DIGITAL TERRAIN EVALUATION FOR MILITARY OPERATIONS IN MINNA AND ENVIRONS IN NIGER STATE, NIGERIA

BY

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M.TECH/SSSE/2006/1504

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NOVEMBER, 2008

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BEING A PROJECT SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF TECHNOLOGY (M.TECH) IN GEOGRAPHY WITH REMOTE SENSING APPLICATIONS

NOVEMBER, 2008

DECLARATION

I hereby declare that this M.Tech thesis titled **Digital Terrain Evaluation for Military Operations in Minna and Environs in Niger State, Nigeria** is my own research work and that it has not been submitted to any other institution for whatsoever reason. The information derived from published and unpublished works have been duly acknowledged.

....
Fagge, Auwal Jibrin Date

20/11/08

CERTIFICATION

This thesis titled: **Digital Terrain Evaluation for Military Operations in Minna and Environs in Niger State, Nigeria** by: Fagge, Auwal Jibrin (M.Tech/SSSE/2006/1504) meets the regulations governing the award of the degree of Master of Technology (M.Tech) of the Federal University of Technology, Minna and is approved for its contribution to scientific knowledge and literacy presentation.

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DEDICATION

I dedicate this work to the memory of my late younger sister Mrs Hadiza Lami Dan'azumi. May the almighty Allah grant her aljanna fiddous, amin.

ACKNOWLEDGEMENT

In the first place, I thank the Almighty Allah, the beneficent, the merciful for his guidance and with whom everything is possible.

I also wish to register my special gratitude and appreciation to my supervisor Dr. Halilu A. Shaba for his wonderful guidance and encouragement at every stage of this research. This was very inspiring.

My ultimate appreciation goes to the Chief of Army Staff (COAS), Nigerian Army, Lt Gen AB Dambazau GSS psc ndc fwc (+) PhD for his kind approval for my sponsorship to undertake this post graduate programme. I also wish to extend my appreciation to the Head, Geography Department, Dr. P.S. Akinyeye for his valuable contributions to the successful writing of this research project. To all the other lecturers that I passed through, I say a big thank you and my God continue to bless you as you empowered me and many others educationally. I am also indebted to Prof. M. Galadima, Dean School of Science and Science Education and Prof. S.L. Lamai, Dean Post Graduate School and all their staffs for their positive contributions in seeing me through this programme. I equally wish to acknowledge my Corps Commander; Maj Gen JB Samuel, Maj Gen AT Ibrahim, Brig Gen (Dr) AA Muhammad-Oumar, HOD, Department of Architecture, FUT, Minna, Mr. Frank Omosigho of Safe Nigeria Limited, Lt Col HS Garba of Headquarters, TRADOC, Minna, Lt Col AM Bello, Dr. M.T. Usman, Dr. L.M. Ojigi, Mal Salihu Saidu, Mr. Shamsudeen Ajose, and Mr. Hamzat Adewale all of FUT, Minna for their valuable contributions to this research project. Indeed despite your tight schedules, you spared time to contribute to the successful completion of this dissertation.

My gratitude equally goes to my bosom friend and brother, Adamu Mohammed of National Universities Commission, Abuja for allowing me the use of the internet system of his office for as long as I wanted. This is apart from the books, journals and other relevant materials he provided to me. Thanks a lot indeed. I shall also appreciate the excellent services rendered to me by the staffs of Niger State Ministry of Land and Survey, especially Mallam Baba Chado. I also wish to appreciate TPL Abdul Hussaini of Niger State Urban Development Board. To my colleagues in 2006/2007 set of M.Tech Remote Sensing Applications who were Mr. Christopher G. Usman, ZAT Suleyman and Balogun Ajose, I say many thanks indeed for your friendship and cooperation during the course of my studies at the University.

To my wife Maryam and my children Safiyya (Safi), Abdullahi (Adi) and Abbas (Indang), I say a very big thank you for your understanding and above all your prayers for my success.

Finally, to all those whose names could not be mentioned here, please bear with me and accept my deep appreciation for all your valuable contributions to this research work. May the almighty God continue to bless us all.

