LAND CAPABILITY INDEX MAPPING OF ENUGU AREA AND ENVIRONS, SOUTH EASTERN NIGERIA

(A GIS APPROACH)

BY

ONUNKWO – AKUNNE, AUGUSTINE
(B.Sc (UNICAL), M.Sc (UNN), PGDE (UNN))
REG NO: 20004149708

A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN HYDROGEOLOGY.

APRIL, 2010.

CERTIFICATION

FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

SCHOOL OF POST GRADUATE STUDIES,

DECLARATION

The Board of examiners declares as follows:

That this is the original work of the candidate. That this thesis is accepted in partial fulfillment of the requirements for the Award of the Degree of Doctor of Philosophy (Ph.D) in Hydrogeology.

Onunkwo – Akunne, Augustine	…………………	………………….
(Candidate)	**Signature**	**Date**
Supervisor (Major) Prof. G.I. Nwankwor	………………….	…………………..
	Signature	**Date**
Prof. C.J. Iwuagwu	…………………..	…………………..
(Head of Dept, Geology Co Supervisor)	**Signature**	**Date**
Co Supervisor Prof. N.N Onu	…………………..	….………………
	Signature	**Date**
Dean P.G. School Prof. C.S. Okereke	…………………..	…………………..
	Signature	**Date**
External Examiner	…………………..	……………………
	Signature	**Date**

DEDICATION

This work is dedicated to the Almighty God, who made it possible for me to go through the stresses of Ph.D engagements. It is also dedicated to all the ambitious minds, my late parents, Mr. Francis and Catherine Onunkwo-Akunne, and my dear wife Mrs. Uzonwanne, Onunkwo-Akunne.

ACKNOWLEDGEMENT

I thank my supervisor Professor G.I. Nwankwor who had been directing, correcting, advising and encouraging me. To other supervisors of this work; Professor C.J Iwuagwu, Professor. K.M. Ibe and Professor N.N Onu, I appreciate your contributions.

I also thank the various ministries and institutions who gave me useful materials and other information. My greatest thanks go to National Remote Sensing Centre Jos, Federal College of Land Resources Development Owerri. (FECOLART). These bodies introduced me to the science of geographic information system.

I thank my wife Mrs. Uzonwanne who remained the source of encouragement especially at the trying periods of the project. I also thank Miss Hope Ihejirika of Dephilips Services MCC Owerri who typed the work.

I thank greatly Mr. Justin Uwazuruonye for his directives during data base organization and GIS processing.

Finally and very importantly, I express my gratitude to the Almighty God who gave me the spirit of perseverance and dedication.

ABSTRACT

It has been projected that the population of Enugu area will grow at approximately 300%. This information is further strengthened by the projected, 237,298, 2006 population figure of Enugu area. By the year 2010, this implies that there is the expectation of over population of the area in future. Problems of housing, unemployment, 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 International system (GIS) is one of the appropriate tools for solving these impending problems. Land capability index mapping of Enugu area and environs has been undertaken using Arc View 3.2a. academic, Excel statistical software and auto card software of GIS. 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 theme which are in map forms are slope, water table, surface and subsurface water conditions, elevation, geology, soil, drainage and geostructural stability (fault, erosion, land slide and flooding). These maps have been scanned, georeferenced digitized and polygonized using authocard drawing capabilities 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 field work, laboratory and literature surveys. The thematic layers were subjected to overlay using the arc view software overlay model builder. The operation yields layers showing areas of preferred waste disposal, residential and industrial land use options in a map form. Three different maps of the land use options were produced. Areas of varying suit abilities were isolated; 3 for waste, 3 for residence and 3 for industry. They represent suitable, low suitability and unsuitable areas respectively. The three land use maps were superimposed to obtain a single one appropriate for purposes of urban and environmental planning.

CHAPTER ONE

1.1 INTRODUCTION

Land capability index mapping is the aspect of land use planning which ensures the maximum and safe utilization of land. Land use planning is a process which involves the determination of the suitability of a particular piece of land for a particular use. The purpose of land use planning is to make the best, most sensible, practical, safe and efficient use of each parcel of land. (Dutra and Hober 1998).

Land capability is the interpretative groupings of land units with similar potentials, limitations or hazards, (Fisher and David 1990). It is important to know the limitations of the land and the uses it is capable of supporting, how susceptible a soil is to such factors as erosion and contamination influences, and what land use it is suitable for. The location of land is a vital factor in deciding its uses. Pearce and Turner (1990) observed that irresponsible development has resulted in severe environmental damage and declining quality of life for many people. Geological problems arise due to hazards from ground displacement, earthquake , landslide and soil which expand on wetting. 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 so as to ascertain the capability of the land for the purpose. For example, septic tanks will not be permitted in land slide areas because they will aggravate sliding problems by introducing water into the ground (Davis and Rogers 1975) .

Until the population stabilizes, growth pressure will force man into relatively underdeveloped environment, such invasion involves tampering with the landscape and disturbing the habitats of the flora and fauna. The growing population will be introducing problems of water supply, waste disposal, water / air pollution and housing. Proper planning for development and land allocation for particular uses are two of the most critical problems facing modern urban centers. Land use planning constitutes an instrument for such planning and allocation of resources. The process is accomplished through the use of a variety of factors. These factors can be divided into four categories; (Chapin 1965): physical (geology and topography) economic, social and political factors. Geologic factors include hydrology, hydrogeology, and geo-structural stability, while topography includes slope and elevation. Economic and social factors include problems of land ownership. Land capability index mapping is the basic tool for planning and allocation of resources. In the third world countries, development is impeded by two common factors – environmental hazards and increased cost of development. Enugu and its environs inherit these two problems. The city originated in a coal miners camp in 1915, and gradually developed into an administrative capital with an area of over 200km^2. This development went without any consideration for land use processes. The main economic activities in the area include commerce, large and small scale manufacturing, transportation and agriculture. The study is necessitated by the increasing report of degradation of the environment, loss of lives and property as a result of structural failures, odour problems and obnoxious gas emissions. The result of this study is expected to provide information towards the development of a sustainable use of land in Enugu area and environs with the hope of minimizing natural hazards and making life more meaningful.

1.1 LANDUSE DETERMINANTS

According to Arthur and Irwin (1982), the land use determinants include topography, climate, geology, soils, drainage, hydrology and hydrogeology. Others are population and economics, government interest and zoning. These factors are described below:

Topography: This includes slope, elevation and relief.

Climate: The elements of climate are rainfall, temperature, wind and air quality.

Geology: These include rocks and structures, aquifers, landslide, faults and seismic hazards.

Soils: The parameters of soil include soil depth, water holding capacity, permeability, shrink and swell behaviour (expansive soils) and septic tank suitability.

Drainage: Drainage involves flooding, erosion and sedimentation.

Hydrology: This aspect involves existing surface water supply, existing sewage disposal, and its effect on water supplies and stream flow.

Hydrogeology: This involves groundwater potential, water table, subsidence due to ground water withdrawal, and water quality.

Land Use: The components of land use are for residential, commercial, agricultural, recreational and other uses.

Population and Economics: Consideration under population factor includes population size, characteristics, projections, and housing, while the economic aspects include economic gains.

Government Interest: These are classified under government agencies, local government, state, country and city. Government allocates land for any purpose.

Zoning: Land areas are zoned based on basic needs. It should be noted that the environment at any one time reflects the impact of these land use determinants. As the original environment is altered, it may lead to the modification of the original determinants. It should also be remembered that the determinants themselves change with changing values and technology (Arthur and Irwin, 1982).

Economic determinant emphasizes why present land use patterns are as we find them. Theories emphasize that location decision are based on optimal economic returns, e.g. a factory is sited based on their needs. Again social determinants are concerned with social values and behaviour. Social scientists advance reasons for change in population location and values. Political determinants express public interest.

Political decisions will determine how the physical environment is to be altered. Of importance in the physical environment is the geologic environment and how it conditions and responds to human activities. From the land use planning point of view, there are two basic ways of categorizing the geologic environment. These are considered as hazards as well as resources. Soil may be a resources or a hazard. According to Smith and Krisjanason 1989 some soils shrink and swell, while others slide or creep down hill causing various degrees of damage. Landslide is often a resource that can be converted into a park or left as an open space. Mountains and beaches are attractive for recreational purposes.

1.2 GEOGRAPHIC INFORMATION SYSTEM(GIS)

With the growing constraints and growing number of factors to be considered in industrial, waste and residential land use selection today, there is an urgent need to adopt modern technology like Geographic Information Systems (GIS) for the analysis and suggestion of best locations (Verbyla and Chang 1997). Presently, the world is experiencing social, scientific and educational revolutions that are technologically driven. GIS is a central component in the world's environmental information culture (Agrawal, 2000). The application of GIS has been widely acclaimed to facilitate efficient decision making and planning. GIS consists of a set of computerized tools and procedures that can be used to effectively store, retrieve, overlay, correlate, manipulate, analyze, query, display (both graphically and numerically) and disseminate land related information (Kang 2002). Today developed and developing countries are applying GIS technology to upgrade their earth resource information system and in some cases to obtain for the first time information on some aspects of their environment. The need for earth resources information and mapping in the developing world particularly Nigeria calls for attention. This will offer valuable source of information that can be used for the development of agriculture, land resources, water resources and ecosystem.

GIS is effectively used in the selection of the proper area for residential, industrial and waste disposal site locations. In the process spatial data is stored as different thematic layers and manipulated to derive new usable information using the existing ones in GIS. (Verbyla and Chang 1997).

1.4 LOCATION, EXTENT AND ACCESSIBILITY

The study area is located between the Latitudes 6^0 16 N to 6^0 31N and between Longitudes 7^0 20E to 7^0 41E. It covers an area of about 200 Sqkm. The area is accessible from Aba, Onitsha, Makurdi and Abakaliki. It is also accessible by air and rail. The railway extends from Port Harcourt to Northern Nigeria via Enugu. The topographic map of the study area is represented in Fig. 1a, while the map showing the road network is shown in (Fig 1b).

Fig 1

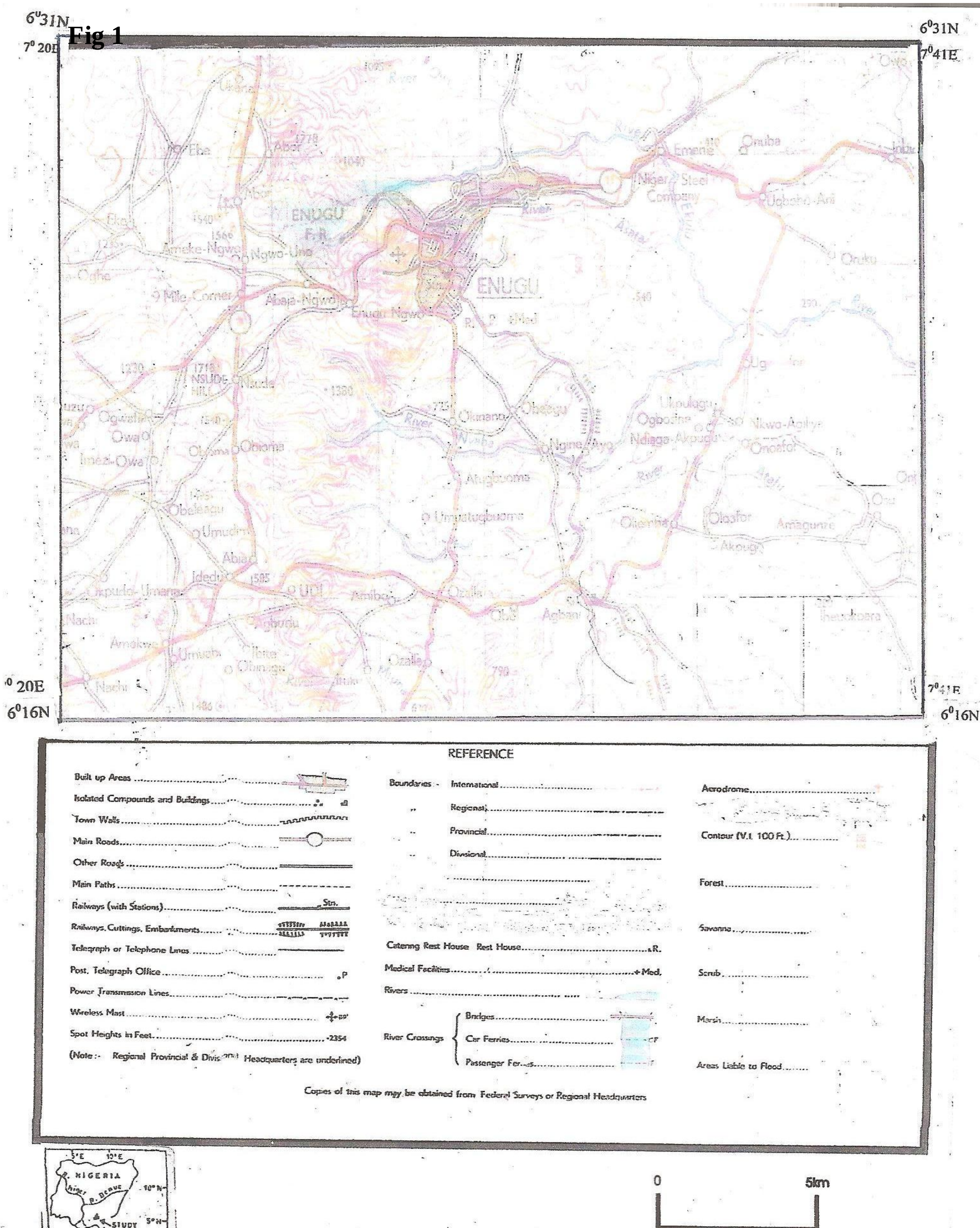


Fig. 1 Location and Topographic Map of the Study Area

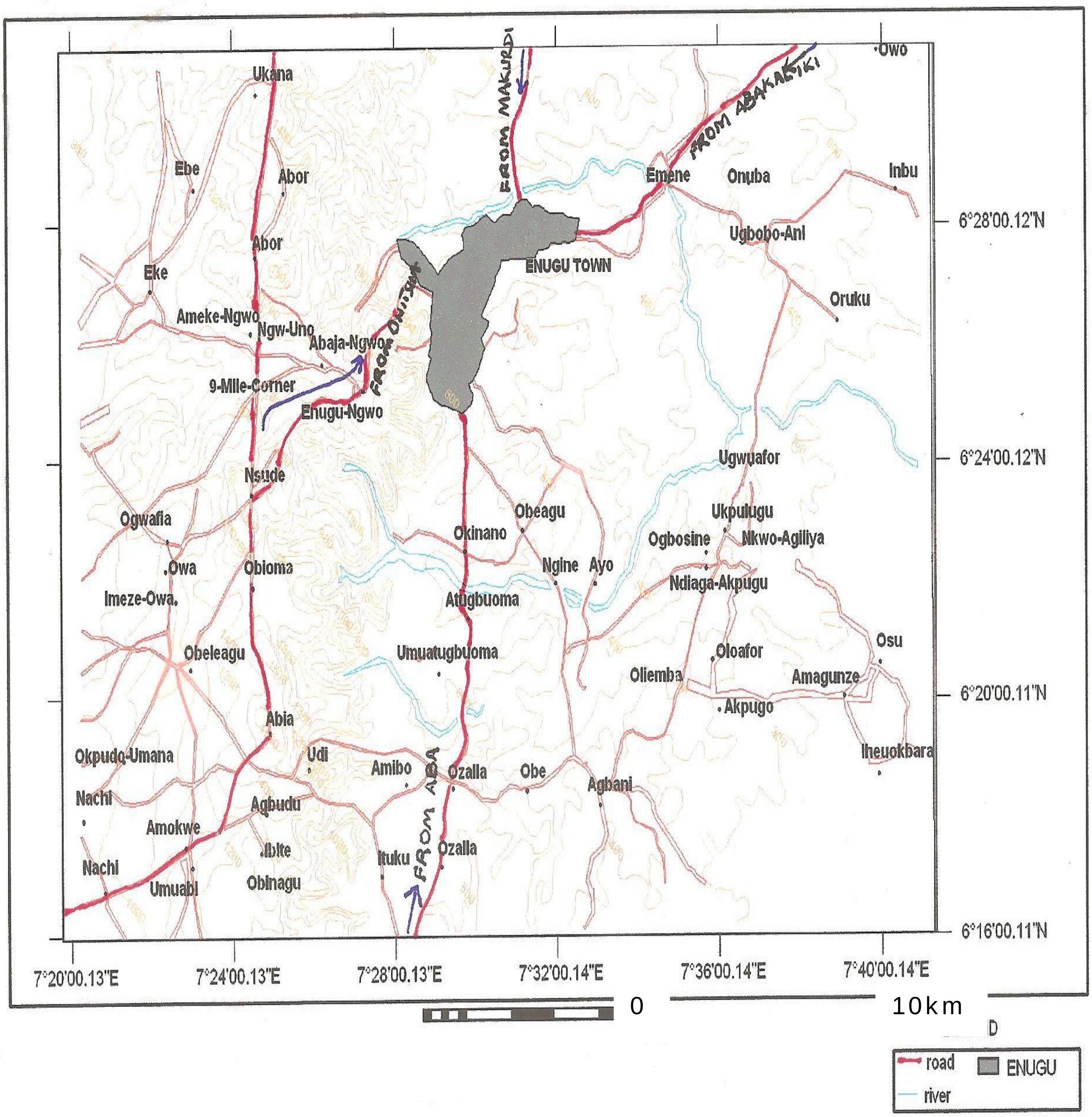


Fig. 1b: Road Network Map of Enugu and Environs
Source: Topographic Map Sheet FSN 72, Enugu Area 1:250,000

1.5 JUSTIFICATION

Enugu originated as coal miner's camp in 1915 and gradually developed into an administrative capital. Over the years, since it assumed the administrative seat of Eastern Nigeria, Enugu has grown both in population and economic activities. It has been estimated that by the year 2010, the population would be about 12279000 at 4% growth rate or 16718960 at 5% growth rate. There is thus the need to plan for waste disposal, build industries and erect more residential buildings. Also over the years, the city has grown industrially from a coal mining activity to other manufacturing outfits e.g. Beer Brewing, soft drink bottling, pharmaceuticals, food processing and petroleum related industrial activities. These industries need to be located on safe geotechnically sound terrain, with good road network. Such industries should not constitute hazards to the people. The need for residential accommodation has been and continues to be of high concern. Current overcrowding conditions are severe, and future requirements for new dwelling units would soon be a serious problem. There is therefore the need to map out areas that are both technically, and geotechnically safe and economically rewarding. The result of this is expected to provide information towards the development of sustainable use of the land for Enugu area and its environs as a means of minimizing natural hazards and making life more meaningful. This work should therefore provide a map showing suitable areas for industrial, residential and waste disposal site locations.

1.6 AIM AND OBJECTIVES

The aim of this study is to minimize the occurrence of environmental hazards and hence raise the quality of life of the greater number of Enugu residents in the most cost effective manner possible. To achieve this, field study, literature survey, and laboratory investigations were undertaken using the GIS facilities as analytic tools.

The objectives of the study are as follow:

1. To carry out an environmental base line survey of Enugu area as the basis for land use/suitability for various uses.
2. To locate areas that are relatively more suitable for residential, industrial and waste disposal land use options.
3. To compare the land capability against the existing land use with the intention of identifying the problems arising from any non compatibility.

1.7 SCOPE

The scope involves a desktop compilation of base line data in relation to land use planning. Considering and examining the appropriate environmental factors of land use determinants would help to produce or develop land capability index map for the area.

CHAPTER TWO

LITERATURE

2.1 LITERATURE REVIEW

The term land capability rating was introduced in a small community of Portolla valley California in the year 1950. This idea of determining the suitabilities of various land portions for certain land uses was aimed at avoiding major unstable areas, faulted and landslide prone zones for residential development, (Becker and Johnson, 2000). In recent years, computers have played an important role in the land use planning process because of their capacity to handle large volume of quantitative information (Froelich 1997).

Many scholars have made meaningful contributions on land use mapping. For example, Swinnen and Lissens (2000), indicated that effective land use studies should be made using a combination of maps, local knowledge and field excursions. Civico and Huru (2002), carried out a composite of several methods of land use selection and concluded that no single method can be used to solve the entire problems. Presently, remote sensing imagery, aerial photographs and GIS faculties are gaining upper hands in land use mapping, (Aria 2003). The author observed a study carried out in Australia and noted that natural land use mapping code adopted certain criteria which include a selection of national scale (1: 250000), viewing of maps and provision of access to data sets, as well as detailed geologic and engineering studies. Civico and Huru (2002), presented a flow chart of land use planning in Australia as problem definition and objectives, basic ground studies of land use determinants, plan preparation and application.

Most geologic studies in Australia was undertaken using aerial photographs and field investigations. In Mc. Henry country in California, the regional planning consists of a compilation of basic soil and geologic data maps.

Arthur and Irwin (1982), in identifying an area for waste disposal listed a set of data, such as bedrock geology, depth to water table, surficial materials, erosion vulnerability and flood zones. Some aspects of land use studies have been done in parts of Nigeria using models. For example, in the study of aquifer vulnerability to pollution in Owerri area Nigeria, Ibe *et al* (2001), made use of four models. These are LEGRAND, GOD, SAIGA and DRASTIC models in the selection of waste disposal land use option. The parameters employed involved rating and point count systems which are based on the evaluation of various parameters in relation to their capacity for enhancing or attenuating contaminants in the groundwater system . The major parameters are the aquifer zone, static water table, hydraulic head distribution, geology and unsaturated zone characteristics. Soil and geological information have been used effectively to assess the intrinsic groundwater vulnerability by utilizing existing data in soil and geological information. Some authors have enumerated the basic criteria for some land use options, for example, Montgomery (2000), set up a criteria for industrial land use such as drainage as well as soils with high load bearing strength. Mongkolsawat and Ponp (1991), indicated that areas with a slope of 10% or less are good for industrial establishment. The more steep a slope is, the more costly grading and preparation of land become. For this reason, in the assessment of topography for land use option, slope classification and slope types were identified as important factors (Sidle 1985). The author noted that a slope 2% - 6% is flat enough for development, slope > 12% provides septic problem while slopes > 20% can cause severe problems. For industries, slopes of 0-5% are ideal. Slope shape, influences the distribution of soil water, while concave slope concentrate soil water and cause slide, convex slopes distribute soil water and are least prone to slide (Sidle 1985).

Related to slope in the same study is the soil thickness, texture and drainage conditions. Soil overburden should be considerable. Soils that are suitable for waste disposal should have thick layers of fine grains as well as impermeable sediments as the base. Well drained, coarse textured soil can present severe limitations. Shallow ground water tables and poor soil drainage conditions cause problems in septic tank installation, while a depth to bedrock of less than one meter, present serious limitations to development . Shah and Ghandi (2004), enumerated the land use mapping procedure as data collation, interpretation of data, drafting of land use map, field checking, GIS editing and final land use map. In the evaluation of residential land use selection, Deckshatolu (1987), considered such variables as topography, flooding, climate, geology, and geologic hazards as well as hydrology. Others are economic and social factors. Mongkolsawat and Ponp (1991), in their use of remote sensing data in conjunction with GIS technology in the selection of site for industry, defined a set of themes required for the mapping as slope (gradient), elevation, land cover, soil type and terrain. A digital terrain model (DTM) which provides slope (gradient and elevation), was generated from existing topographic maps. The mapping procedure include several steps of image interpretation and ground truth survey. Ahmadu (1999), also did a comprehensive land use mapping of the central water shed area of Iran based on satellite data interpretation .

Many workers have studied some aspects of the environmental geology of Enugu area and its environs. In the feasibility study of the erosion/ land slides in Enugu area, Ofomata (1985), noted that about five sites of instability was observed in territories of steep slopes having sandstone outcrops sculptured by a dense hydrographic drainage. The Atterberg limits show a general lack of plasticity and high porosity (39% to 56%). The angles of internal friction vary between 30^0 and 42^0, while cohesion values are on the average of $0.2kg/cm^2$. Ofomata (1985), also indicated that areas liable to flooding are located at the foothill of the Enugu escarpment along a few stretches of Ora and Nyaba rivers. Ugwuogo (1989), studied the geotechnical characteristics of the Enugu Shale clays and their implications on engineering structures and foundations and observed that Enugu shaly clays may have a cohesion lower than 15kpa and angle of internal friction of around 15^0. Okeke and Ihediwa (2001), studied geotechnical characteristics of Mamu Formation. They observed that the formation is weak for building constructions. Generally, shales with cohesion lower than 20kpa and an apparent angle of internal friction of around 20^0 or less are likely to present construction problems, (Aria 2003). Nwankwor *et al* (1988), studied the mode of groundwater occurrence and flow pattern in the Enugu Coal Mine Area. The result indicated that the 9th Mile Corner area and environs are the recharge zones. The Enugu plains east of the area are the discharge environment. The depth to water table ranges from about 65m in the 9th Mile area to about 6m in the Enugu Township. In some of the plains area, water has a high level of coliforms, (Ezeanyim 1988, Ugochukwu 2000). This indicates that the underlying aquifer is vulnerable to pollution and further suggests that wastes should not be disposed off indiscriminately in those areas.

Nwankwor *et al* (2004), did a single purpose residential land use study of Enugu area, using analogue method of data overlaying and observed that the present densely populated areas fall within the low capability zone of their studies. This growth was noted to be mainly in response to the needs of the early miners to settle close to the coal mines rather than as a planned development.

2.2 GENERAL ENVIRONMENTAL SETTING

CLIMATE

The area is located within the rain forest belt of Nigeria and has an average annual rainfall of about 1100mm a year (Iloeje 1981). According to the author, the rainy season lasts from April to October with heavy down pour which results in heavy flooding and soil erosion. The dry season which lasts from November to March is characterized by dry and dusty harmattan winds causing high evapotranspiration rate. High temperature and low relative humidity prevail during the period. The wet season is associated with low temperature of around 30^0C and high humidity of around 90%, while the dry season temperature is about 32^0C with humidity between 60-70%, Mananu (1995). The meterological data for Enugu area is shown in appendix 23.

Passage of the overhead sun and rainfall seem to be the two factors influencing the annual diurnal temperature variations (Mananu 1995).

Pressure and Air Masses: Figure 2, shows the pressure and wind pattern which affect the climate of the study area. The tropical maritime air mass originates from the Atlantic ocean and supplies the area with abundant rain especially during June/July months. The Tropical continental air mass which originates from the Asian and Sahara desert, pick little or no moisture and therefore brings dryness around December to January. It starts to retreat in March and by July, it is completely absent. The seasonal variation of rainfall shows that July is the middle of wet season. At this period, the relative humidity is high because the warm wet air masses prevail. The study area experiences a double maxima of rainfall, one in June/July and the other in September/October (Iloeje 1981)

In July-August, the South Westerly winds blowing across Enugu axis have little incentive to rise because the sun is not overhead to generate convectional currents, and so they drop little or no rain. This comparatively dry period is known as August break. It forms a gap between two periods of heavy rainfall, one in May-June-July and the other in September –October.

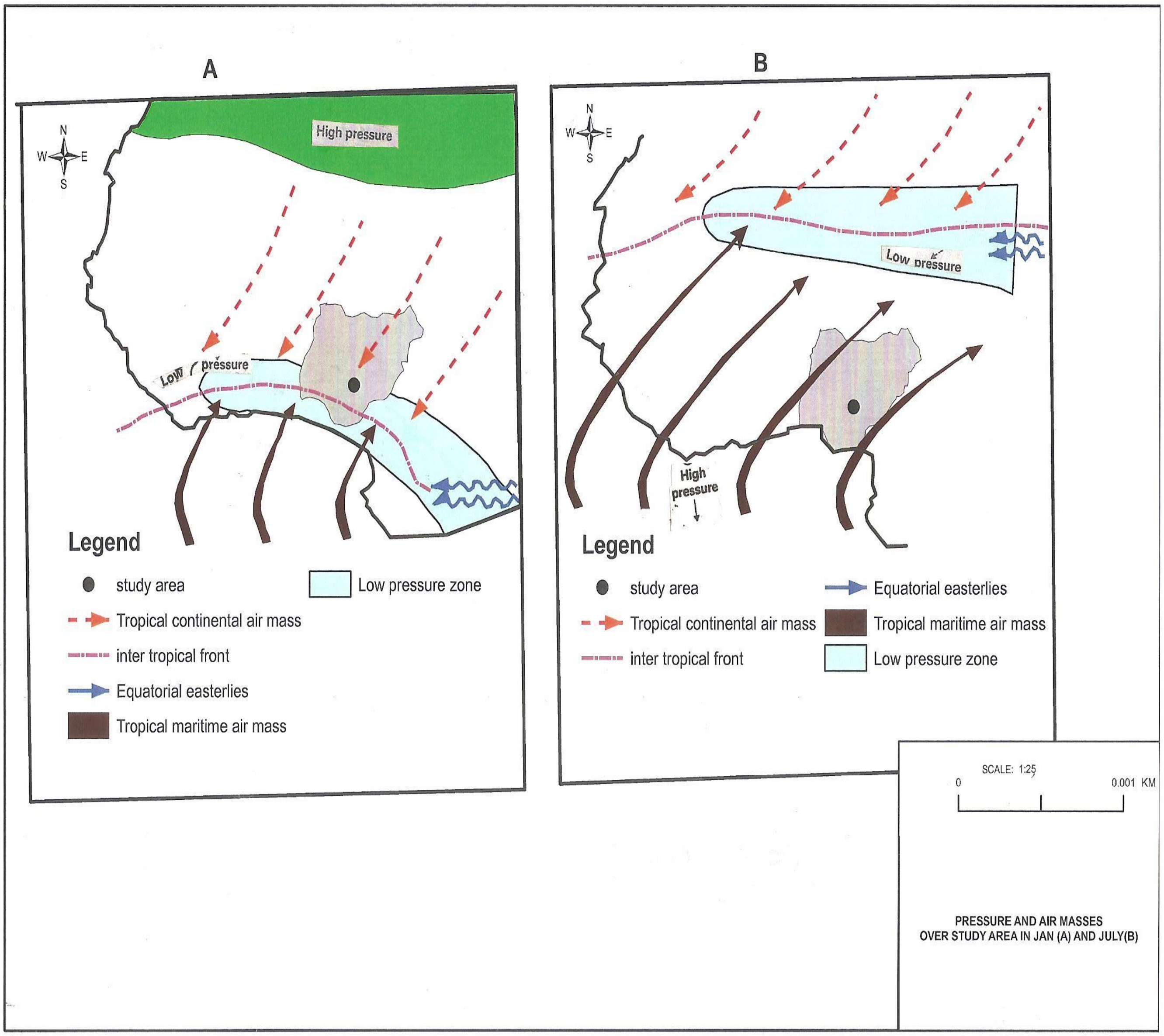


Fig. 2: Climatic Map of the Study Area
(Source: Iloeje 1981)

GEOMORPHOLOGY/ PHYSIOGRAPHY

The most striking feature within the study area is Enugu-Awgu escarpment (Fig. 2a). This escarpment is part of Nsukka-Okigwe Cuesta, a prominent landform region in eastern Nigeria. The Enugu escarpment is formed by the resistant sandstones of the Mamu Formation and the lower part of the Ajali Sandstone which forms the gentle upper slopes and crest of the escarpment (Reyment 1965) There is a gentle rise in slope from the west to escarpment crest. Towards the east , the slope falls abruptly from the scarp face unto the Cross River plains. North of Enugu, the crest remains at between 457.31 metre and 487.80 metre, but there is a gentle descent to the plains. The escarpment has a rugged and heavily dissected valleys to the east and broad rolling dip slope to the west. The summit of the escarpment is broad with gentle slopes. The elevation of the escarpment ranges from about 450 metres to about 530 metres, while the slopes range from about 3% to 6% in the dip slope to between 55% and 65% along the scarp face (Ofomata 1985). Terminating at the foot of the escarpment is an extensive undulating plane underlain by Enugu Shale.

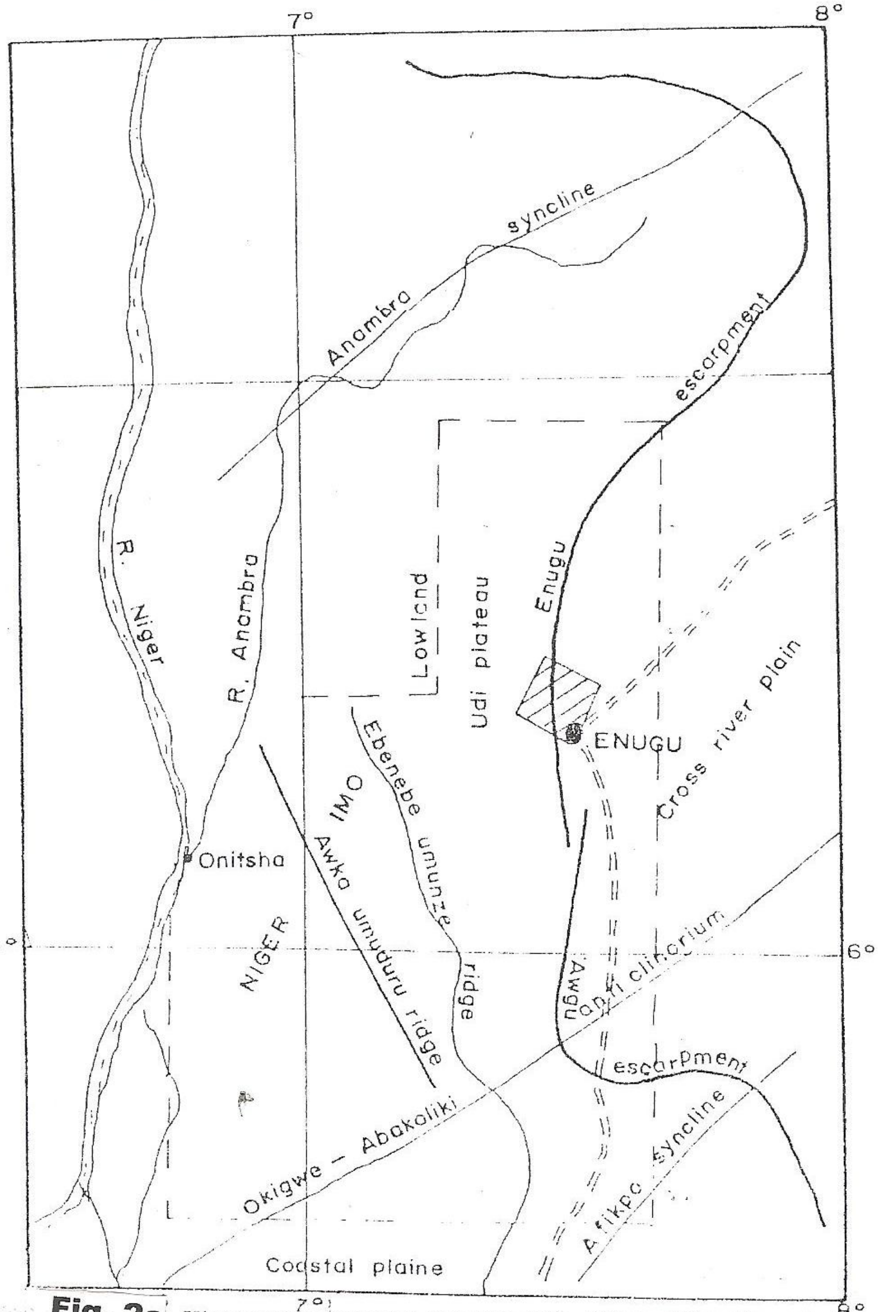


Fig. 2a Escarpment Map of the Study Area

after simpson (1954)

DRAINAGE

The Enugu-Awgu Escarpment form the most important watershed separating the Cross River system to the east from the stream network flowing west wards. The escarpment is much indented by river valleys, most of the streams rising at about 304.88m contour and flowing in deep canyons and v shaped gullies incised in the soft false bedded sandstones and superficial sands (Offodile 1973). The streams which rise in the middle levels of the escarpment near the base of the false bedded sandstones are perennial but the valleys at higher levels are dry except for short periods during the rains. The head waters of the Cross River system rise from springs in the Enugu and Awgu escarpments. These springs descend with frequent water falls formed by the hard sandstones beds that are sometimes capped by coal seams (gboka 1983). The valleys widen at the foot of the escarpment and the streams wind east wards across the plains. The rivers and rivulets give rise to dendritic pattern of drainage. This pattern develops upon rocks of uniform resistance, (Egboka 1985). The drainage map of the area is shown in Figure 2b.

The geology and drainage of the area are related. The geology consists of the impermeable Enugu Shale overlain by permeable sandstone units of the Mamu Formation and highly permeable Ajalli Sandstone (Reyment 1965). This sequence results in high rate of infiltration. The ground water seepages at the middle horizon of the escarpment occur between the Ajalli and Mamu Formation and the interface between Mamu and Enugu Shale as well as from the fractures within Mamu Formation (Uma 1987). These seepage waters gather to form perennial springs that emerge from the base of Mamu Formation to feed Ekulu, Iva, Ogbete and Nyaba Rivers. Mamu Formation contains sandstones, shale, mudstone and sandy Shale beds. This sequence form the lithologic variations along the vertical succession of the escarpment. This Formation can be divided into two units in the study area.

They are the sandstone / shale unit and the white sandstone unit. These constitute the aquifers and aquicludes that form the source of springs at the middle level of the escarpment.

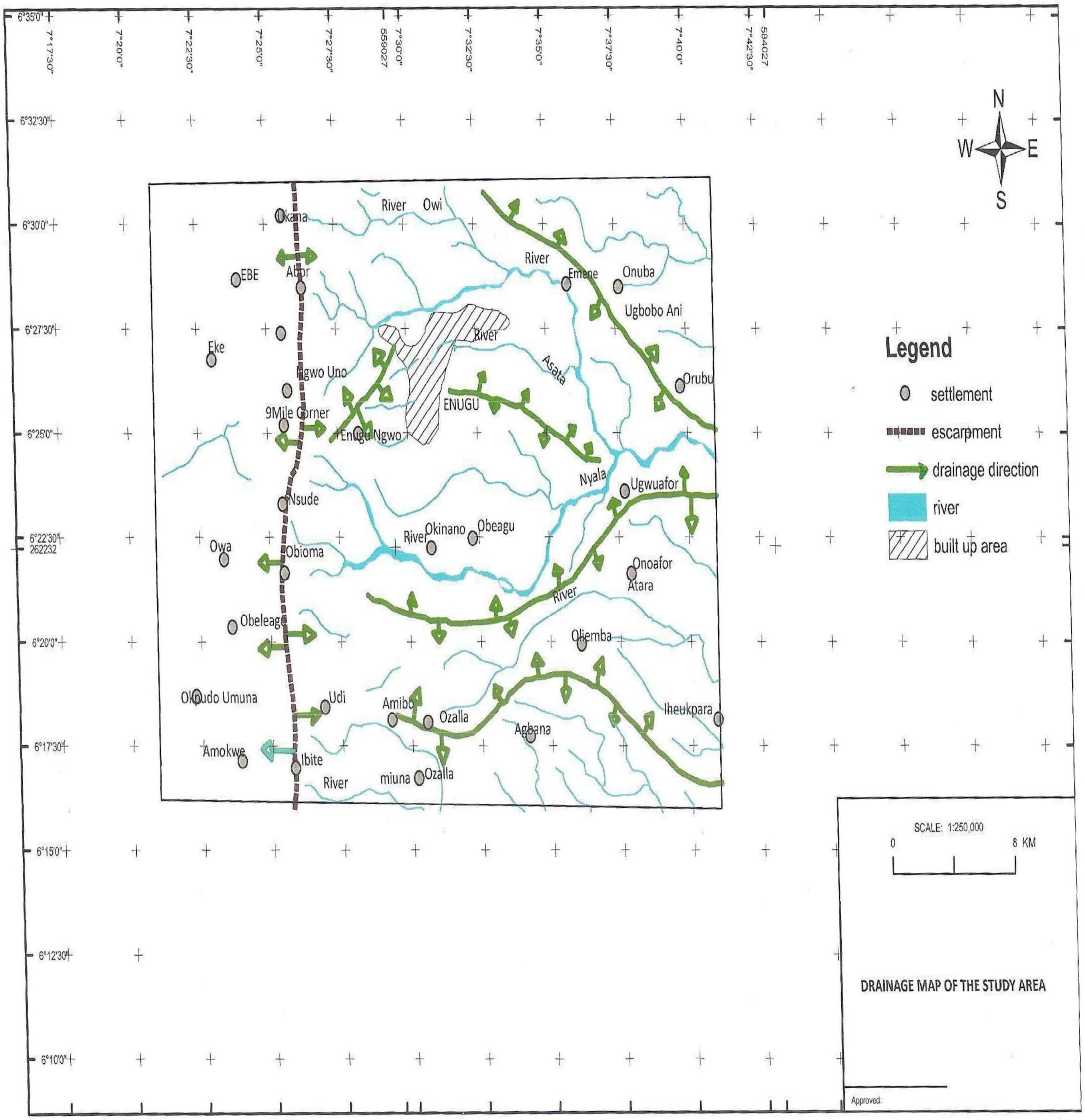


Fig. 2b: Drainage Map of the Study Area
(Source: Enugu State Ministry of Agriculture)

GEOLOGY

Geologically, the study area lies within the Anambra Basin of South Eastern Nigeria. The basin is of Cretaceous to Tertiary age (Reyment 1985, Murat 1972). Five formations underlie the area namely Ajali Sandstone (Upper Maestrichtian), Mamu Formation (Lower Maestrichtian) Enugu Shale (Campanian –Maestrichtian), Awgu Ndiabo Shale (Santonian) and Ezeaku Formation (Turonian) (Fig 3a).

The stratigraphic succession is shown in table 1a and 1b. The Formations are conformable, although minor discordance may be present, but there is no evidence of any prolonged break in sedimentation (Simpson 1954).

The fractured Enugu Shale underlies plains east of the escarpment. It consists of soft gray blue to dark grey shales with fragment bands and nodules of clay- iron stone. These shales weather rapidly to red clay soil which form lateritic caping of considerable thickness.

The Mamu Formation contains sandstones, shale, mudstone and sandy-shale beds which are fine to medium grained and white to yellow in colour and normally well bedded. Coal seams in commercial quantity occur, and frequently alternate with thin bands and lenses of sandstone. The Formation is about 395m thick in the study area and is highly fractured (Simpson 1954). Such variations in lithology within small thickness is indicative of frequent changes in faces common to low energy environment (Reyment 1965).

The Ajali Sandstone is about 406m thick. It consists of thick, friable, poorly sorted sandstones, typically white in colour but occasionally iron stained (Amajor 1984). The Ajali Sandstones are marked by bands of coarse and fine layers. The bed, have a regional dip 1^0 to 3^0 N (Kogbe 1975). The sands are dominantly of coarse clastic nature, poor to well sorted and coarse to fine. Petrographic study on several thin sections by Shadiya 1979, and Okwuosa 1986, showed all the sandstones in the study area as quartz arenite.

All the sandstone show mineralogical maturity. Feldspars are generally less than two percent. The grains are generally sub-angular to sub-rounded. The sandstones are commonly poorly cemented. This characteristic enhances the ground water potentials of the sandstones.

