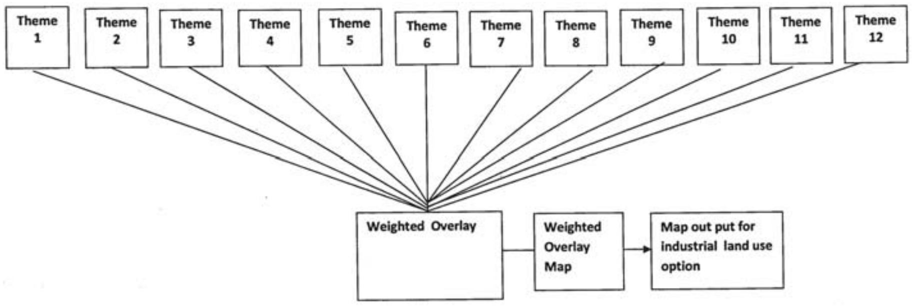

Fig-8 : Overlay procedure for industrial landuse option

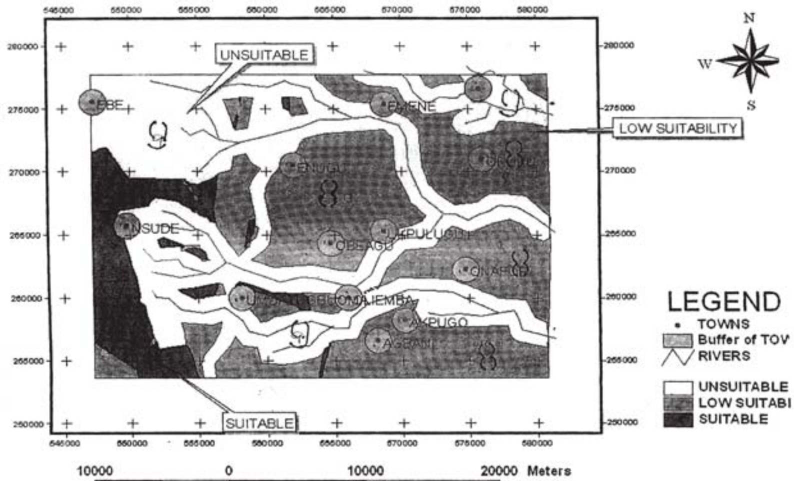

Fig-9 : Suitability Map for Industrial Landuse

Composite landuse map emerged when the resulting waste, residential and industrial landuse maps were superimposed. A different and new form of landuse map emerged, this is shown in fig 10.

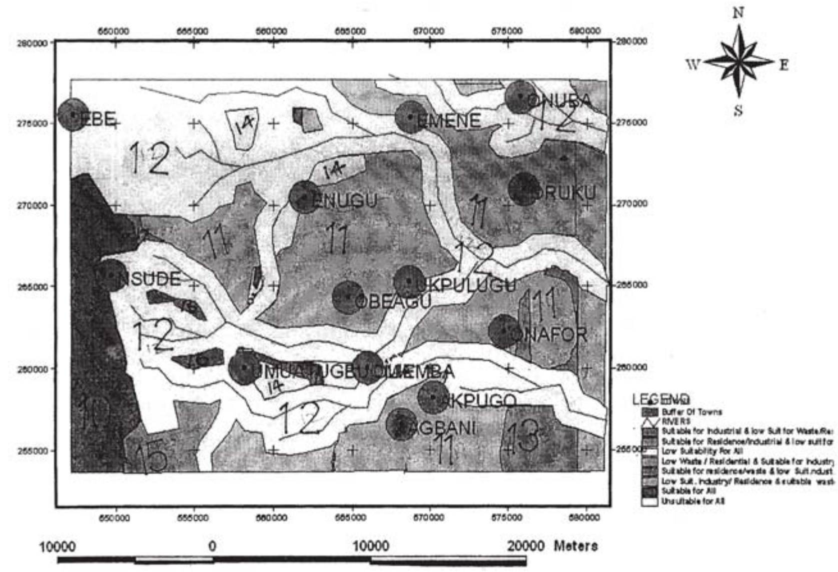

Fig-10 : Composite Landuse map (Waste, Residence and Industry)

The resulting suitability lands are areas 10, 11, 12..... 17 inclusive, giving a total of 8 classes of composite suitability zones. Area 10 occupies 12% of the entire area and is suitable for the 3 landuse options. Area 11 is suitable for waste disposal landuse but has low suitability for residential and industrial landuse options and occupies 46% of the study area. Area 12 occupies 15% and are unsuitable for the 3 landuse options. Area 13 is suitable for residential and waste disposal landuses, but has low suitability for industrial landuse and occupies 10% of the entire area. Area 14 which occupies only 6% of the area has low suitability for all the landuse option. Area 16 has low suitability for waste and residential land uses but suitable only for industrial landuse option and covers 4% of the land unit. Finally, area 17 is suitable for residential and industrial landuses, but low for waste disposal and occupies an insignificant portion of 1% the land uses, but low for waste disposal and occupies an insignificant portion of 1% of the land area. The composite landuse map is ideal for urban and environmental planning.

Conclusions and recommendations

This study shows that the greater percentage of Enugu land unit is unsuitable for industrial and residential landuse and are centered within the western segments and to some extent the east. Area suitable for waste disposal cover the greater percentage of the land unit found within the western and central portions of the study area. Some of the available lands are unsuitable for any landuse due to fault erosion landslide, flooding and to some extent the scrap face. Comparison of the results of the study against the existing landuse, clearly exposed the limitations of the central landuse of the area. In the light of the findings of this project, it is recommended that the allocation of land for industrial, residential or waste disposal development should not be done at random,. Environmental management authority should be on hand to assess the land for any engineering construction since the grater percentage of the land unit is unsuitable for residential and industrial land use options.

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