ABSTRACT

Terrain evaluation in land based military operations requires the knowledge of terrain conditions which includes amongst others, mobility corridors and elevations for manoeuvring Armour Personnel Carriers and tanks. In addition, accuracy in the detection of vegetation cover, road networks and communication lines is of paramount importance for a successful military campaign. Accordingly, this research on digital terrain evaluation for military operations, using Minna and environs as a case study was undertaken to evaluate military terrain attributes of the study area through the application of digital terrain modelling. Remotely-sensed satellite data from Landsat 7 ETM+ of 2001 and topographic map of Minna SW of 1967 were used in graphic digitizing and image drape methodology to create a Digital Terrain Model (DTM), in which the processed satellite image was draped upon a created surface image to generate a 3-D perspective view of the study area. Military operational requirements such as inter-visibility, mobility, cover and concealment were examined in relation to the terrain of the study area. Analysis of the result indicated that remotely-sensed data can be used in conjunction with topographic map to create a DTM for military terrain analysis. Thus, the research found that DTM techniques are ideal in the generation of data for the interpretation and analysis of a terrain in terms of its varying degrees of suitability and unsuitability for the conduct of successful military campaign. For instance, 4.9% of the terrain of the study area would provide excellent cover and concealment for both ground and aerial observations during military operations. Amongst the recommendations of the research project are the need for the Nigerian Military to commence as a matter of importance the training of its personnel in the acquisition of remote sensing and GIS knowledge and also to establish an adequately equipped remote sensing/GIS laboratories in order to take advantage of the inherent capabilities of these new technologies in terrain analysis, especially in the present battlefield military manoeuvres.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Digital Elevation Models (DEMs) otherwise known as Digital Terrain Models (DTMs) have been an important topic in geography and surveying services due to their geomorphologic importance as reference surfaces for a wide range of uses and applications (Juha, 2006). DTMs have become a major constituent of geographical information processing. The earliest definition of a digital terrain model as a statistical representation of the continuous surface of the ground by a large number of selected points with known xyz co-ordinates in an arbitrary coordinate field dated back to the 1950s (Miller and Laflamme, 1958). Thus, a digital terrain model which is a three – dimensional representation of a terrain surface includes not only heights and elevations, but other geographical elements and natural features such as rivers, ridge lines, etc. Equally, with the increasing use of computers in engineering and development of fast three-dimensional computer graphics, the DTM is becoming a powerful tool for a great number of applications in earth and engineering sciences (Nihal, 2000). Therefore, DTM is one of the most important datasets for the greater part of spatial-based studies and research. It is indispensable for many analyses such as topographic feature extraction, runoff analysis, slope stability analysis and landscape analysis in general. Such analyses require high accuracy, which is usually represented by spatial resolution and height accuracy (Masataka, 1996). Terrain analysis could then be said to be an essential study of the interrelationship among the various elements of the terrain. It comprises of a set of activities which lead to the compilation of terrain attributes in terms of its characteristics, qualities and capabilities (Townshend, 1981).

Accordingly, people live on Earth and learn to cope with its terrain. Civil engineers design and construct buildings on it; geologists try to study its underlying construction; geomorphologists are interested in its shape and processes by which the landscape was formed; topographic scientists are concerned with measuring and describing its surface and presenting it in different ways. For example by using maps, ortho-images and perspective views, the military is concerned with the attributes that affects military manoeuvre (Zhilin, Zhu and Gold, 2004). Despite these differences in emphasis and interests, these specialists have a common interest which is ensuring that terrain surfaces are represented conveniently and with certain accuracy.

The monitoring of terrain with its associated attributes is undertaken by various researchers using a myriad of techniques and analysis methods. Digital Terrain Modelling is one such technique in the monitoring or analyzing the terrain for a wide range of human endeavour such as rural and urban development, agricultural activities and military activities or operations. Military operations now require a good knowledge of terrain evaluation in order to perform efficiently. It is also necessary for effective conservation of dwindling resources through good management practices and their efficient utilization. Consequently, the aim of terrain evaluation in support of military operations revolves around gaining maximum operational advantage from the ground in order to ensure a successful military campaign.

The need to understand terrain has always been an essential skill for the military commander. Understanding of terrain has been supported by paper mapping for at least 1,000 years at the strategic level and at least 300 years at the tactical level (Taiwo, Nwagwu and Dashan, 2004). The military domain is not only a leading consumer of DTMs, they are also significant producers. Almost every aspect of the military environment depends on a reliable and accurate understanding of the terrain for a particular military operation. The military usage of DTMs combines facets and methods of all civil application domains and their end objectives are very specialized and demanding.

According to Mitchel (1973), military interest in terrain is of long standing, but its width and ramifications have increased rapidly in recent years as a result of the escalating sophistication of modern weapons. Military terrain evaluation may therefore be defined as the process by which we analyse the terrain of an area, classify it into distinctive units which differ from one another with respect to some selected criteria and appraise it for military purposes (Katsina, 1988). Military assessment of the terrain has two aspects namely military strategic and tactical aspects. At the strategic scale, concern is with the gross spatial distribution of economically important lowlands with their cities and associated transportation lines and also with mountains, seas and river barriers that divide them. Tactical assessment of terrain on the other hand considers the landscape in more detail. The assessment is focused on four types of problems; those concerning visibility, cross country mobility, reaction of terrain to deformation and the availability of water and constructional materials.

Terrain models have always appealed to military personnel, planners, landscape architects, civil engineers as well as other experts in various earth sciences. Originally, terrain models were physical models made of rubber, plastic, clay sand, wood, e.t.c. For instance, during the Second World War, many models were made by the United States Navy with rubber. Equally, in 1982 Falkland War, the British forces used sand and clay models extensively to plan military operations (Zhilin, Zhu and Gold, 2004).