Ezeaku Shale (Turonian to Coniacian) consists largely of hard, flaggy calcareous shales and siltstones which are usually dark grey or black in colour minor bands of sandstones are also present. The Formation is underlain by Asu River group. (Albian).

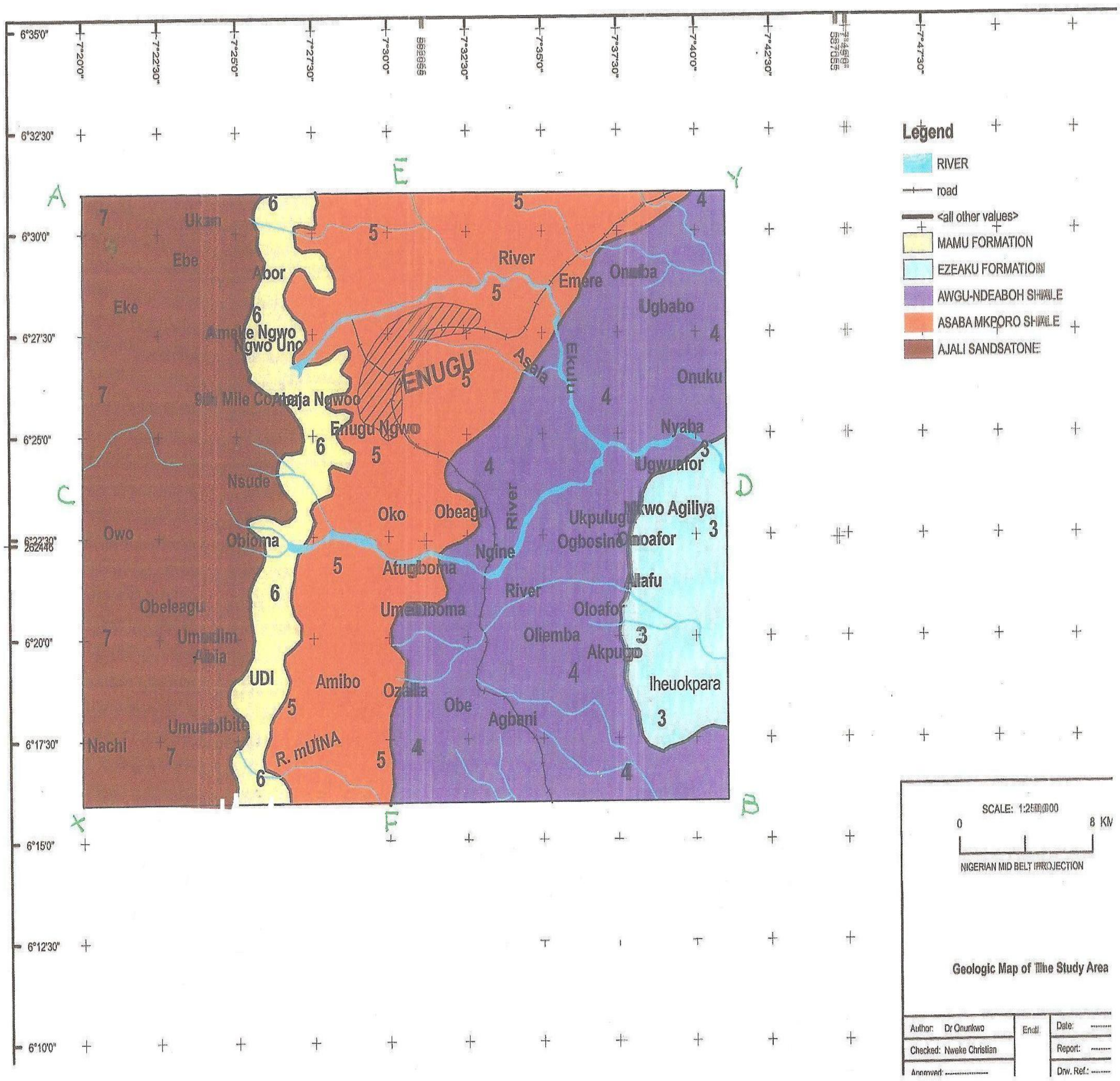


Fig 3a: Geologic map of Enugu Area and Environs

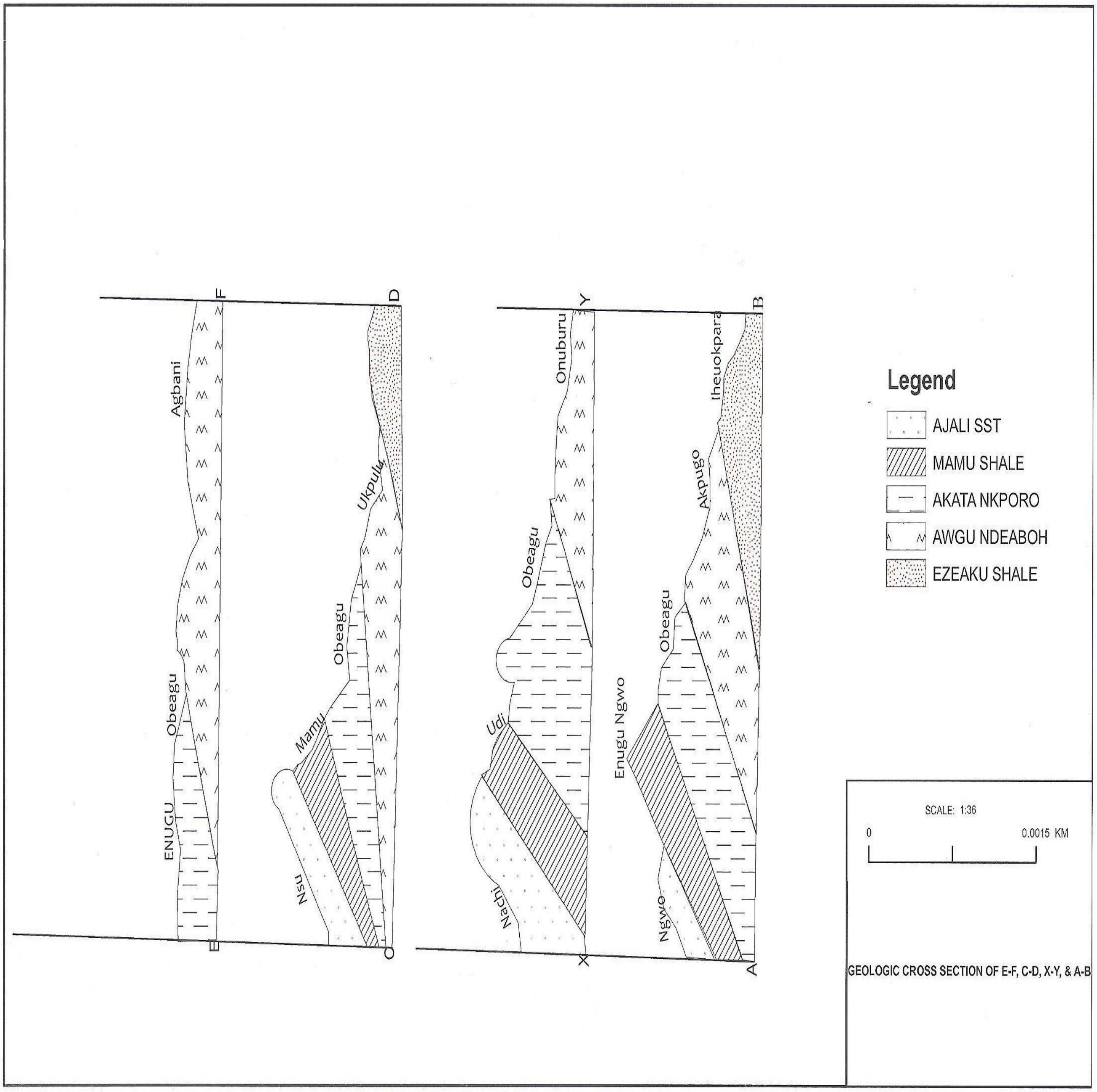


Fig. 3b: Cross Section EF,CD, XY and AB

Table 1a GENERALIZED SEDIMENTARY SEQUENCE IN SOUTH EASTERN NIGERIA (Modified from HOQUE,1976)

<table>
<tr><td>AGE</td><td>LITHOSTRATIGRAHIC SEQUENCE</td><td>PETROLOGY OF SANDSTONE</td><td>BASIN</td></tr>
<tr><td>EOCENE</td><td>Ameki Formation</td><td rowspan="5">QUARTZ ARENITE</td><td rowspan="5">ANAMBRA
AND
AFIKPO BASIN</td></tr>
<tr><td rowspan="3">PALEOCENE
UPPER CRETACEOUS
MAESTRICHTIAN</td><td>Imo Shale
Nsukka Fm.</td></tr>
<tr><td>Ajali Sandstone</td></tr>
<tr><td>Mamu Fm.</td></tr>
<tr><td>CAMPANIAN</td><td>Nkporo/Enugu Shale</td></tr>
<tr><td>CONIACIAN
SANTONIAN</td><td>Awgu Shale</td><td>FELDSPATHIC SANDSTONE</td><td rowspan="3">ABAKALIKI
BASIN</td></tr>
<tr><td>TURONIAN
CENOMANIAN</td><td>Eze–Aku Shale
Odukpani Fm.</td><td></td></tr>
<tr><td>LOWER CRETACEOUS
ALBIAN</td><td>Asu River Group</td><td></td></tr>
</table>

Table 1b GENERALIZED SEDIMENTARY SEQUENCE IN SOUTH EASTERN NIGERIA (REYMENT 1965)

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

STRUCTURAL SETTING

The beds have regional dip to the west of 1^0 to 2^0 (Fig 3b). There are two fault systems – Obwetti and Eva. The Obwetti fault system has hades 283^0 and strikes at 324^0 with throw of 12ft (3.66m). It consists of a group of close parallel fractures running generally S 28^0 E. The Eva fault system is well developed with numerous fractures that are parallel to the Obwetti fault system. Beside these two important faults across the area, there are the minor ones the Juju (70 metres displacement) and the Hayes fault. The Hayes fault has hade 20^0, it strikes 330^0 and has a throw of 10metres. The Juju fault cuts the base of a long ridge running East of Enugu scarp. There is no indication that the faults are active. Fig 4 shows the location and orientation of the various faults.

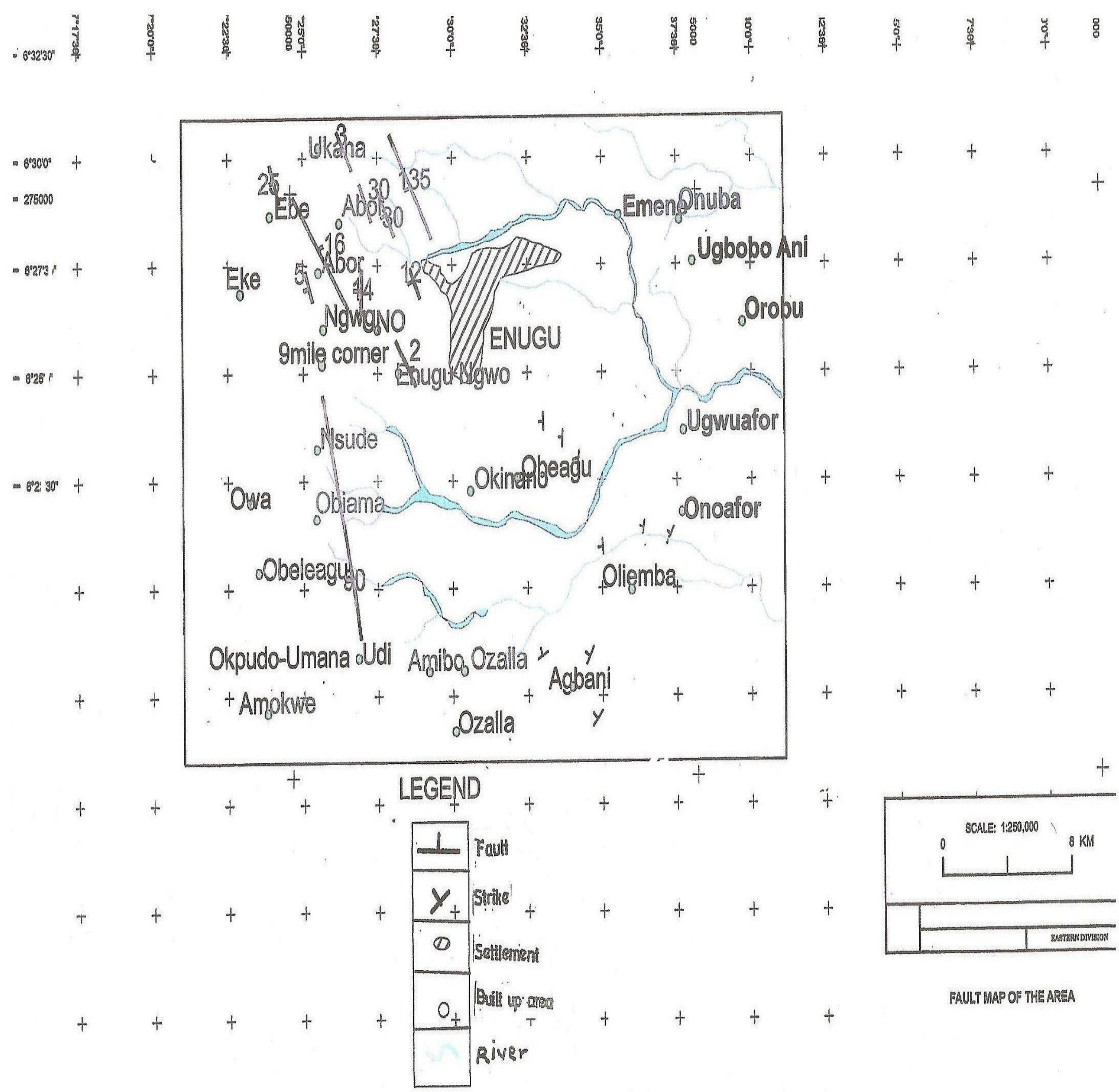


Fig. 4: Fault Map of the Study Area
Source: Nigeria Geological Survey Dept,

HYDROGEOLOGY

The hydrogeology of Enugu area has been studied in details by a number of workers such as Nwankwo *et al* (1988) and Ezeanyim (1988).

The main aquifer unit occurs in the Ajali Sandstone to the west with the water table lying at a depth of 30 to 40 meters. Aquitards occur within the Enugu Shale. The aquitards are fractured and are tapped by handdug wells. These wells show high coliform counts (Ezeanyim 1988). Towards the east, Enugu Shale contains aquifer within the sandstone units and weathered shales. Yields are however small and subject to marked seasonal variations. In the eastern axis of Enugu area, the water table occurs at an average depth of 5 metres to 9 metres. At the crest of the escarpment, springs occur as spring eyelets from the sandstone unit cut back into the shaley unit of the Mamu Formation (Egboka 1985). This was also observed during field studies. The generalized water table configuration of the area is shown in Figure 5. It shows that water depth varies from the west to the east. At the western section of the study area, water table elevation is low, on the average of 160metres. At the eastern section of the Cross River plain, the water table elevation is high, and approaches the surface at the average depth of 9 metres. The GPS elevation measured at Agbani area, is 135ft (41.16m). Also within the area, it was discovered that most of the outcropping Enugu Shales within the eastern area are weathered. The weathered Enugu Shale and Agbani Sandstone are the aquiferous units.

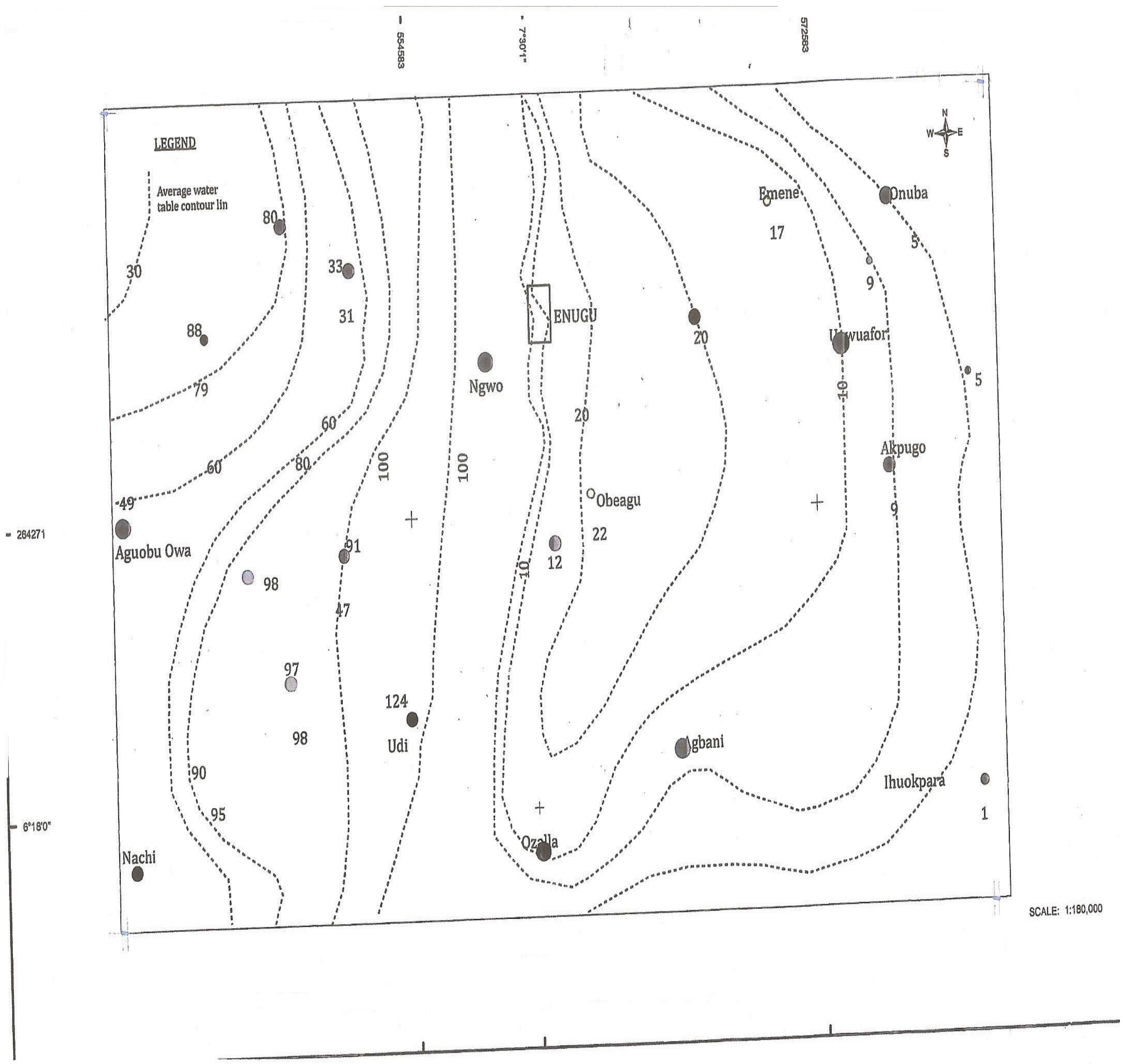


Fig. 5: Water Table Map of the Study Area
(Source: Enugu State Water Corporation, and Field

SURFACE WATER HYDROLOGY

The hydrology of the area is governed by the physical characteristics of the landscape and the geology. Enugu and Awgu escarpments which run north and south form the most important watershed separating the streams that flow to the east of the Cross River Basin from the streams flowing westwards to Imo River and Niger River Basins. There are as many as 30 rivulets originating as springs from the deeply incised valleys of the scarp face. These springs form water falls developed by the hard sandstone beds capped by coal seams (Simpson 1954). The rivulets combine to form the major rivers (Nyaba, Eva, Asata and Ekulu).

WATER SUPPLY SITUATION

Despite the high annual rainfall of about 1100mm, in the region, shortage of water still persists over some parts of the area (Groove 1951). The Ajali Sandstone aquifers constitute the major groundwater supply from the springs emerging from the head waters of the major rivers. Aquitards occur within Enugu Shale to the east. The sandstone units of Enugu Shale provide insignificant seasonal water supplies. The aquitards which are fractured are tapped by several hand dug wells. The residents living close to the crest of the escarpment, travel several kilometers down the slope in search of water.

VEGETATION

Harrison-Church (1957) noted that the zonation of climate is closely related to the zonation of vegetation. This applies also to the area under study. Eastern Nigeria falls within the tropical rainforest of West Africa which has a remarkable diversity of vegetation types. Igbozuruike (1975) divided Eastern Nigeria into vegetation zones in which Enugu area falls within the rainforest-savanna zone. The forests occur on the scarp face while the savanna types are found in the eastern and western areas of the escarpment (Fig 6). However, the present vegetation in the area is really secondary type due to intense farming. The densest vegetation cover occur at the scarp face and along river channels especially Ekulu and Nyaba Rivers (Adejuwon 1973).

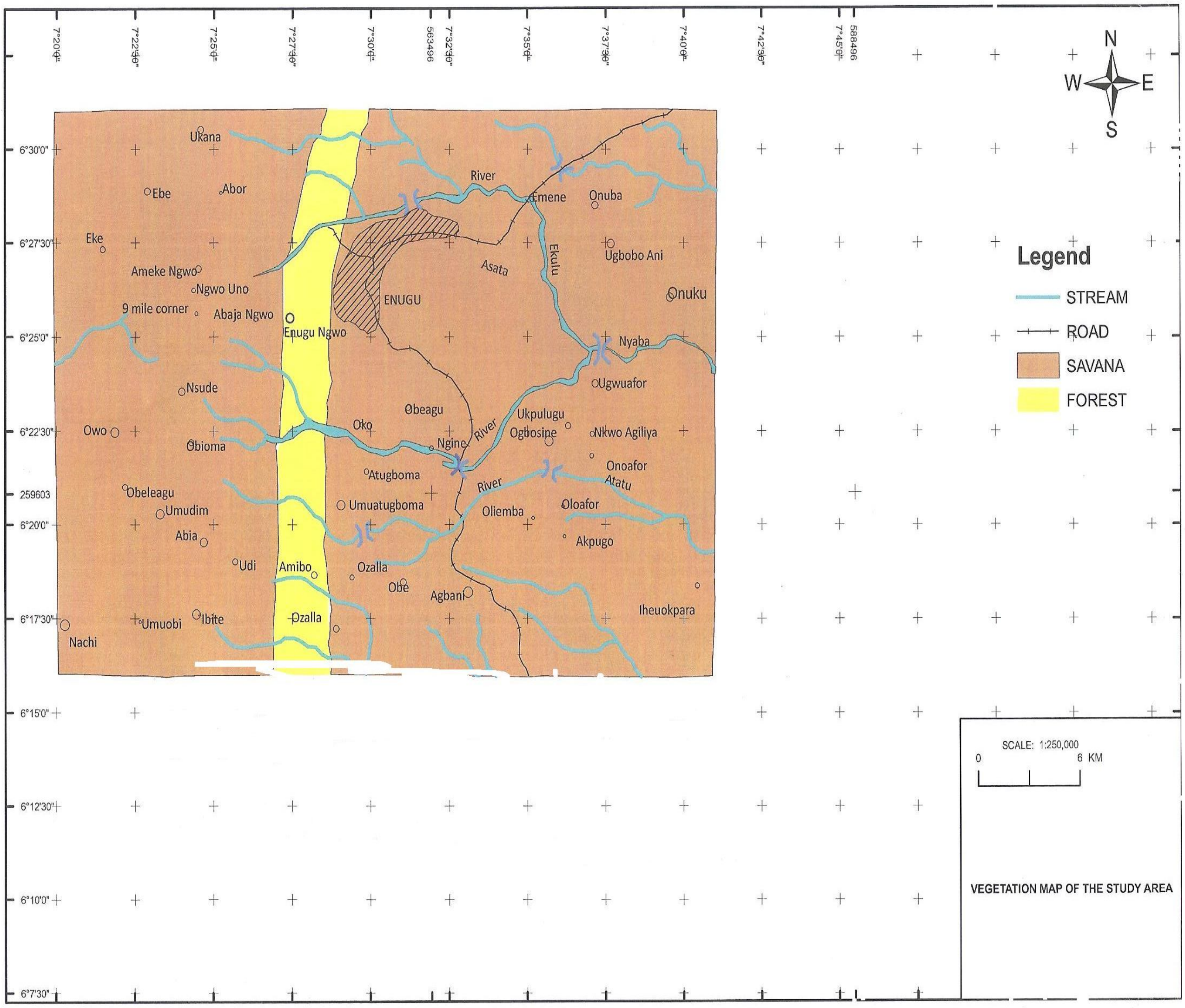


Fig. 6: Vegetation Map of Enugu Area and Environs
(Source: Adejuwon 1973)

SOILS

The major soils of Enugu area are ferralithic and hydromorphic products of Ajali sandstone and Enugu Shale (Ogbukagu 1976);

The soils derived from Enugu Shale are expansive and have hydraulic conductivity values of about 10^{-8}m/s making them poor drainage materials while those derived from Ajali Sandstone have conductivity values of about 10^{-5}m/s (Egboka and Onyebueke 1999). These soils can be grouped into four classes as

Ferralithic Soil: Ferralithic soils are deep, friable and porous. They are normally formed where weathering and leaching processes have reached their final stages. The soil has low reserve of weatherable minerals (Hunt, 2002).

Hydromorphic Soil: These are soils which are vertisols or saline. Some of the criteria for characterization of this soil is their morphology, texture and depth. Under these conditions we have dystric gleysols and are the clayey hydromorphic soils, their pecolation rate is very slow and have poor to imperfect drainage (Gauley and Krone 1966). Eutric gleysols have unweathered shale fragment and hard iron stones. Their percolating rates are higher. The impermeability of the subsoil impeded the free movement of water.

Lithosoils: These are thin soils mostly found on hill slopes. At Enugu this soil group correspond to scarp environment (Ofomata 1985). They are weakly developed soils, shallow, with no genetic horizon. They have solid rock within 30cm depth. Since they are young soils, and products of recent weathering, they usually contain abundant weatherable minerals.

Foralithic Soil: These are ferralithic soil having sand members. They have moderate to high permeability. The soil map of the study area is shown in (Fig 7).

Fig 7

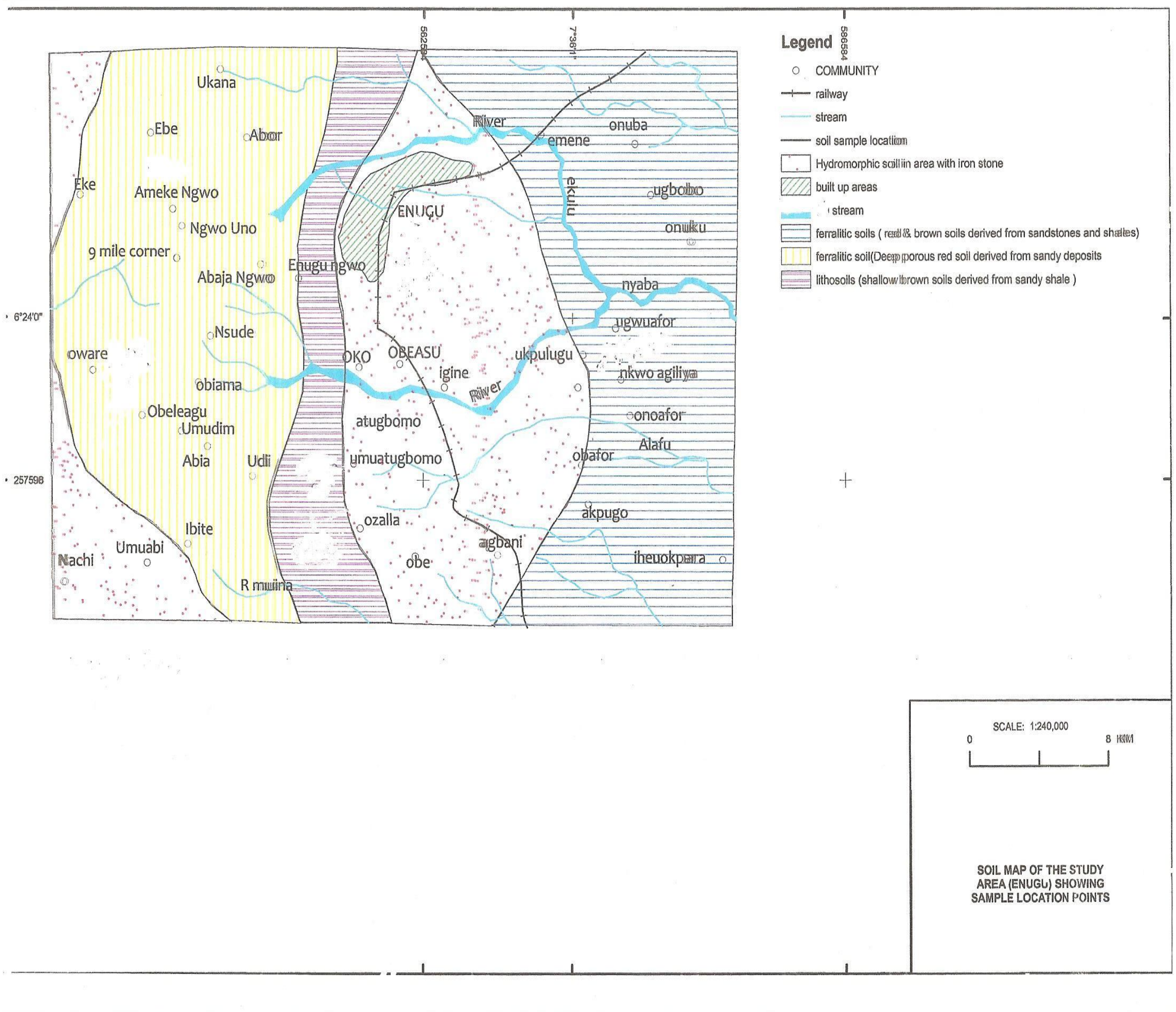


Fig. 7: Soil Map of the Study Area
(Source: Enugu State ministry of Environment)

2.3 POPULATION AND INDUSTRIAL GROWTH

The provisional population totals as released by National Population Commission of Nigeria in 2006, indicates that Enugu area has a population of 3,237,298 (Vanguard 10th May 2007). Using this figure, Concept Eco Design International Consultants Ltd projected population of Enugu area to be in the range from 12,277,900 to 16,718960 by 2010 based on annual growth rate of 4% and 5% (Fig 8). With this projected population and the likely attendant increase in waste production, industrial and residential needs, there is the need to map out areas for residential, waste disposal and industrial establishments. These areas should be safe and environmentally acceptable.

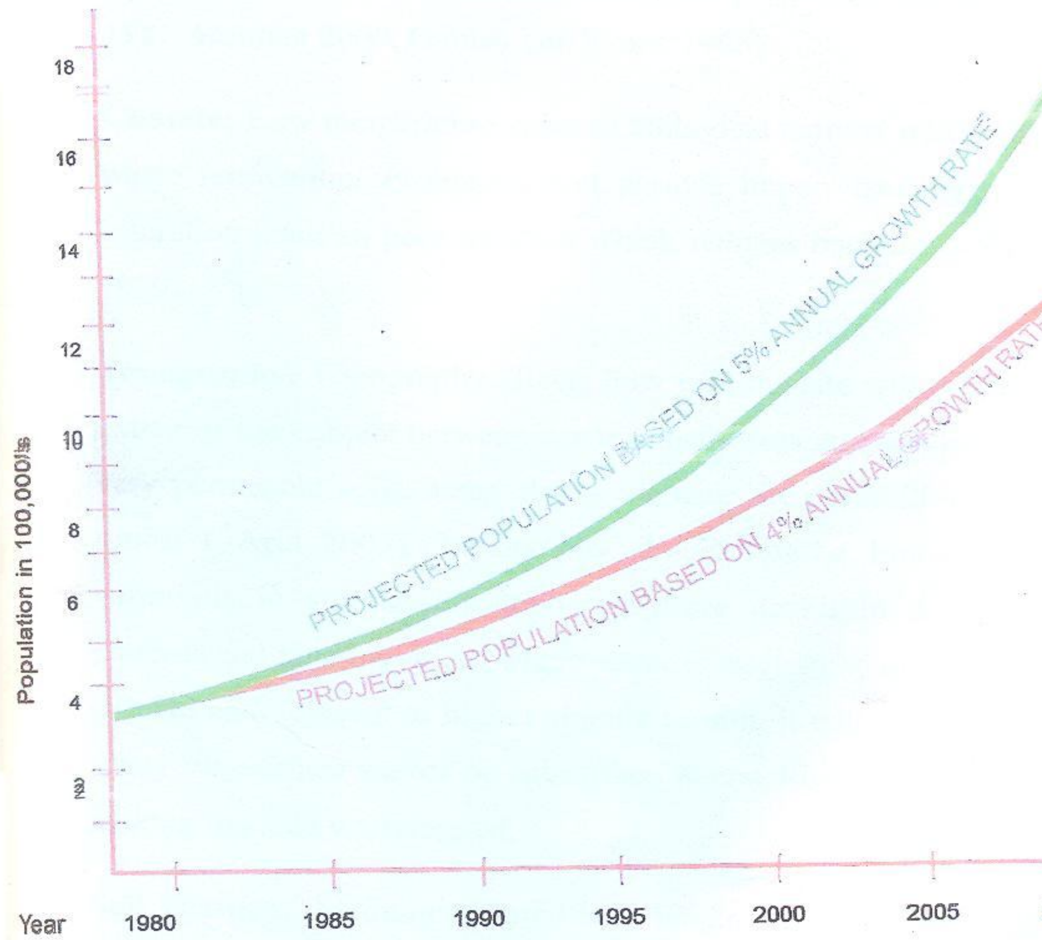


Fig. 8: Graph of Projected Population for Enugu, 1979-
(Source: Concept Eco Design Consultants Ltd, Enugu

2.4 SITING CRITERIA FOR WASTE DISPOSAL

According to Holman (2000), site evaluation for waste disposal involves a basic understanding of soil component and properties. The reaction mechanism operating in the soil and limitations of these mechanisms in terms of pollutant loading rates. Site evaluation describes the important criteria to use in evaluating land for waste disposal. The factors to consider are climate, topography, drainage characteristics, soil properties and geology (Griffiths, 1981, Holman 2000, Gauley and Krone 1966).

Climate: Low temperature reduces biological activity and reduces the rate of waste attenuation. Prolonged wet periods impair bacterial activity because saturation leads to poor aeration which reduces bacterial activity (Raymond 1979).

Topography: Topography affects how well the site will handle water and the extent of the contact between waste constituents and soil particles. Except on very permeable soils, steep slopes increase the possibilities of rapid surface runoff (Aria 2003). Topography should not be limited to slopes, local variations in surrounding topography are useful in determining drainage patterns and locating areas where water is discharged or accumulates. According to Chengliu and Evett (2000), if a site is level and adjacent to higher sloping terrain, it will probably receive excess water via surface runoff or subsurface lateral flow from the highland hence, making the area waterlogged.

Soil Texture: Medium textured soils ranging from sandy loams to silty clay loams are generally suitable. Coarse textured soils such as sands and gravels can accept large quantities of water without runoff, but attenuation capabilities are often low. (Davis and Rogers 1975).

Effective Depth of Soil: The actual thickness of the unconsolidated material above a permanent water table, bedrock, or some other restricting layer constitutes the effective depth of soil useful in the attenuation of wastes. For rapid, infiltration at least 3.05m of permeable unconsolidated material above a water table is generally recommended (Raymond 1979).

Drainage: According to (Mark 2001), drainage as a condition of the soil refers to the frequency and duration of periods when the soil is free of saturation. Soils which are very poorly drained, are not suitable for any kind of waste application. Well drained soils offer the greatest potential for waste treatment. (Crynine 1977).

Geology: Fractured rocks facilitate pollutant migration. Sites with more overburden are preferable, provided it is not a carbonate rock since solution channels provide pathways for the migration of contaminants (Hunt 2002).

Fault: Faults affect the stability of a facility and potential release of pollutants.

Other criteria to be considered during siting of waste disposal include cation exchange capacity (CEC). This is the capability of the soil to exchange cations. (Gauley and Krone, 1966). It also indicates the ability of soil to attenuate some contaminants particularly heavy metals. Soils with higher CEC are preferable.

Surficial Soils: This is an unconsolidated material at the earths surface. It affects the degree of attenuation. Surficial soils with lower permeability are preferable for waste disposal (Hammer 2003)

Ground Water: Sites with high ground water table should be avoided.

Aquifer Use: Aquifer with low potential use are preferable for siting purpose.

Ground Water System: Sites where direction of groundwater flow is upward are preferable.

Slope: Slope causes the release of contaminants. Slop > 22% are considered too steep (Sidle 1985).

Surface Water: Proximity to streams or lakes causes runoff and contaminants polluting lakes/streams. Also proximity to wells and aquifers should be avoided. Sites closer than 100m to a high yielding well should be excluded (Crynine 1977).

Proximity to flood prone zone: Land areas affected by flood of high frequency should be avoided.

Topography: High slope is unsuitable as this causes migration of contaminants by surface runoff (Aria 2003).

2.5 SITING CRITERIA FOR RESIDENTIAL AND INDUSTRIAL BUILDINGS

In the siting of residential and industrial buildings, a lot of factors has to be considered. Industrial buildings should be located in an area that will minimize the negative impacts on the natural environment. The factors to be considered are:

Topography/Slope: Industrial/ Residential buildings should be sited in an environment of flat or gentle slope (Sidle 1985). Sites with slopes of less than 15% usually do not create any serious problem in building construction. Construction is more difficult and costly on steep slopes (Dimitri and Krynine, 2003).

Flood Plain: The acceptable site should be at a distance of at least 1000meters away from the flood prone zone (Dunne and Leopold 2003).

Surface and Ground Water Resource: Building site for both industrial and residential purposes should be in an area of available surface/groundwater resource. Water is essential for industrial plants, chemical reactions as well as for human consumption. Care should be taken since high water table can cause a severe damage to foundations.

Soil Factor: Soils play an important role in determining the choice of a site for building of any type. Expansive soils are problematic in foundation engineering. In industrial buildings, the sensitive aspects to vibrations are relatively loose sands and gravels (Arthur and Irwin 1982).

CHAPTER THREE
METHODOLOGY

3.1 Methods of Study

The study was undertaken in stages namely: Desk studies, Fieldwork, Laboratory investigations and Ground truthing.

Desk Studies: Previous works related to the project were examined to assess data and techniques which would be employed in the execution of this task. Case studies of land use in different parts of the world were reviewed. This involved selection for various purposes across the world. Consideration was given to site selection for various purposes of land use within Murray Darling plain in Australia, the central water shed area of Iran, industrial location site in Japan, California, United States of America and Nigeria. Critical reviews were made on the mode, orientations of the approach, the parameters considered during information gathering and presentations. Information dealing on the subject of land use was down loaded from the internet and different texts. . Other ideas gathered from the works of Chin et al (1975); Crynine (1977); Florich (1977); Deckshatolu (1987), Nepomoceno (2003) and Ibe et al (2001), were integrated to design effective land use mapping model for residential, industrial buildings, waste disposal land use options.

Field Work: This was done by studying the rock and soil outcrops across the traverse axis of Enugu Area (N-S, E-W, NE-SW. SE-NW). Necessary measurements were made. These include strike and dip of beds as well as elevation.

Laboratory Investigations: The soils properties likely to influence industrial residential and waste disposal landuse, were measured in the laboratory.

Ground truthing: Information obtained from the resulting landuse maps, were investigated by revisiting some key areas for a check of accuracy.

3.2 LABORATORY STUDIES

The engineering properties of the soils of the area were investigated in the laboratory as to obtain information necessary for the rating of landuse determinants.

SURFICIAL SEDIMENTS /SOIL STUDIES

Soils vary enormously in their mode of formation, burial history, chemical composition, density and colour. The main factor affecting their physical behaviour is the size of the soil particles and consistency (Buol et al 2000). These characteristics are employed in the determination of soils class. The soils of Enugu area are forralithic soils, hydromorphic soils, ferralithic soils and lithosoils. The lithosoils are the soils of high slopes (Weltman and Head 1983). Ofomata (1985), studied extensively the geotechnical properties of the lithosoils in scarp environment area. His results were used in supplementing the present study.

Soil samples were collected at locations shown in (Fig 9). The general profiles and dispositions of the soils were first examined insitu, followed by soil sample collection. Fresh samples were collected at the average depths of 2 miters to 5metres, depending on soil thickness within the area. Stony surfaces, humus section and gravel beds were avoided. Soil collection was performed using polythene bags in accordance with ASTMD – 98 (2000) provisions, and then transported to the laboratory for the required analysis.

LABORATORY ANALYSIS

The laboratory investigations carried out on hydromorphic, forralithic, and ferralithic soils include:

1. Particle size distribution.(Including hydrometer analysis)
2. Atterberg limits.
3. Compaction tests
4. Compressive strength.
5. Shear strength tests.
6. Consolidation tests
7. Porosity and permeability tests.