1.2 **Statement of the Problem**

The evaluation of terrain for military purposes such as determination of line of sight for targeting activities, suitability of the ground for excavation of trenches and erection of fortification has been of long standing. This is due to the fact that accurate and adequate knowledge of terrain would be a great advantage to military commanders in battle. However, the provision and acquisition of accurate information about the terrain using topographic maps has its inherent inaccuracy in terms of measurement of distances and spatial distribution of terrain features on the ground. Additionally, the hitherto traditional method of military briefing using sand models to depict a 3-D view of battlefield scene is not only obsolete and having a large margin of error but time consuming. Traditional surveying in the military using compasses, theodolites and measuring tapes is also very much time consuming and limits the timeliness of producing maps.

It is therefore in response to these inadequacies that this research seeks the application of digital terrain model to military terrain evaluation that would present terrain features accurately and in a more concise 3-D format for military purposes.

1.3 Significance of the Study

The study is about the evaluation of application of digital terrain modelling to terrain analysis for military operations, using Minna and environs as a case study. Satellite systems can provide timely and accurate information on land cover and its associated characteristics in the realm of vegetation, hydrology and geology. Equally compared to traditional analogue representation of terrain features, a DTM has some specific advantages. These are:

a. ***Variety of Representation Format.*** In digital format, representation of terrain features can easily be produced, such as topographic maps and 3-D animations.

b. ***No loss of accuracy of data over time.*** As time goes on, paper maps may be deformed, but DTM can keep its precision owing to the use of digital medium.

c. ***Greater Feasibility of automation and real time processing.*** In digital form, data integration and updating are more flexible than in analogue form.

d. ***Easier Multi-Scale Representation.*** DTM can be arranged in different resolutions corresponding to representations at different scales.

Thus, past and recent war events have indicated that knowledge of terrain is indispensable to tactical military operations. For instance, the costly prices paid by armies of the world over an account of failure to take terrain sufficiently into account in the planning and execution of campaigns will further give credence to this assertion. Such experience was the fatalities suffered by the Nigerian Army 2 Division during the Onitsha crossing in the Nigerian civil war of 1967 – 1970 as a result of poor terrain analysis.

It is therefore in this respect that this research work attempts to analyse the terrain of the study area using digital terrain modelling which not only has a better accuracy in analysis but will also project the various terrain features in a 3-D format. The result could also be applied in other parts of Niger State and Nigeria in general and would hopefully serve as a guideline for future tactical and strategic military deployment. Equally, In addition to contributing to existing knowledge on the subject, it would also serve as a reference material for further research on the subject.

1.4 Aim and Objectives of the study

The aim of the research is to analyse terrain attributes through the application of digital terrain modelling using Minna and environs as a case study for military purposes. Specific objectives of the study are to:

a. Determine the effects of terrain attribute of the study area on military operations.

b. Outline the practicability of the application of DTM to terrain evaluation for military operations using the study area as a case study.

1.5 Scope and Limitations of the Study

Digital Terrain Models are used in a number of applications in the earth environment and engineering sciences. The main application areas therefore are in the areas of civil engineering, earth science, planning and resource management, surveying and photogrametry and military applications. The scope of this study is restricted to the application of DTM to military terrain evaluation. Equally, the area covered by this study is central Minna and terminates at its fringes to the North, South, East and West which are Maikunkele, Chanchaga, Gurusu and Kpakungu respectively. Secondary data in the form of topographical map information and satellite imagery acquired are not up to date in view of their date of production and acquisition respectively and hence limit the accuracy of information that may be derived from them. Consequently, processing of data derived from these sources is much dependent on their inherent accuracies. However, this limitation did not affect the quality of the research work.

1.6 **The Study Area**

Niger State is located between Latitudes 3^0 58′ and 7^0 42′ North of Equator and Longitudes 8^0 20′ and 11^0 35′ East of the Greenwich Meridian. Niger State lies within the North Central Zone of Nigeria sharing boundaries with Kaduna and FCT in the East and Southeast respectively as well as with Sokoto, Kebbi and Zamfara in the North and Kwara State in the West (Osho, 2005). Minna, the capital of Niger State is located in the Northern Guinea Savannah Belt of Nigeria. It lies at Latitude 9^0 37′ North of Equator and Longitude 6^0 33 ′East of Greenwich Meridian on a geological base of undifferentiated Basement Complex of mainly gneiss and magmatite (Niger State Government, 1980 and Iloeje, 1981). It has Bosso Local Govt Area to the North, Gbako Local Govt Area to the East, Shiroro Local Govt Area to the West and Paikoro Local Govt Area to the South. Chanchaga River is the prominent river flowing through it to the South. River Suka is another river that flows from west to east of Minna. There is also Bosso and Tagwai dams within the Minna locality. Fig. 1.1 is the location of Minna in a political map of Nigeria.