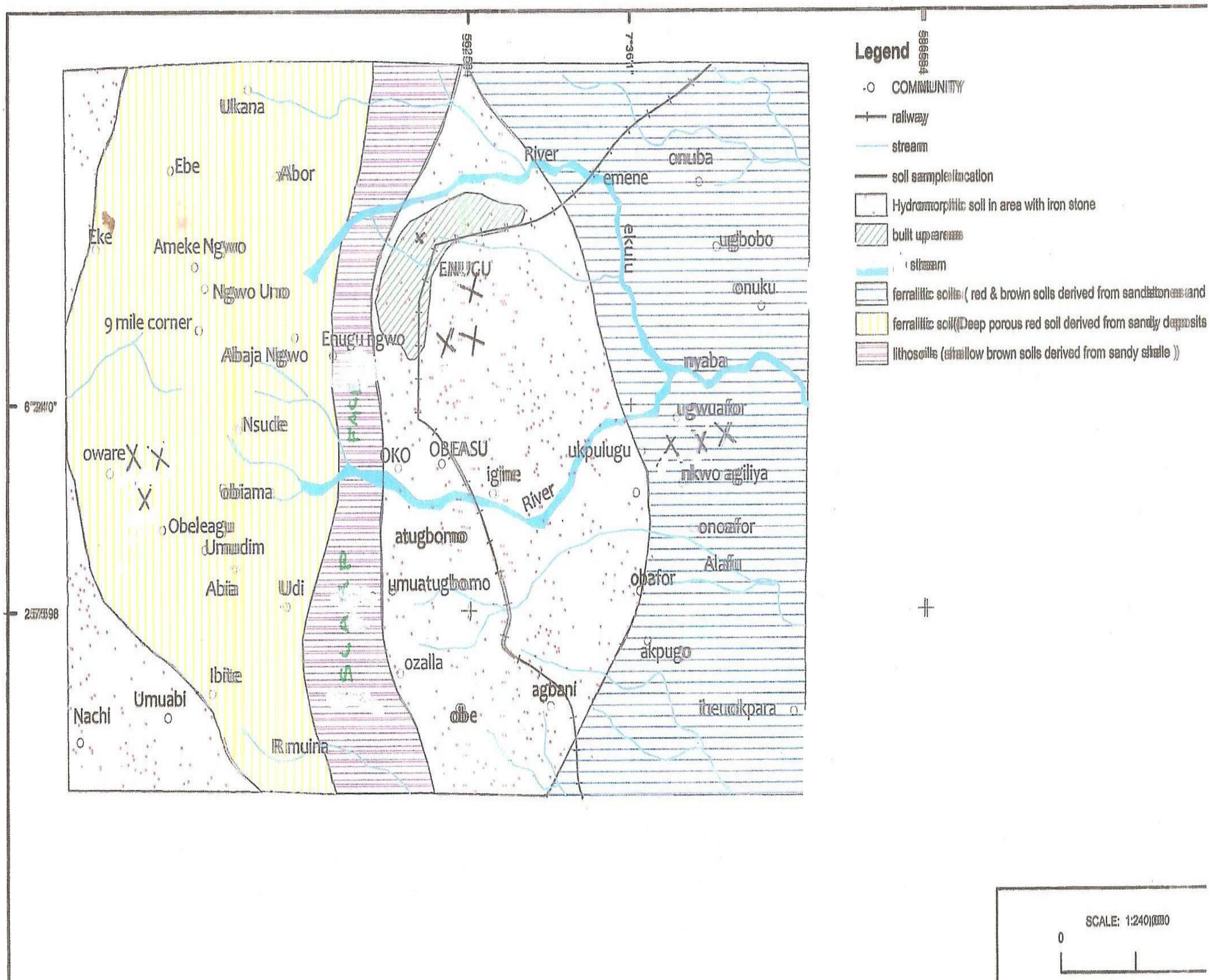


Fig. 9: Soil Sample Collection Points, Enugu

SOIL MAP OF THE STUDY AREA (ENUGU) SHOWING SAMPLE LOCATION POINT

PARTICLE SIZE DISTRIBUTION

The particle size analysis involves the determination of the percentage by weight of particles within the different size ranges. This analysis is performed in two stages namely:

i Sieve analysis.

ii Sedimentation Analysis (Hydrometer analysis)

The first stage is reserved for coarse grained soils, while the second stage involves the fine particles less than 0.075mm.

The test procedure for sieving is as described in ASTMD 422-98, (2000). The objective of this analysis is to obtain the relative grain size properties of the particles that make up the given mass of soil.

Samples for particle size distribution were thoroughly disintegrated by alternate cycles of wetting and drying as recommended by ASTMD 421-98, (2000). The disintegrated material was sieved through 3.35mm, 0.425mm to 0.075mm. The particle size of material passing 0.075mm sieve was determined using hydrometer method in accordance with ASTMD 421-98 (2000).

The particle size distribution of the soil often referred to as grading was done using British standard electric shaker machine. It was determined by passing a sample of soil through a series of sieves and weighing the portions retained. The particle size distribution curves indicate the range of sizes of the percentage of various grain fractions present. This would indicate the attenuative power of the soil in the handling of wastes, also indicates the strength of the soil. The particle size distribution data are presented in Appendices 1,2,3, and Figures 10,11,12. They show that foralithic soils can be grouped as silt-clay. Krynine and Judd (1957) observed that the grading of soil material blended with little fines makes it an excellent engineering material for the foundation of heavy industrial structures. According to the author, attenuative power of soil increases with fines.

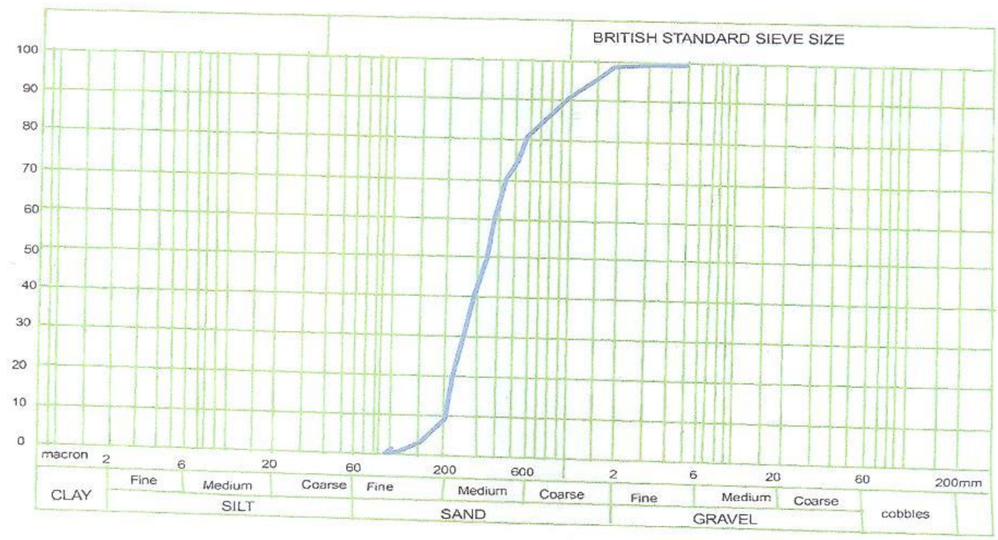


Fig. 10: Grain Size Graph of the Forralithic Soil (Owa

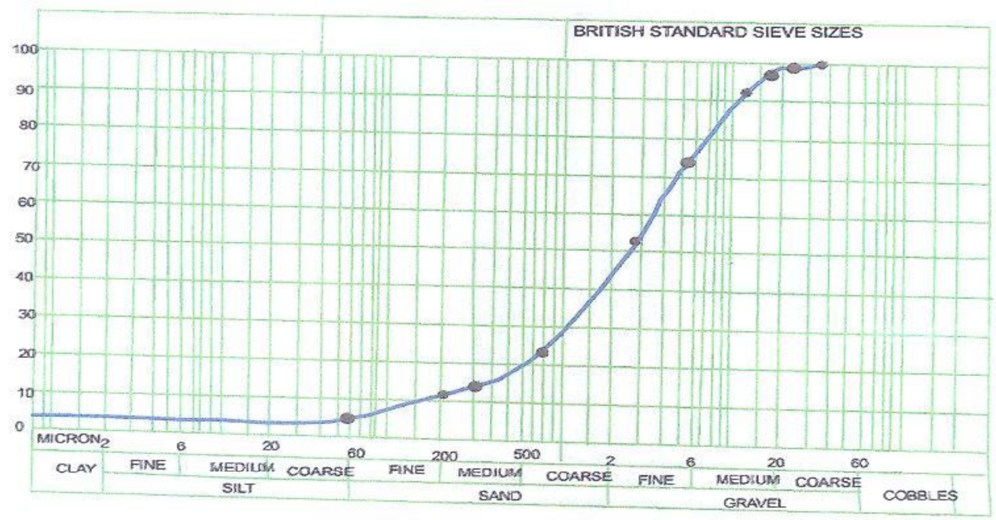


Fig.11: Grain Size Graph of the Ferralithic Soil

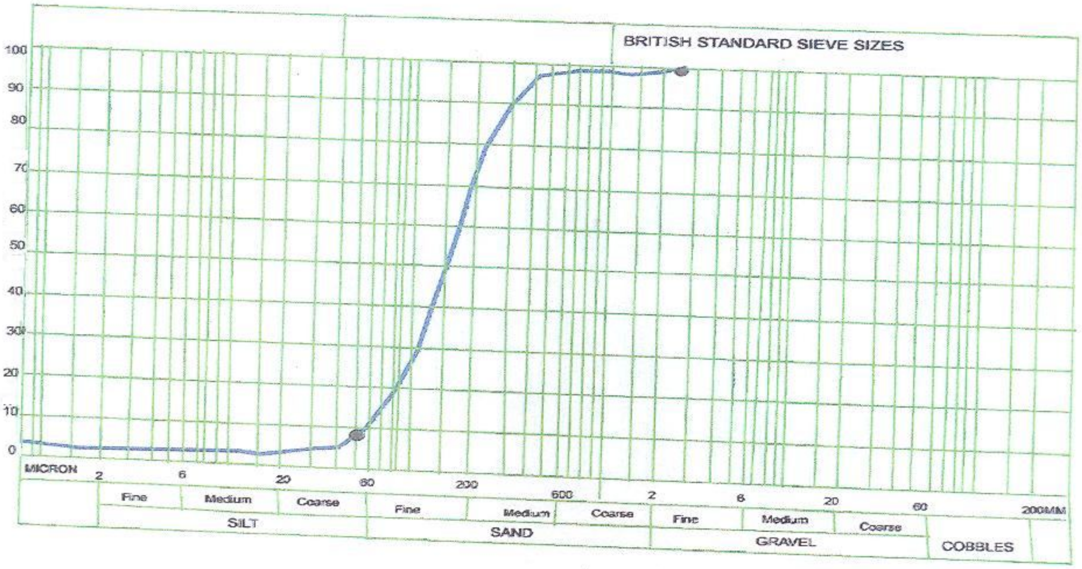


Fig. 12: Grain Size Graph of the Hydromorphic Soil (Enugu)

SEDIMENTATION/HYDROMETER ANALYSIS

The percentage of fines passing No 200 sieve correspond to 0.075mm. This is analyzed for grain size distribution using hydrometer apparatus. Only hydromorphic and ferralithic soils plot under this category.

Test procedure is as specified in ASTMD 422-98 (2000). The hydrometer analysis is based on Stokes law, which says that the larger the grain size of the soil, the greater the settling velocity in the fluid. The hydrometer analysis indicates the percentage of clay fraction present in a sample of soil. The experiment is carried out in Appendix 24.

The plot of hydrometer analysis for the two soil types, ferralithic and hydromorphic soils is shown in Fig 12a and 12b. The result shows that while the clay fraction of hydromorphic soil is 13%, that of ferralithic soil is 13.5%

ACTIVITY AND LIQUIDITY INDICES OF FERRALITHIC &HYDROMORPHIC SOILS

It is necessary to verify the activity and liquidity indices of the ferralithic and hydromorphic soil as this would give insight into their expansive nature. It is not possible to describe the activity of clay soils without the basic understanding of the natural moisture content of the material .The natural moisture content of the soil is an indicator of the amount of water present in the soil.

According to Robert (2001), the amount and type of clay minerals present in a soil have a significant effect on the soil engineering properties such as in plasticity, swelling characteristics, shear strength, consolidation and permeability. Robert (2001) defined activity (A) of clay as

$$A = \frac{P1}{\text{Clay Fraction}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where A = Activity, P1 = Plasticity Index . Clay fraction is that part of the soil finer than 0.002mm, based on dry weight. According to the author, inactive clays have activity less than 0.75, Normal activity is 0.75-1.25, while active clays have activity greater than 1.25 respectively.

Since, the clay fraction of ferralithic and hydromorphic soils are respectively 13.5% and 13% (See Figs. 12a and 12b), when these values are substituted in equation (1), and using plasticity index of 25.14 and 26.46, shows that ferralithic soil has activity (A) = 1.86, while hydromorphic soil has (A) = 2.04. This information shows that both the clay content of ferralithic and hydromorphic soils are in the range of active clays (Robert 2001).

Another parameter that measures the nature of clay content in a soil sample is liquidity index. The liquidity index of soils (L1) is the term also used to identify sensitive clays.

The liquidity index (LI) is given by the relation.

$$LI = \frac{w - PL}{PI} \quad \text{.............................(2)}$$

Where w = natural moisture content of the soil, PL = Plastic Limit and PI = Plasticity Index. The two soils tested for liquidity indices are hydromorphic and ferralithic soils of Enugu area. The test (Appendix 30) indicated that the natural moisture content of ferralithic and hydromorphic soils of the area are 5.2 and 6.3. Therefore, for Hydromorphic soil -

$$w = 6.3$$

$$pL = 16.89$$

$$PI = 26.46$$

The result of calculation shows that liquidity index of hydromorphic soil is – 0.40 while that of feralithic soil is – 0.23. This indicates that the two soil types have very low shear strength (Robert 2001). It should be noted that the shear strength of hydromorphic soil is by far smaller than that of ferralithic type.

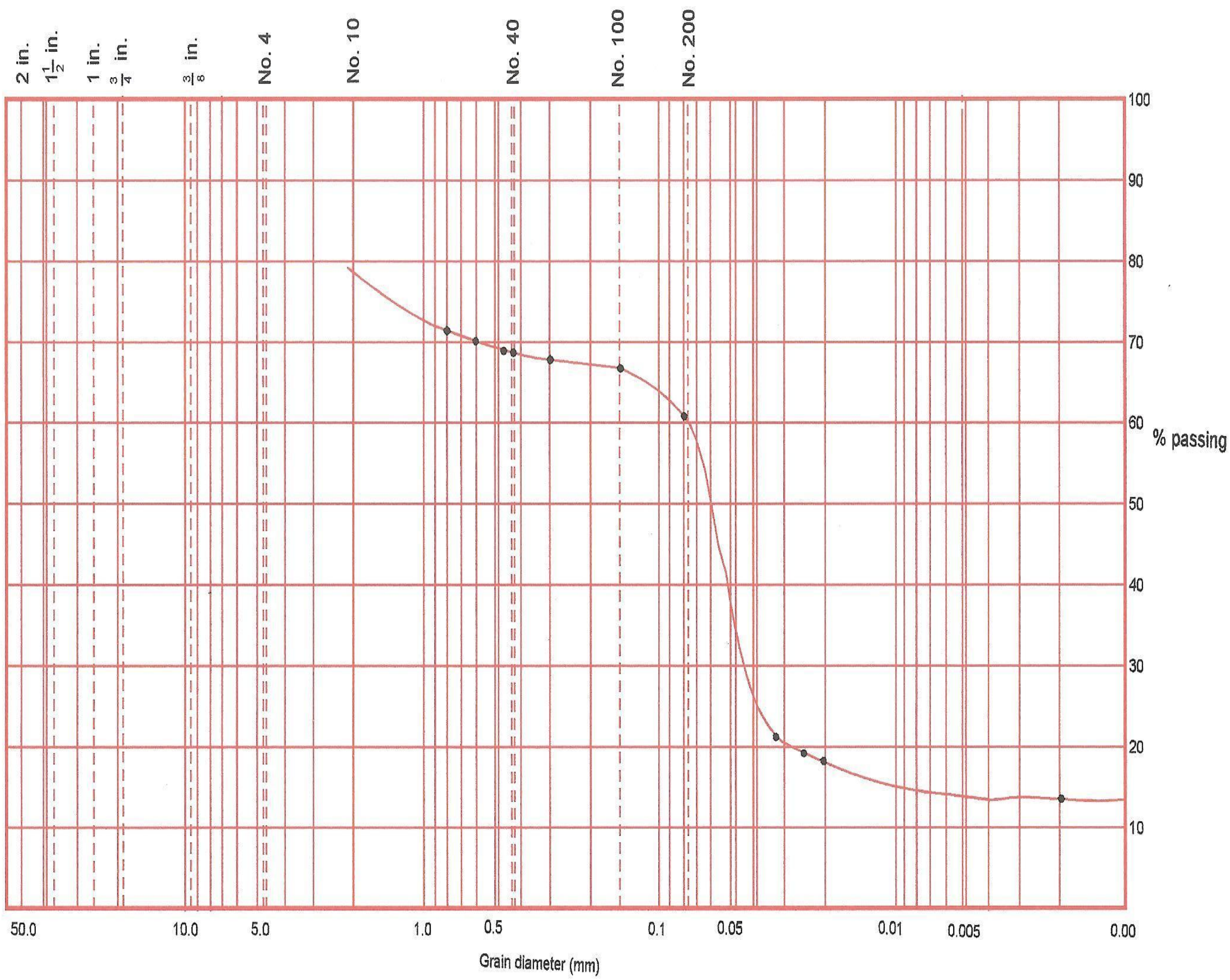


Fig. 12a: Hydrometer Analysis, Ferralithic Soil, Enugu

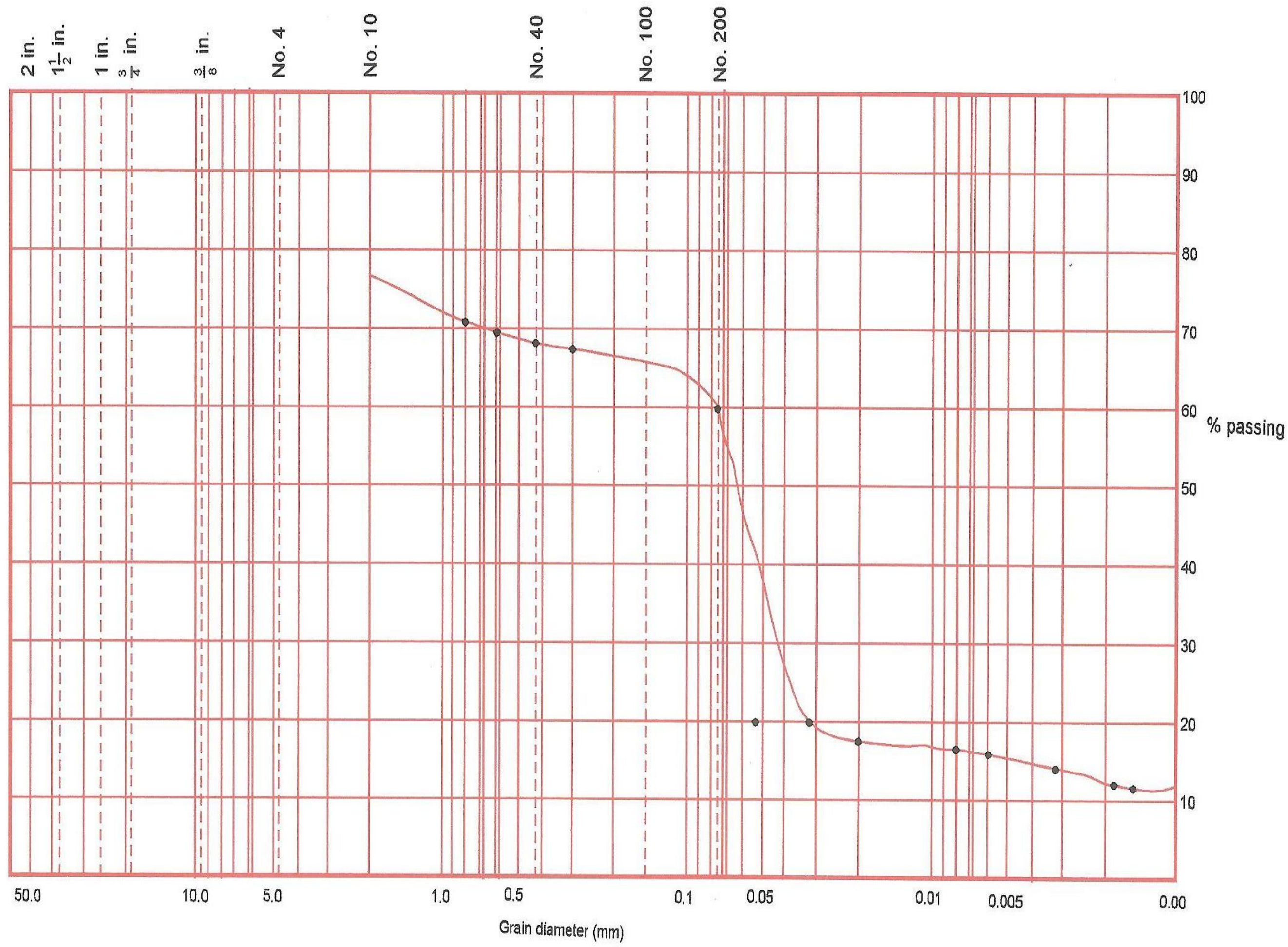


Fig. 12b: Hydrometer Analysis, Hydromorphic Soil, Enugu.

ATTERBERG LIMITS

Atterberg limits are moisture contents of the soil mass as it passes from one consistency stage to the other. The Atterberg limits are tests which are used to give empirical information on the soils reaction to water and helps to explain engineering attribute of the soil. Atterberg limits have four states of consistency for fine grained soils. These are liquid limit, plastic limit and shrinkage limit. They are useful numbers in soil engineering classification and are valid in making judgments with regards to the soils applications. The liquid and plastic limits are the water contents at which the shear strength of the soil becomes so small, that the soil 'flows' to close a standard groove cut in a sample of soil when it is jarred in a standard manner.(Bell 1992).

Atterberg Limits were determined following the procedure outlined in ASTMD 4318-98 (2000) and ASTMD 4318-98 (2000). The results are shown below for various soils of Enugu area.

Forralithic Soil:	Liquid Limit (%)	=	26.06
	Plastic Limit (%)	=	19.75
	Plasticity Index	=	6.31
Hydromorphic Soil:	Liquid Limit (%)	=	43.35
	Plastic Limit (%)	=	16.89
	Plasticity Index	=	26.46
Ferralithic Soil:	Liquid Limit (%)	=	39.84
	Plastic Limit (%)	=	14.70
	Plasticity Index	=	25.14

The results clearly show that the Plasticity Index of hydromorphic and Ferralithic soils are high. This indicates 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). Appendix 18 shows Federal government of Nigeria's specifications for building constructions and foundations. The table indicates that hydromorphic and ferralithic soils of Enugu area are not suitable for building foundations. The failure of two storey building at Independence Layout, Enugu in 2002, (as announced by Enugu State Radio Corporation within the said period), is likely to be as a result of this non suitability. Above all, field observation made in some areas of Enugu, especially within Independence Layout, shows that majority of the buildings develop cracks, and this is likely to be due to the expansive nature of the soil.

COMPACTION TESTS

Compaction test is another laboratory investigation carried out as an aid to characterization of the soils for construction purposes. Results of compaction tests (see appendices 8, 9 and 10) were used to determine the optimum moisture contents at which a given soil has to be compacted in order to attain maximum dry density. The compaction test was determined in accordance with ASTM (1988). Bell (1992), indicated that compaction increases soil density thereby increasing the soils shear strength, decreases future settlement and the soil's permeability. As the moisture content increases, dry density increases to a certain maximum then decreases (Weltham 1994). Plotting dry density against moisture content gives a moisture density curve corresponding to a given compactive effort (Dimitri and Crynine 2003). The result of the test is shown in Table 2a.

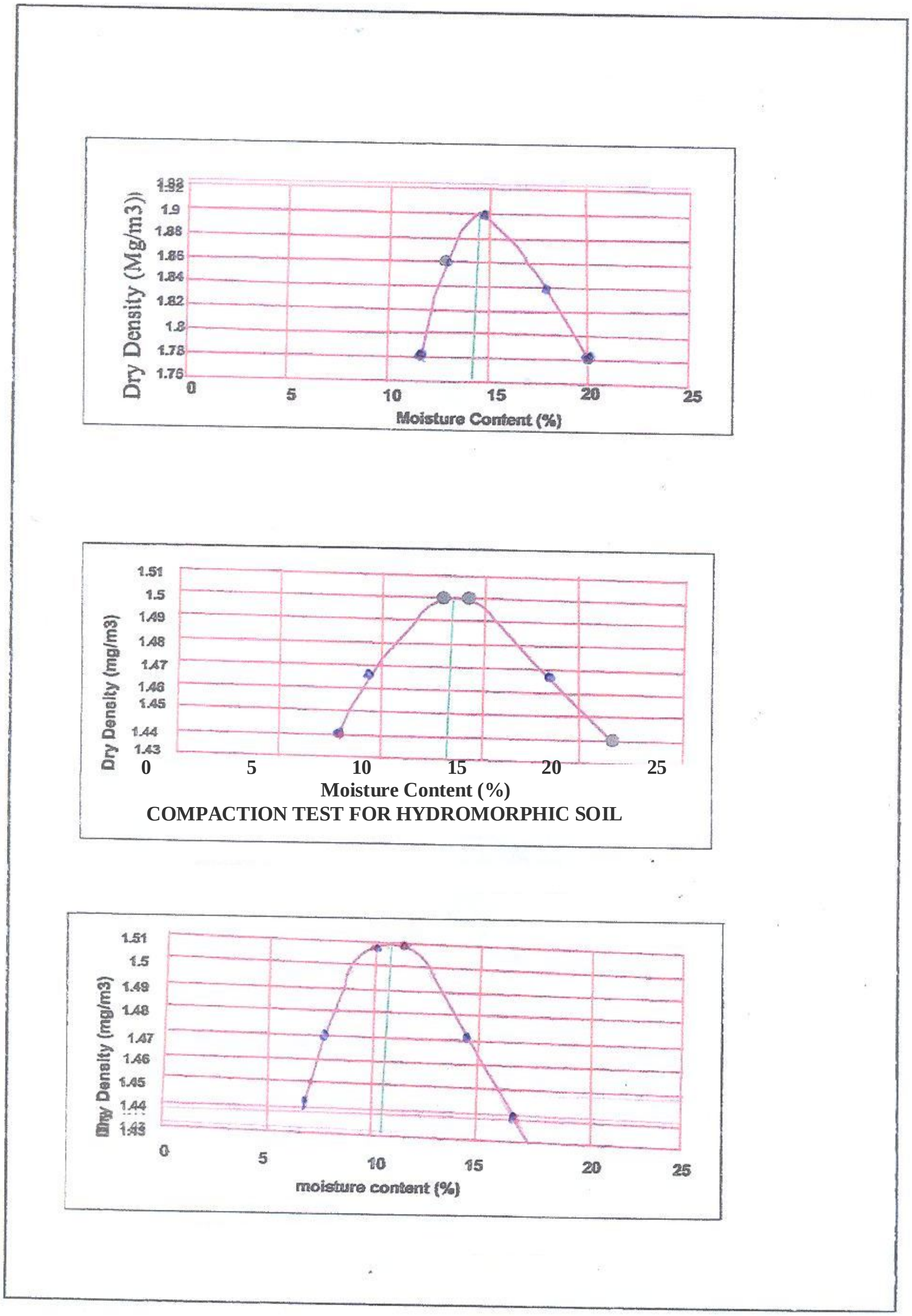
An examination of the maximum dry density (MDD) of the three soils indicate that Forralithic soil has higher maximum dry density. A comparism of the engineering properties of the soil with standard specifications for engineering purposes as shown in appendix 18, shows clearly that the Forralithic soil investigated for maximum dry density and optimum moisture content satisfies the specification of accommodating industrial structure and residential buildings. The lower dry density and higher moisture content of the hydromorphic and ferralithic soils indicate that the soils have higher affinity for water. Figure 13 shows the graph of moisture content plotted against dry density. The graph indicates the maximum dry density (MDD) of the soils with their corresponding optimum moisture content as:

Ferralithic Soil: MDD = 1.51, OMC = 11.02

Hydromorphic Soil: MDD = 1.52 , OMC = 13.01

Forralithic Soil: MDD= 1.90, OMC = 14.0

Table 2a summarizes the result.



ig. 13: Compaction Test Graphs for the Forralithic, Ferralithic and Hydromorphic

Table 2a RESULT OF COMPACTION TEST

SOIL TYPE	MOISTURE CONTENT			OMC
Forralithic Soil	1 13.35	2 14.80	3 20.30	14
	DRY DENSITY			MDD = 1.90
	1 1.86	2 1.90	3 1.78	
Hydromorphic Soil	MOISTURE CONTENT			OMC =13.01
	1 13.12	2 14.23	3 20.3	13.01
	DRY DENSITY			MDD=
	1 1.50	2 1.50	3 1.44	1.52
	MOISTURE CONTENT			OMC
	1 7.45	2 11.1	3 11.4	11.02
Ferralithic soil	DRY DENSITY			MDD
	1.51	1.51	1.50	1.51

COMPRESSIVE STRENGTH

The compressive strength test of the residual soils was also carried out to ascertain the strength of the soil samples. Compressive strength of a soil mass is the stress required to break a loaded sample that is unconfined at the sides. The compressive strength of soils depends on their porosity. The move compact the soil is, the higher the compressive strength. According to Terzaghi and Peck (1967), any rock or soil mass with a compressive strength between $2KMN^{-M2}$ and $7KMN^{-M2}$ are moderately weak, while those above these values are high. Hence the result obtained from the experiment is shown below as :

Forralithic Soil has compressive strength of $9.10MN/M^2$, Test load is $56.44MN/M^2$

Hydromorphic Soil has compressive strength of $2.176MN/M^2$, Test load is $14.43MN/M^2$

Ferralithic Soil has compressive strength of $2.10MN/M^2$, Test load is $20.16MN/M^2$

From these, it is clear that ferralithic and hydromorphic soils are of weak strength while that of forralithic soil is on the high side.

SHEAR STRENGTH

Another engineering property of the residual soil sample considered is shear strength. This is the resistance of the soil mass to shearing stress under a given normal load. The shear strength of a rock depends on the angle of internal friction and the cohesion between the particles of the material (Weithman and Head 1983).

The shear strength test was performed by undrained triaxial shear test in accordance with ASTMD 4767-95 (2000)

Equipment: The triaxial device consists of a heavy steel cylinder filled with liquid which supplies the lateral pressure. The specimen was placed in a rubber jacket placed at the axis of the cylinder and pressed by an upward acting force against the heavy cover of the same cylinder. This was done in accordance with ASTMD 4767-95 (2000) specifications. Forralithic, Hydromorphic and Ferralithic soil were tested.

Two tests were conducted for each soil. The compressive strength in both cases is the unit axial load at failure.

Sample Collection and handling: The sample was collected at the locations already specified. Core cutter was used to collect the samples in test pits. The samples were then placed in a square box in an undisturbed manner and carefully transported to the laboratory for shear strength measurements. The test results were analyzed by plotting Mohr Circles for the stress conditions of each specimen when failure occurs. The results of the experiment plotted on Mohr-graph is shown in Figs 14,15,16. This was accomplished with the results shown in Appendix 33. From the graphs, the cohesion value of forralithic soil is low. The hydromorphic and ferralithic soils show high cohesion, there is likelihood of shear failure. Saturated clays fail if subjected to vibrations. (Braja 1998). The Mohr-Coluomb failure specified for the computation of shear stress is

$$\tau = c + \delta n \tan \varphi \qquad \text{.........................(3)}$$

Where τ = Shear strength of soil in N/M^2 or Kpa

C = Cohesion

δn = Effective stress on soil N/M^2 or Kpa

φ = Frictional angle based on total stress analysis.

From the graphs, and applying equation (3), the shear strength is as follows:

Hydromorphic soil is 85.56N/M^2, average value = 88.56 N/M^2 (+Lit.Inf.)

Forralithic Soil is 96.09N/M^2, average value = 100.09 N/M^2 (+Lit.Inf.)

Ferralithic soil is 87.82N/M^2, average value = 90.82 N/M^2 (+Lit.Inf.)

Lithosoils: Information on Lithosoil of Eungu area according to Ofomata (1985) shows the following:

Shear Strength	=	88.36N/M^2
Compressive Strength	=	2.04N/M^2
Optimum Moisture Content	=	9.25N/M^2
Maximum Dry Density	=	1.63
Liquid Limit	=	28.06%
Plastic Limit	=	20.45%
Plasticity Index	=	7.61%
Soil Type	=	Silty Sand, Poorly graded
Porosity and permeability	=	0.30 and 1.70 x 10-2 cm/s
Consolidation value:		Void ratio (e) = 0.892,
Coefficient of volume settlements	=	1.23.

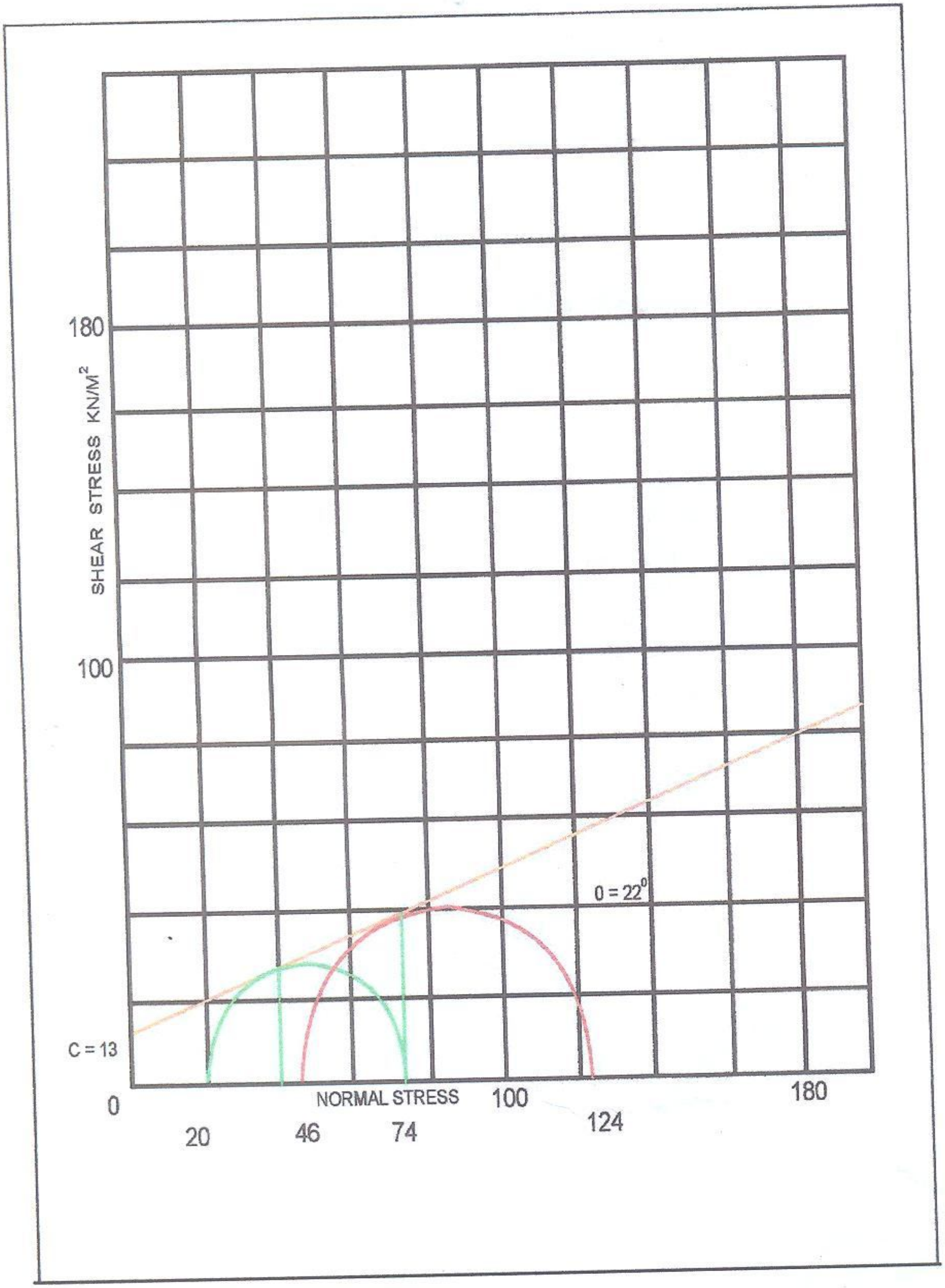


Fig. 14: Shear Strength Graph for the Forralithic Soil (Owa)

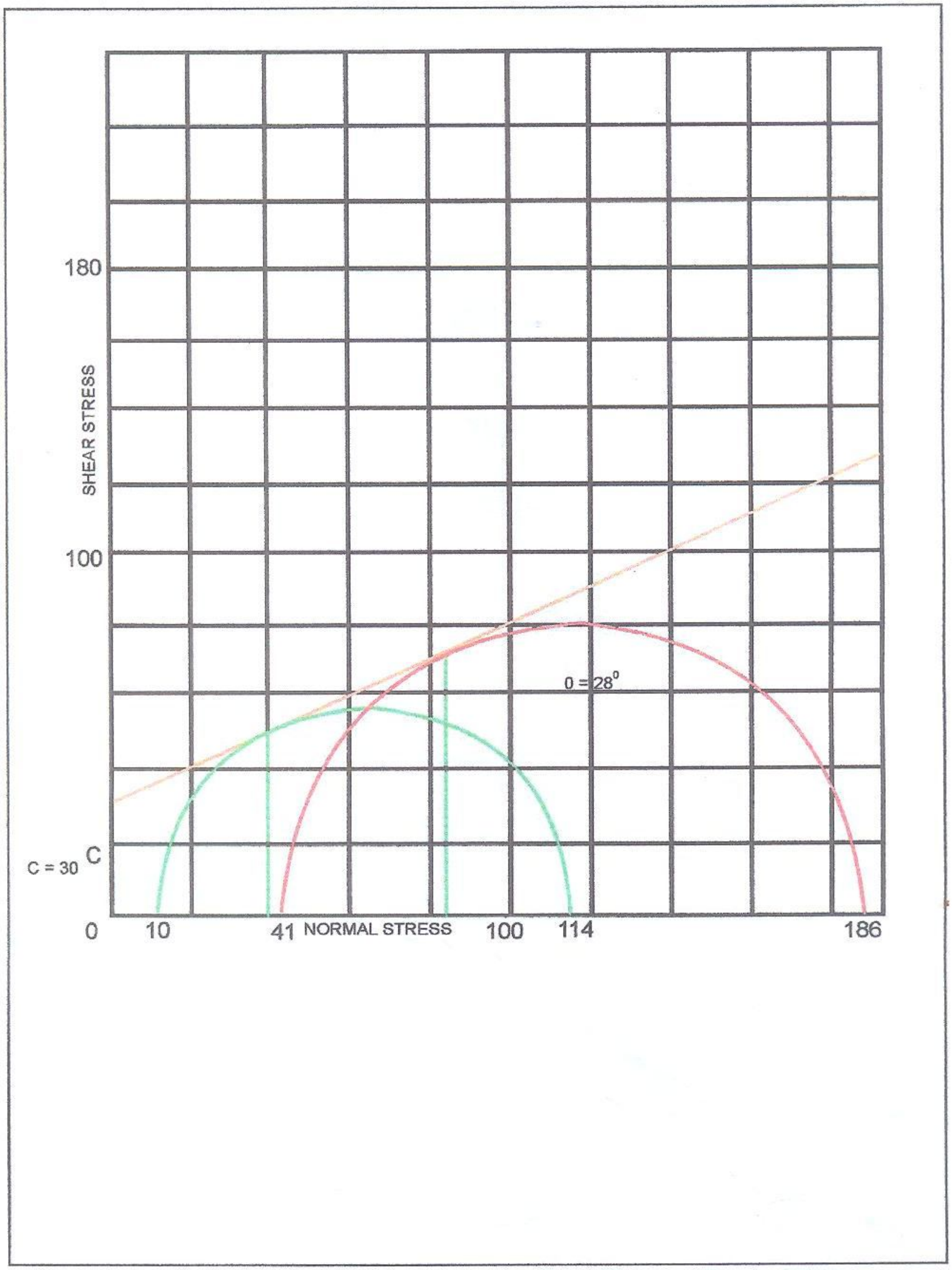


Fig. 15: Shear Strength Graph for the Ferralithic Soil

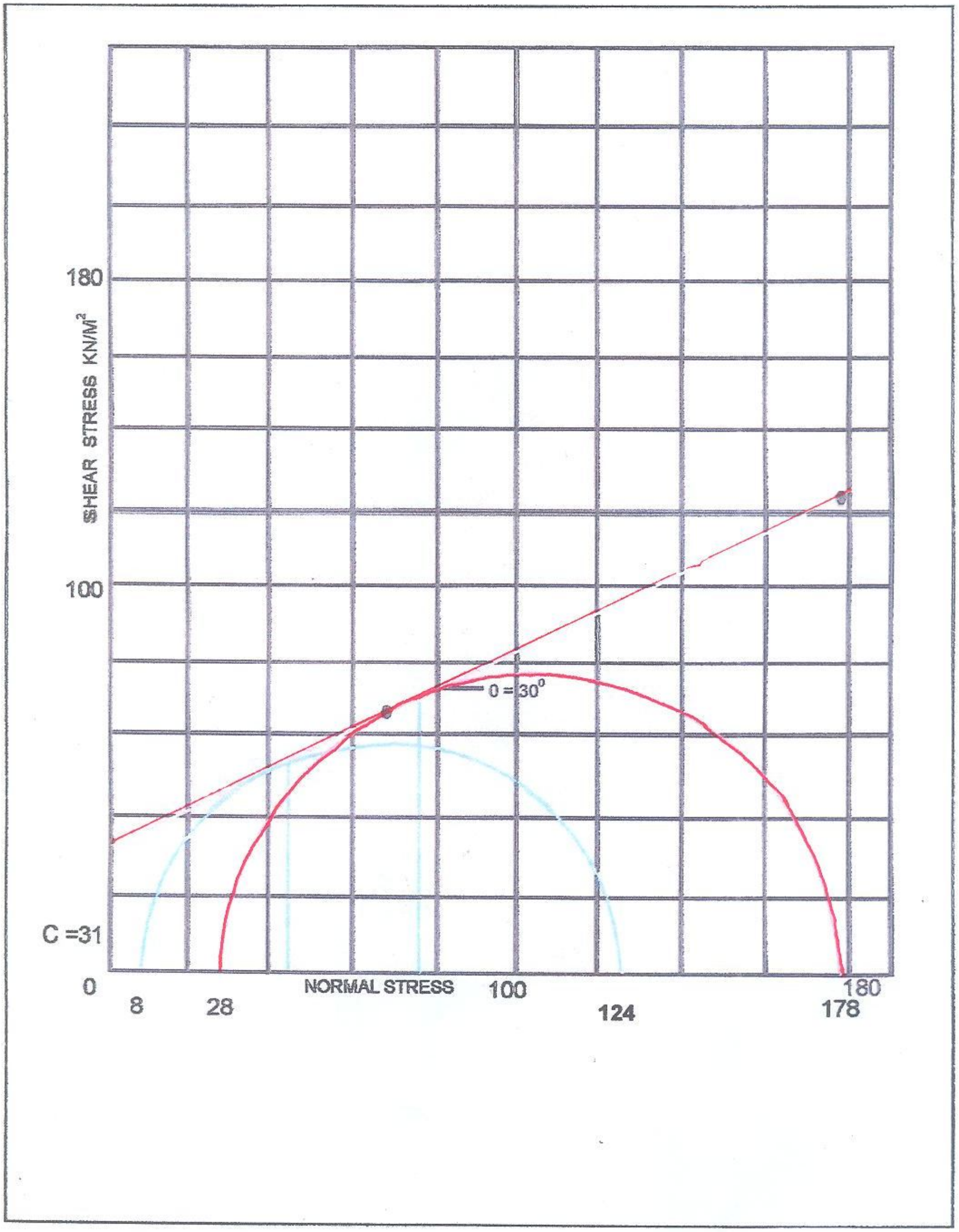


Fig. 16: Shear Strength graph for the Hydromorphic Soil

CONSOLIDATION TEST

Introduction: According to Terzagh and Peck (1995), consolidation theory states that if a mass made of saturated clays is suddenly loaded and the load remains acting on it for a long time, an instantaneous initial compression first occurs as in any other loaded body, then the pore moisture will be gradually squeezed out with a consequent decrease in porosity and overall volume. This is primary compression. The fact is that the consolidating clay deposit usually is covered with an overburden of various soil types. The structure supported by overburden gradually settles at a decreasing rate from year to year. Theoretically the consolidation process lasts indefinitely. Terzaghi and Peck (1995), observed that if additional load acts on a clay body thus consolidated, the consolidation process starts again. According to the authors, the initial load is carried by incompressible water within the soil, because of additional load on the soil, water tends to be extruded from voids causing a reduction in void volume and settlement of the structure. In coarse grained soils (soils of high permeability) the process requires a long time interval for completion, with the result that strain occurs very slowly. It is important to be able to predict both the rate and magnitude of the consolidation settlement. This is done with a constant stress being applied until excess pore water pressures have dissipated for each increment. During the compression process, measurements are made of the decrease in sample parameters that describe the relationship between effective stress and void ratio as well as the rate at which compression can occur, (Bell 1992).

The consolidation test was carried out on the hydromorphic, ferralithic and Forralithic soils of Enugu area. The experimental data, and the computations of relevant parameters (void ratio(e) and volume settlement(cv)) are contained in appendix 26a, 26b and 26c.

Graphs of time versus deformation is used to evaluate the coefficient of volume settlement/consolidation. These graphs are shown is figures 16a, 16b and 16c. The results of consolidation test are shown in table 2b.

Table 2b Result of consolidation Test

Soil	Void ratio (e)	Coefficient of volume Settlement/Consolidation (cv)
Forralithic Soil	0.94	0.63
Ferralithic Soil	0.934	1.30
Hydromorphic Soil	0.92	1.12

The settlement readjustment of forralithic soil is small. This makes the soil suitable for building foundation. (Arthur and Irwin, 1982, Bell, 1992). The ferralithic and hydromorphic soils on the other hand have high coefficient of volume consolidation and are therefore less suitable for building foundation.

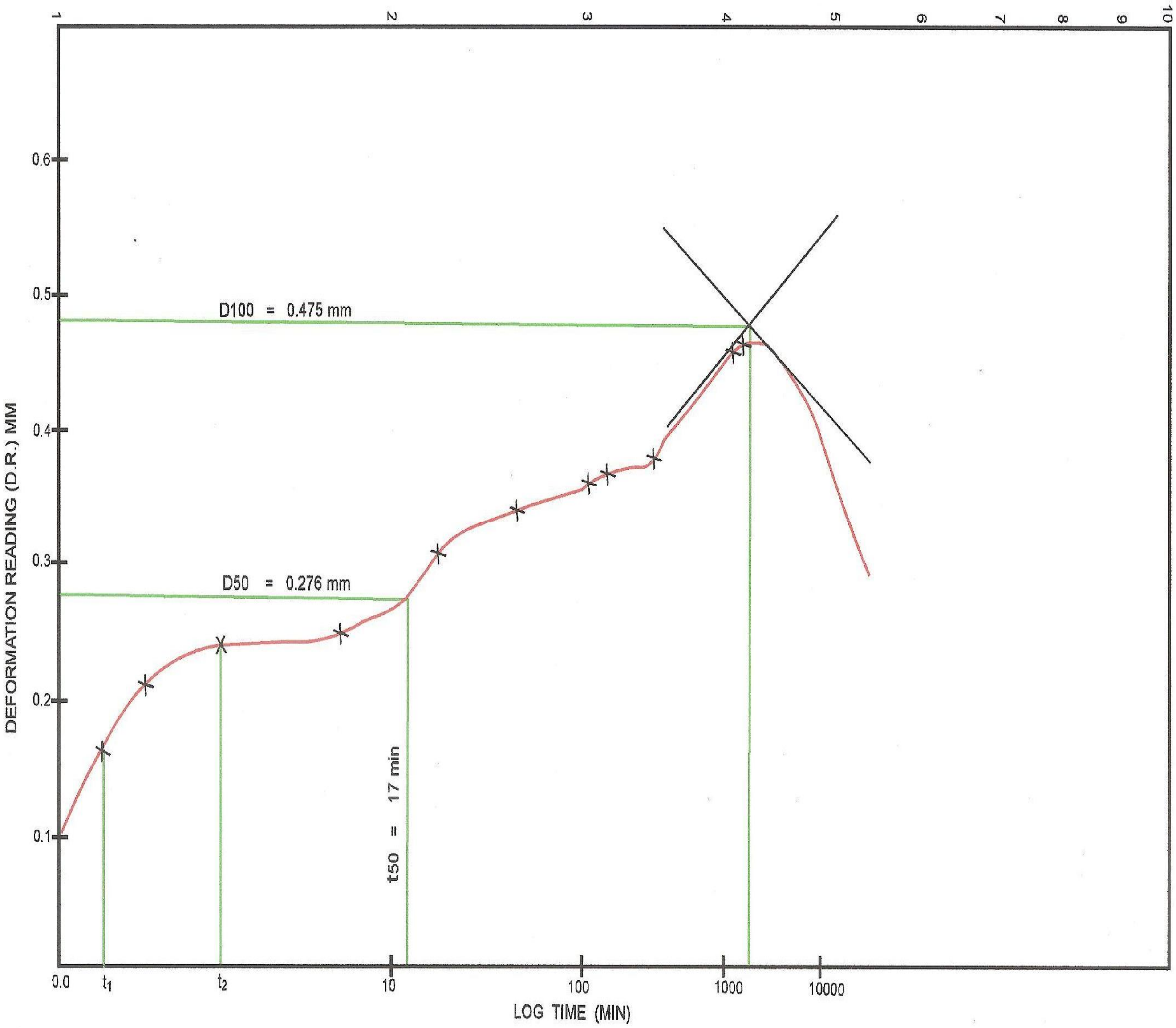


Fig. 16a Deformation Reading Graph for Forralithic Soil Enugu

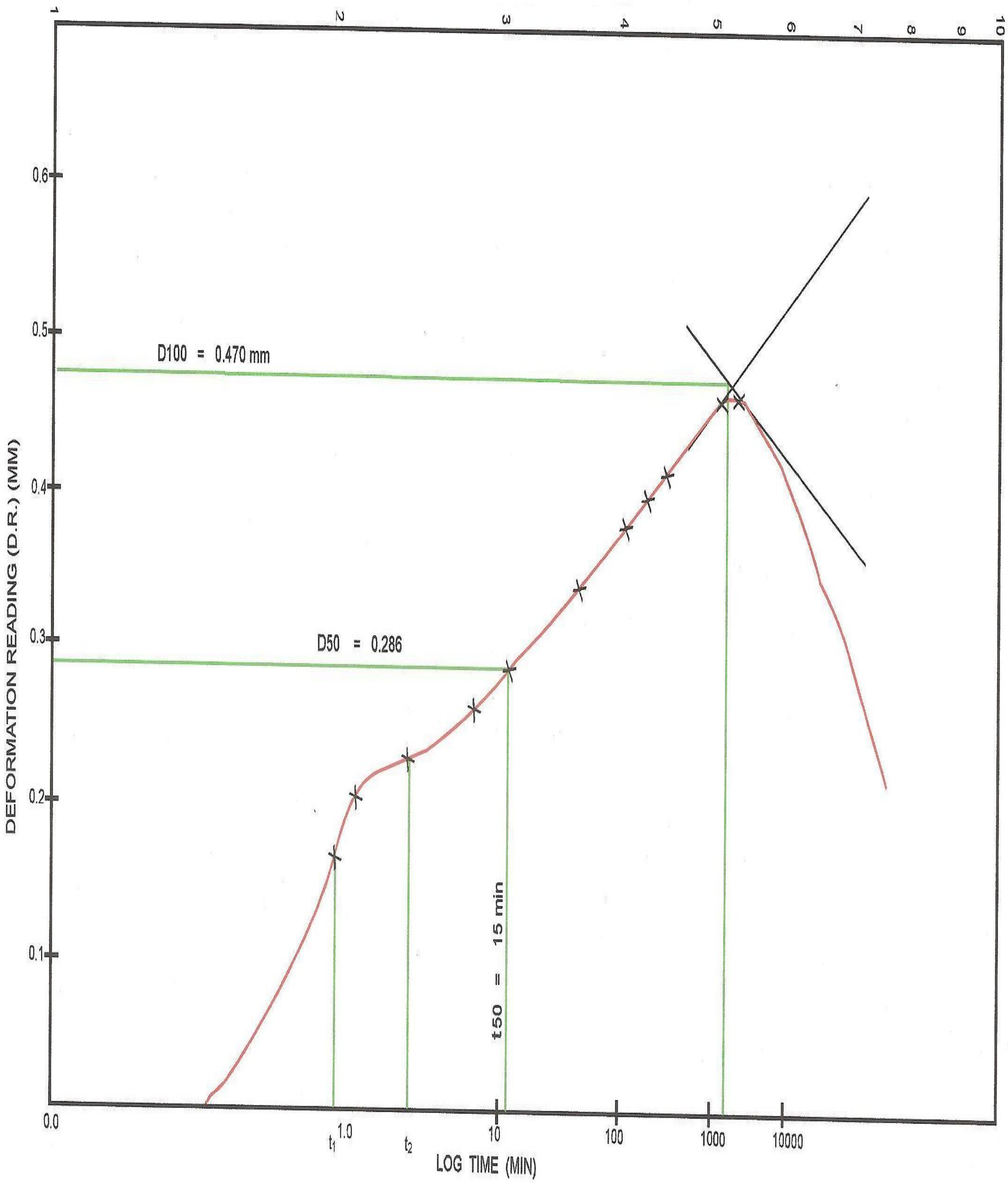


Fig. 16b: Deformation Reading Graph for Ferralithic Soil Enugu

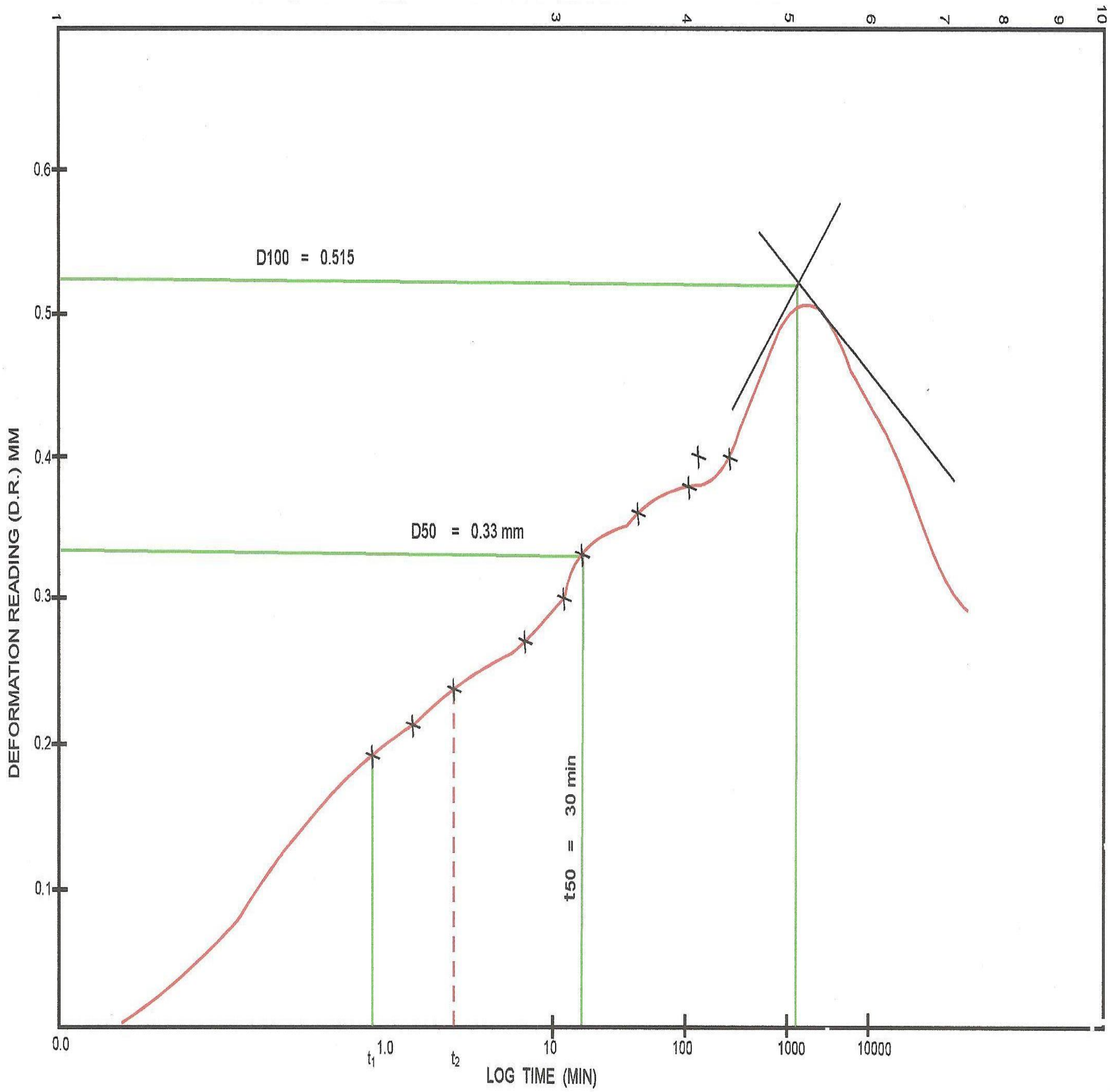


Fig. 16c: deformation Reading Graph for Hydromorphic Soil Enugu

POROSITY AND PERMEABILITY

Introduction

Porosity and permeability involve the ability of rocks or soils to contain fluids and to allow fluids to pass through them. Porosity is the proportion of void space in the soils/rock, unfilled by solid material within or between individual mineral grains (Montgomery 2000). Permeability is a measure of how readily fluids pass through the soils/rocks and is related to the extent to which pores or cracks are interconnected . The greater the value of permeability, the greater the flow in a given area. Porosity and permeability of geologic materials are both influenced by the shapes of mineral grains or rock fragments, the range of grain sizes present and the way in which the grains fit together. Well rounded equidimentional grains of similar size can produce sediments of quite high porosity and permeability. Sediments consisting predominantly of flat, platelike grains, such as clay minerals or micas may be porous, but because the flat grains can be packed closely together parallel to the plates, these sediments may not be very permeable, especially in the direction perpendicular to the plates. Permeability is an important soil parameter for any project where flow of water through a soil is of utmost concern, example seepage through a dam and drainage from sub grades (Montgomery 2000). The factors influencing soil permeability include particle size, shape and viscosity of the water, which is a function of temperature, degree of saturation and void ratio (Freeze and Cherry 1979). The apparatus employed in the estimation of these parameters include permeameter – constant-head filter tank and manometer tubes, large funnels timing device, thermometer, vacuum pump and weighing balance. These were carried out using a specified standard-ASTMD422 98 (2001) method.

The permeability and porosity tests were carried out on hydromorphic, ferralithic and forralithic soils (See Appendix 27). These tests are needed as their results form part of the database for use in the weighting and rating of landuse determinants.

The result shows that while the permeability and porosity of hydromorphic soil measured 1.97 x 10^{-2}cm/s and 0.31, that of ferralithic soil is 1.89 x 10^{-2}cm/s and 0.30, also the forralithic soil measured 1.92 x10^{-2}cm/s and 0.31. In terms of waste disposal and building siting, the choice of site should also consider the underlying geology and the location of water table (Buol et al 2000). This should also be considered before the site is selected for any of the land use options. The summary of all the laboratory, field and literature information is shown in Table 2b.

TABLE 2b SUMMARY OF LABORATORY, FIELD AND LITERATURE DATA

Soil/Rock type	Liquid Limit %	Limit %	Plasticity Index %	Dry Density DD	Consolidation values	OMC%	Compressive strength N/M^2	Shear Strength N/M^2	Cohesion N/M^2	Permeability porosity	Angle of internal friction Ø
Forralithic Soil	26.06	19.75	6.31	1.85	e 0.94, cv 0.63	16.2	9.10	96.09	13	1.92 x 10^{-2} cm/s & 0.31	28
Ferralithic Soil	39.84	14.7	25.14	1.78	e 0.934, cv 1.3	12.97	2.10	87.82	30	Ferralithic 1.89 x 10^{-2} cm/s & 0.30	30
Hydromorphic Soil	43.35	16.89	26.64	1.48	e 0.92, cv 1.12	13.349	21.76	85.56	31	1.97x 10^{-2} cm/s & 0.31	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	2.3	35.60			24.5					
Ezeaku FM+ Solution cavities	50.8	39.47	15.63	1.53							
Lithosoil:					e 0.892, cv 1.23					1.70 x 10^{-2} cmls & 0.30	

ENGINEERING CLASSICATION OF THE SOILS

Introduction: The purpose of soil classification is to provide the geotechnical engineer with a way to predict the behaviour of the soil for engineering projects. There are several different soil classifications in use. In this work, the Unified Soil Classification System (USCS) was used. An important part of this soil classification system, is particle size distribution and Atterberg limit.

THE UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

The Unified Soil Classification System was developed and modified by Casagrande in 1952.

In this system, soils were separated into two main groups –coarse grained soils and fine grained soils. The basis of USCS is that the engineering behaviour of coarse grained soil is dependent on their grain size distribution and the engineering behaviour of fine grained soils is related to their plasticity characteristics. The following group symbols are used in the unified system:

G (gravel)
S (sand)
M (Silt)
C (Clay)
O (Organic)
PT (peat)
W (well graded)
P (poorly graded)

Two group symbols are used to classify soils for example, Sw indicates well graded sand, while SP indicates poorly graded sand. Appendix 32 adapted from ASTM2487-98 (2000), presents a summary of the USCS.

In order to classify a given soil by the unified system, its grain size distribution, liquid limit, plastic limit and plasticity index must be known. The Unified Soil Classification System is published as ASTMD 2487-85 and ASTMD 2487-98, (2000). The coarse-grained soils are defined as those having more than 50% of soil retained on no 200 sieve. The coarse grained soils are divided into gravels and sands. Both gravels and sands are further subdivided into four secondary classifications. The four secondary classifications are based on whether the soil is well graded, poorly graded, contains silt size particles, or contains clay size particles.

The fine grained soils are defined as those having 50% or more of the soils passing no 200 sieve. The fine grained soils are divided into silts and clays. Both silts and clays are further divided into four secondary classifications based on whether the soil contains organic or inorganic silts and clays.

The plasticity chart (fig. 16d), together with the standard procedure outlined in appendix 32, is used to classify the soils based on the nomenclature of the Unified Soil Classification System by employing grain size data and Atterberg Limits. The three soils classified are: forralithic Soils, hydromorphic Soil and ferralithic soils, using informations of Tables 2d, 2e, and 2f.

Table 2d: Data on Forralithic Soil

US Sieve Size	% Passing
No 4 (3.35)	99.96
No 10 (2.0)	99.54
No 40 (.425)	61.04
No 100 (0.15)	7.36
No 200 (0.075)	0.8

ATTERBERG LIMITS

LL = 26.06

PL = 19.75%

PI = 6.31%

Table 2e: HYDROMORPHIC SOIL

In hydromorphic soil the following is applicable

U.S. Sieve Size	% Passing
No 4 (3.35)	100
No 10 (0.2)	99.6
No 40 (.425)	93.8
No 100 (0.15)	47.3
No 200 (0.075)	9.5

ATTERBERG LIMITS

LL = 43.35%

PL = 16.89%

PI = 26.46%

Table 2f: FERRALITHIC SOIL

In Ferralithic soil, the following is applicable

US Sieve Size	% Passing
No 4 (3.35)	56.12
No 10	42.35
No 40	21.72
No 100	12.96
No 200	5.57

ATTERBERG LIMITS

LL = 39.84

PL = 14.70

PI = 25.14%

The three soils were classified as:

Forralithic Soil: SP, ML-CL	(poorly graded silt and clay)
hydromorphic Sol: SP-CL	(poorly graded silty clay)
Ferralithic Soil: SW-CL	(well graded silty clay)

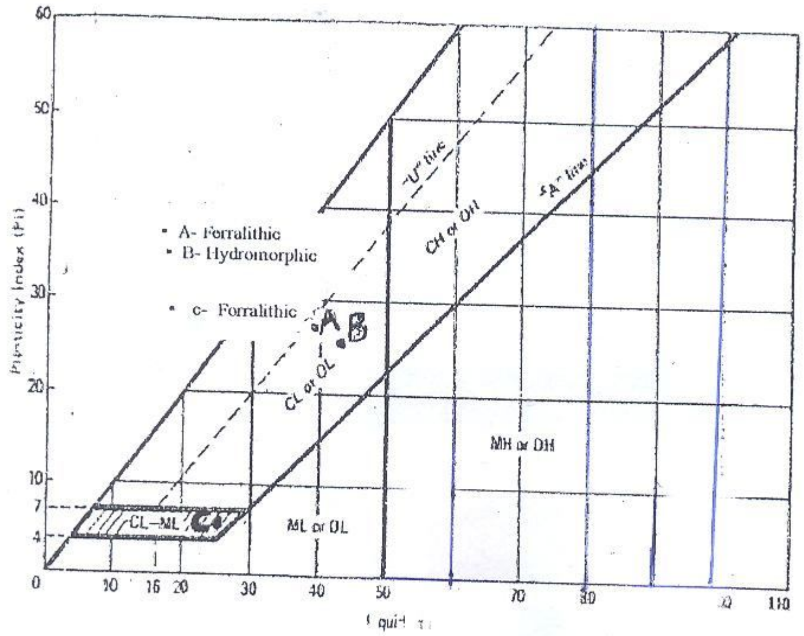


Fig. 16d: Unified Soil Classification System – Plasticity Chart

3.4 A GIS SPATIAL MODEL

Kang (2002), listed the basic information which serve as a guide for the confirmation of the accuracy of the land use map for industrial, residential or waste disposal siting options. The outcome of the analysis of data using Geographic Information System, should invariably lead to the adoption of certain criteria which act as a check of accuracy. These criteria are:

For Residential Purposes:

- Site should be on the terrain having mild slope (3^0-10^0).
- Site should not be situated within 1000meters from land slide, faulted and flooded areas.
- Site should not be located where the aquifer is not prolific.
- Site should not be located in an area of expansive soil.

For Industrial Purposes:

- Industries should not be located in an area of high slope. This can affect easy haulage of industrial materials and movement of heavy trucks.
- Industries should be isolated from the areas of dense settlement so as to avoid environmental pollution.
- There should be available water supply.

For Waste Disposal Purposes:

- Site should be in area of mild slope, not water logged.
- Site should be in an area where water table is not shallow.
- Sandy clay environment is preferable.
- Site should not be located in an area of active fault or flooded and /or land slide areas.
- Sites should lie at a minimum distance of 1000meters from the major streams.

3.5 RANKING

Ranking procedure involves the choice of the appropriate rating scale. The ranking scale ranges from 0-100% for the percentage influence, while 0-2 was selected for the scale values. This choice produces three land use rankings as follows:

0	-	Unsuitable
1	-	Low suitability
2	-	Suitable

Where a zero value renders the land valueless, the capability values for the area remains zero irrespective of how suitable other environmental factors are (Chapin 1965). The percentage influence is the measure of importance of the factors (theme), while the scale value signifies how capable the attribute values can achieve the anticipated land use.

3.6 DATA/MAP INTEGRATION

The various data obtained from field investigations and literature surveys were integrated and updated to produce relevant digitized thematic maps on a common scale of 1: 500,000. These maps are shown in figs 17-28. They are updated in preparation for the overlaying process. The maps are:

Digitized Elevation Map of Enugu Area. The map was produced by measuring spot heights and coordinates across the length and width of the entire Enugu area, using a geographic positioning system (GPS Eterex 76). The collected elevation values and coordinates at the designated points, were converted from Universal Transverse Mecator (UTM) to Nigeria datum with the aid of a computer soft ware called geocal. They were scanned, digitized, geo-referenced and converted to the common scale of 1:500, 000, fig. 17.

2D and 3D-Digital Terrain Model (DTM) of Enugu Area and Digitized Slope Map

The digitized Elevation value data was imported in the computer soft ware geocal, and stored in text document (TxT format). The converted values were used to produce 2D, DTM (fig. 18a) using the resulting contour map (fig. 18b), from where 3D, DTM and slope map were also generated (Fig 18c and 19), employing surfew 7.0 soft ware. The 2D digital terrain models indicates Elevation classes; while the 3D digital terrain models shows the 3 dimensional variation of elevation values which form the basis of terrain differentiation and shows the entire Enugu area as they would appear when viewed from the air (Smith and Holland 2003). It also shows the configuration of the drainage pattern.

Digitized Soil Drainage Map

The soil drainage map was obtained from Enugu State Ministry of Environment. The map which was drawn on a scale of 1:250,000 was also scanned, geo-referenced, digitized, polygonized and converted to the common scale, (fig. 20). The polygon covers areas of identical drainage characteristics designated as well drained and moderately drained. . The operations described above were also repeated in soil depth map (fig. 21) geology map (fig. 22a), soil class map (fig. 22b) surface water map Fig 23 and escarpment map (Fig 28).

Digitized Soil Depth Map

The soil depth map which was obtained from Enugu State Ministry of Environment was in an analogue form on a scale of 1:250,000. The map was scanned, digitized, geo-referenced and converted to the common scale of 1:500,000. The estimation of the depth of the deep and shallow soils of the area was carried out by conducting a vertical electrical sounding survey covering the different soil depth Locations- Nkanu, Enugu and Ngwo axis. These represent deep and shallow soils whose depths were estimated. These depths were estimated as 6.3m, 19m and 2.6m. The depth at Owa area was got from Enugu State Water Corporation, and this stands as 19.3m

The Ves Survey:

ABEM Terrameter SAS 300B under Schlumberger electrode array was used to obtain soil depths. The method applied in carrying out this measurement involves passing into the earth of a direct current. Four electrode array were used, one pair for introducing current into the earth the other pair for measurement of the potential associated with the current.. The result of the depth estimation is described in Appendix 31.

The computer modeled curves for three locations are shown in figures 21a, 21b and 21c showing Agbani axis, Enugu area, and Ngwo axis. Already made information about depth from Owa area, (deep soil) was obtained from Enugu State Water Cooperation.

Digitized Geology Map

The geology map of Enugu area was traced from FSN Sheet 72, on a scale of 1:250,000 using transparent overlay. This map was updated by using Geographic Positioning System (GPS Eterex 76), to adjust the geological boundaries where they were discovered to be faulty and the legends also were readjusted where they were also found to be wrong. The map was then scanned, digitized, geo-referenced, polygonized, and then converted to the common scale of 1:500,000 in preparation for the overlay process, fig.22a. Characteristics of Ajali Sandstone, Mamu Formation and Enugu Shale were got from literature, and field survey.

Digitized Water table Map

The water table map of Enugu area was sourced from Enugu State water corporation, Enugu. The map shows depth to the water tables only at the western segment of the map. Effort was made to measure the depths to water table at the Eastern segment starting from Enugu Metropolis to Iheuokpara in the East. Graduated measuring tape was used to measure the depth of static water tables. Their locations were fixed using GPS Eterex 76. Digitization, geo-reference and polygonization was carried out and areas of deep moderate and shallow water tables were delineated in polygonal forms (Fig 24).

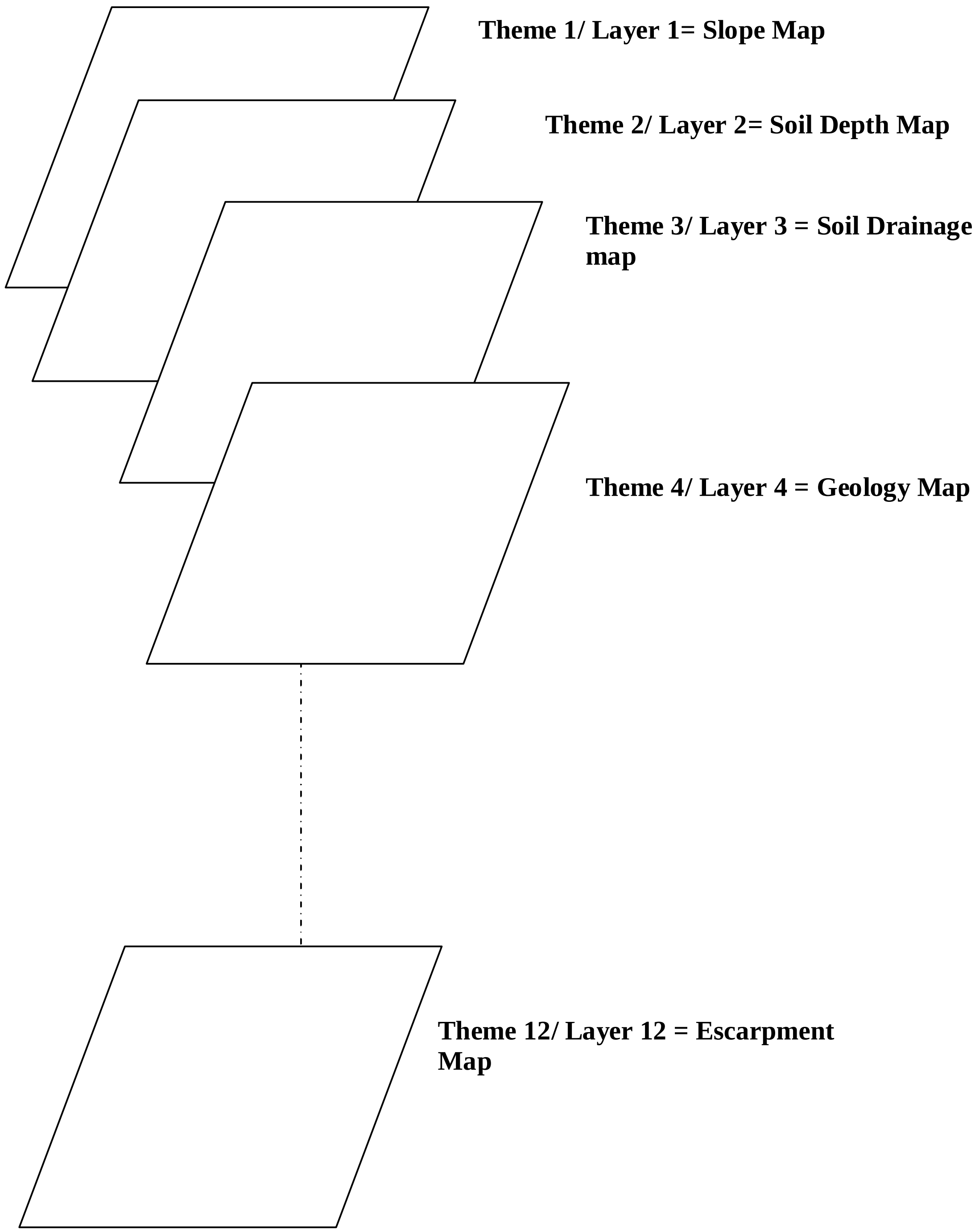
Gully Erosion, Flood plain/landslide map and fault map. The overlay preparations for these land use determinants involve buffering approach.

BUFFERING

A buffer is a polygon created around a point, line or polygon feature on the map. The polygon could be of constant width (equidistant) or variable width from the feature been buffered. Generally, buffer zones form new polygons and these could be used in conjunction with other map layers in the same area for overlay operations. (Weltman and Head 1983). By creating a buffer around a feature, it becomes easy to determine an area of safety where development can take place as in the case of a fault zone, landslide or gully erosion. In this work areas of gully erosion, landslides, flooded regions, and fault zone, were buffered a distance of 1000meters (1km). This is the distance where no development/ activity of any type can take place.
(see figures 25, 26, and 27).

OVERLAY MODE WITH FIGS. 17 – 28

(After Kang 2002)



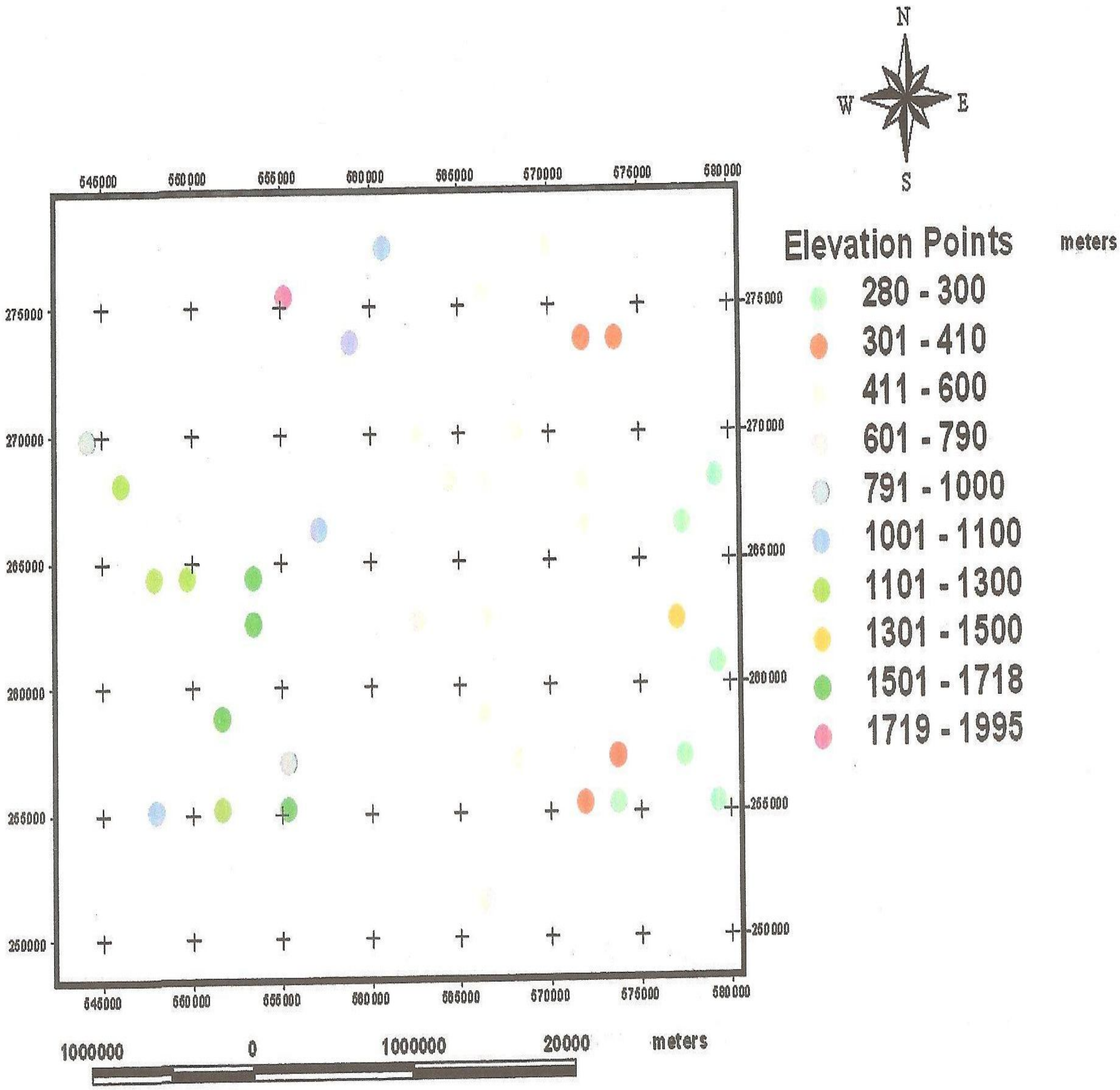


Fig. 17: Elevation Map of Enugu Area and Environs
(Source: Field Observation)

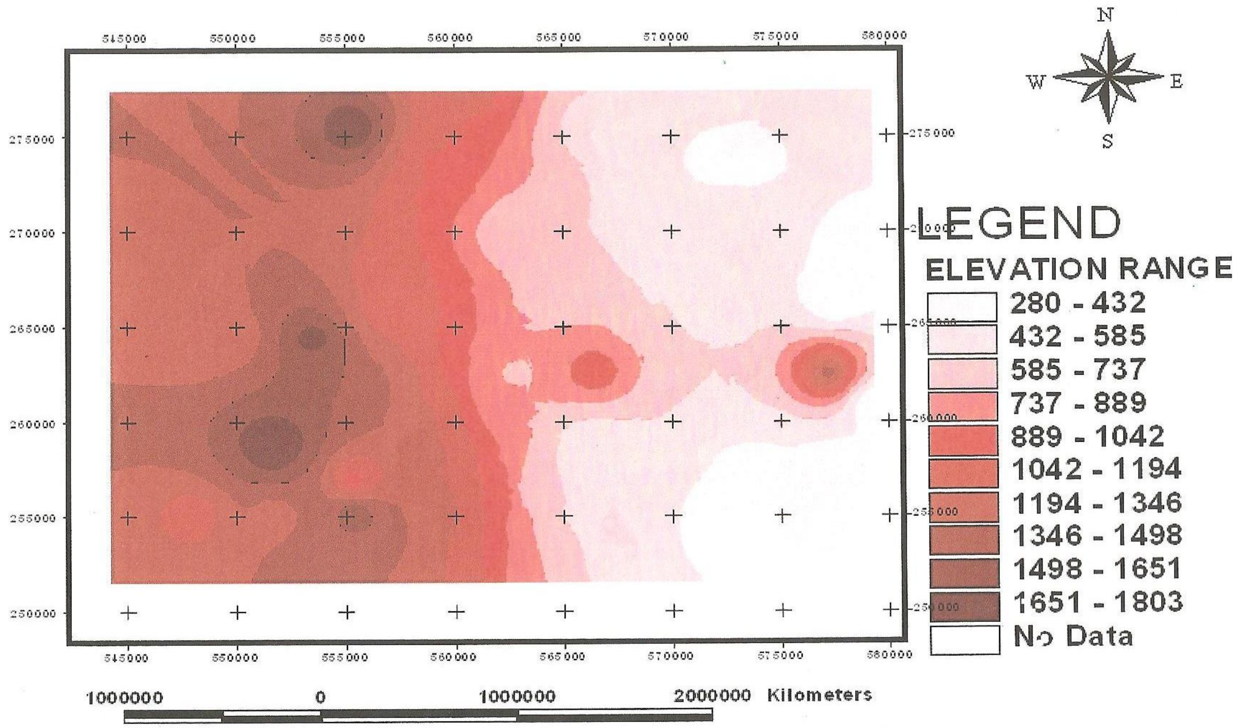


Fig. 18a: 2-D Digital terrain Model of Enugu Area (Digitized)

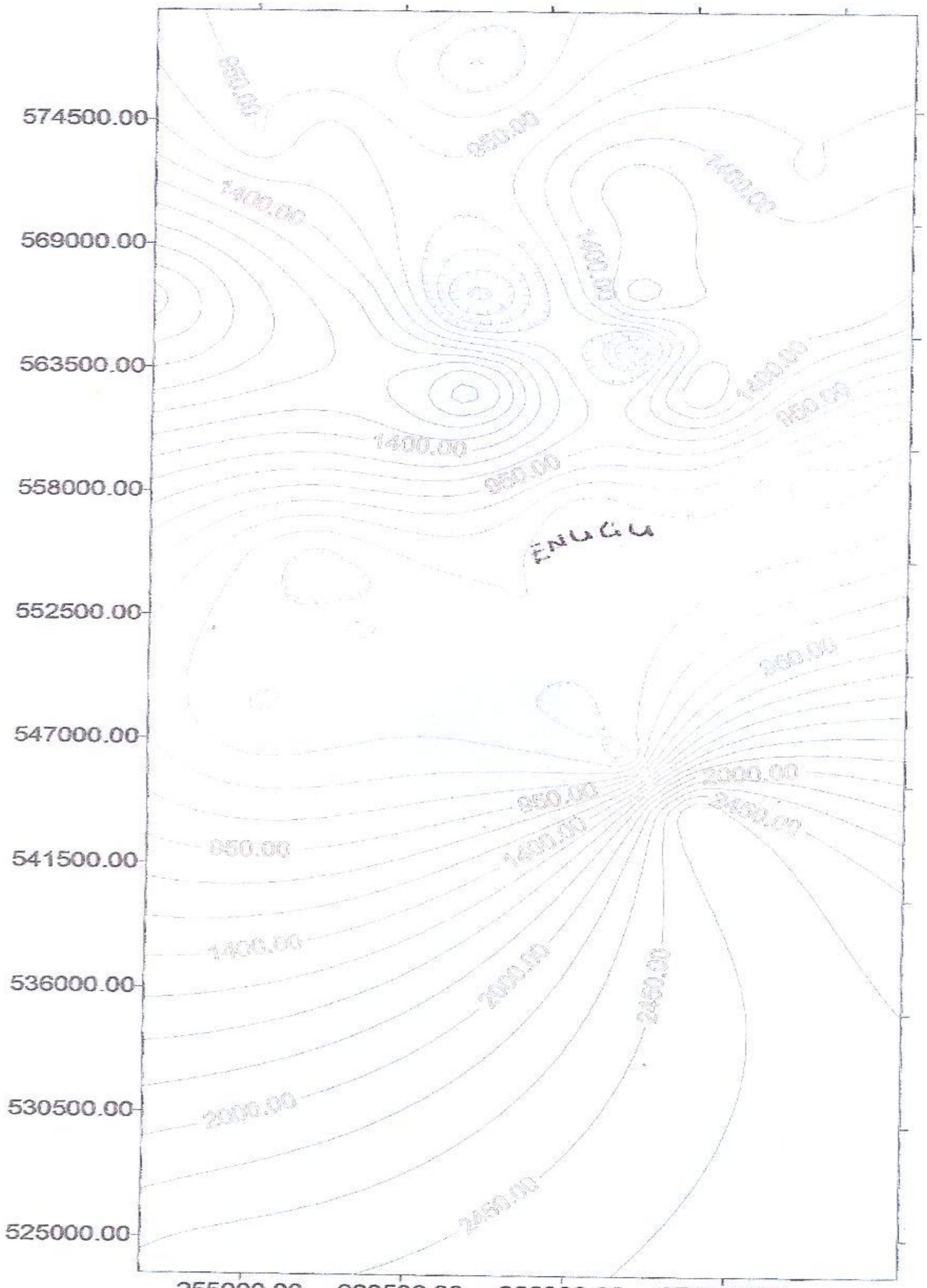


Fig. 18b: Contour Lines of Enugu

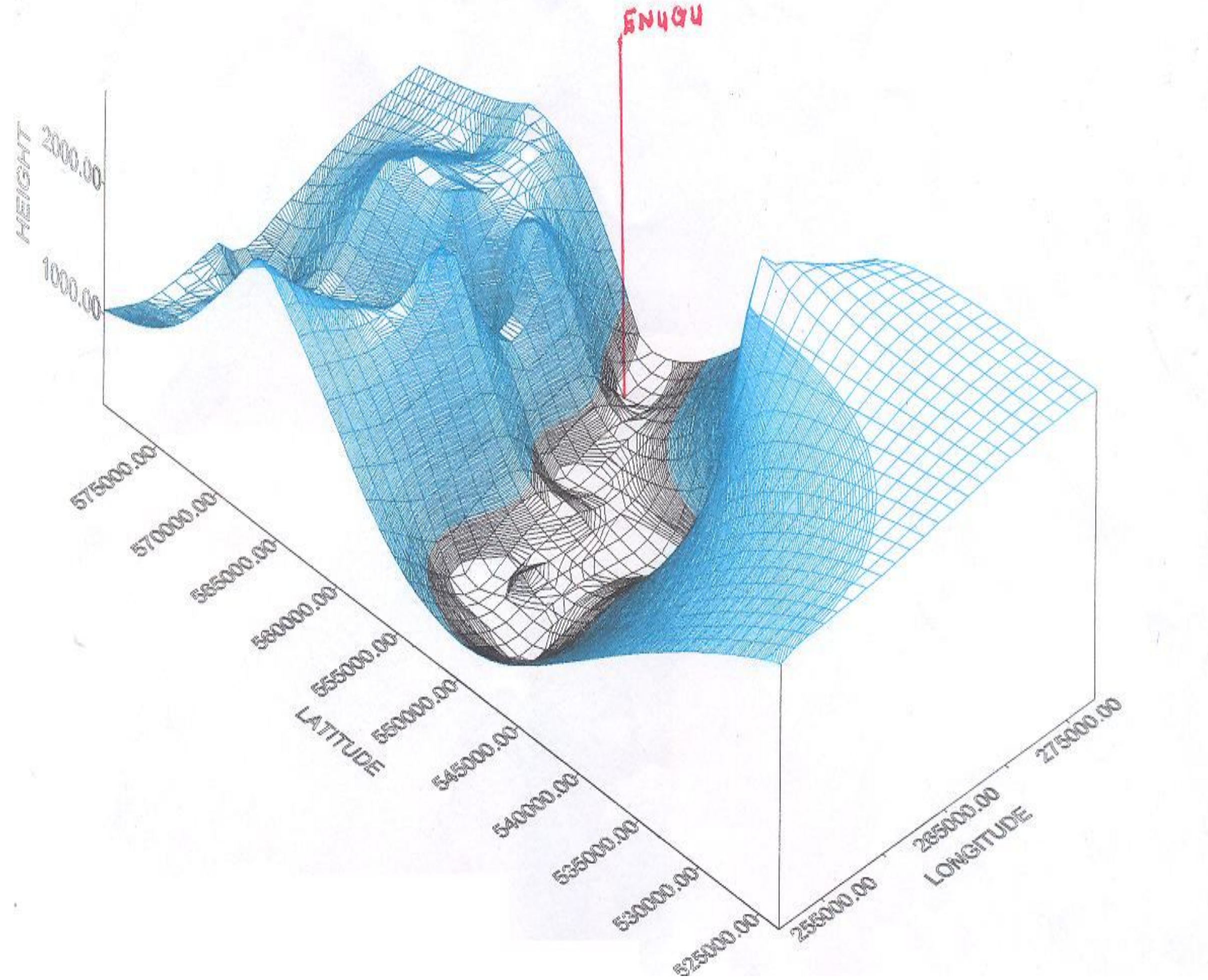


Fig. 18c: Digital Terrain Model of Enugu Area (3-Dimensional View)