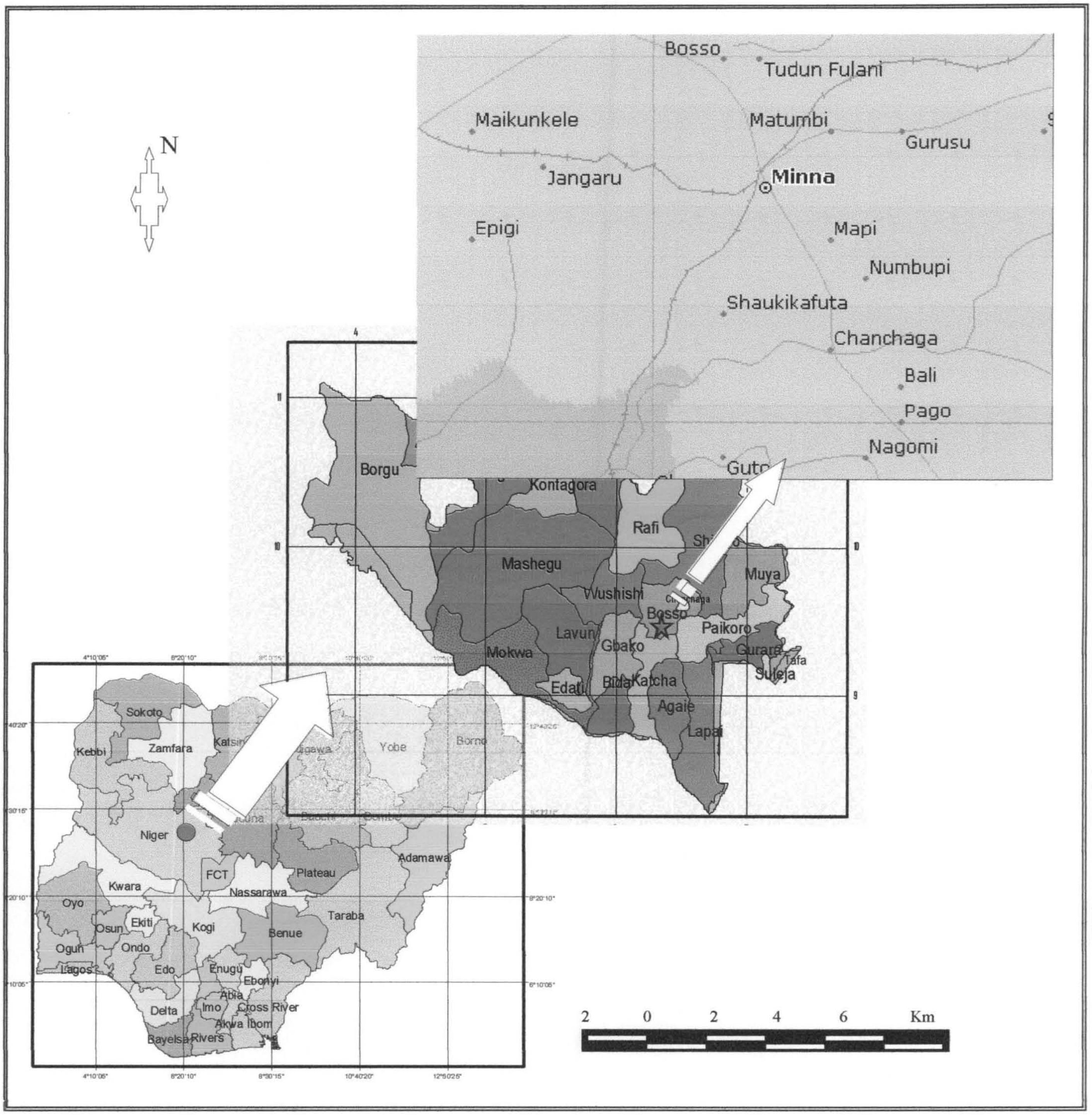

Fig. 1.1: Location of Minna in a Political Map of Nigeria.

Source: Adopted from Osho, 2005.

The study area for this research work covers Minna town and its environs with boundaries at Chanchaga in the South, Maikunkele in the North, Gurusu in the East and Saukakahuta in the West. Specifically, this area is covered by Latitudes $9^0\ 30' - 9^0\ 40'$ North of Equator and Longitudes $6^0\ 30' - 6^0\ 37'$ East of Greenwich Meridian. Fig. 1.2 depicts the topographic map of Minna and its environs showing the sub map of the study area.