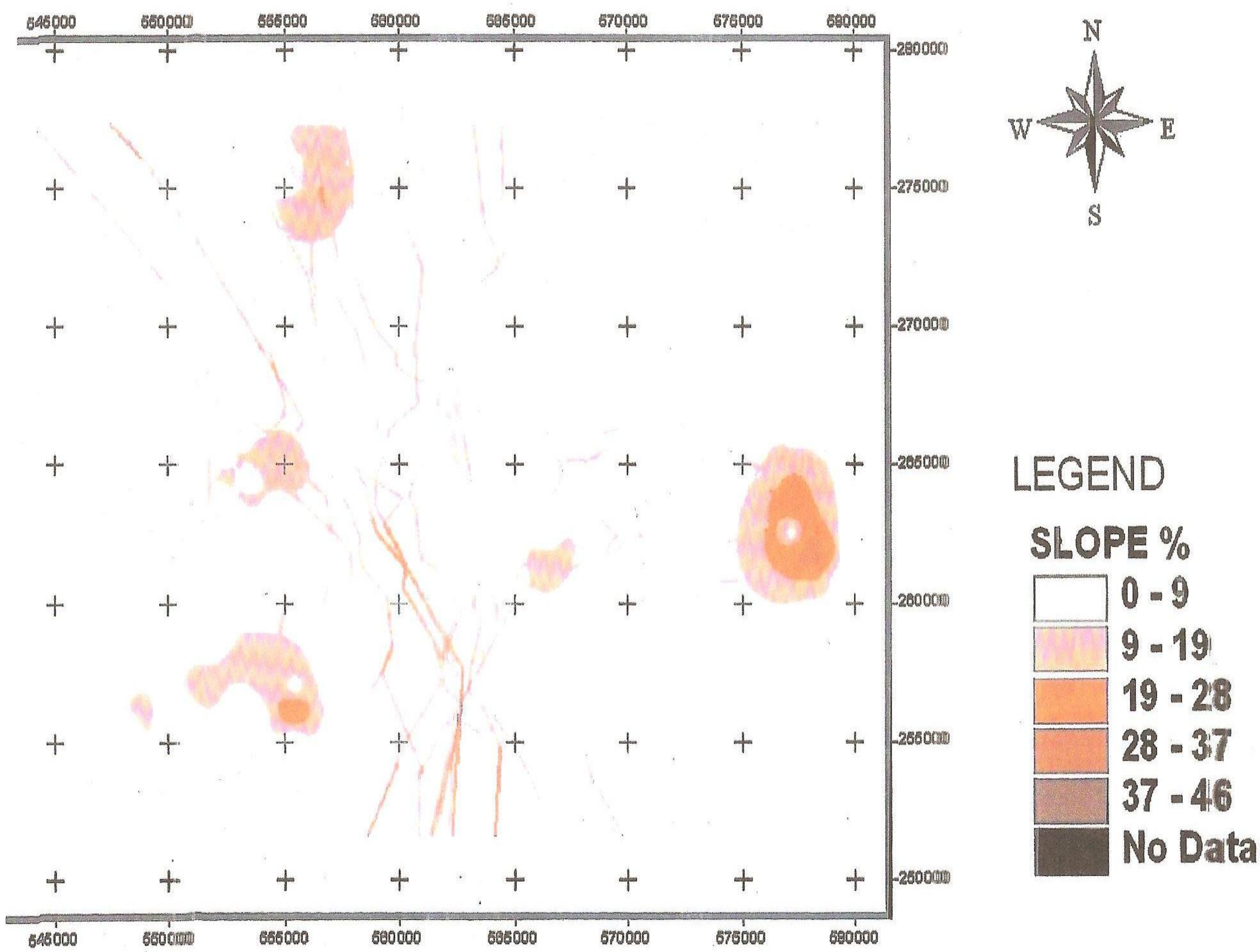


Fig. 19: Slope Map of Enugu Area and Environs (Digitized)
Source: Field Observation

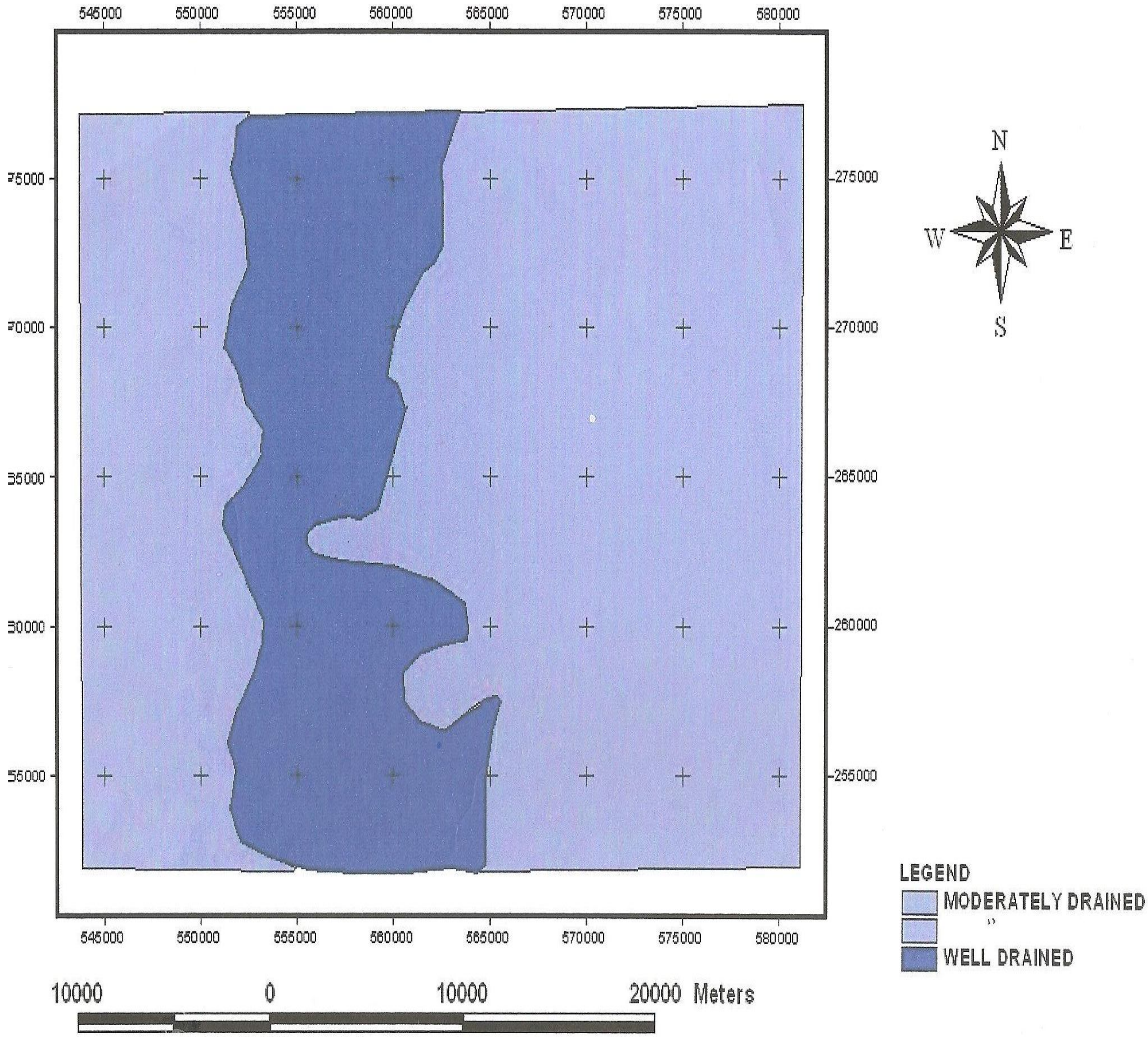


Fig. 20: Soil Drainage Map of Enugu Area and Environs
Source: Enugu State Ministry of Environment

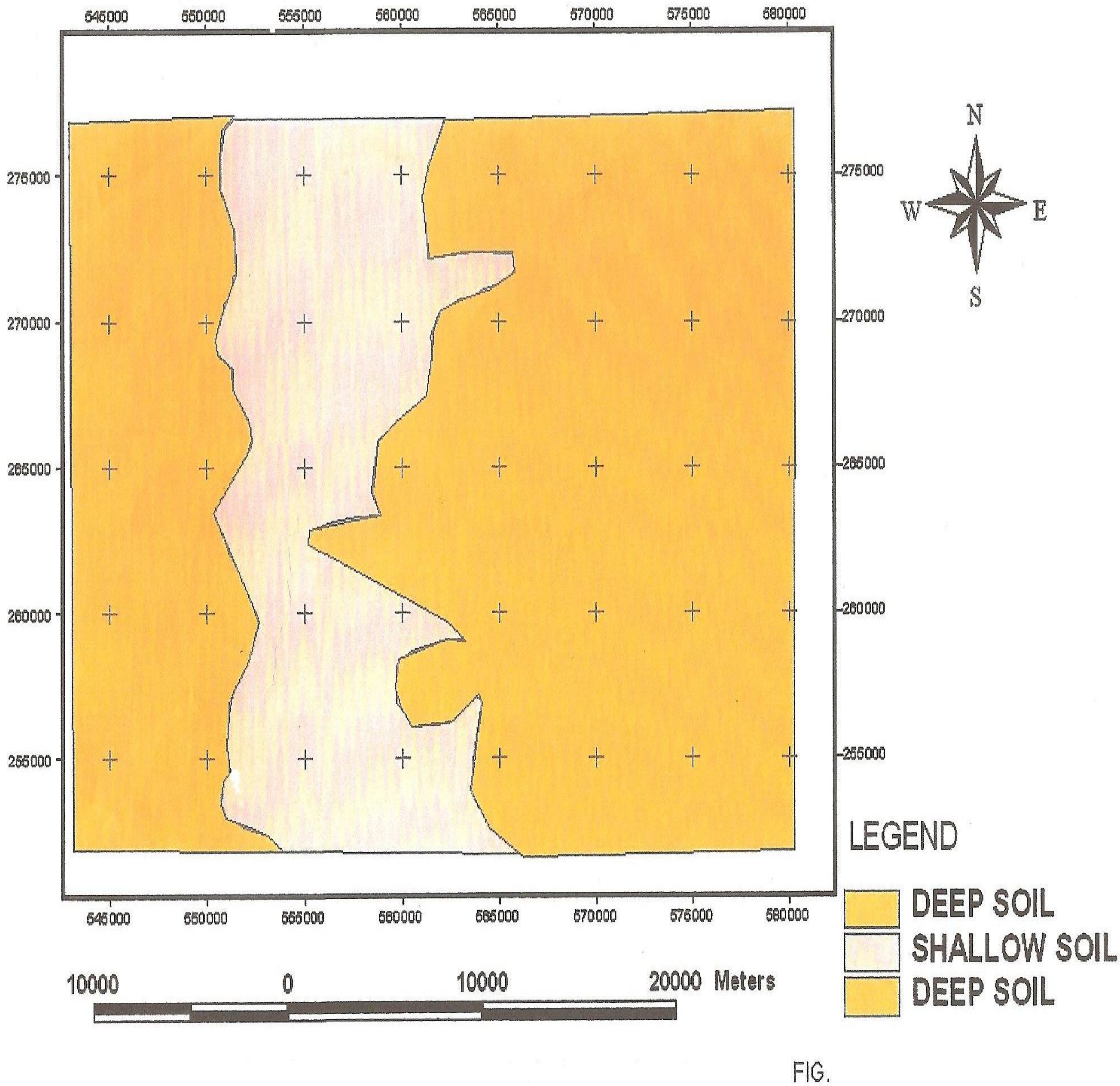
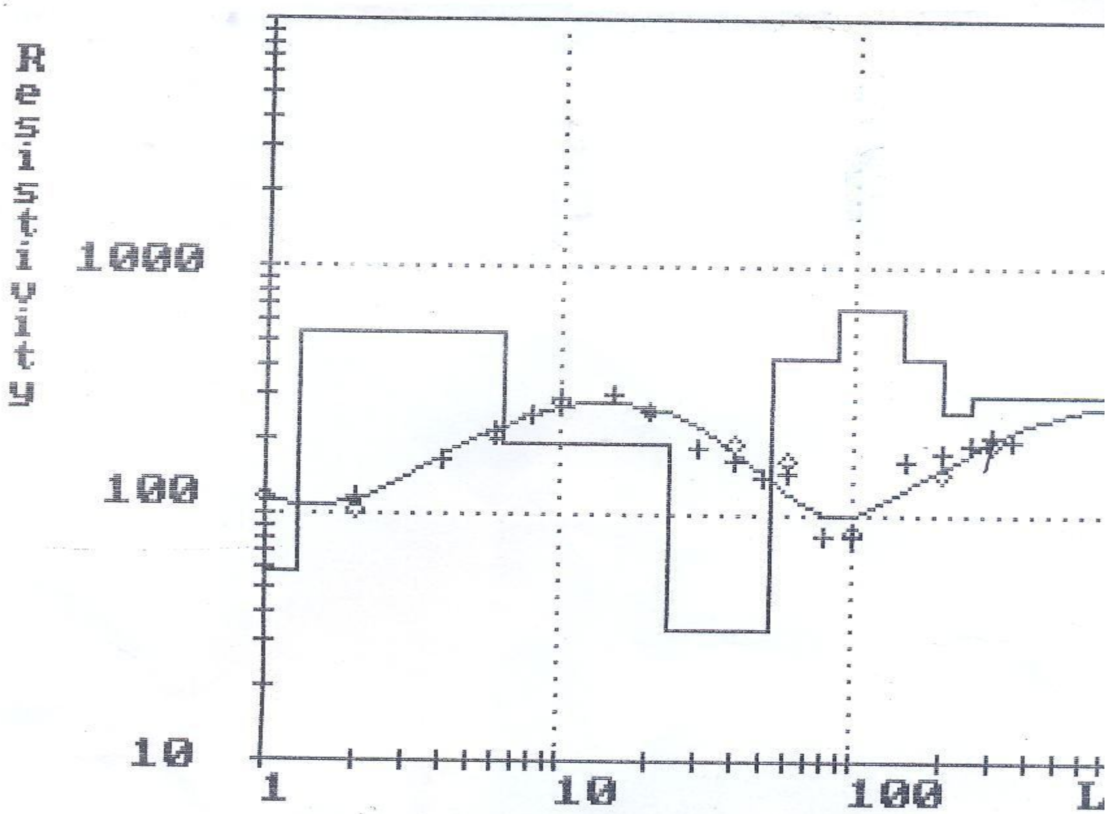


Fig. 21: Soil Depth Map of Enugu Area and Environs (Digitized)
Source: Enugu State Ministry of Environment



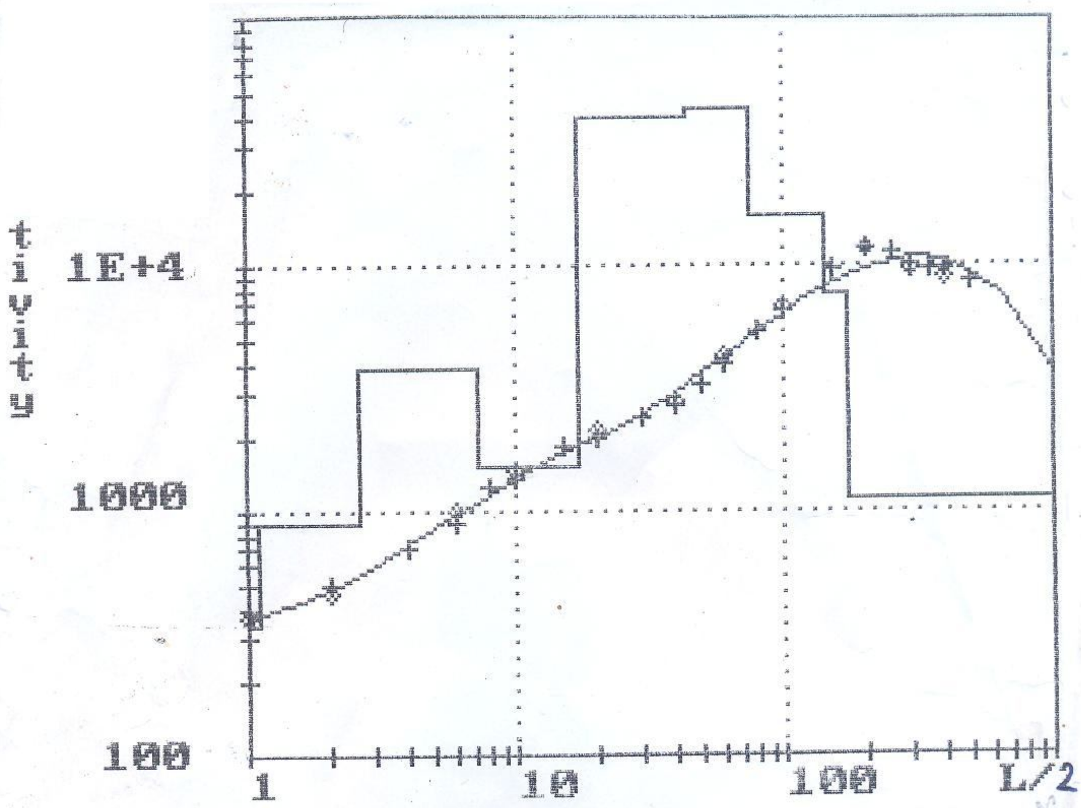
Data (File) name	NKG	Date	30-11-2007
Project name	WATER BOREHOLE	Direction lay out	Dir:N-S
Code name	VES 1	Remarks	ENUGU STATE
Coordinates	NKWO-AGBANI, NKANU WEST L.G.A.		
		Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	117.1	20.0	255.3	100.0	85.4
2.0	114.3	20.0	258.8	150.0	162.3
2.0	104.5	30.0	184.7	200.0	175.7
4.0	164.8	40.0	166.1	200.0	144.3
6.0	214.1	40.0	192.4	250.0	191.5
6.0	206.3	50.0	143.0	300.0	202.7
8.0	247.5	60.0	145.1	300.0	189.3
10.0	286.7	60.0	161.5	350.0	199.0
10.0	284.6	80.0	81.1		
15.0	301.5	100.0	80.6		

Resistivity (Ohm.m)	Depth (m)
147.0	0.5
58.1	1.3
536.0	6.3
194.0	23.6
34.8	52.4
435.0	88.9
673.0	145.0
435.0	201.0
263.0	251.0
309.0	

FIG

FIG. 21a Vertical Electrical Soundings Nkanu Area-Deep Soil

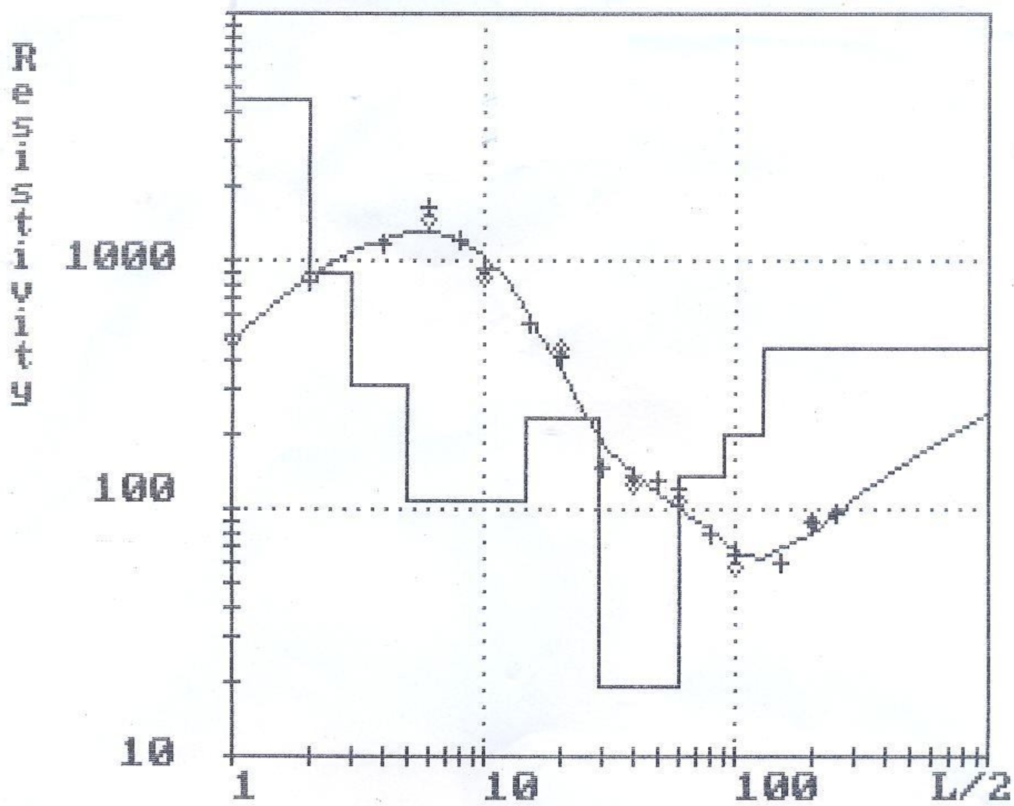


Data (File) name	KND	Date	1-05-2002
Project name	WATER BOREHOLE	Direction lay out	Dir: N-S
Code name	VES 1	Remarks	Enugu State
Coordinates	NGWO	Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	368.2	20.0	2139.9	200.0	11507.0
2.0	504.7	30.0	2408.9	200.0	11628.0
2.0	463.0	40.0	2724.4	250.0	11224.0
4.0	715.3	40.0	2835.0	300.0	9750.1
6.0	869.1	50.0	3309.8	300.0	9475.8
6.0	984.0	60.0	3957.5	350.0	9403.8
8.0	1229.6	60.0	4257.1	400.0	9522.8
10.0	1360.1	80.0	5372.0	400.0	8985.6
10.0	1434.1	100.0	6373.1	500.0	8552.9
15.0	1823.5	100.0	6778.5		
20.0	1987.3	150.0	9494.3		

Resistivity (Ohm.m)	Depth (m)
346.0	1.1
880.0	2.6
3820.0	7.3
1530.0	17.3
39500.0	43.7
42400.0	75.9
15700.0	141.0
7640.0	175.0
1102.0	

FIG 21b: Vertical Electrical Soundings Ngwo Area (Escarpment)



Data (File) name	NGG	Date	26-04-2007
Project name	WATER BOREHOLE	Direction lay out	Dir: N-S
Code name	VES 1	Remarks	Enugu State.
Coordinates	ENUGU (Independent Layout, Igboeze St.)		
		Schlumberger	O'Neill

L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)	L/2 (m)	Rho (Ohm.m)
1.0	478.0	15.0	556.0	80.0	79.0
2.0	804.0	20.0	410.0	100.0	64.7
2.0	837.0	20.0	437.0	100.0	59.0
4.0	1163.0	30.0	144.0	150.0	60.2
6.0	1620.0	40.0	137.0	200.0	88.9
6.0	1457.0	40.0	126.0	200.0	90.1
8.0	1206.0	50.0	132.0	250.0	94.2
10.0	923.0	60.0	122.0		
10.0	861.0	60.0	109.0		

Resistivity (Ohm.m)	Depth (m)
239.0	0.4
4470.0	2.0
890.0	3.0
316.0	4.9
108.0	14.6
234.0	28.5
19.3	60.1
135.0	91.9
203.0	129.0
442.0	

Fig. 21c:Vertical Electrical Soundings Enugu Area – Deep Soil

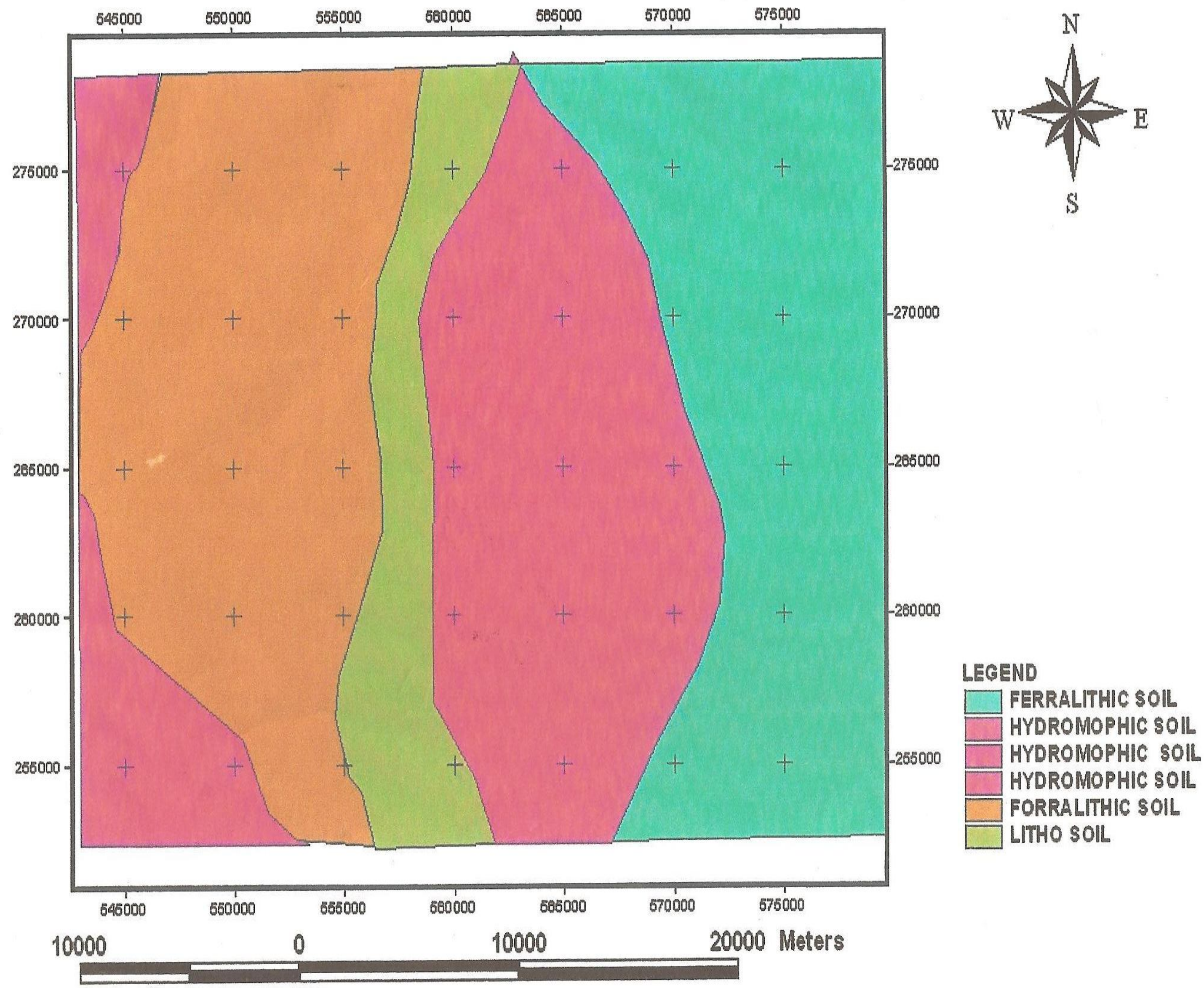


Fig. 22: Soil Class Map of Enugu Area and Environs (Digitized)
Source: Enugu Ministry of Environment

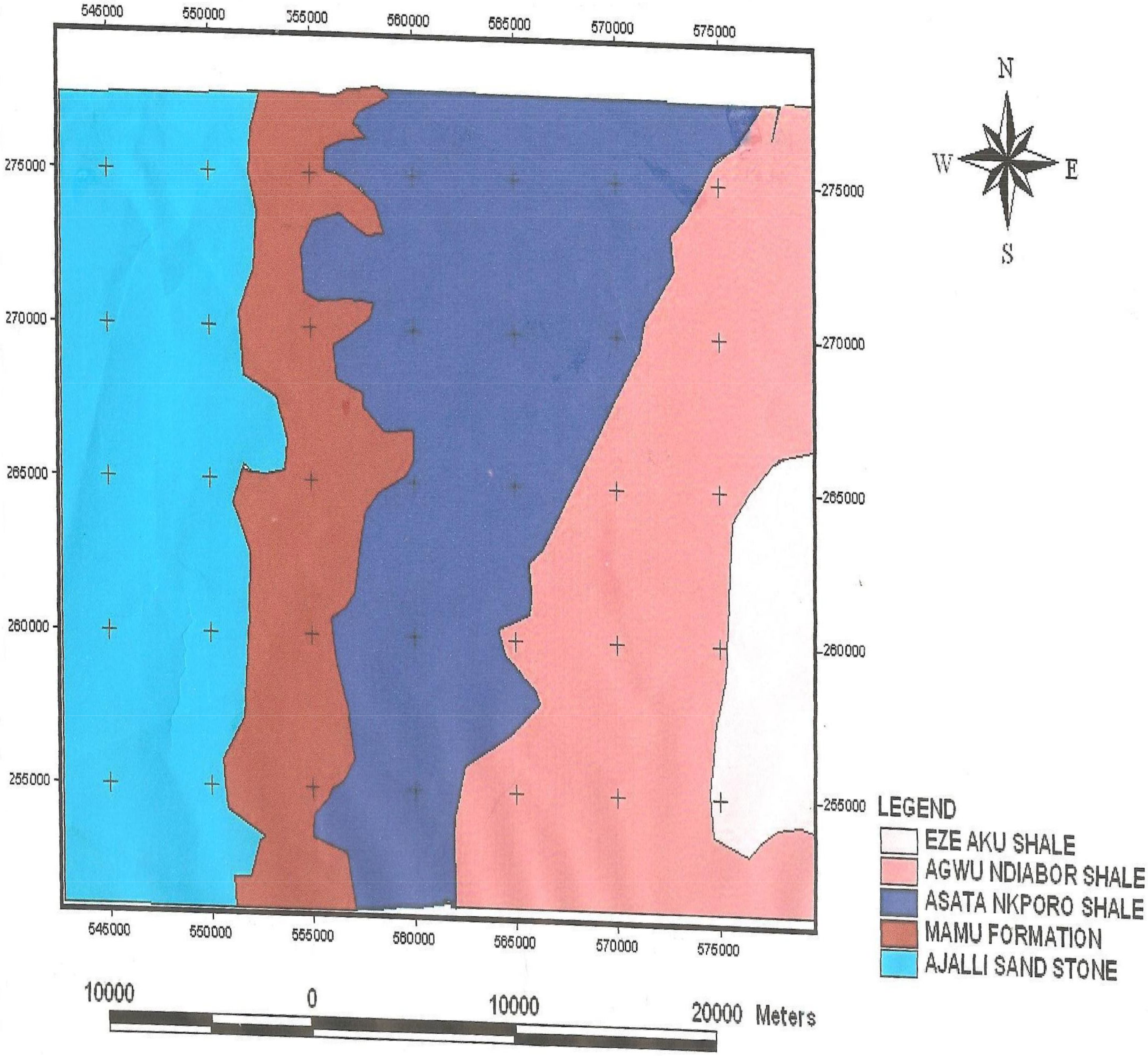


Fig. 22a: Digitized Geology Map
Source: FSN SHEET 72

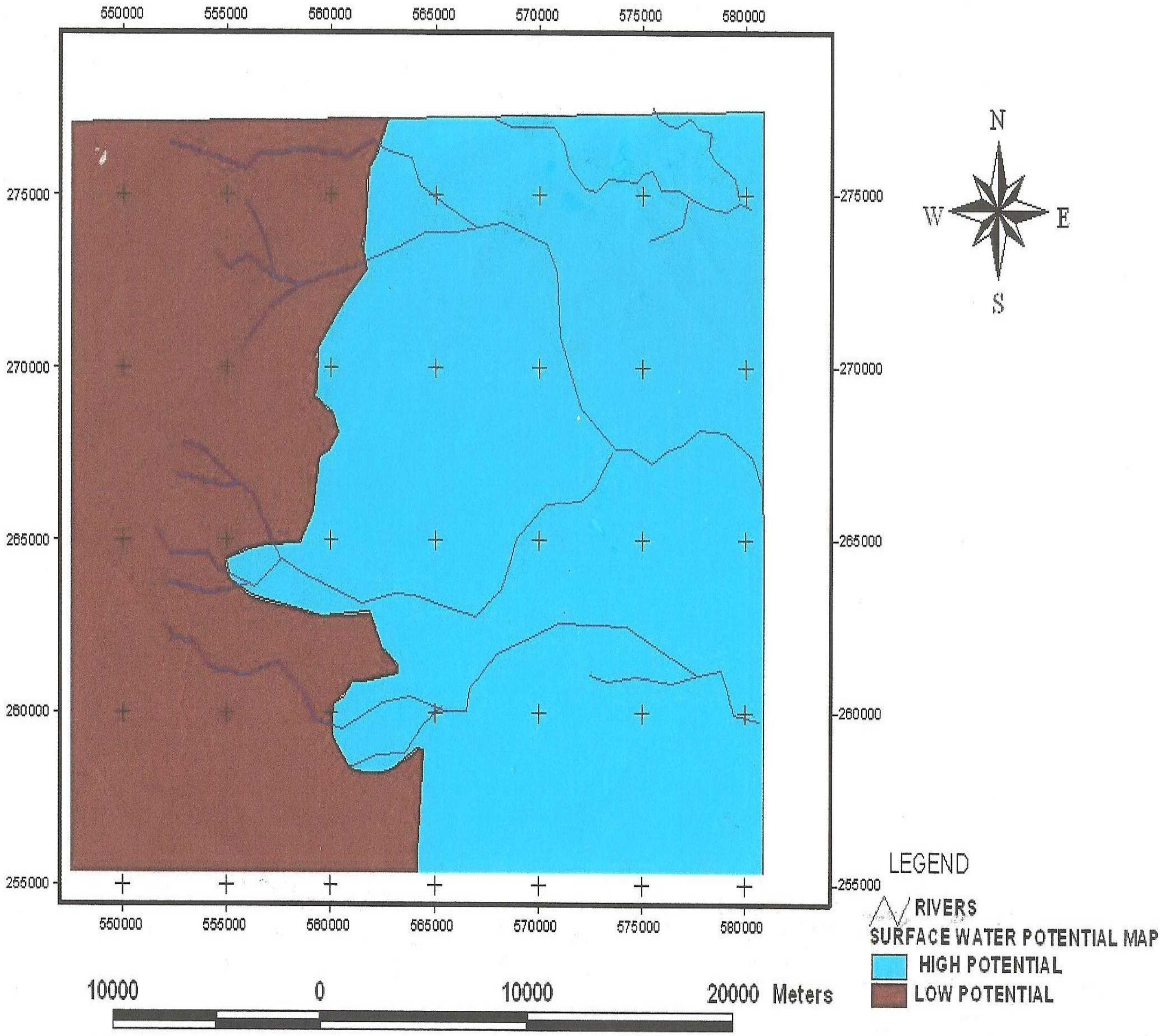


Fig. 23: Surface Water Map of Enugu Area (Digitized)
Source: FSN SHEET 72

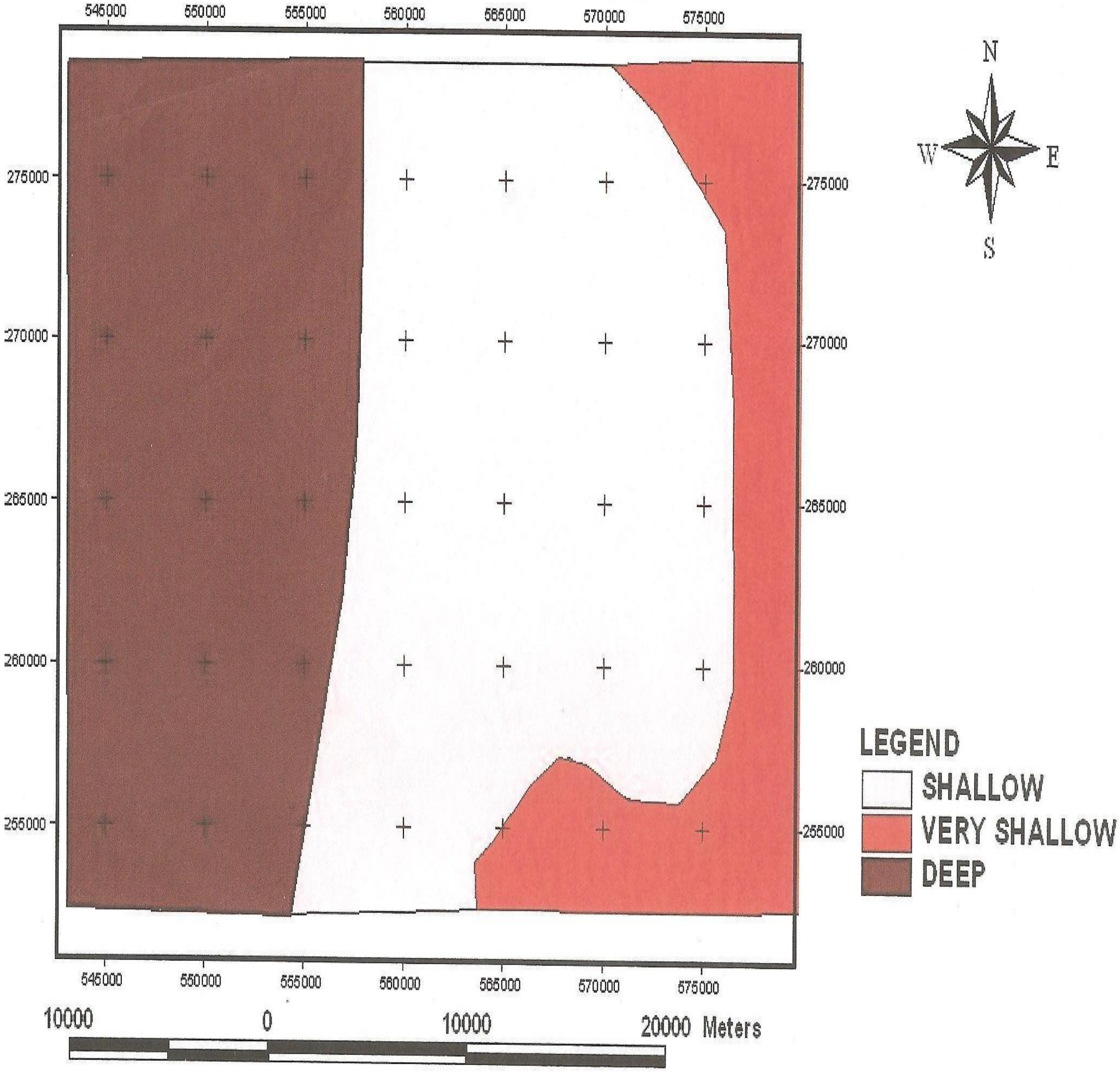


Fig. 24: Water table Map of Enugu Area and Environs (Digitized)
Source: Enugu State Water Cooperation

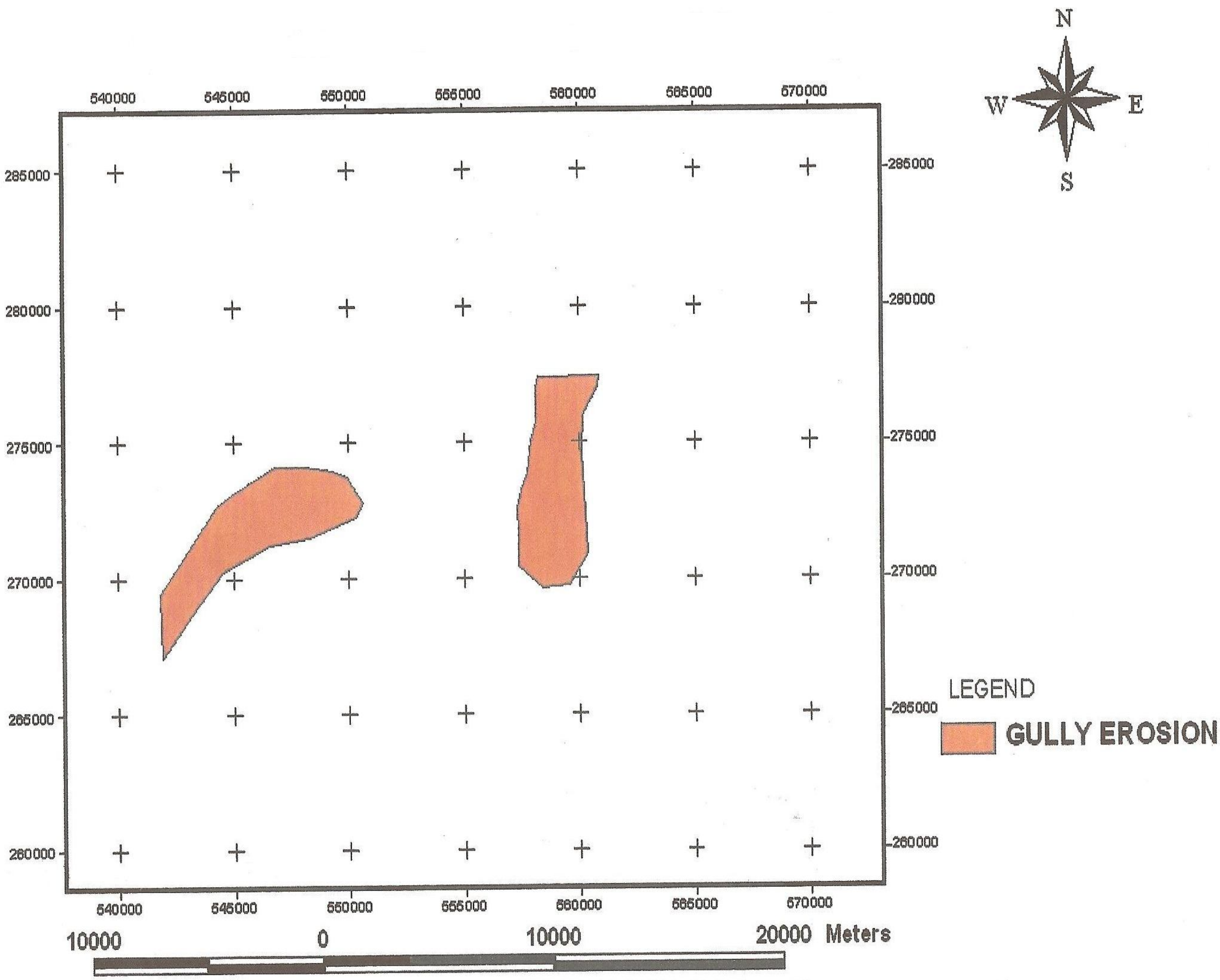


Fig. 25: Gully erosion Map of Enugu Area and Environs (Digitized)
(Buffer Distance = 1000Metre (1km)
Source: Enugu State Ministry of Environment

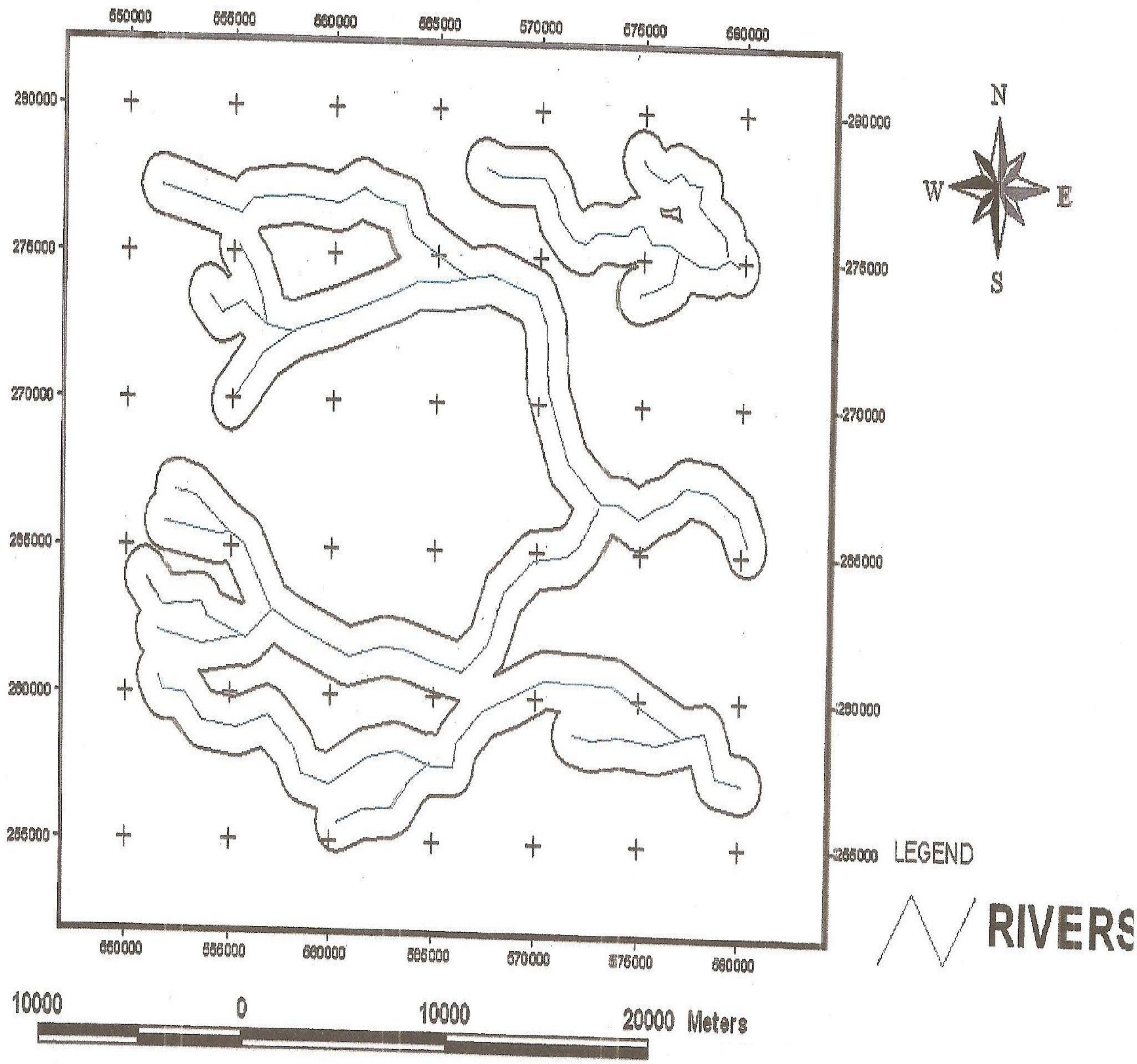


Fig. 26: Flooded/Landslide Map of Enugu Area and Environs (Digitized)
(Buffer Distance = 1000m = (1km)

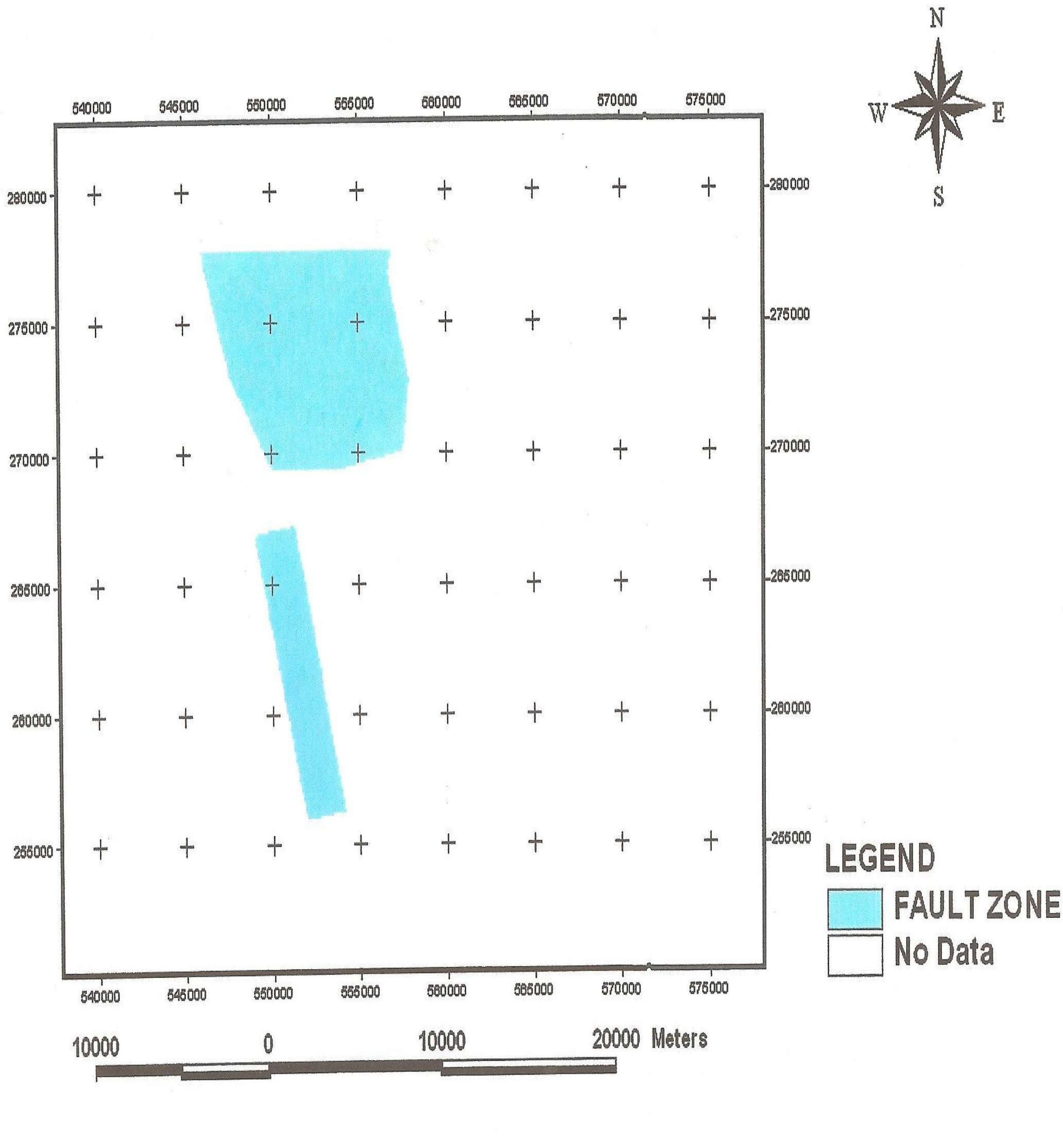


Fig. 27: Fault Map of Enugu Area and Environs (Digitized)
(Buffer Distance = 1000m (1km)

CHAPTER FOUR
DATA ANALYSIS

In this section, the data base was developed. The soft ware used in the analysis include: Excel Statistical soft ware, Geographic calculator, Auto card soft ware and Arc view. The first stage was the data base development which involved the conversion of the collected elevation values and coordinates to the national grid (Nigeria Datum) using excel statistical soft ware, Geographic calculator and Autocard as shown in Appendix 19. Data base development also involved the arrangement of the data in layers. Each traced determinant map was first scanned at 150 dpi resolutions. The scanned map was first imported into the autocard map software, geo-referenced with 4 control points to cover the boundaries of the study area. The control points are 7^0 21E to 7^0 41 E and 6^0 16N to 6^0 31N. The points were converted to the national grid using geographic calculator. The scanned maps were digitized using autocard drawing capabilities to convert them to vector formats, saved in different layers and later exported to Arc view soft ware for analysis.

Digitization of the maps was performed as to convert the analogue map to digital form. The process of digitization was also employed to create polygons considered to be areas of identical features. Twelve thematic maps were employed as the basic factors of the land use environment within the area. These maps are the themes which form the thematic data layers for the GIS operation.

With the aid of the topographic map of Enugu area, in combination with GPS elevation values, the Digital Terrain model was developed in Arc View GIS by the extrapolation of the elevation values at 100meter range and subsequently a slope map was generated.

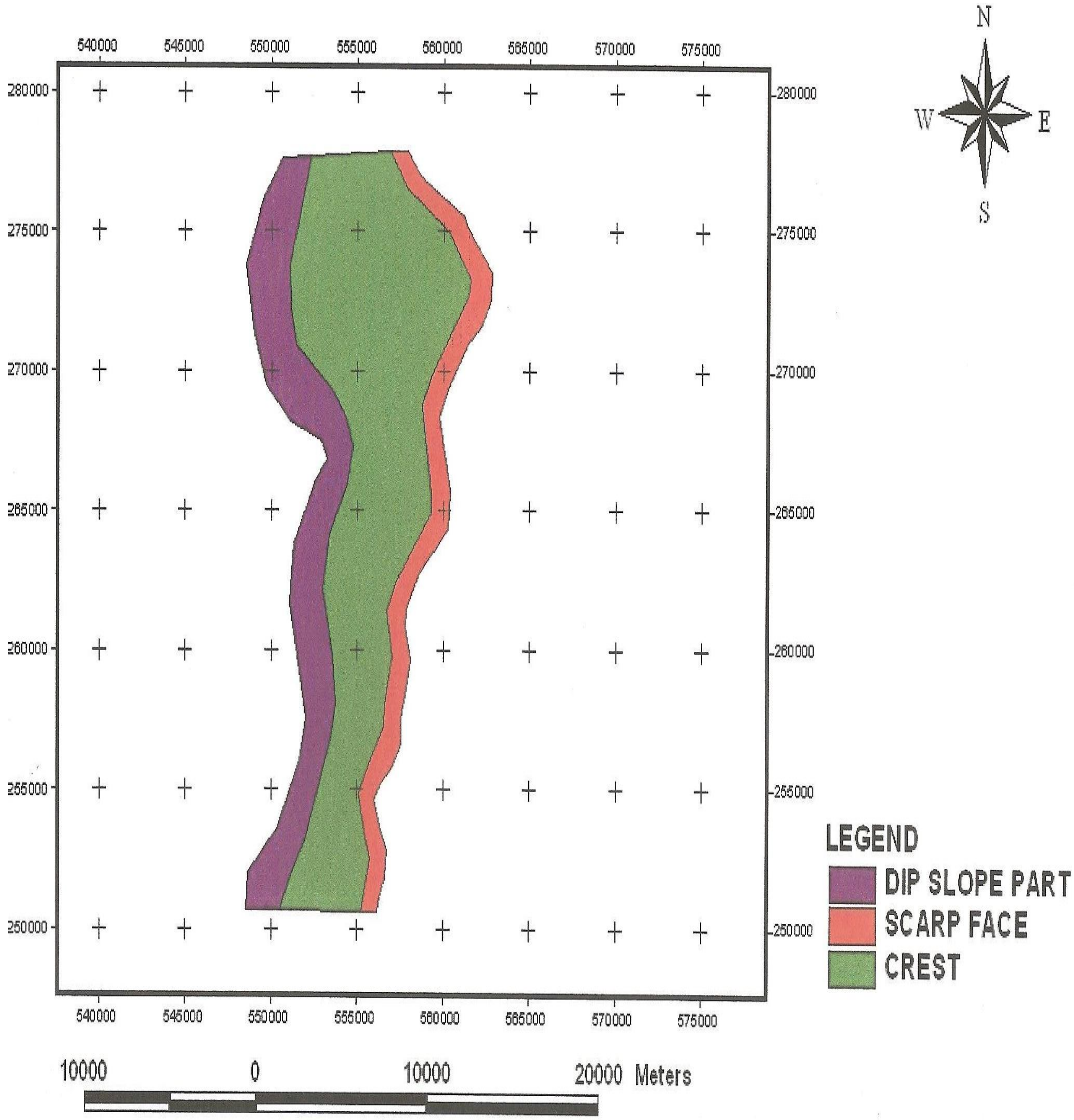


Fig. 28: Escarpment Map of Enugu Area

4.1 ORGANIZATION OF GEOGRAPHIC INPUT DATA AND ESTABLISHMENT OF GIS DATA LAYERS

Here, the land area of Enugu and Environs is allocated into capability classes by integrating class value attributes of the determinants. Each determinant is a theme and thematic input layer for GIS operation. The thematic layers (theme) adopted in this study include: slope, elevation, soil, geo-structural stability (fault land slide and erosion), surface and ground water. Others are soil drainage and escarpment. The organization of thematic data layers adopted in this work are for residential, industrial and waste disposal land use options – Tables 3, 4, and 5 . The table is a computer model and is tabulated as:

Input Theme: - these are the land use determinants considered in the study.

Percentage Influence: This determines the degree of importance of the determinant to the land use. The higher the value the more important the determinants become. The scale ranges from 0-100%.

Input label: The input labels are the attribute values which should be assigned capability ratings depending on their importance to the land use under consideration.

Scale Value: Scale values are the capability ratings. In this work, capability values were assigned to each environmental factor based on a scale of 0-2 (i.e. 0,1,2) to make up three classes of the land use.

Table 3: ORGANIZATION OF THEMATIC DATA LAYERS FOR WASTE DISPOSAL LAND USE

INPUT THEME	PERCENTAGE INFLUENCE	INPUT FIELD	INPUT LABEL	SCALE VALUE	REMARKS
SLOPE THEME 1 (LAYER 1)	10%	1 2 3	0-9 (Gentle.Slope) 9-19 (sloppy) > 19 (steep)	2 1 0	High slope causes down migration of leachate.
ELEVATION Theme 2 (LAYER 2)	6%				Elevation is not very important but it is used in the derivation of Digital Terrain Model of the area.
SOIL DEPTH THEME 3 (LAYER 3)	5%	1 2 3	Deep Deep Shallow	2 2 1	Attenuation of pollutants. The depth of the two polygons of deep soil measure on the average of 19.3m and 19m, while the third polygon of shallow soil measures 6.3 metres.
GEOLOGY THEME 4 (LAYER 4)	20%	1 2 3 4 5	Ajalli Fm. Mamu Fm. Asata/Nkporo Awgu-Ndi Abo EzeAku	1 1 2 2 1	Ajaili Fm. is porous, Mamu Fm. Is fractured. Ezeaku Fm may have solution cavities.
DRAINAGE (Soil) (LAYER 5)	10%	1 2 3	Moderate Moderate Well Drained	1 1 2	Poorly Drained Soil can lead to water logging.
SOIL CLASS THEME 6 (LAYER 6)	5%	1 2 3 4	Clay and Silt (Foralithic) Silty Clay (SP) (Hydromorphic) Silty Sand (SP) (Lithosoil) Silty Clay (SW) (Ferralithic)	1 1 1 2	Ferralithic soil has lower permeability and porosity (1.89x10^{-2} cm/s and 0.30). Forralithic soil has 1.92x10-2cm/s and 0.31. Hydromorphic has 1.97x10-2cm/s and 0.31.
SURFACE WATER THEME 7 (LAYER 7)	8%				
DEPTH TO WATER TABLE THEME 8 (LAYER 8)	9%	1 2 3	Very Shallow Shallow Deep	1 1 2	Underground water can be polluted when the water table is shallow to very shallow. Deep water table is ideal.
EROSION (Soil) THEME 9 (LAYER 10)	8%	1 2	Buffered Active Non Active	0 0	Can distribute wastes buffer distance ≥ 1000m
ESCARPMENT	4%		Scarp	0	The dip slope part is gentle,

THEME 10 (LAYER 10)			Crest Dip	1 2	the scarp is very steep, while the crest may experience migrating of leachate. Down hill.
FLOODED/LAND SLIDE THEME 11 (LAYER 11)	5%	1 2	Buffered Active Non Active	0 0	Can cause the distribution of waste and water logging. Buffer distance. ≥ 1000m.
FAULT THEME 12 (LAYER 12)	10%	1 2	Buffered Active Non Active	0 0	Can create pathway for leachate migration to ground water. Buffer distance ≥ (1km)
TOTAL	100%				

Table 4 : ORGANIZATION OF THEMATIC DATA LAYERS FOR RESIDENTIAL LAND USE

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 increases with slope angle. Slope is important for the stability of buildings slope of low value is ideal.
ELEVATION Theme 2 (LAYER 2)	6%	1 2 3	280-432 432-585 >585	-	Not very important, but elevation is used in the development of digital terrain model (DTM).
SOIL DEPTH THEME 3 (LAYER 3)	10%	1 2 3	Deep Deep Shallow	2 2 1	Deep soil is good for building foundation. The two polygons of deep soil measure 19m and 19.3m on the average, while the third polygon of shallow soil measure 6.3m. This gives a high scale value to the deep soil.
GEOLOGY THEME 4 (LAYER 4)	12%	1 2 3 4 5	Ajalli Fm. Mamu Fm Asata/Ekporo Shale Agwu-Ndi Abo shale EzeAku Fm.	2 1 1 1 1	Ajali Fm. has high shear strength. While Mamu Fm is fractured and expansive, Asata Nkporo, Awgu Ndiabo are also expansive and of low shear strength. Ezeaku Fm is characterized by limestone deposits. This may harbour solution cavities.

DRAINAGE (Soil) THEME 5 (LAYER 5)	12%	1 2 3	Moderate Moderate Well Drained	1 1 2	Poorly drained soil can lead to water logging. This likely increases the water pore pressure thereby reducing the effective strength of the soil.
SOIL CLASS THEME 6 (LAYER 6)	15%	1 2 3 4 5	Silt - Clay (SP) (Forralithic) Silty Clay (Hydromorphic) Silty Clay (SP) (Lithosoil) Silty Clay (SW) (Ferralithic)	2 1 1 1	Soil strength depends on class. Forralithic soil has higher shear strength (100.09N/m^2), higher compressive strength and lower consolidation settlement (0.63).
SURFACE WATER THEME 7 (LAYER 7)	5%	1 2	High Availability Low Availability	2 1	Important source of water supply.
DEPTH TO WATER TABLE THEME 8 (LAYER 8)	8%	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 10)	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	S c a r p Crest Dip	0 1 2	The dip slope part is likely to be more stable than the crest and scarp parts.
FLOODED/LAND SLIDE THEME 11 (LAYER 11)	5%	1 2	BUFFERED Active Non Active	0 0	Could result in environmental devastation of structures and hazard. Buffer distance ≥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%				

Table 5: ORGANIZATION OF THEMATIC DATA LAYERS FOR INDUSTRIAL LAND USE

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 increases with slope angle. Slope is important in the stability of industrial building. Slope of low value is ideal.
ELEVATION Theme 2 (LAYER 2)	6%	1 2 3	280-432 432-585 >585	-	Not very important but used in the development of DTM of the area.
SOIL DEPTH THEME 3 (LAYER 3)	10%	1 2 3	Deep Deep Shallow	2 2 1	Deep soil is good for building foundation. The two polygons of deep soil measure 19m and 19.3m on the average. This gives a high scale value to the deep soil. The third polygon of shallow soil measures 6.3m.
GEOLOGY THEME 4 (LAYER 4)	20%	1 2 3 4 5	Ajalli Fm. Mamu Fm. Asata/Enugu Shale Agwu-Ndiabo shale EzeAku Fm.	2 1 1 1 1	Ajali Fm. has high shear strength of 276.67m, Mamu Fm is fractured and expansive Asata Nkporo Shale and Awgu Ndiabo are also expansive and of low shear strength. Ezeaku Fm is characterized by limestone deposits. This may harbour solution cavities, which may be affected by vibrations of heavy industrial machines.
DRAINAGE (SOIL) THEME 5 (LAYER 5)	10%	1 2 3	Moderate Moderate Well Drained	1 1 2	Poorly drained soil can lead to water logging. This increases the water pore pressure. Increase in water pore pressure reduces the effective strength of the rock/soil.
SOIL CLASS THEME 6 (LAYER 6)	6%	1 2 3 4 5	Silt-clay (SP) (Foralithic) Silty clay (SP) (Hydromorphic) Silty Sand (Lithosoil) Silty clay (SW) (Ferralithic)	2 1 1 1	Soil strength depends on class. Forralithic soil has higher shear strength higher compressive strength and lower consolidation ratio.
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 by industrial effluents when shallow.
EROSION THEME 9 (LAYER 10)	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	The dip slope part is likely to be more stable, than the crest and scarp parts.
FLOODED/LAND SLIDE THEME 11 (LAYER 11)	5%	1 2	BUFFERED Active Non Active	0 0	Could result in environmental devastation of structures. Buffer distance ≥1000m (1km).
FAULT THEME 12 (LAYER 12)	4%	1 2	BUFFERED Active Non Active	0 0	Promote instability and failures of slopes and structures especially when fault planes slope towards the buildings.
TOTAL	100%				

4.2 OVERLAY PROCESS

INTRODUCTION:

The overlay process involves identifying the areas (polygons) where specified combinations of conditions occur together and the procedure involves selection of a model builder from the operational table of the arcview software. The individual theme is added up to the number of themes. Each theme is attached to the table related to it at the appropriate spaces to make up the weighted overlay. After inserting the scale of the percentage influence and the scale values, the model operation when applied produces a land capability overlay map layers for the particular land use options under consideration.

The requirements for this operation is that the theme must be compatible with the table of values of the weights. The maps must be of the same size, scale and coordinate, so as to establish compatibility and easy marching, (Civico et al 2002). The operation when performed separately produces different land use maps-industrial, waste and residential options.

4.3 OVERLAY MODEL FOR WASTE DISPOSAL AND RESULT

The overlay model procedure for waste disposal is shown in Fig 29a and when applied produces a waste disposal land use map Fig 29b, made of suitability areas 1,2,and 3.

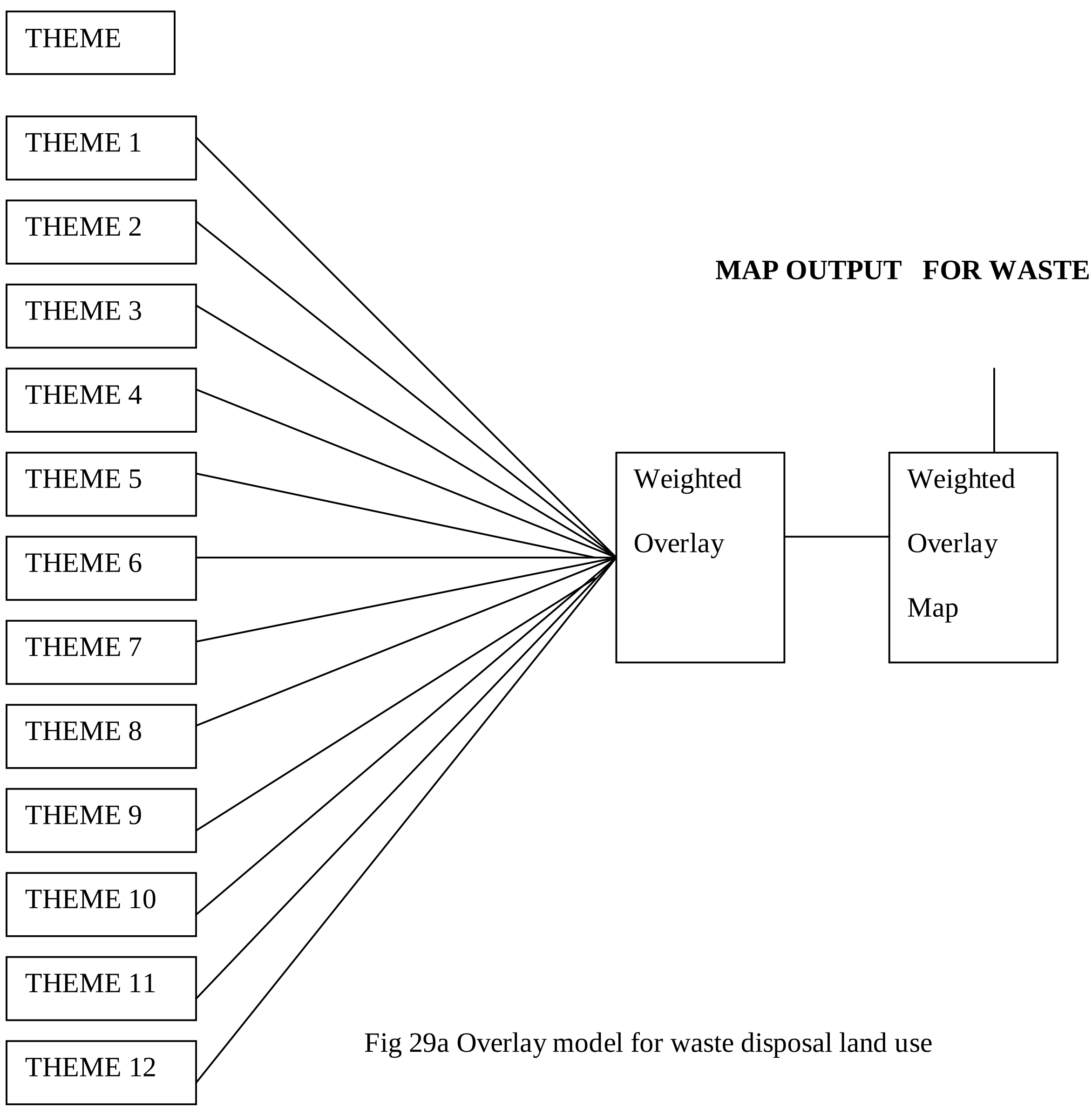


Fig 29a Overlay model for waste disposal land use

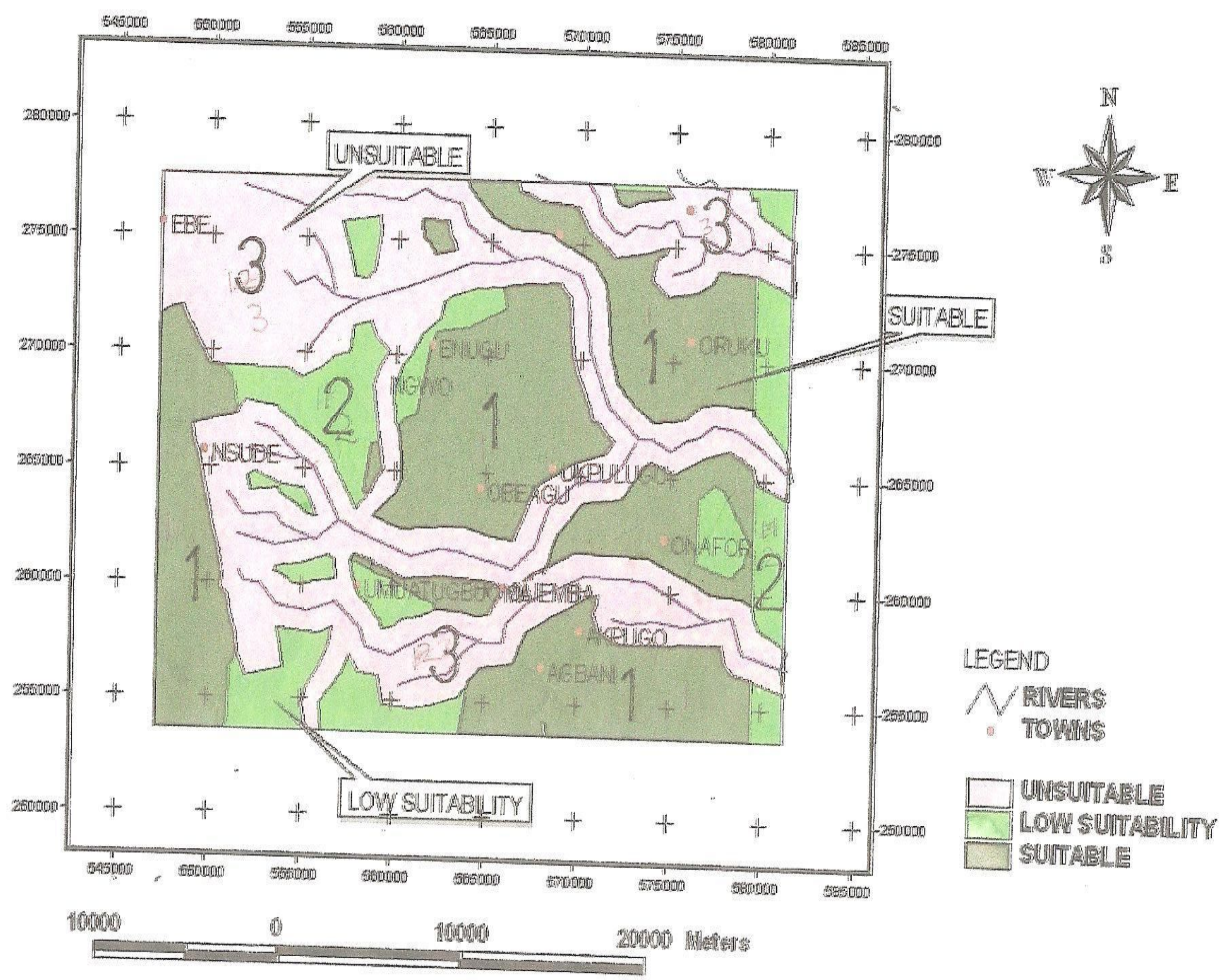


Fig. 29b: Suitability Map for Waste Disposal Enugu Area and

4.4 OVERLAY MAP FOR RESIDENTIAL LAND USE OPTION AND RESULT

The overlay model chart for residence (Fig. 30a), when applied, produces residential land use map made of three areas: Area 4, Area 5, and Area 6, reflecting areas suitable for residence, areas of low suitability and areas that are unsuitable (Fig 30b)

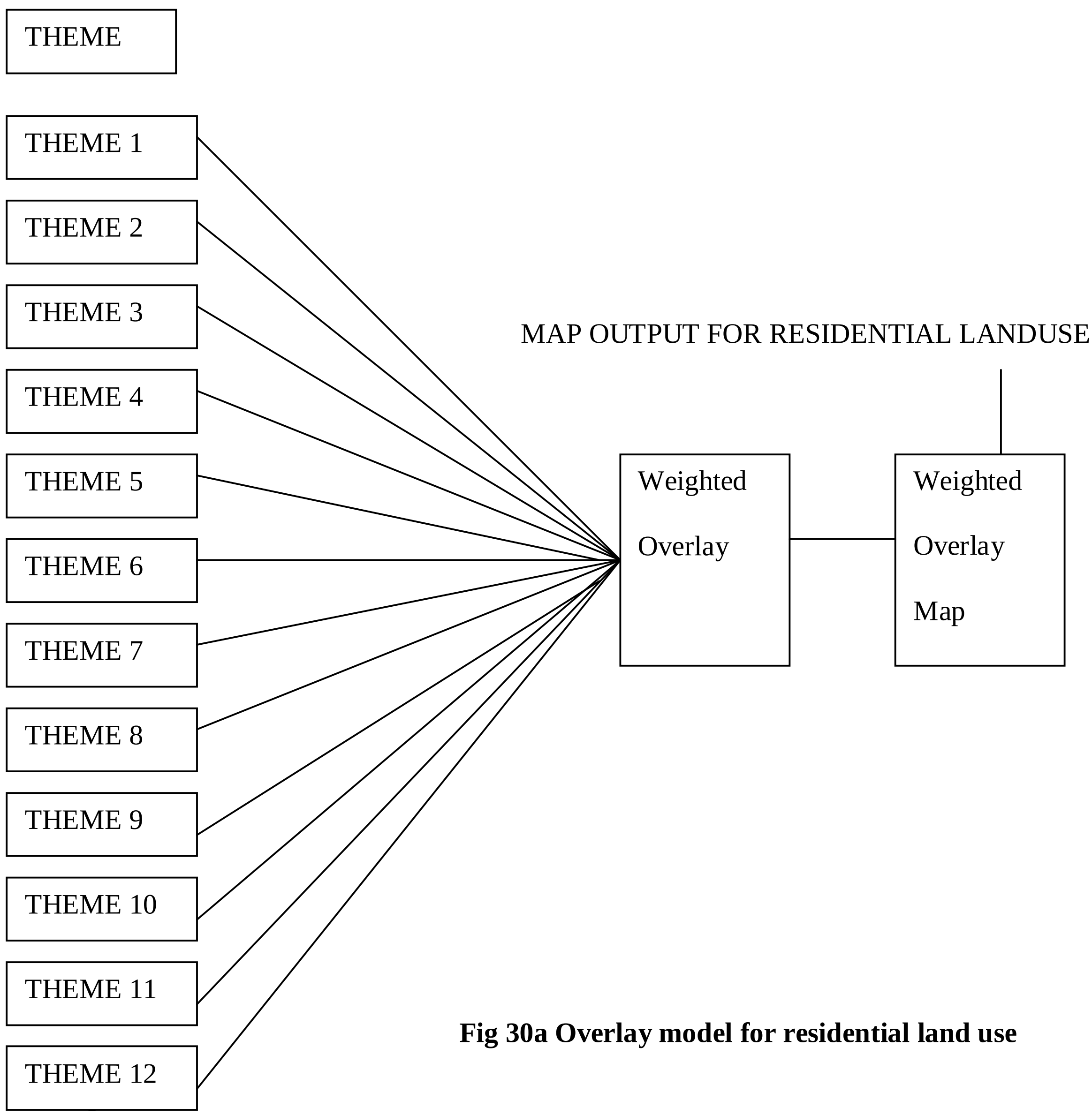
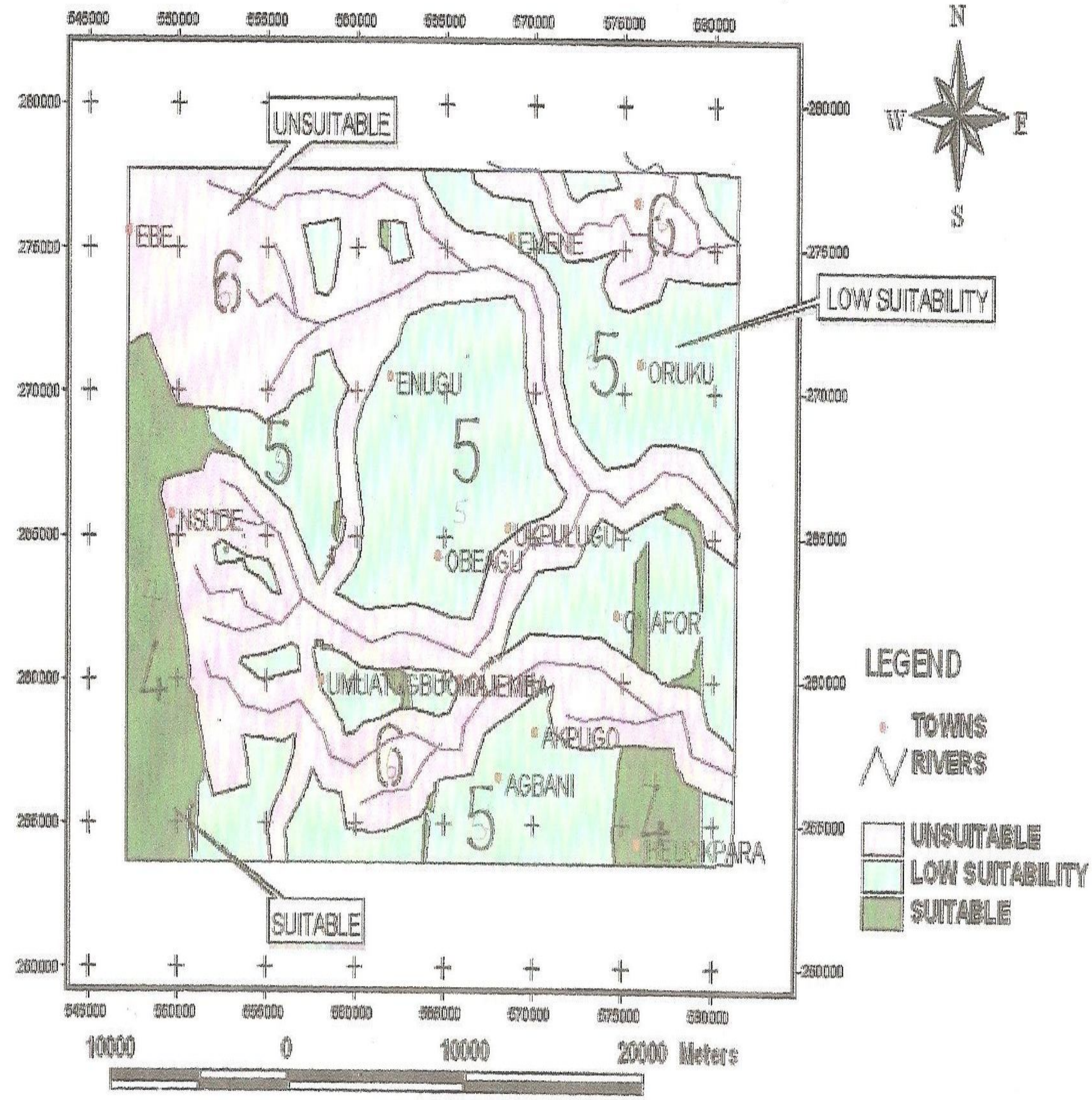
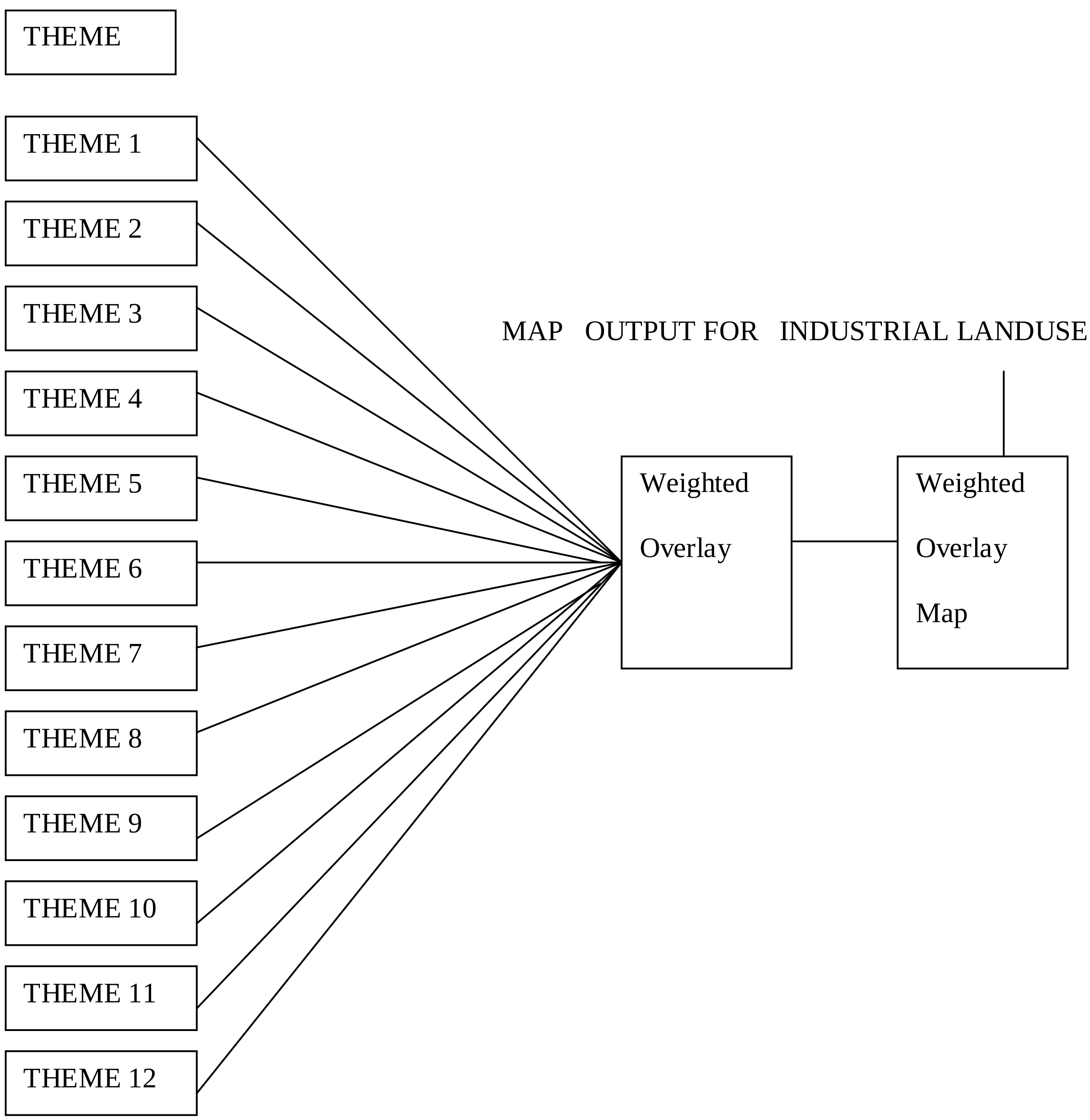


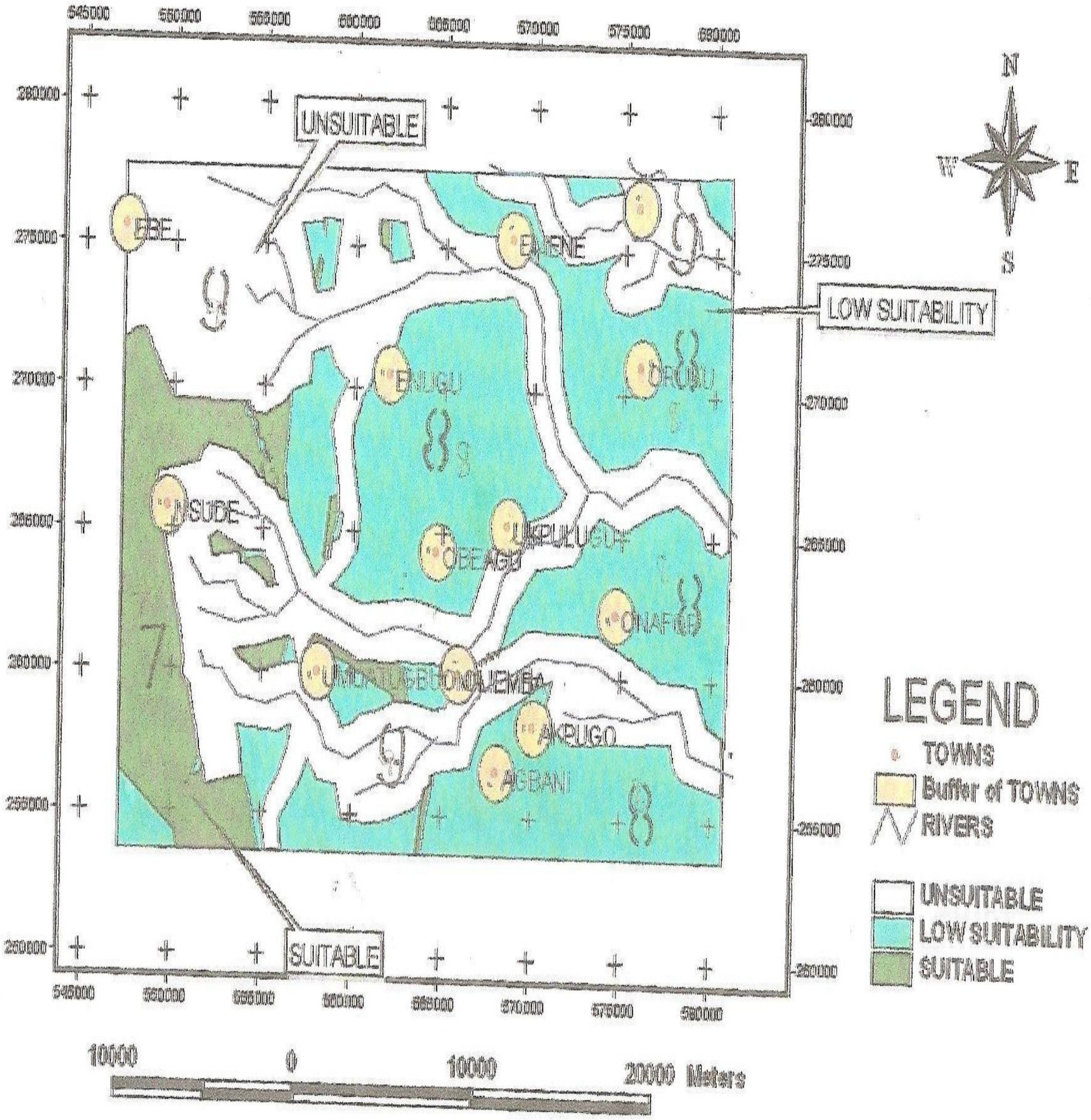
Fig 30a Overlay model for residential land use


UNSUITABLE
LOW SUITABILITY
SUITABLE
EBE
EMENE
ENUGU
ORUKU
NSUDE
OBEAGU
AKPUGO
AGBANI
LEGEND
TOWNS
RIVERS
UNSUITABLE
LOW SUITABILITY
SUITABLE
N
S
W
E
10000
0
10000
20000 Meters

4.5 OVERLAY MAP FOR INDUSTRIAL LAND USE OPTION AND RESULT

When the overlay model process for industrial land use was applied (fig. 31a), the result gives industrial land use map made of three areas namely: Area 7, Area 8 and Area 9, showing in the order areas suitable for industry, area of low suitability and unsuitable areas (Fig 31b)





UNSUITABLE
LOW SUITABILITY
SUITABLE
EBE
ENUGU
NSUDE
OBEAGU
AKPUGO
AGBANI
N
S
E
W
LEGEND
TOWNS
Buffer of TOWNS
RIVERS
UNSUITABLE
LOW SUITABILITY
SUITABLE
10000
0
10000
20000 Meters

CHAPTER FIVE

RESULTS AND DISCUSSIONS

The results of the overlay operations produced the preferred areas for waste, residential and industrial land use options. The resulting maps are shown in figures 29b , 30b, and 31b respectively. Their capability values are designated as areas 1,2,3,4……..9 inclusive. They are generally classified as suitable, unsuitable and low suitability. The resulting maps are described below.