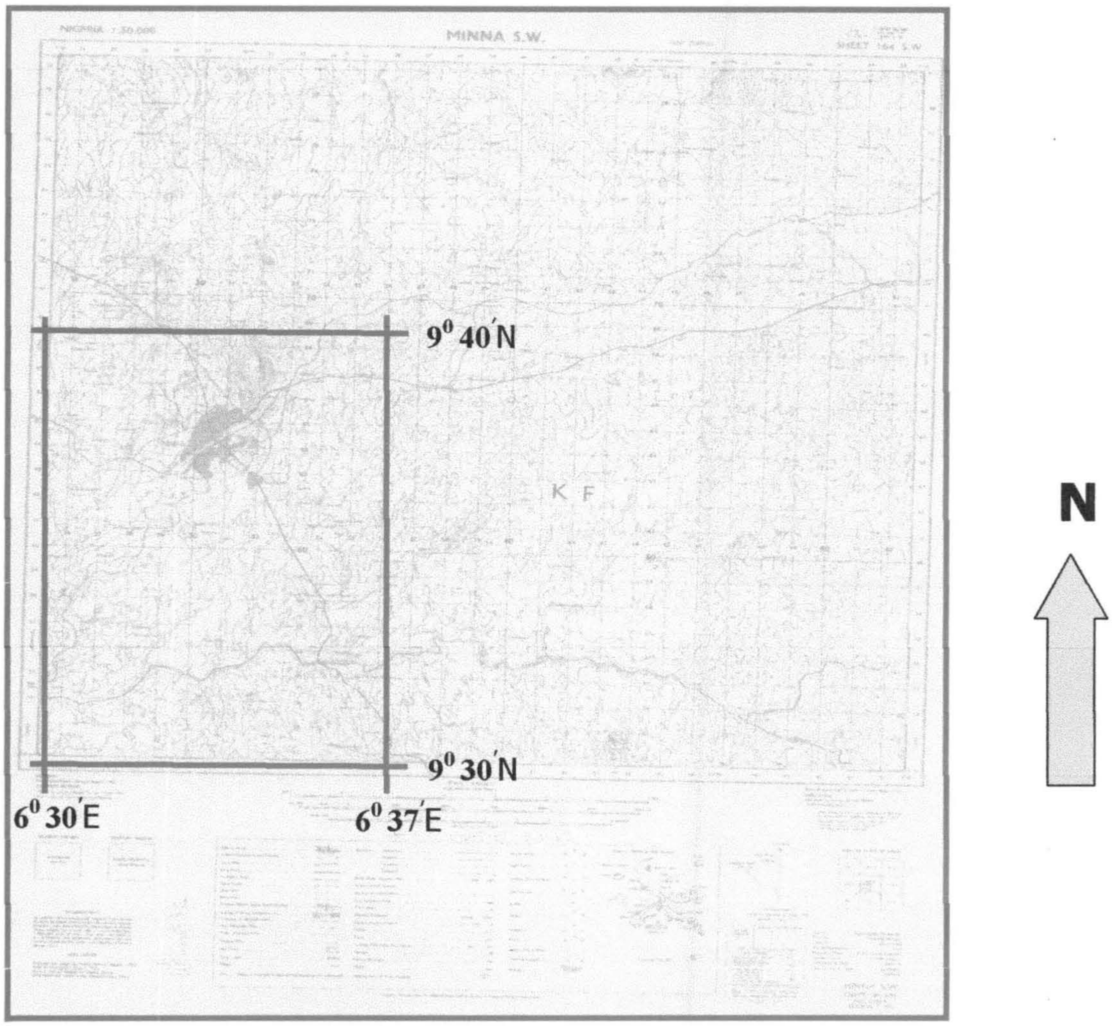

Fig. 1.2: Sub map of the Study Area in a Topographical Map of Minna Sheet 164 SW, NIGERIA, 1: 50,000.

Source: Ministry of Lands and Survey, Niger State.

1.6.1 **Climate**

The climate of Minna just like other areas within the Guinea Savannah Belt is characterised by a single maximum rainfall pattern with about 600 – 700 mm of annual rainfall. Annual rainfall of Minna is about 1334mm (52 inches). The highest mean monthly rainfall occur in September with almost 300mm (11.7 inches). The rainy season starts on the average between 11th – 20th April and lasts for between 190 – 200 days (Niger State Govt, 1980).

Relative humidity generally rises to over 70% during the wet season. The seasonal change is greatly influenced by the annual migration of the Inter-Tropical Zone of Convergence (ITZC). This is where the wet moisture laden tropical maritime air mass associated with Southwest Trade Winds meet the dry dust laden tropical continental air mass associated winds from the northern subtropical high pressure belt in the Sahara. This period is commonly known as the wet season or planting season where there is plant and vegetation growth. On the other hand, the dry tropical continental air mass brings dusty winds referred to as Harmattan. This occurs between November and March when the relative humidity is low and the vegetation growth is deceased as the soil is dried out.

The mean monthly temperature is highest in March at 30.5^0 C (87^0 F) and lowest in August at 25.1^0 C (77^0 F). This temperature range is greatly influenced by seasonal climatic changes in Minna. During the wet rainy season, temperatures are at their lowest due to prevalence of cloud cover. Also during the dry harrmattan season, night temperatures fall to about 24^0 C (67^0 F).

1.6.2 **Vegetation**

The vegetation of the study area is generally that of savannah vegetation. Thick vegetation is however found along river valleys due to the constant soil moisture of such areas. Sparse vegetation is noticeable in areas that are not along river valleys. During the dry season, the landscape of the study area appears barren and dark which is as a result of lack of rainfall and clearing of the vegetation for farming activities. The onset of the rainy season, signals the change of vegetation to green once again.

1.6.3 **Geology and Topography**

The geology of the study area is made up of basement complex rocks. However, the major landform is that of outcrop of granite gneiss and a few isolated rock outcrops which occur in close proximity of the hills. The north eastern part of the study area is covered by continuous steep hills and rock outcrops of granite and patches of organic matter are fairly scattered around the lower slopes and river valleys (NALDA, 1996). The area north east of Minna town is thus generally very hilly with the highest peak reaching up to 1500 feet above sea level. The southern and south western parts of the study area are generally flat landscapes with a lot of farm lands.