Suitability Map for Waste Disposal:

The overlay result of waste disposal land use produces the suitability map for waste disposal fig 29b. The map shows various areas of capabilities designated as areas 1, 2 and 3 respectively. This study shows that large portion of the area is suitable for waste disposal (Area 1). The western quadrant is suitable due to low water table and considerable soil thickness which has in addition high percentage of fines.

Area of low suitability for waste disposal (Area 2), fall mainly around escarpment and eastern section of the map. The low suitability can be accounted for by steep slope, seepage at the foot of the escarpment due probably to high pore water pressure, and the very shallow water table to the east. The presence of fractures and faulted formations contribute to the low suitability. The unsuitable zones for waste disposal (Area 3), correspond with fault zone, scarp face, flooded and land slide prone areas.

Suitability Map for Residential Land Use:

The overlay result for residential land use produces the weighted overlay map for residential land use fig 30b. The map shows various suitability areas 4, 5 and 6 respectively. Area 4 shows suitable zones for residential land use. They are found within the western quadrant of the map and the eastern portion. They also occur as pockets around the scarp environment. These areas are associated with sediments of high shear strength and water availability. Area 5 corresponds to the zones of low capability and occupies a large portion of the map area. The low suitability is as a result of steep slope to the west, high pore water pressure which could accelerate gully erosion as well as the presence of expansive soil characterized by low shear strength, low angle of internal friction and high consolidation ratio Ugwuogo 1989, Waltham 1994).

A preliminary comparative study of the land capability map against the existing land use pattern of fig 33, indicates that the bulk of the present residential area lie within the zone of low capability. However, most of the areas projected for new residential development fall within the high capability zone. Area 6 in the residential land use map is unsuitable for residential use as it is characterized by potential gully erosion problems and excessive steepness of slope. Furthermore, the area falls within a fault zone; however; the fault is not known to be active. Other unfavourable attributes of the area include its flood plain status and associated landslide hazards.

Suitability Map for Industrial Land Use:

The separately weighted overlay map for industrial land use delineation are areas 7, 8, and 9 respectively. Area 7 (Western portion) is suitable for industrial land use, while areas 8 and 9 are of low and no suitability. Area 7 is associated with water availability, thick surficial sediments of high shear strength necessary to withstand stresses associated with industrial machineries. Area 8 covers all the zones of low suitability for industrial land use. The low suitability is due to the shallow water table and the low shear strength initiated by high pore pressure as well as the expansive nature of the soil. The later would have adverse effects on foundations of heavy industrial buildings, while the former could predispose the ground water environment to potential contamination by industrial effluents /waste. Area 9 is unsuitable due to hazards associated with faults, erosion, flooding and landslide.

When the industrial, residential and waste disposal land use maps were superimposed, a different and a new form of composite land use maps emerged, this is shown in fig 32. The resulting land use elements are designated as areas 10, 11, 12, 13, 14, 15, 16 and 17 respectively, giving a total of eight classes of composite land uses. These are described below.

Area 10: This area is suitable for industrial, residential and waste disposal. They occur only at the western end of the study area and as pockets within some portions of the escarpment base and braided rivers.

Area 11: The area is of low suitability for industrial and residential land uses, but suitable for waste disposal.

Area 12: These areas are unsuitable for industrial, residential and waste disposal land uses.

Area 13: Area thirteen is the terrain suitable for residence and waste, but has low suitability for industrial land use. This area falls only at the South Eastern segments of the map.

Area 14: This area has low suitability for all the land use options. They occur at the base of the scarp face. Enugu metropolis belong to this category.

Area 15: This segment belongs to the areas suitable for industrial land use, but of low suitability for waste disposal and residential land uses.

Area 16: This axis belongs to areas of low suitability for waste and residential land use, but suitable only for industrial land use options.

Area 17: This section is suitable for residential and industrial land uses but low for waste disposal.

It appears that the composite land use map has a more reliable advantage for effective choice of land for any use. It therefore appears to be better than the single purpose land use map. Where the terrain appears suitable for the three land use options, such a land is an advantage because the handling of leachate from the industrial or residential effluents is taken care of by the natural processes, hence the environment is protected. This also saves cost in waste management. The selection of areas of low suitabilities for any building construction entails a lot of capital, since it requires a special building design and reinforcement; also the disposal of wastes is a capital expenditure. Industrialists consider the economic cost of setting up industries, and when the cost exceeds the advantage due to wrong site locations, the project is abandoned. Environmental pollution is likely in all areas suitable for residential and industrial land uses, but unsuitable for waste disposal. Areas of high suitability for industrial land use, but prone to environmental pollution should observe the international standard practice of leachate treatment and discharge into the environment, and this entails a lot of capital.

Existing and Projected Land Use Plan:

The present and the 2010 projected land use plans for Enugu area presented by Eco-design international consultants Ltd is shown in figure 33. It should be observed that all the present existing residential and industrial areas, including Emene industrial estate, fall within the low capability zones as shown by the result of the present study. The present waste disposal site for Enugu –Port Harcourt express way falls within the high capability area for waste disposal of the present study. This means that its present position is well sited. The areas mapped out for residential use by Eco-design consultants, conforms with the low suitability areas of the present work. The new areas added to master plan fall partly within the high capability zone for industrial and residential use, but to a large extent conforms with the areas of low suitabilities for the three land use options.

In all cases, appropriate environmental impact assessment should be conducted prior to the implementation of land use projects. However, the development of all the suitable areas will depend upon the available land, as well as on basic needs. For example where an area is suitable for the three land use options, its actual use for waste disposal, residence or industry, will be influenced by the size of the land available. Areas of high suitability for industry and residence of this study are relatively limited and in many cases occur in isolated patches. In the light of the apparent shortage of suitable areas, those of low suitablities can be influenced for use by appropriate engineering design and their implementation can upgrade the areas to suitable status or it can be improved by proper down stream environmental management and routine environmental maintenance. In view of the fact that areas of waste disposal dominate as compared to the residential and industrial land uses which are mainly located in the west, and to the fact that unsuitable areas abound due to flood plains, land slide, erosion and flooding, some of these unsuitable areas can be reclaimed and used.

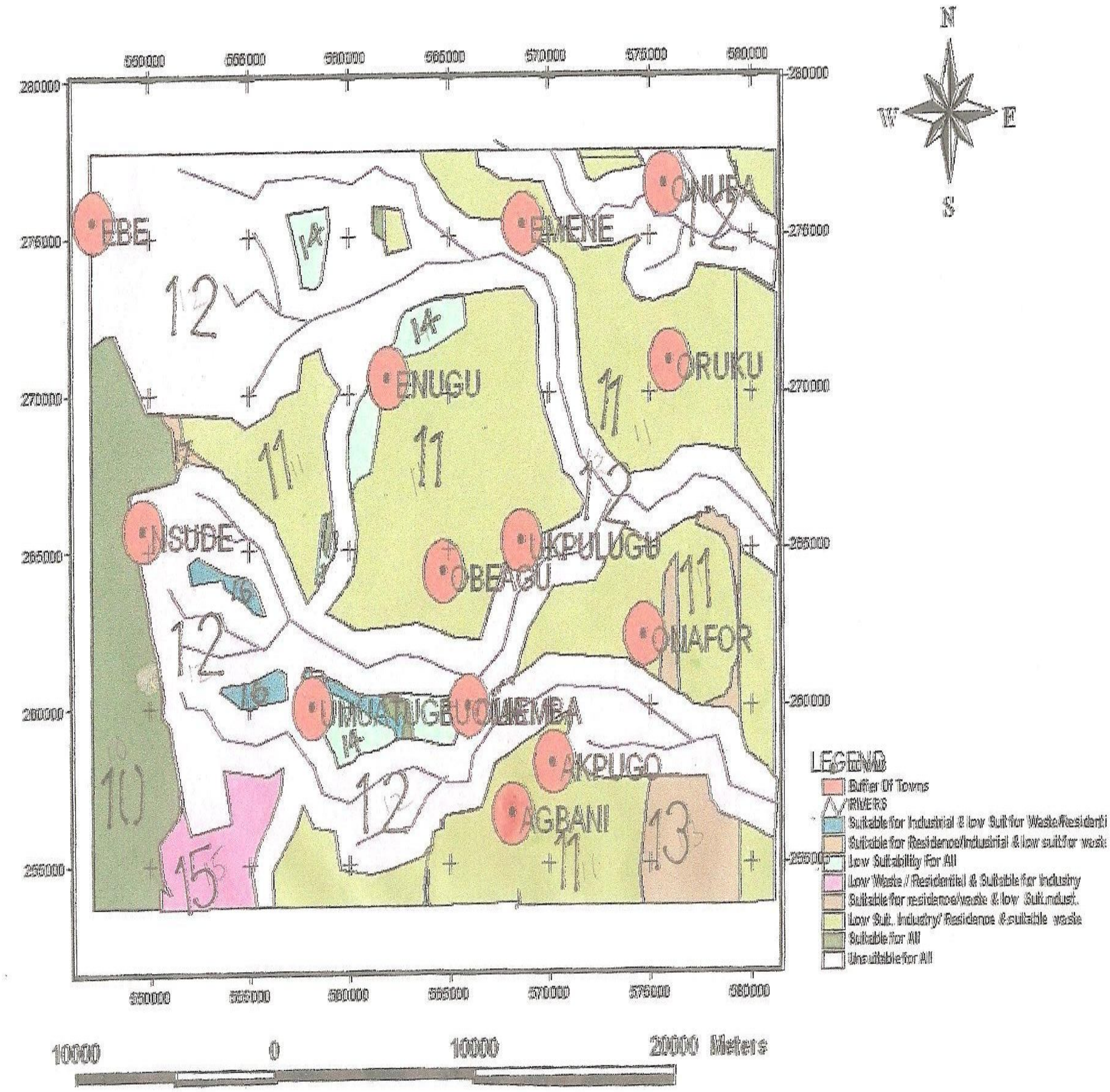


Fig. 32: Composite Land Use Map of Enugu Area for Industry, Waste

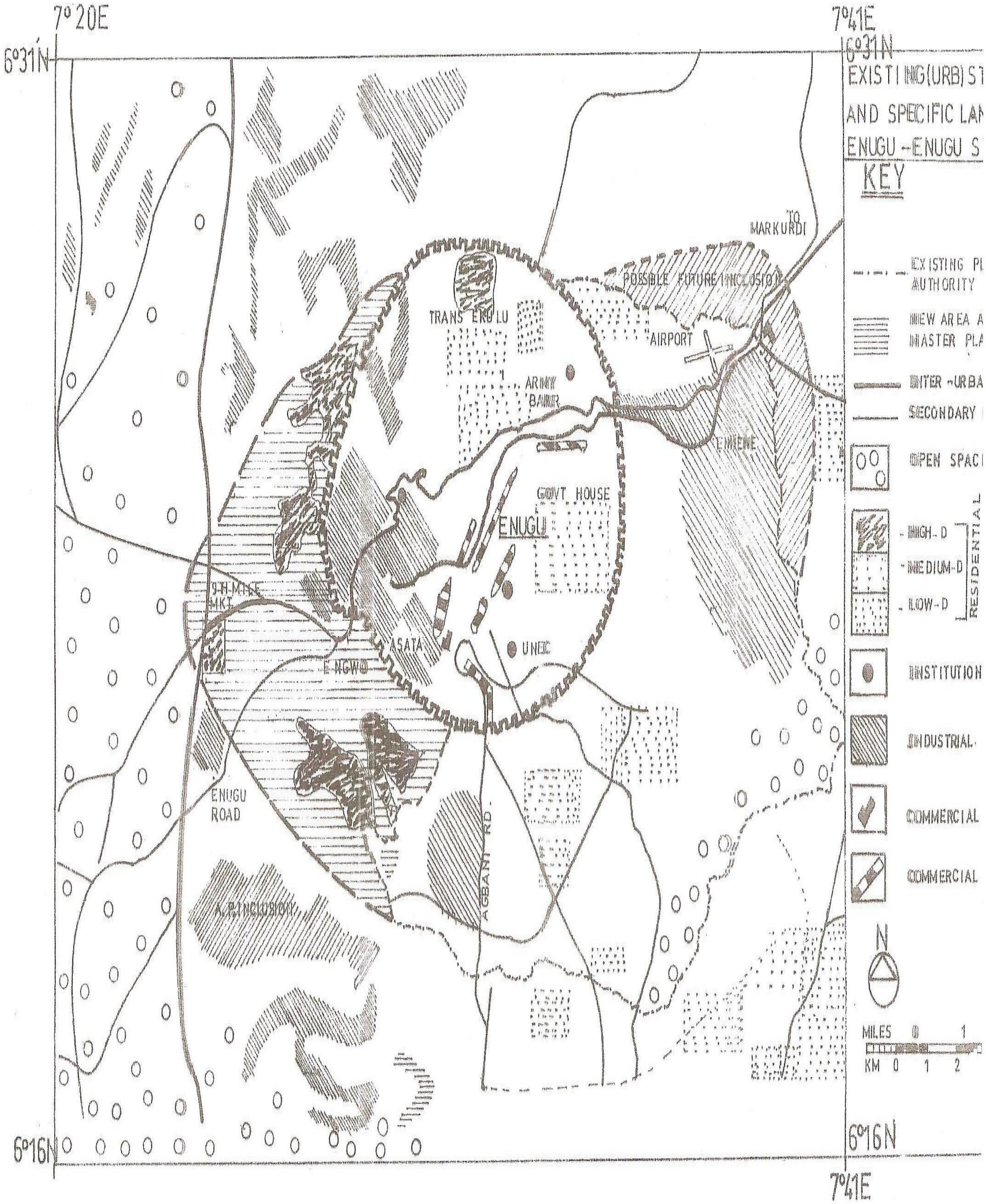


Fig. 33: Present Land Use Map of Enugu Area and Environs
Source: Concept Eco Design Consultant Ltd, Enugu

CHAPTER SIX

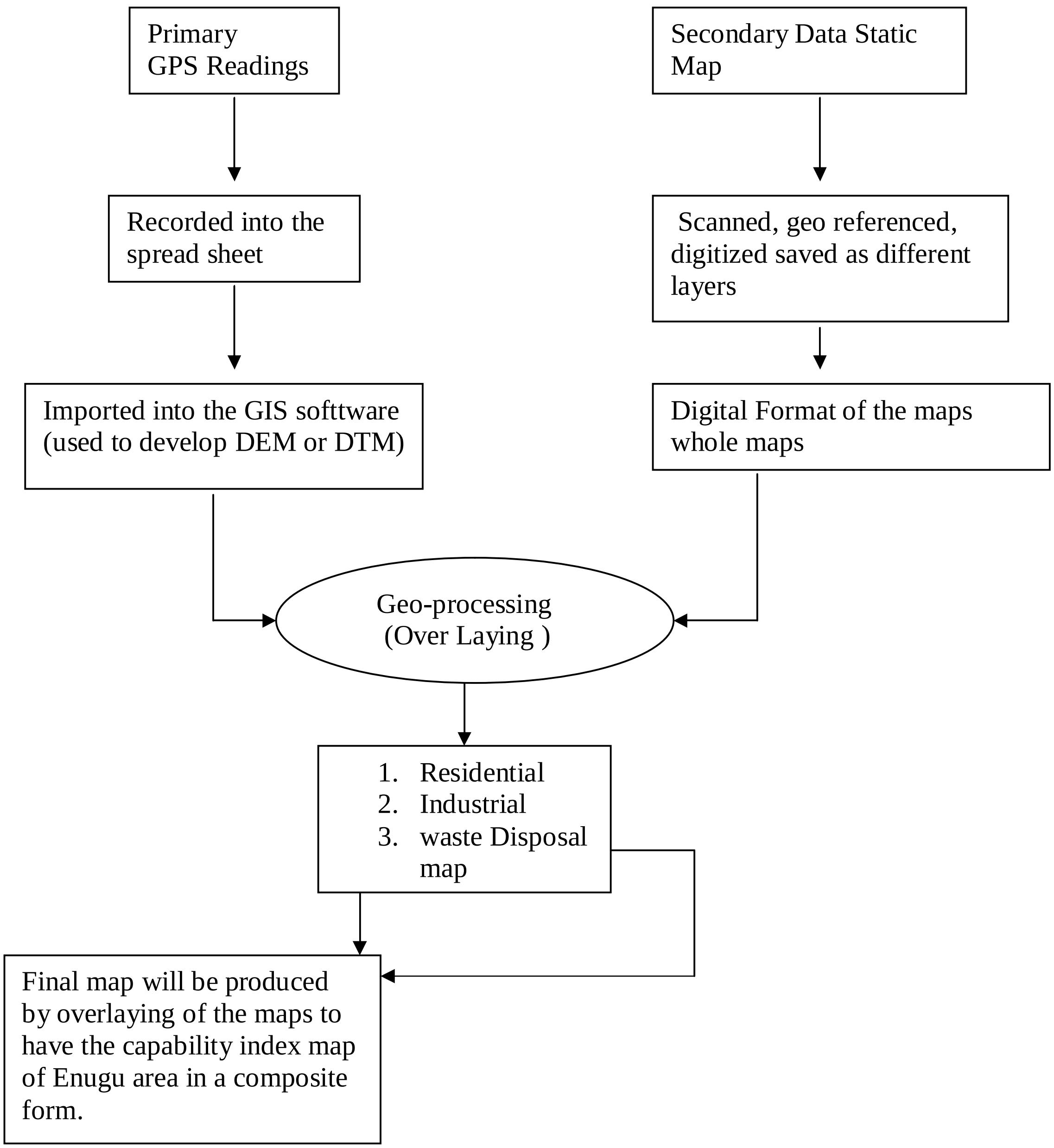
CONCLUSION AND RECOMMEDATIONS

CONCLUSION: This study shows that the high proportion of Enugu land unit has low suitability for industrial and residential land uses. The few areas that are suitable for these land use options are located within the western segments and to some extent the east. Areas suitable for waste disposal cover the greater percentage of the land unit and are found within the western, central, and to some extent the east. Some of the available lands are unsuitable for any land use due to fault, erosion,land slide, flooding and to some extent the scarp face of the escarpment. Ezeagu Local Government Area, Udi Local Government Area and Nkanu east are highly favoured in industrial and residential siting. Problems of collapsed buildings and water pollution are attributed to improper use of the land. Though this work centers on physical and social factors of land use, economic and political factors are equally important in the choice of land for any functional use. If the findings of this research is adhered to the occurrence of natural hazards should be minimized, hence the quality of the lives of the greater number of Enugu residents should be raised in the most cost effective manner possible.

RECOMMENDATION: In the light of the findings of this project, It is recommended that the allocation of land for industry, residence or waste disposal should not be done at random, politics notwithstanding. Land allocation for any project within the area should reference the present land use index map of Enugu area and environs. Environmental management authority should be put in place to assess the land for any engineering construction, since the greater percentage of the land unit is unsuitable for residential and industrial land use options.

6.2 **SUMMARY MODEL OF THE MAPPING PROCEDURE FIG. (34)**

The mapping processes described above are summarized in the form of flow chart diagram as follows:



REFERENCES

Adejuwon, J.O. 1973. A biographical Survey of Savanna Vegetation in Nigeria,
geogr Ass. of Nigeria vol 114, p 31 – 48.

Agrawal, C.S. 2000. Remote sensing in natural resource monitoring and management, whealter publisher, New Delhi, India pp 221 - 233

Ahmadi, .S. 199. Land use Mapping in central watershed of Iran area based on satellite data interpretation, proceedings of the 5th Asian conference on remote Sensing pp 9 15.

Alexander, C. and Javis, C. 2006. 3D Visualization of Master Map using height data from LIDAR in G15 research U.K. 14th Annual conference on geographic in formation systems, Canada pp 11 – 15.

Amajor, L.C. 1984. Sedimentary facies analysis of the Campano-Maestrichtian Ajalli sandstone Okigwe area, Nig. 20th annual conference of Nigeria Mining and geosciences society, Nsukka abstract vol 13 p 11.

Anon, T.C. 1981. Basic geotechnical description of rock masses ISRM Commission on classification of rocks and rock masses. Journal of Rock mechanics, Mineral Science Canada pp 85 – 124.

Aria, W.R. 2003. Principles of Geotechnic, env. Prot. Service, Canada pp 85 – 124 Har Wood academic publishers New York. Pp. 124-126.

Arthur, D.H. and Irwin, R. 1982. Geology in Environmental planning, Graw-Hill Inc New York pp 20 – 35.

ASTM, D 421 – 98(2001). Annual book of ASTM standard vol 04 08, soil and rock standard no D 421 – 98, standard practice for particle size analysis and determination of soil constants West Conshokocken p A PP 8 – 9.

ASTM D, 422 – 98 (2001). Annual book of ASTM standards, vol 04.08 soil and rock standard no D 422 - 98 standard test method for particle size analysis of soils West Conshohocken pp 10 – 17.

ASTM, D. 4318 – 98 (2000). ASTM Standard vol 04:08 rock and soil standard test for liquid limit, plastic limit and plasticity index of soils, West Conshohocken P.A. pp 546 – 558.

ASTM, D. 4767 – 95 (2000). Annual book of ASTM standards vol. 04.08 rock and soil standard No D 4767 – 95, standard test method for consolidated undrained Triaxial compression test for cohesive soils, West Conshohocken p.A pp 882 – 891.

ASTM, 1988. Annual book of ASTM standards Philadelphia 1988, copy right. American society for testing and materials 1916, Race street Philadelphia PA 19103 reprinted with permission.

Becker, J. and Johnson, D, 2000. District plans and regional policy statements, society of New Zealand & Ann Abor Science publishers State University of New York press pp230 – 320.

Bell, F.G 1992. Description and classification of rock masses in Bell F9 (Ed), Engineering in rock masses, Butterworth/Heineman Ltd London pp 53 -77.

Benson, S. and Jones, R.C 2003. The Combined EMT / VES geophysical methods for sitting boreholes, ground water 26, pp 54-63.

Bouwer, H. 1978. Ground water hydrology MC Graw-Hill New York pp 25 – 35.

Brain, P.C. 1987. Optimal ground water management under parameter uncertainty water resources 23, No 7 Washington D.C. Govt printing office pp 162 – 174.

Buol, S.W. Hole, F.D. and Cracken, R.J 2000. Soil genesis and classification 2nd Ed Ames Iowa University Press. Pp. 18-36.

Casangrande, A. 1952. Classification and Identification of soils. Trans ASCE Vol. 113, Pp. 40-60.

Chinpin, F.J. 1965. Urban land use planning, Illnois University Press, Illnois USA pp 34-48.

Chengliu, J. Evett, B. 2000. Soil properties 2nd ed, prentice Hall inc, A Div of Simon and Schuster Englewood Cliffs New Jersey 07632 pp 28.

Civico, D.J. and Huru, D.J 2002. A Comprise of land and land cover change detection methods proceedings of 6th American conference on remote sensing pp 20 – 200.

Crynine, P. 1977. land disposal of solid wastes cbs publishers and distributors, Darya Garji New Delhi pp 850 – 930.

Davis, S.N and Dewest, R.J. 1996. Hydrogeology, John Wiley and Sons inc New York pp 372.

Davis, R. and Rogers, G. 1975. Land fill evaluation and siting study, New Jersey, John Wiley and Sons publishers pp 240 – 285.

Dimitri, P. and Krynine, W. 200. Principles of Engineering geology and geotechnics S.K. Jain for Cbs publishers and distributors, New Delhi pp 111 – 122.

Dunne, T. and Leopold, L.B 2002. Water in environmental planning, SanFrancisco, John Wiley and Sons publishers pp 73 – 92.

Dutra, I.V. and Hober, R. 1998. Primary forest and Landcover contextual Brazil proceedings on international geosciences and remote sensing symposium U.S.A. pp 25 – 35.

Egboka, B.C.E. and Onyebueke, F.O. 1999. NAH Journal on acute Hydro geological problems vis a vis planning and management of developing economy. A case study of Enugu area, Nigeria, Pp. 10-12.

Egboka, B.C.E. 1993. Water resources problem in the Enugu area of Enugu state Nigeria Nigerian Journal of Min geology vol 20 pp 1 -6.

Ezeanyim, E.C 1988. Hydrogeology of Enugu area and Environs, unpublished M.sc. Thesis, University of Nigeria, Nsukka .

Fischer, A. C. and David, R.J. 1990. Land transformation. Proceedings of National conference on remote sensing, Canada pp 21 – 43.

Foster, S.S D and Skinner, 1995. Ground-water protection. The Science and practice of land surface zoning in Kovar pp 67 – 80.

Freeman, H.M 2000. Hazardous waste minimization New York M.C. GrawHill pp. 221 – 232.

Freeze, R.A. and Cherry, J.A. 1979. Ground water. Prentice hall Inc, New Jersey Pp. 280-285.

Froelich, A.J. 1997. Planning a new community in an urban setting, Lenish in U.S Geological Survey; professional paper pp 69 – 89.

Gabelli, J.O 1983. Health effect Criteria for marine recreational water U.S Env. Protection Agency claredon press London pp 31 – 80.

Gauley, P.N and Krone, R.B 1966. Soil mantle as a waste treatment system. University of California Berkely California, serial Report no 6607 pp 120 – 131.

George, B. and Korte, F.E. 2000. The GIS book 5th ed M.C Graw- Hill book Company U.S.A pp 214 – 218.

Goa, J. 2000. Resolution and accuracy of terrain representation by Grid DEMS at microscale, international journal of Geographic information Science 11(2), claredon press, London pp 99 – 212.

Griffiths, S.A. 1981. Land treatment of Leachate for Municipal land fills Nayea Publications. pp 210 – 216.

Groove, A.T. 1951. Land use, soil conservation in parts of Onitsha, Owerri and Benue provinces of Nigeria, Geological survey No 8 pp 20 – 41.

Hammer, M.J. 2003. Water and waste water, Technology 2nd Ed. New York: Wiley publishers pp 230 – 238.

Harrison, Church R.J. 2001. West Africa a study of Environment and of mans use of it Long man publishing company, London.

H.O Linan, and T.C. Winner, 2000. Introducing Multidisciplinary ground water vulnerability mapping to the Philippines, A case study from journal of geological society Philippine pp 158 – 179.

Holland, D.A and Smith, S.L. 2003. The effect of changing grid size in the creation of Laser scanner, Digital surface models in Geo computation, oxford university press pp 230 – 240.

Homes, K.W Chadwick, O.A. and Kyriakiais, P.C 2000. Error in U.S.G.S 30 – melter Digital Elevation model and its impact on terrain modeling, Iowa State University press pp 130 – 200.

Hunt, C.B. 2002. Geology of Soils, their evolution classification and uses, san Francisco W.H. Freeman pp 130 – 172.

Ibe, K.M, Nwankwor, G.I. and Onyekuru S.O. 2001. Assessment of groundwater vulnerability and its impact to the development of protection strategy for water supply aquifer in Owerri SE. Nigeria Env. Monitoring and Ass. 67, 323-360.

Igbozuruike, M.U. 1975. Vegetation types in Ofomata, GEK (Ed), Nigeria in maps Eastern State, Ethiope publishing House Benin p 27-28.

Iloeje, N.P. 1981. A new geography of Nigeria (A new revised edition) published in Great Britain by William Clowes (Beccles) Limited, Beccles London. Pp 85 – 120.

Johnson, L.E. 2002. A digital map based hydrologic modeling system, photogramatic engineering and remote sensing 155, Cambridge university press, pp 911-913.

Kang, V.C. 2002. Introduction to geographic information system Tata M.C. Graw-Hill publishing Company Ltd New Delhi pp 20-25.

Katertzis, A. and Shal V.I. 2004. Remote Sensing as mine field indicators, Madrid Spain, Cambridge University press pp 16-29.

Khmas, J.J. A 1995. Impacts of urbanization protection of water resources in the villinius District Lithuania, Hydrological Journal 3, 24 – 35.

Kogbe, C.A. 1975. Geology of Nigeria Elizabethan publishing company-Lagos Nigeria pp 213-220.

Krynine, D.P. and Jude, W.R. 1957. Principles of Engineering geology and Geo-technics M.C. Graw-Hill book company pp 47-60.

Lal, R. 2000. Managing the soils of sub-Saharan Africa Science 236. University . of North Dakota press pp 1069 – 1106.

Longley, P.A. and Smith, S.C. 2003. Investigating the spatial structure of error in Digital surface models in ISPR, 3D Reconstruction from Laser scanning International Journal of geographic information Science 14(3) 85 – 96.

Mananu, P.C. 1995. Humidity in Ofomata G.E.K. (Ed), Nigeria in maps, Eastern States, Ethiope publishing House, Benin pp 19-21.

Mark, D.M 2001. Authomatic detection of drainage net work for digital elevation models-cartographica, pergamon press New York pp 168 – 178.

Martin, G.A. 1977. Introduction to soil microbiology 2nd Ed, Krieger publishing company, p 21.

Mongkolsawat, C and Ponp, S. 1991. Land capability mapping with land sat data, A Gis methodological study for NE Thailand Oxford University Press pp 230-240.

Montgomery, C. 2000. Environmental geology published by Edward E. Bart all ed M.C. Graw-Hill co, pp 210 – 218.

Murat, R.C. 1972. Stratigraphy and paleogeography of cretaceous and lower Tertiary in Southern Nigeria, African geology Ibadan university press pp 251-266.

Nepomoceno, G.S. 2003. Changing urban Land use and its impact on the environment. A case study of Japur city. Technical report on land use evaluation for urbanization in California pp210-215.

Nwankwor, G.I., Okeke, O.C and Ahiargkwem, C.A. 2004. Land capability Index mapping of Enugu area and environs for residential land use option, Advances in geosciences vol 2 no 1: Cape publishers international Ltd. 27 Alaenyi street, Owerri pp 4- 64.

Nwankwor, G.I., Egboka, B.C and Orajaka, I. P. 1988. Groundwater occurrence and flow pattern in Enugu coal mine areas, Enugu State, Nigeria. Hydrological Journal 33, 465 – 482.

Offodile, M.E. 1973. A hydrological approach to drainage problems at onyeama mine (Enugu coal field) Journal of mining and geology vol II Nos. 1 and 2, 1975 Abstracts of unpublished paper presented in 1973 at NMGS Conference pp 114.

Ofomata, G.E.K 1985. Technical report on feasibility study of erosion vulnerability areas in the eastern part of Nigeria, Ethiope publishing house Benin pp35-37.

Okeke, O.C and Ihediwa, 2001. Geotechnical characterization of mudrocks associated with the coal bearing rocks of the Mamu Formation in the Enugu area, SE Nigeria Journal of Nigeria Mining and Geosciences society.

Oguntoyinbo, J.S. (1987). A geography of Nigerian development, Heinemann Education books (Nig), ltd pp 45-70.

Okwuosa, I.I. 1986. Geology and hydrogeology of the area West of Enugu area and Environs-unpublished Bsc Thesis, university of Nigeria, Nsukka pp 9-15.

Oleary, P.R, Walsh, P.W and Ham, R.K 2004. Managing solid waste, scientific American 259 (DEC) Arbor Science Publishers State University of New York press. Pp 36-42.

Palmer, R.C., Holman, I.P., and Lewis, M.A. 1997. Guide to groundwater Vulnerability mapping in England and H M.S London Claredon press, London pp 210 – 215.

Pearce, D.W. and Turner, R.K. 1990. Economics of Natural resource and the environment, harvest wheat sheaf London platt 1966, the step to man wiley New York pp 21-28.

Raymond, C.L. 1979. Land application of wastes, vol I, John Wiley and sons publishers pp 150-160.

Reyment, R.A. 1965. Aspect of the geology of Nigeria, Ibandan University press pp 25-38.

Robert, W.D. Krebs, D, and Richart, D.W. 2001. Highway materials M.C.Graw Hill book company, New York pp 211-224.

Rogers, E. G. 1985. Hunterdon County, Land Fill evaluation and sitting study prepared for county of Hunterdon Fleminaton New Jersey, Oceana publishers pp 11-141.

Seed, H.B, Wood, W, and Lundgren, R.J. 1962. Prediction of Swelling potential for compacted days ASCE.J. Soil Mechanics 53-57.

Sidle, P.C. 1985. Relative importance of factors influencing land sliding in coastal Alaska in proceeding of annual engineering geology and soil engineering symposium Juneau, Alaska pp 34 – 38.

Shah, T.R. and Ghandi,M.C 2004. Land cover change and trustees study Blackie publishers U.K. pp 621 – 740.

Shadiya, E.O. and Lool, C.A. 2003. Geology of the area west of Enugu, unpublished B.sc thesis university of Nigeria, Nsukka, p 20-25.

Smith, P.L, and Krisjanason, C. 1989. Parametric approaches to rating the importance of land for agriculture Journal Environmental management 29, 345 – 362.

Stephen, O.G. and Osito .G. 2004. The chemistry of soil New York Oxford University press pp 33-60

Swinnen, E.E, and Lissens, G. 2000. Subpixel land cover classification with spot vegetation imagery; proceedings of the international geosciences and remote sensing symposium Sydney, Australia pp 300-340.

Terzahi, K and Peck, R.B 1995. Soil mechanics in Engineeering practice 2nd Ed. John Wiley and sons publishers, New York pp 35-50.

Troeh, F.R, and Hobbs, J.A 1980. Soil and water conservation, Engle wood cliffs N.J. prentice-Hall pp 610-620.

Ugochukwu, .C. 2000. Bacteriological and chemical evaluation of surface and underground water from Enugu metropolis unpublished B.sc thesis, Enugu State University of science and Technology, Enugu pp 18-35.

Ugwuogo, M.C.1989. Geotechnical characteristics of the Enugu Shaley clay and their implications. Unpublished M.sc thesis, Dept. of Geology University of Nigeria, Nsukka pp. 16-25.

Uma, K.O. 1987. Appropriate investigation techniques for water supplies to rural Communities in Nigeria 2nd proceedings of the conference, Nigeria water sanitation association (NIWASA) P. 3-8.

Verbyla, D.L. and Chang, K. 1997. Processing digital images in geographic information system, academic and professional publishers U.K. pp 621-741.

Walthman, A.C. 1994. Foundations of Engineering geology, Blackie academic and professional publishers, Glaslow UK. Pp 130 – 140.

Welthman, J, and Head, J.M. 1983. Site investigation manual, construction Industry research and information association, London pp 333-370.

Wilson D.G. 1981. Waste management planning, evaluation technologies, Oxford England clarendon press pp 110-130.