1.6.4 **Hydrology**

There are rivers and streams that flow through the study area; Rivers Chanchaga and Suka with their associated tributaries are prominent in the study area and flow from north eastern part of Minna town and then to the south western outskirt of the town. Minor drainage channels feed both Rivers Chanchaga and Suka especially during the rainy season. Bosso dam is found at Bosso in the hilly north eastern part of the study area.

1.7 **Organisation of the Thesis**

The thesis was carried out to evaluate the application of digital terrain modelling to terrain analysis for military operations using Minna and environs as case study. The thesis was arranged in series of five chapters. Chapter one highlighted the background of the study which was the application of digital terrain modelling to terrain evaluation in military operations, using Minna and environs as a case study. The location of the study area, its climate, vegetation, geology and hydrology were also delineated in this chapter. Chapter two looked into the existing works/researches that were embarked upon by various scholars. This chapter also highlighted the capabilities and limitations of such works/researches. The methodology employed in the research project was mentioned in Chapter three. Chapter four covered the presentation of results of the research. Chapter five presented the analysis of the results based on the author's research, a summary of the whole thesis, implications and findings of the research work. This chapter equally presented the author's recommendations.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a review of the previous works and literature on the application of digital terrain modelling for military operations. The chapter in Section 2.1 deals with concepts of digital terrain modelling as one of the applications of remote sensing technique and its application to terrain evaluation. In the same light, a review of relevant works of scholars/researchers on the application of digital terrain modelling to terrain evaluation and in particular for military operations was undertaken in Section 2.2.

2.1 **Remote Sensing Techniques / Digital Terrain Modelling**

Remote sensing refers to the process of obtaining information about an object, area, or phenomenon through analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer, 1994). The eyes are an excellent example of a remote sensing device. With this, it is possible to gather information about the surroundings or even reading the text as in this case. However, this simple definition of remote sensing is more commonly associated with the gauging of interactions between the earth surface and the electromagnetic energy. Remote sensing systems are very important sources of information for Geographic Information System (GIS), as they provide access to spatio-temporal information on surface processes on scales ranging from regional to global. A wide range of environmental parameters can be measured including land use, vegetation types, surface temperatures, soil types, precipitation, turbidity, surface elevation and geology. Remote sensing and GIS immensely aid the study of terrain evaluation.

Remote sensing represents a major though still under-used source of terrain data providing spatially consistent coverage of large areas with both high geometric detail and high temporal frequency. Several recent developments in remote sensing have the potential to significantly improve the mapping of terrain attributes. These relate to the availability of data from new remote sensing systems such as IKONOS, SPOT and Landsat satellites; all of which can support detailed and accurate data about the terrain at different spatio-temporal scales. Remotely-sensed images range from high-resolution aerial photographs and digital imagery to low-resolution satellite images (which may be either photographs or digital imagery). Most imagery used in social science fall in the middle of this range. Resolution refers to the size of the scene on the ground captured by the smallest pixel (picture element) in the image. Thus, a 1-meter image means that the smallest amount of detail in the image is 1 meter by 1 meter in size on the ground. Images also vary according to the bandwidth of light captured by the sensor (camera or other recording device), ranging from panchromatic (gray scale) to multi-spectral (visible red, green, blue, and near-infrared bands, as well as other bands that are not visible to the naked eye). A basic premise of remote sensing is that the earth's features and landscapes can be discriminated, categorized, and produce electromagnetic energy, and this energy is propagated by electromagnetic radiation at the speed of light through space, reaching the earth's atmosphere practically unchanged. Part of it is absorbed as it passes through the atmosphere, and the remainder continues on to the earth's surface. The part that continues is then either reflected or absorbed by objects on the earth's surface and re-radiated as thermal energy. 'Passive' remote-sensing systems operate by measuring the energy which is re-radiated or reflected from the object of interest back to the remote sensor. The sensors are most often optical (measuring light reflectance), but they may also be thermal (measuring heat reflection), or something else, depending upon the wavelength of the specific kind of energy that the sensor is designed to measure (Lillesand and Kiefer, 1994).

The earth's surface is a continuous phenomenon. There are various ways of representing such surfaces in digital form using a finite amount of storage. Digital elevation models (DEMs) are used as a way of representing such surfaces. Digital terrain model (DTM) is also used to refer to any digital representation of a topographic surface. The DEM is the simplest form of digital representation of topography and the most common. Therefore Digital Terrain Model (DTM) is a topographic model of the terrain surface removing objects that are on but not part of the surface which is often termed the bare ground or bare earth surface (Stan, 2005). Combined with other digital data, such as maps or orthophotographs, DTM can provide a 3-Dimensional image of the land surface. Consisting of terrain elevations for ground positions at regularly spaced horizontal intervals, the added dimension and visualization offered by a DTM can help in many decision-making processes. DTM is applicable in Planning, Engineering, Visualisation, Height Analysis, Environmental Impact Analysis, Sight Lines, wind flow and pollution dispersion, soil erosion modeling, flow direction and accumulation and watershed delineation. The digital record of land surface elevations was one of the first widely available forms of geographical information. Such digital records are often distributed in the form of a digital elevation model and their derivatives are frequently employed throughout physical geography for applications ranging from geomorphometry (Pike, 2000) to hydrological modelling (Kenward, Lettenmaier, Wood, and Fielding, 2000) and the physiographic correction of digital satellite imagery (Goyal, Seyfried, and O'Neills, 1998).

2.2 **Application of Digital Terrain Modelling to Terrain Evaluation**

Various scholars have made tremendous contributions in the realm of application of digital terrain modelling in general and to military terrain evaluation in particular. The review of their works is important to this research effort as this would depict not only the successes but also the shortcomings of such works.

Strahler (1981) and Franklin, Logan, Woodcock, and Strahler, (1986) used a strategy of scene stratification to improve the classification of forest vegetation at a regional level and to improve a timber inventory. They employed elevation, gradient and aspect masks. Shasby and Carneggie (1986) applied a class-sorting method to the classification of land-cover types obtained by Landsat MSS data processing. They used strata masks of elevation, gradient and aspect to determine mountain and valley shrub patterns that had equal spectral characteristics. Skidmore (1989) developed a rulebased expert system for the classification of eucalyptus forest types. This system was based on a non-parametric classifier of Landsat TM images and data on gradient, aspect and topographic position (i.e., valleys and ridges). Prior knowledge on the relief location in which particular forest types occur was included as rules in the classification.

It is the opinion of Igov (1988), that the main problem with the studies of Strahler et al (1981) and Shasby et al (1986) is that they ignored land-surface curvatures. This is possibly connected with an underestimation of the role of topographic variables indicated in the formation and development of plant cover. Igov, 1988 further acknowledged the important role of land-surface curvatures in soil formation and explained the results obtained by the local influence of plan and profile curvatures on landscape properties.

However, Florinsky, Kulagina, and Meshalkina, (1994) in applying digital terrain models in their research were able to demonstrate sufficient correlations between plan, profile and mean curvatures and the landscape radiational plant-controlled temperature using a thermo-image and DTMs with a resolution of 3.5 m in central Russia. They concluded that this indicates the lessened sensitivity of boreal (describes a region that has a northern temperate climate, with cold winters and warm summers) and sub-boreal vegetation to variations in land-surface curvatures as compared with soils. In the same direction, Florinsky and Kuryakova (1996) showed that vegetation properties correlate strongly with plan, profile and mean curvatures as well as with elevation, gradient, aspect, specific catchment area, topographic and stream power indices in a mountainous boreal region. In these scholars' studies, vegetation data were derived from large-scale aerial photos and a DTM grid size of 400m was used. The conclusions they reached on the minor effects of land-surface curvatures on vegetation according to Florinsky, et al, 1994, may either be correct for some ranges of DTM grid sizes or were arrived at following inadequate descriptions of plant characteristics. It is therefore this researcher's opinion that digital models of land-surface curvatures should be included in data processing to obtain correct results in vegetation studies carried out with remotely sensed images.

Lee, Lee, and Tyler, (1988) argued that methods of pre-classification of image stratification using DTMs are not appropriate to the study of soil properties in hilly terrains. They believed that such stratification can be useful for terrains with several water/temperature soil regimes. Thus, Lee et al (1988) applied the logical channel method to improve a soil-cover classification using Landsat TM data. The DEM and data on gradient were used as ancillary channels. They thus obtained results which indicated a 72% agreement between an existing soil map and the classification obtained.

In investigating water erosion, Anys, Bonn, and Merzouk, (1994) compiled maps of soil loss, potential erosion and sediment delivery rate using a DEM, digital models of gradient, a topographic factor and a sediment delivery ratio, a soil map, Landsat-5 TM aerial scenes and ground meteorological data. Images were applied to map land use by calculating a vegetation index. The land use map and the DTMs were used as initial data in calculating a universal soil loss equation. Therefore, Anys et al (1994) demonstrated that the highest soil loss rate correlates not only with the absence of vegetation cover but also with combinations of topographic factors and soil fragility.

The works of some other scholars provide us with further insight into the application of digital terrain modeling in terrain evaluation. One of such works was the application of 3-Dimensional (3-D) modeling in land surface analysis. McMahon and North (1993) used 3-D modelling of the land surface, basement surface, gravity and magnetic fields, the draping of Landsat TM scenes over block diagrams and perspective viewing of the 3-D models were obtained. This approach allowed them to enhance the lithological interpretation of the imagery, the recognition of lineaments and the determination of fault strikes and dips.