APPENDICES

APPENDIX 1 GRAIN SIZE DATA FOR FERRALITHIC SOIL

Sieve Size (mm)	Mass Retained (g)	Cummulative Mass Retained (g)	% Cum. Mass Retained	%Passing (%)
28.0	0	10	0	100
19.0	18.4	18.4	374	96.26
14.0	6.2	24.6	5.00	95.00
10.0	27.3	51.9	10.55	89.45
5.6	76.6	131.5	26.75	73.25
3.35	81.3	212.8	43.26	56.12
2.0	70.6	283.4	57.65	42.35
1.18	57.3	340.9	67.34	30.66
0.6	30.5	371.4	75.34	24.46
0.425	13.4	384.8	78.28	21.72
0.3	10.5	395.3	80.41	19.59
0.212	6.3	401.6	81.69	18.31
0.15	26.3	427.9	87.04	12.96
0.075	36.3	464.2	94.43	5.57
Received	17.7	481.9	98.03	1.97

APPENDIX 2 GRAIN SIZE DATA FOR FORRALITHIC SOIL

Sieve Size (mm)	MASS Retained	Cumulative Retained (g)	%Cum. Mass Retained (%)	% Passing (%)
5.56	0	0	0	100
3.35	0.2	0.2	0.004	99.96
2.0	2.1	2.3	0.46	99.54
1.18	33.1	35.4	7.08	92.92
0.6	60.8	96.2	19.24	80.76
0.425	98.6	194.8	38.96	61.04
0.5	97.8	292.6	58.52	41.48
0.212	84.0	377.6	75.52	7.36
0.15	85.6	463.2	92.64	0.8
0.075	32.8	496.0	99.20	
Received	3.4	499.4	99.98	

APPENDIX 3 GRAIN SIZE DATA FOR HYDROMORPHIC SOIL

Sieve Size (mm)	**M ass Retained**	**Cumulative Retained (g)**	**%Cum. Mass Retained (%)**	**% Passing (%)**
3.35	0	0	0	100
2.0	0.2	0.2	0.04	99.56
1.18	2.8	3.0	0.6	99.4
0.6	8.7	11.7	2.34	97.66
0.425	19.1	30.8	6.16	93.84
0.3	21.7	52.5	10.5	89.5
0.212	56.0	108.5	21.7	78.3
0.15	153.2	261.7	52.34	47.3
0.075	191.0	452.7	90.54	9.46
Received	47.0	495.7	99.94	

APPENDIX 4 ATTERBERG LIMITS FOR FERRALITHIC SOIL

SOIL SAMPLE	LIQUID LIMIT (LL)			PLASTIC LIMIT (PL)	
	TEST NO	AVER. NO. OF BLOWS	M.C %	TEST NO	M.C. %
FERRALITHIC SOIL	1	11	32.37	1	14.6
	2	21	33.35	2	14.8
	3	30	39.60		
	4	40	54.05		

APPENDIX 5: ATTERBERG LIMITS FOR FORRALITHIC SOIL

SOIL SAMPLE	LIQUID LIMIT (LL)			PLASTIC	
	TEST NO	AVER. NO. OF BLOWS	M.C %	TEST NO	M.C. %
FORRALITHIC SOIL	1 2 3 4	10 20 33 44	27.98 25.62 26.67 23.89	1 2	18.57 20.93

APPENDIX 6: ATTERBERG LIMITS FOR HYDROMORPHIC SOIL

SOIL SAMPLE	LIQUID LIMIT (LL)			PLASTIC LIMIT	
	TEST NO	AVER. NO. OF BLOWS	M.C %	TEST NO	M.C. %
HYDROMORPHIC SOIL	1 2 3 4	13 23 32 44	44.41 43.77 42.98 42.24	1 2	16.96 16.81

Appendix 7 Shear Strength Result (undrained Triaxial Test)

Forralithic Soil		
Unit lateral pressure	20	46
Critical unit axial load at failure	54	78
Shearing Stress	40	74
Hydromorphic Soil		
Unit lateral Pressure	8	26
Critical Unit axial load at failure	116	152
Shearing Stress	46	74
Ferralithic Soil		
Unit lateral Pressure	10	42
Critical Unit axial load at failure	102	138
Shearing Stress	50	90

APPENDIX 8: COMPACTION TEST FOR FERRALITHIC SOIL

TEST NO	1	2	3	4
Wt. of Mould + Wet Soil W_2 (g)	52.00	53.80	53.80	54.10
Wt. of Mould : W_1 (g)	33.00	33.00	33.00	33.00
Wt. of Wet Soil: W_1-W_2 (g)	19.00	20.80	20.80	21.10
Density of Wet Soil	1.9	2.08	2.08	2.11

MOISTURE CONTENT TEST FOR FERRALITHIC SOIL

TEST NO	**1**	**2**	**3**	**4**	**5**	**6**
Wt. of Wet Soil + Container Ww (g)	77.3	92.6	64.7	64.1	19.6	51
Wt. of Dry Soil + Container wd (g)	75.1	90.5	61.5	60.0	75.7	47.1
Wt. of Container wc (g)	31.2	66.7	40.8	38.8	54.2	12.1
Wt of Dry Soil wd-wd (g)	43.9	23.8	20.7	21.2	21.5	30.0
Wt of Moisture ww-wd (g)	2.2	2.1	2.6	4.1	3.9	3.9

RESULT

MOISTURE CONTENT	7.45	15.90	15.55
Dry Density	1.76	1.8	1.79

APPENDIX 9: COMPACTION TEST FOR FORRALITHIC SOIL

TEST NO	1	2	3	4
Wt. of Mould + Wet Soil W_2 (g)	54.10	54.90	54.50	54.00
Wt. of Mould : W_1 (g)	33.00	33.00	33.00	33.00
Wt. of Wet Soil: W_1-W_2 (g)	21.10	21.90	2.15	2.1

MOISTURE CONTENT TEST FOR FERRALITHIC SOIL

TEST NO	**1**	**2**	**3**	**4**	**5**	**6**
Wt. of Wet Soil + Container Ww (g)	100.1	89.5	76.2	81	90	95.1
Wt. of Dry Soil + Container wd (g)	97.0	63.1	71.2	76.1	83.1	70
Wt. of Container wc (g)	65.5	41.2	41.3	39.1	53.6	40.2
Wt of Dry Soil wd-wd (g)	31.5	21.9	29.9	37.0	29.5	29.8
Wt of Moisture ww-wd (g)	3.1	26.4	5.0	4.9	6.9	25.1

RESULT:

MOISTURE CONTENT	13.35	14.8	20.2
Dry Density	1.86	1.90	1.78

APPENDIX 10: COMPACTION TEST FOR HYDROMORPHIC SOIL

TEST NO	1	2	3
Wt. of Mould + Wet Soil: W2 (g)	60.15	60.25	60.55
Wt. of Mould: W_1 (g)	44.00	44.00	44.00
Wt. of Wet Soil: W_2 W_1 (g)	16.15	16.25	16.55
Density of Wet Soil: $\Phi mg/m^3$	1.701	1.711	1.743

TEST NO	**1**	**2**	**3**	**4**	**5**	**6**
Wt. of Wet Soil + Container Ww (g)	72.5	73.98	79.2	70.5	69.4	
Wt. of Dry Soil + Container wd (g)	67.5	67.50	72.3	61.4	61.4	
Wt. of Container wc (g)	18.1		23.4	23.9		
Wt of Dry Soil wd-wd (g)	49.4		48.9	37.5		
Wt of Moisture ww-wd (g)	5.0	6.48	6.9	9.1	8.0	

RESULT:

MOISTURE CONTENT	13.12	14.23	21.3
Dry Density	1.50	1.50	1.44

APPENDIX 11: COMPRESSIVE STRENGTH RESULTS

Residual Soil	Test Load (ka)	Compressive Strength
Forralithic Soil	56.44	9.10MN/m^2
Hydromorphic Soil	14.43	21.76MN/m^2
Ferralithic Soil	20.16	2.10MN/m^2

APPENDIX 12: SHEAR STRENGTH RESULTS OF OKIGWE AREA

(After Ofomata 1985)

	SANDY SOIL			SILTY SOIL			SANDYSILT SOIL		
SHEAR STRESS KN/m^2	37.64	53.78	77.24	65.0	90.0	122.5	70.0	101.3	135.28
NORMAL STRESS KN/m^2	66.67	122.22	177.78	66.25	122.5	177.5	75.5	125	183.75

APPENDIX 13 WORLD HEALTH ORGANIZATION GUIDELINE FOR DRINKING WATER QUALITY (1985)

	Physical analysis		**WHO STD**
	Appearance		Clear
	Temperature ^{o}c		25
	Colour		50
	Turbidity		25
	Odour		Nill
	Chemical analysis		Range
	PH		6.5-8.5
	Conductivity Ohm/cm		500
	Total Dissolves solid mg/L		500
	Salinity mg/L		250
	Chloride (cl) mg/L		200
	Carbonate (Co_3)mg/L		500
	Bicarbonate mg/L		500
	Calcium (Ca+) mg/L		500
	Magnesium mg/L		200
	Sodium (Na^+)		250
	Potassium (k)		0.1
	Sulpate mg/L		0.1
	Nirate $(No_3)^2$ mg/L		0.3
	Iron Fe_2^+ mg/L		0.1
	Manganeses (Mn^{2+})		0.1
	Copper		10

APPENDIX 14 DISTRIBUTED SOURCES OF POLLUTION AND CONTAMINATION

Source	Examples
Agriculture	Cropland pasture and Rangeland irrigated land wood land, feed lots
Silyiculture	Growing stock logging Road building
Construction	Urban Development High way construction
Mining	Surface/underground
Terrestrial (scattered)	Land fills dumps
Utility maintenance	High ways and streets deicing
Urban Runoff	Floods and snow melt
Precipitation	Rainfall, snowfall etc
Background sources	Native forests Diaries land etc

APPENDIX 15 THE FEDERAL GOVERNMENT OF NIGERIA SPECIFICATION CONTROL NO 58 GOVERNMENTOF EAST CENTRAL STATE OF NIGERIA.

Parameter	Values for sub-base course materials
Liquid limit	<35 should not be greater than 35
Plasticity index	<20 should not be greater than 20
Linear shrinkage	<8 should not be greater than 8
CBR	<30 should not be greater then 30
Max dry density mg/m3	> 0.47 should not be less than 0.47
Optimum moisture contest %	< 25% should not be greater than 25
Compressive strength	>2-7KN/m^2 (any thing 2-7 is moderately weak)

APPENDIX 16 ENGINEERING EVALUATION OF SHALE AFTER (Welthman and Head 1983).

Physical properties	Average value unfavorable	Range of Favourable value
Compressive strength (KPG)	350-2070	2070-35600
Angle of internal friction (ϕ) in degree	$10^{-}20^{0}$	$20\text{-}65^{0}$
Dry Density	1.8.1.78	1.78-2.58
NMC	20-25	5-15
Clay minerals	Montmorilonite	Kaolinite

APPENDIX 17: TERRAIN CLASSIFICATION (Walthman 1994)

Slope Class

0-2%	Almost Flat
2-6%	Gently Sloping
6-13%	Sloping
13-25%	Moderately Steep
> 55%	Very Steep

Slope Length Remarks

< 15m	very short
15-50m	moderately long
250 -500m	Long

APPENDIX 18: ENGINEERING PROPERTIES OF THE SOIL WITH FEDERAL GOVERNMENT OF NIGERIA STANDARD SPECIFIACTION FOR BUILDING FOUNDATION

				Federal Govt of Nigeria Standard values for building foundation.
Parameter	Average Values			
Parameter	Forralithic Soil	Hydromorphic Soil	Ferralithic Soil	
Liquid Limit %	26.06	43.35	39.84	< 35 should not be> 35
Plasticity Index %	6.31	26.46	25.14	< 20 should not be > 20
Maximum Dry Density KN/m^2	1.9	1.53	1.8	> 0.47 should not be less than 0.47
Optimum Moisture Content %	14.8	14.3	15.9	< 25 should not be greater than 25

APPENDIX 19

CONVERSIONS OF UNIVERSAL TRANVERSE MECATOR TO NATIONAL GRID (NIGERIA DATUM)

The coordinates computed using Geographic Positioning System (GPS) is converted to the National Standard using geographic calculator soft ware as follows:-

UTM	Conversion to Nigeria Datum				
S/No.	Northings	Eastings	Northings	Eastings	Height (m)
1.	$6^0$30’	$7^0$29	277338.5425	560790.6393	1095
2.	$6^0$29’	$7^0$26’	275461.2655	555264.9376	1778
3.	$6^0$28’	$7^0$28’	273637.8051	558966.7413	1040
4.	$6^0$25’	$7^0$35’	268179.3097	571920.0626	540
5.	$6^0$28’	$7^0$36’	273725.9356	57372.4174	410
6.	$6^0$25’	$7^0$39’	268224.2474	579304.1492	290
7.	$6^0$25’	$7^0$39’	251540.8576	566479.4613	790
8.	$6^0$16’	$7^0$32’	255307.5484	579382.9178	280
9.	$6^0$22’	$7^0$30’	262589.5272	562722.8312	725
10.	$6^0$18’	$7^0$39’	255167.5813	555380.7026	1582
11.	$6^0$22’	$7^0$27’	262557.6097	577184.9086	1380
12.	$6^0$20’	$7^0$24’	258836.5822	551667.9034	1585
13.	$6^0$22’	$7^0$25’	262536.6307	553493.0963	1540
14.	$6^0$23’	$7^0$23’	264360.6904	549791.0744	1230
15.	$6^0$23’	$7^0$25’	264381.4833	553482.6594	1718
16.	$6^0$24’	$7^0$38’	266367.7061	577469.3911	300
17.	$6^0$21’	$7^0$39’	260843.2715	579349.3546	300

18.	**$6^0$18’**	**$7^0$36’**	**255274.3590**	**573843.5218**	**300**
19.	**$6^0$19’**	**$7^0$36’**	**257119.5128**	**573832.5414**	**400**
20.	**$6^0$18’**	**$7^0$35’**	**255263.4145**	**57199.1138**	**400**
21.	**$6^0$19’**	**$7^0$33’**	**257086.7721**	**568293.5805**	**500**
22.	**$6^0$19’**	**$7^0$38’**	**257141.6372**	**577525.3246**	**280**
23.	**$6^0$20’**	**$7^0$32’**	**258921.0191**	**566436.5452**	**500**
24.	**$6^0$22’**	**$7^0$32’**	**262611.1050**	**566414.9175**	**500**
25.	**$6^0$26’**	**$7^0$33’**	**270002.2781**	**56817.1673**	**500**
26.	**$6^0$22’**	**$7^0$32’**	**262611.1050**	**566414.9175**	**1000**
27.	**$6^0$24’**	**$7^0$27’**	**266247.4237**	**557163.7678**	**1100**
28.	**$6^0$26’**	**$7^0$30’**	**269969.4874**	**562679.7179**	**600**
29.	**$6^0$29’**	**$7^0$32’**	**275526.4333**	**566338.3302**	**500**
30.	**$6^0$30’**	**$7^0$34’**	**277393.7503**	**570018.5065**	**500**
31.	**$6^0$20’**	**$7^0$25’**	**258846.9283**	**553513.8885**	**1000**
32.	**$6^0$18’**	**$7^0$24’**	**255146.9370**	**551688.4682**	**1300**
33.	**$6^0$20’**	**$7^0$24’**	**258836.5822**	**55167.9034**	**1995**
34.	**$6^0$18’**	**$7^0$22’**	**255126.5296**	**547996.3406**	**1100**
35.	**$6^0$23’**	**$7^0$22’**	**264350.3839**	**547945.3218**	**1230**
36.	**$6^0$24’**	**$7^0$27’**	**266247.4237**	**557163.7678**	**1100**
37.	**$6^0$26’**	**$7^0$20’**	**269864.1172**	**544223.3249**	**900**
38.	**$6^0$25’**	**$7^0$21’**	**268029.6330**	**546079.1213**	**1230**
39.	**$6^0$19’**	**$7^0$26’**	**257012.4572**	**555370.3152**	**1000**
40.	**$6^0$17’**	**$7^0$31’**	**253375.2172**	**253375.2172**	**790**
41.	**$6^0$25’**	**$7^0$32’**	**268146.2404**	**566382.264**	**600**
42.	**$6^0$28’**	**$7^0$35’**	**273714.7064**	**571886.6097**	**400**
43.	**$6^0$19’**	**$7^0$36’**	**257119.5128**	**573832.5414**	**400**
44.	**$6^0$28’**	**$7^0$35’**	**273714.7064**	**571886.6097**	**410**
45.	**$6^0$24’**	**$7^0$35’**	**266334.1793**	**571931.1562**	**500**
46.	**$6^0$20’**	**$7^0$24’**	**258836.5822**	**551667.9034**	**1500**
47.	**$6^0$25’**	**$7^0$31’**	**268135.3380**	**564536.3872**	**700**

	COORDINATES	
TOWNS	**NORTHINGS**	**EASTINGS**
Enugu Main Town	**269969.4874**	**562679.7179**
Obioma	**260798.7930**	**571964.2643**
Ugwuafor	**264511.2836**	**575634.4692**
Nsude	**264381.4833**	**553482.6594**
Udi	**255167.5813**	**555380.7026**
Agbani	**253407.4331**	**570161.5674**
Okunano	**262589.5272**	**562722.8312**
9th Mile Corner	**268071.1910**	**553461.7042**
Emen	**273714.7063**	**571886.6097**
Enugu Ngwo	**266258.0574**	**559009.5946**
Ukana	**275440.0305**	**551574.0243**

	Coordinates	
Towns	**Northings**	**Eastings**
Enugu main town	**$6^0$23**	**$7^0$30**
Obioma	**$6^0$21**	**$7^0$35**
Ugwuafor	**$6^0$23**	**$7^0$37**
Nsude	**$6^0$23**	**$7^0$25**
Udi	**$6^0$18**	**$7^0$26**
Agbani	**$6^0$17**	**$7^0$34**
Okunano	**$6^0$22**	**$7^0$30**
9TH Mile Corner	**$6^0$25**	**$7^0$25**
Emene	**$6^0$28**	**$7^0$35**
Enugu Ngwo	**6024**	**7028**

Ukana	**6029**	**7024**

APPENDIX 20: RELATIONSHIP BETWEEN SWELLING POTENTIAL (SP) AND PLASTICITY INDEX Seed et al (1962)

Swelling	Plasticity Index	Inherent Swelling Capacity
Potential	Seed et al (1962)	Ola (1981)
Low	0-15	Low
Medium	10-35	Medium
High	20-55	High
Very High	Above 55	

APPENDIX 21: DRY DENSITY CLASSIFICATION OF ROCKS (AFTER ANON 1981)

Class	**Dry Density mg/m^3**	**Description**
1	1-81	Very Low
2	1.80 -2.20	Low
3.	2.20-2.55	Moderately
4.	2.55-2.75	High
5.	Above	Very High

APPENDIX 22 POINT SOURCE OF POLLUTION AND CONTAMINATION

(Freeze, R.A. and Cherry, J.A. 1979)

Types of Pollution	Examples
Sewage Disposal Systems	Sewage lagoons septic system
Surface wastes disposal sites	Barn yards/feed lost land fills/garbage dumps, surface waste dumps.
Under ground waste disposal sites	Storage of anks (low medium, high level wastes) pit latrines, tunnels trenches, caves wastes subsurface injections.
Spills, washing and intrusions	Oil/gas wastes soils Auto workshop washings research /laboratory washings, sea water/salt water instructions.
Mining Sources	Acid mine drainages gas explosions/seepages mine dumps and gangue deposit, tune/excavate out flows.
National minerals/ore deposit	Saline ponds/lakes Hot springs/mineralized waters, analydrite/pyrite deposits Eva porties

Appendix 23(a)

MEAN MINIMUM MONTHLY TEMPERATURE ^{O}C (2001-2005)
(Courtesy of Enugu State Ministry of Agriculture)

Station	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Enugu	2001	34.0	34.8	34.0	33.4	31.5	30.4	29.4	29.2	29.2	30.0	31.6	32.6	380.1
Enugu	2002	31.6	35.1	36.4	35.4	32.4	30.2	30.3	28.0	30.0	31.2	28.7	32.9	382.2
Enugu	2003	33.0	34.6	34.2	32.2	31.6	30.7	29.9	30.1	30.4	30.7	31.9	32.1	381.4
Enugu	2004	32.9	34.8	33.7	30.9	31.6	30.3	29.0	29.5	29.2	30.7	32.0	32.9	377.1
Enugu	2005	33.4	34.4	33.2	32.8	31.9	30.7	28.6	29.0	29.7	30.6	31.5	30.9	376.9
Enugu	Average	33.0	34.74	34.30	33.0	31.80	30.5	29.16	29.1	29.70	30.70	31.14	32.2	379.5

Appendix 23 (b)

MEAN MINIMUM MONTHLY TEMPERATURE ^{O}C (2001-2005)
(Courtesy of Anambra State Ministry of Agriculture)

Station	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Enugu	2001	22.0	21.6	23.0	24.0	22.6	23.0	22.4	22.7	21.7	22.0	22.1	22.2	269.3
Enugu	2002	19.3	23.9	24.4	24.5	23.5	23.3	22.9	22.1	21.5	22.9	22.6	21.2	272.1
Enugu	2003	21.7	24.9	24.5	22.1	22.1	22.5	22.3	22.5	21.6	22.7	23.0	21.2	271.2
Enugu	2004	23.5	22.3	24.9	24.2	23.4	22.9	22.4	22.6	22.1	22.6	23.7	21.9	276.5
Enugu	2005	21.8	25.0	24.0	23.9	23.4	23.3	22.6	22.	22.5	23.0	22.7	20.6	275.2
Enugu	Average	21.66	25.54	24.16	23.74	23.0	23.04	22.48	22.48	21.88	22.64	22.82	21.42	272.86

Appendix 23 (c)

MONTHLY DISTRIBUTION OF RAINFALL 1982-1986
(Courtesy of Anambra State Ministry of Agriculture)

State	Year	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb	March	Annual Total
Enugu	2001	94.4	175.6	164.2	188.7	61.0	122.2	146.2	8.7	0.00	7.2	28.7	63.2	895.9
Enugu	2002	25.4	127.3	67.4	110.9	31.0	274.9	3.0	0.0	0.0	0.0	0.0	1.2	641.6
Enugu	2003	88.0	88.4	176.5	203.7	250.9	179.3	168.9	40.9	0.0	0.0	0.0	21.9	1218.5
Enugu	2004	78.4	172.9	97.61	184.6	261.6	170.7	82.3	0.0	0.0	41.2	0.0	152.1	1241.4
Enugu	2005	58.5	104.7	57.2	120.1	31.3	116.4	97.9	39.0	0.0	18.1	0.0	123.9	767.2
Mean		68.94	94.24	112.58	161.6	127.16	172.7	99.66	17.74	0.00	13.30	72.46	72.46	952.92

APPENDIX 24 HYDROMETER ANALYSIS

For Hydromorphic Soil

Initial Mass of Sample before washing and drying = 60g
Final mass of sample after washing and drying = 26.2g(residue)
Weight of fines = 60-26.2g = 33.8g
% Percentage of fines = 56.3%

Dry Sieving of residue, Mass = 26.2g

Sieve Size Lim	**Mass Retained (g)**	**Mass Passing (g)**	**% Passing (%)**
2000	19.3	40.7	67.8
1180	1.8	38.9	64.4
850	1.0	37.9	63.2
600	0.7	37.2	62.0
425	0.5	36.7	61.2
300	0.5	36.2	60.3
150	1.5	34.7	57.8
75	0.7	34.0	56.7
Pan	0.2	33.8	-

Hydrometer Reading on filtrate

Data:

Initial mass of samples, M = 60G

Test Temperature = 23.5^0C

Meniscus Correction (cm) = + 0.5

Temperature Correction (mt) = + 1.0

Dispersant Correction x = 3.5

Specific gravity of particles GS = 2.65

Viscosity of water η = 0.8909 m Pas

1	2	3	4	5	6	7	8
Date	**Time (Mins)**	**Hydrometer Reading (Rh^1)**	**True Reading (Rh)**	**Effective Depth HR(mm)**	**Fully Corrected Reading (R)**	**Particle diameter (D) um**	**% finerthan D, %**
26:01:09	0	0	0	0		0	0
	1	8.5	9.0	177.1	8.3	54.1	22.2
1	3	8.0	8.5	179.2	7.8	31.4	20.9
Date	8	7.8	8.3	180.0	7.6	19.3	20.4
	20	6.5	7.0	185.3	6.3	12.4	16.9
	43	6.0	6.5	187.4	5.8	8.5	15.5
	90	5.5	6.0	189.4	5.3	5.9	14.2
	157	5.0	5.5	191.5	4.8	4.5	12.9
27:01:09	1200	5.0	5.5	191.5	4.8	1.6	12.9
	1440	4.8	5.3	192.3	4.6	1.5	12.3
Procedure		Rh^1	$Rh^1 + 0.5$	214-4.1Rh	Rh -0.7	$4.064\sqrt{HR/t}$	2.68 R%

APPENDIX 25 HYDROMETER ANALYSIS ON FERRALITHIC SOIL

Ferralithic soil Hydrometer analysis

Initial mass of sample before washing on no 200 sieve and drying = 60g

Final mass of sample (residue) after washing and drying = 24.2g

Weight of fines (mass loss to washing) = 35.8g

Percentage of fines = 59.5%

Drying Sieving

Dry sieving of residue, wt. 24.2

Sieve Size (um)	**Mass Retained (g)**	**Mass Passing (g)**	**% Passing**
2000	14.3	45.7	76.2
1180	2.4	43.3	72.2
850	1.3	42.0	70.0
600	0.6	41.4	69.0
425	0.5	40.9	68.2
300	0.4	40.5	68.5
150	0.7	39.8	67.5
75	3.8	36.0	60.3
Pan	0.2	35.8	60.0

Hydrometer readings on filtrate

Data:

Initial mass of samples, M = 60g

Test Temperature = 23.5^{0}C

Meniscus Correction (cm) = + 0.5

Temperature Correction (mt) = + 1.0

Dispersant Correction x = 3.5

Specific gravity of particles GS = 2.65

Viscosity of water η = 0.8909 m Pas

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Date	**T (mins)**	**Rh1**	**Rh**	**HR(mm)**	**R**	**D (μm)**	**K%**
26:01:09	0	0	0	0	0	0	0
	1	4.0	4.5	195.6	3.8	56.8	10.2
	3	3.7	4.2	196.8	3.5	32.9	9.4
	8	3.5	4.0	197.6	3.3	20.2	8.8
	20	3.0	3.5	199.7	2.8	12.8	7.5
	43	3.0	3.5	199.7	2.8	8.8	7.5
	90	2.5	3.0	201.7	1.8	6.1	4.8
	157	2.0	2.5	203.8	1.3	4.6	3.5
	1200	1.8	2.3	204.6	1.1	1.7	3.0
	1440	1.8	2.3	204.6	1.1	1.5	3.0

APPENDIX 26a: CONSOLIDATION TEST RESULTS OF FORRALITHIC SOIL, (ENUGU AREA).

Experimental Data:

Information on the specimen are as follows:

Initial height of specimen = 20mm

Area of specimen = 1963.5mm^2

Initial volume of specimen = 39270mm^3

Weight of specimen and specimen = 121.2g

Date	**Time(Min.)**	**Deformation Reading**	**Adjusted Reading X 0.002mm**
04:02:09	0	0	0
	1	96	1.192
	2	105	0.210
	4	119	0.238
	8	134	0.268
	15	150	0.300
	30	165	0.330
	60	180	0.360
	120	190	0.380
	240	198	0.396
	480	200	0.400
	1380	253	0.506
	1560	253	0.506

APPENDIX 26b: CONSOLIDATION TEST FOR FERRALITHIC SOIL, (ENUGU AREA).

The pressure deformation increment of Ferralithic soil is from 0.0Kpa to 20.4 kpa

Time Vs Deformation reading data

Date	Time (Min)	Deformation Reading	Adjusted Reading X.002mm
04:02:09	0	0	0
	1	83	0.116
	2	102	0.204
	4	115	0.23
	8	130	0.26
	15	145	0.29
	30	160	0.32
	60	170	0.34
	120	188	0.376
	240	199	0.398
	480	206	0.412
05:02:09	1380	229	0.458
	1560	229	0.458

APPENDIX 26c: CONSOLIDATION TEST FOR HYDROMORPHIC SOIL, (ENUGU AREA).

Pressure Increment: 0.0kpa to 20.4 kpa

Date	**Time**	**Determination**	**Adjusted reading**
04:02:09	Min	Reading	X.002mm
	0	0	0
	1	78	0.156
	2	104	0.208
	4	118	0.236
	8	123	0.246
	15	135	0.270
	30	153	0.306
	60	168	0.336
	120	179	0.358
	240	185	0.370
	480	190	0.380
05:02:09	1380	230	0.460
	1560	230	0.460

Void Ratio computation of Forralithic soil

Initial void ratio e_0 = 1.62

Volume of solid in specimen = 15.0cm3

Area of specimen = 19.635cm2

Height of solid in specimen h_s = 0.76

Pressure P Kpa	Initial D.R. at the beginning (mm)	D100 (mm)	Change in thickness Δh	Change in void ratio $\Delta e = \frac{\Delta h}{\Delta hs}$	Void ration $e = e_0 - \Delta e$
20.4	0.0	0.515	0.515	0.68	0.94

Coefficient of Volume Consolidation (CV)

Pressure p(kpa)	h_0	D_{50}	Thickness at 50% Consolidation (2H)	H (mm)	T_{50} (min)	CV mm^2/min
20.4	20.0	0.33	19.07	9.835		0.63

Void Ratio Computation of Ferralithic soil

Initial Void ratio (e_0) = 1.53

Vol. of solid in specimen (V_s) = 15.5 cm^3

Area of Specimen = 19.635cm^2

Height of solid h_s = 0.789cm

Pressure p kpa	Initial D.R at first reading 0.0(mm)	D_{100} (mm)	Change in thickness of specimen Δh	Change in void ratio $\Delta e = \frac{\Delta h}{\Delta hs}$	Void Ratio $E = e_0 - \Delta e$
20.4	0.0	0.470	0.470	0.6	0.934

Coefficient of Volume Consolidation (CV) Computation

Pressure p(kpa)	Ho(mm)	D_{50} (mm)	Thickness of specimen at 50% (mm)	H mm	T_{50}	CV mm^2/min
20.4	20.0	0.286	19.714	9.857	15	13

$D_{100} = 0.470$

$D \equiv t_1 = 0.166$

$D \equiv t_2 = 0.23$

$D_0 = 0.166 - (0.23 - 0.166)$

$= 0.102$ mm

$$D_{50} = \frac{D_{100} + D_0}{2} = 0.286mm$$

Void Ratio Computation - Hydromorphic Soil

Initial Void ratio (e_0) = 1.52

Volume of solid in specimen (Vs) = 15.59 cm^3

Area of Specimen (A) = 19.635cm^2

Height of solid in specimen (h_s) = 0.79cm

Pressure p (kpa)	Initial D.R at beginning (mm)	D100 1 (mm)	Change in thickness of specimen Δh	Changes in void ratio $\Delta e = \frac{\Delta h}{\Delta hs}$	Void ratio $e = e_0 - \Delta e$
20.4	0	0.475	0.475	0.6	0.92

Coefficient of volume Consolidation (CV) Computation

Pressure P (kpa)	Ho	D_{50}	Thickness of specimen at 50% consolidation	H	t_{50}	cv
20.4	20.0	0.276	19.724	9.862	17	1.12

From Graph

D100 = 0.475mm

$D \equiv t_1$ = 0.156mm

$D \equiv t_2$ = 0.236mm

D0 = 0.076m (0.165- (0.236-0.156)

$D_{50} = D_{100} + D_0$ = 0.276mm, t_{50} = 17min

APPENDIX 27: POROSITY AND PERMEABILITY TEST FOR HYDROMORPHIC, FERRLAITHIC AND FORRALITHIC SOIL (FALLING HEAD METHOD)

	SAMPLE	Hydromorphic Soil	Ferralithic Soil	Forralithic Soil
1	Wt.of Permeameter + Soil sample (g)	6202.6	6213.9	6208.9
2	Wt. of Permeameter (g)	4400	4400	4400
3	Length of specimen L (cm)	11.6	11.6	11.6
4	Diameter of Specimen D (cm)	10.2	10.2	10.2
5	Moisture content of air dried sample (%)	2.1	1.8	1.9
6	Cross sectional area of burrette a, (cm^2)	1.8	1.8	1.8
7	Hydraulic head at the beginning of test h_1 (cm)	1.50	1.50	1.50
8	Hydraulic head at the end of test h_2 (cm)	20.0	20.0	20.0
9	Total times for water in burette to drop from h_1 to h_2 (respective values for each of three trials			
	t1 (s)	25	26	26
	t2 (s)	24	25	25
	t3 (s)	23	25	25
10	Temp. of water, (^{0}C)	23.5	23.5	23.5
11	Specific gravity, (GS)	2.71	2.72	2.72

Computations: (1) Hydromorphic Sample

A (i) Unit Weight Determination

Wt. of Permeameter + Soil Sample = 6202.6 (g)

Wt. of Permeameter = 4400(g)

∴ Lot of soil sample = 6202.6 -4400 = 1802.6 g

Volume Area of soil sample, A = $\prod D^2/4 = \prod \times 10.2^2/4 = 81.7cm^2$

Volume of soil sample, V = A x L = 81.7 x 11.6 = $947.7cm^3$

Bulk Unit Weight (Sd) = 1802.2 ÷ 947.7 = $1.90Mg/m^3$

Moisture Content of air dried sample, ω = 2.1 %

∴ Dry UnIT Weight of sample (Sd) = $\frac{Sd}{1 + \omega}$ $\frac{1.90}{1 + 0.021}$

$\rho d = 1.86\ Mg/m^3$

A (ii) POROSITY, n , Determination:

Volume of solid in sample, Vs, = $\frac{\text{Dry Unit Wt}}{Gs}$

= 1.86 ÷ 2.71 = $0.69cm^3$

∴ Volume of Voids in sample, Vv, = 1-0.69 = $0.31cm^3$

∴ Void ratio, e $\frac{Vv}{Vs}$ = $\frac{0.31cm^3}{0.69cm^3}$ = 0.45

But Porosity, n $\frac{e}{1 + e}$ = $\frac{0.45}{1 + 0.45}$ = 0.31

Porosity, n for Hydromorphic soil 0.31

Computation of permeability.

a	=	$1.80 cm^2$
L	=	11.6cm
A	=	$81.7 cm^2$
t_1	=	25s
h_1	=	150.0cm
h_2	=	20.0cm
Temp	=	23.5^0C

(i) For Trial (l) t_1 = 25s

Permeability, $$K = \frac{2.3\ aL}{A\ t} \operatorname{Log} \frac{h_1}{h_2}$$

$$K\ 23.5^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 25} \operatorname{Log} \frac{150}{20}$$

$$= 2.0575 \times 10^{-2} \text{ cm/s}$$

To correct for permeability at 20^0C, the ration of the viscosity of water at 23.5^0C to that at 20^0C is determined from table (1b-2) to be 0.9204.

The permeability at 20^0C is therefore

$K_{20}{}^0C$ = 2.0575 x 10-2 (0.9204) = 1.89 x 10-2 cm/s

(ii) For trial (2) t2 = 24s,

$$K_{23.5}{}^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 24} \operatorname{Log} \frac{150}{20} = 2.143 \times 10^{-2} \text{cm/s}$$

$K_{20}{}^0C$ = 2.143 x 10-2 (0.9204) = 1.97×10^{-2} cm/s

(iii) For Trial (3), t_3 = 23s,

$$K_{23.5}{}^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 23} \operatorname{Log} \frac{150}{20} = 2.24 \times 10^{-2} \text{cm/s}$$

$K_{20}{}^0C$ = 2.24×10^{-2} (0.9204) = 2.058×10^{-2} cm/s

Average $K_{20}{}^0C$ = $\underline{(1.89 + 1.97 + 2.05)} \times 10^{-2}$

3

$= 1.97 \times 10^{-2}$ cm/s

Therefore for hydromorphic soil
Porosity = 0.31
Permeability = 1.97×10^{-2}

(2) Ferralithic Sample

A (i) Unit wt determination

Wt. of permeameter + soil sample = 6213.9
Wt. of permeameter = 4400g
∴ Wt. of soil sample = 1813.9g
Area of sample A = $81.7cm^2$
V = $947.7cm^3$
ρb = $1.91mg/m^3$
W = 1.8%

$$\therefore \rho d = \frac{1.91}{1 + 0.018} = 1.88mg/m^3$$

A (ii) Porosity, n , determination

$Vs = 1.88 \div 2.70 = 0.70 \text{ cm}^3$
$\therefore Vv = 1 - 0.70 = 0.30 \text{ cm}^3$

$$\therefore e = \frac{Vv}{Vs} = \frac{0.30}{0.70} = 0.43$$

$$n = \frac{e}{1 + e} = \frac{0.43}{1 + 0.43} = 0.3$$

B Computation of Permeability

(i) For trial (l), t_1 = 26s

$K_{23.5}{}^0C = \frac{2.3\ aL}{A\ t} \text{ Log } \frac{h1}{h2} = \frac{2.3 \times 1.88 \times 11.6}{81.7 \times 26} \text{ Log } ½$

$= 1.98 \times 10^{-2}$ cm/s

$K_{20}{}^0C = 1.98 \times 10^{-2} (0.9204) = 1.822 \times 10^{-2}$ cm/s

(ii) for Trail (2), tr = 25s

$K_{23.5}{}^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 25} \text{ Log } \frac{150}{20} = 2.06 \times 10^{-2}$cm/s

$K_{20}{}^0C = 2.06 \times 10^{-2} (0.9204) = 1.89 \times 10^{-2}$ cm/s

Therefore for ferralithic soil

Porosity = 0.3
Permeability = 1. 89 x 10^{-2} cm/s

Computations: Forralithic Soils

A (1) unit weight determination

i Wt of permeameter + Soil Sample = 6208.9g
Wt. of permeameter = 4400g
∴ Wt. of soil sample = 6208.9 = 4400 = 1808.9g
Area of soil sample, A = $\prod D^2/4 = \prod \times 10.2^2/4 = 81.7cm^2$
Volume of soil Sample, A = A x L = 81.7 x 11.6 = $947.7cm^3$
Bulk Unit Weight (ρb) = 1808.9 ÷ 947.7 = 1.91 mg/m^3

∴ Dry Unit Wt. of Sample (ρb) = $\frac{\rho b}{1 + w} = \frac{1.91}{1 + 0.019}$

$\rho b = 1.87\ mg/m^3$

A (ii) POROSITY, n DETERMINATION

Volume of solid in sample, Vs $= \frac{\text{Dry Unit wt}}{Gs}$

$= 1.87 \div 2.72$

$= 0.69cm^3$

$\therefore$ Vol. of voids in sample, Vv $= 1 - 0.69 = 0.31cm^3$

$\therefore$ Void ration, e $= \frac{Vv}{Vs} = \frac{0.31\ cm^3}{0.69cm^3} = 0.45$

But Porosity, n $= \frac{e}{1 + e} = \frac{0.45}{1 + 0.45}$

Computation of Permeability (Forralithic Soil)

a	=	1.80cm2
L	=	11.6cm
A	=	$81.7cm^2$
h1	=	150.0cm
h2	=	20.0cm
Temp	=	23.5^0C

(i) For Trial (1) time $t_1 = 26s$

Permeability $K = \frac{2.3\ a\ L}{A\ t} \text{Log} \frac{h_1}{h_2}$

$K_{23.5}{}^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 26} \text{Log} \frac{150}{20}$

$= 1.978 \times 10^{-2}$ cm/s

$\therefore K20^0C = 1.978 \times 10^{-2} (0.9204) = 1.82 \times 10^{-2}$ cm/s

(ii) For trial (2) $t_2 = 25s$

$K_{23.5}{}^0C = \frac{2.3 \times 1.8 \times 11.6}{81.7 \times 25} = \text{Log} \frac{150}{20}$

$= 2.0575 \times 10^{-2}$ cm/s

$K_{20}{}^0C = 2.0575 \times 10^{-2} (0.9204) = 1.89 \times 10^{-2}$ cm/s

(iii) For trial (3), t_3 = 25s

$K_{23.5}{}^0C$ = 2.0575×10^{-2} cm/s

$K_{20}{}^0C$ = 2.0575×10^{-2} (0.9204)

= 1.89×10^{-2} cm/s

Average $K_{20}{}^0C$ = $\frac{(1.978 + 1.89 + 1.89)}{3} \times 10^{-2}$

= 1.92×10^{-2} cm/s

Therefore, for Forralithic soil

Porosity = 0.31

Permeability = 1.92×10^{-2} cm/s

APPENDIX 28: VERTICAL ELECTRICAL SOUNDINGS (AGWO AREA.)

Layer	**Resistivity**	**Depth**	**Probable**
1	(ohm-m)	(m)	Lithology
1	346	1.1	Top soil
2	880	2.6	Top soil
3	3820	7.3	Sand
4	1530	17.3	Clayey Sand
5	39500	43.7	Sandstone
6	42400	75.9	Sandstone
7	15700	141.0	Sand
8	7640	175	Sand
9	1102	>175	Sandy Shale

APPENDIX 29a: TYPICAL RANGE OF INDEX PROPERTIES OF SOME COMMON CLAY MINERALS (AFTER ROBERT 2001)

	Clay Minerals	**Liquid Limit Range**	**Plasticity Index (PL)**	**Activity**	**Remarks**
1	Kaolinite	40-60	10-25	0.4	Low
2	Illinite	80-120	50-70	0.9	Low
3	Na Montmorillonite	700	650	7	High
4	Other Montmorillonites	300-650	200-250	1.5	Low/Mod.
5	Granular soils (eg sands + gravels)	20 or less	0	0	Very Low

Activity of Clays

Description	**Activity**
In active Clays	< 0.75
Normal Clays	0.75-1.25
Active Clays	1.25-2
Highly active Clays	> 2

APPENDIX 29b

RELATIVE CONSISTENCY AND LIQUIDITY INDEX (AFTER ROBERT 2001).

MOISTURE CONTENT RANGE (W)	RELATIVE CONSISTENCY (C)	LIQUIDITY INDEX (LI)
Below PL	> 1	Negative
At PL	1 to 0	0
Between PL and LI	0	0-1
At LL	0	1
Above LL	Negative	>0

APPENDIX 30: NATURAL MOISTURE CONTENT FOR FORRALITHIC, HYDROMORPHIC AND FERRALITHIC SOILS.

Sample	**Forralithic**	**Hydromorphic**	**Ferralithic**
Can Identification No	24	20	Z
Can + wet Soil (g)	84.3	99.2	79.8
Can + dry Soil (g)	81.0	94.5	74.8
Can (g)	17.6	19.6	19.4
Dry Soil (g)	63.4	74.9	55.4
Water (g)	3.3	4.7	5.0
Water Content, w, %	9.0	6.3	5.2

APPENDIX 31

Vertical Electrical Soundings (Ngwo Area)

The lithological result is shown below as:

Layer	Resistivity (Ohm-m)	Depth (m)	Probable Lithology
1.	346	1.1	Top Soil
2.	880	2.6	Top Soil
3.	3820	7.3	Sand
4.	1530	17.3	Sand
5.	39500	43.7	Sandstone
6.	42400	75.9	Sandstone
7	15700	141.0	Sand
8	7640	175.0	Sand
9	1102	>175	Sandy Shale

Western Axis East (Nkanu Area).

Layer	Resistivity(ohm-m)	Depth (meter)	Probable
1	147.0	0.5	Top soil
2	58.1	1.3	Top Soil
3	536.0	6.3	Top Soil
4	194.0	23.6	Shale
5	34.8	52.4	Shale
6	435.0	58.9	Shale
7	673.0	145.0	Shale
8	435.0	201.0	Shale
9	263.0	251.0	Shale
10	309.0	>251	Shale

Western Axis Owa Area (Eugu state water corporation).

Layer	Resistivity (ohm-m)	Depth (meter)	Lithology
1	1300	0.4	Top soil
2	16500	3.5	Top Soil
3	6500	19.0	Top Soil
4	18000	30.0	Sand
5	30000	70.0	Sandstone
6	10000	90.0	Silt

The soil depth at the Eastern segment is 6.3 meters, Ngwo Area is 2.6meters Western section is 19.3meters.

APPENDIX 33

Shear strength Computations

Unit Lateral pressure = 20KN/M^2 and 46KN/M^2

Critical Unit axial load at failure = 54KN/M^2 and 78KN/M^2

Shearing Stress 40KN/M^2 and 74 KN/M^2

For Hydromorphic Soil (2 tests)

Unit Lateral pressure = 8KN/M^2 and 26KN/M^2

Critical Unit axial load at failure = 116KN/M^2 and 152KN/M^2

Shearing Stress 46KN/M^2 and 74 KN/M^2

For Ferralithic Soil (2 tests)

Unit Lateral pressure = 10KN/M^2 and 42KN/M^2

Critical Unit axial load at failure = 102KN/M^2 and 138KN/M^2

Shearing Stress 50KN/M^2 and 90 KN/M^2

Hydromorphic soil τ = 31 + 94.50 x .5774 = 85.56KN/M^2

Forralithic soil τ = 13 + 205.68 x .4040 = 96.09KN/M^2

Ferralithic soil τ = 30 + 108.50x .5317 = 87.82KN/M^2