The availability of Landsat satellite imagery and advancement in image processing techniques allows researchers to efficiently study the relationship between digital terrain modelling and terrain evaluation. In this regards, Barberi, Bernstein, Pareschi, and Santacroce, (1991) and Butler, Walsh, and Brown, (1991) have shown that an analysis of Landsat TM data together with a DEM and data on gradient; and a visual analysis of 3-D landscape models permit one to determine the sites of natural hazards (i.e., the location of lava outflows, landslides and avalanches). Equally, Shikada, Muramatu, Kusaka, and Goto, (1996) analysed landslide distribution with the use of landslides and geological maps, Landsat TM data and DEMs. DEMs were utilized to derive gradients, drainage networks and catchments. These researchers concluded that the correlation of

DEMs in the effective visualisation of landscape during natural hazards or disasters is important.

John and Kris, (2006), carried out a research on cognitively-based approach for hydrogeomorphic land classification using digital terrain model. In the study, hydrogeomorphic land types were mapped for all of North Carolina, USA using digital terrain models with a resolution of 300 feet. Separate land type classifications were developed for each of the six major physiographic provinces of the state. These were Blue Ridge, Piedmont, Sandhills, Upper Coastal Plain, Lower Coastal Plain and Coastal Island. The resulting classifications were then expressed in terms of expected ranges of water table depth for each land type.

Considerable research has been conducted in examining DEM interpolation errors. Wise (1998) investigated the effect of interpolating DEMs from contours using different algorithms. Differences in results were attributed to the complex interactions between algorithms for both interpolation and derivation of DEM-derived topographic parameters. Equally, Erxleben, Elder, and Davis, (2002) evaluated the accuracy of snow water equivalents derived from DEMs generated using four interpolation methods. Kienzle (2004) too tested the quality of DEMs interpolation at different resolutions and identified an optimum grid cell size that was determined to be between 5-20m depending on terrain complexity. These studies revealed the variety of applications that were affected by DEM error and the effort of researchers to document and accommodate such errors.

In the same light, Juha (2006) carried out a research on digital terrain model error in terrain analysis at Finnish Geodetic Institute (FGI). The focus of the research was on the fine topo scale DEMs, which are typically represented in a 5 – 50m grid and used in the application of topo scale of 1:10,000 - 1:50,000. Three-step framework for investigating error propagation in DEM-based terrain analysis was presented. The framework included methods for visualizing the morphological gross error of DEMs, exploring the statistical and spatial characteristics of the DEM error and making analytical simulation-based error propagation analysis and interpreting the error propagation analysis results. The results of the research indicated that appropriate and exhaustive reporting of various aspects of fine topo scale DEM error is a complex task.

According to Mitchel (1973) the development of military interest in terrain since 1914 has resulted chiefly from the greatly increase in size, range and destructiveness of bombs, missiles and projectiles and the development of internal combustion engines, tyre and tracked vehicles and aircrafts. Equally, with the advent of gun powder, the question of cover and inter-visibility of sites became more important. The exploitation of terrain information during the Second World War proved crucial and various armies produced cross-country maps for their tanks and other vehicles. For instance, in Britain as in other countries, notably Germany, France, USSR and the United States, military interest in terrain has led to the development of methods of predicting it. Thus, simple "tank maps" to show the passability of ground were produced by the French Army Service Geographique in 1918.

In Britain, MEXE (Military Engineering Experimental Establishment) at Christ Church, Harts, later changed to MVEE (Military Vehicles and Engineering Establishment) in 1971 and Soils Laboratory at Oxford conceived a system for predicting terrain information by storing it according to generic, uniform, operationally defined physiographic form which had analogues in the same climatic zone recognisable on aerial photographs and which could form the basis of a new practical worldwide regionalisation. MVEE made a study of 5,000 km^2 area of English midlands, roughly centred on Oxford. Topographical maps of a scale of 1: 250,000 and 1: 1,000,000 were used in the study. Conclusion of this research was the development of terrain prediction capability in the United Kingdom.

In the United States Marine Corps, Olender, 1980, undertook a research on the analysis of Triangulated Irregular Network (TIN) terrain model for military applications. The report of the research described a comparative evaluation of two digital terrain models (DTMs) in the context of tactical terrain analysis in Marine Corps ground combat operations. The two DTMs applied by the researcher were, Triangulated Irregular Network (TIN) model and Uniform Rectangular Grid (URG) model. The finding of the research was that the URG model represents terrain by simply encoding the terrain elevations on a uniform grid, while the TIN model fits a series of irregular triangular facets to the terrain. The conclusion reached was that fewer points (triangle vertices) are required to model a given surface with a TIN compared to the URG.

According to Fagge (1990), Captain Donatus Edi of the Nigerian Army had also conducted a research on military terrain analysis. He made use of air photographs and topographic maps of a scale of 1: 50,000, covering a total area of about 400 km^2. With this area of coverage, he assessed the military terrain attributes of Nguroge, Gembu, Mayo Ndaga and Gashaka areas of the Mambilla Plateau. Finally, he reached conclusion on the limitations of the terrain on trafficability of troops and vehicles. However, greater level of detail is required when his conclusion is viewed from the tactical level.

Stephen (2006) carried out a research aimed at examining the appropriateness of Jaji Military ground for multipurpose training and exercise using remote sensing techniques. The objectives of the research were to identify the physical landscape of the study area, classification of the identified landscape attributes and the determination of capability of each land unit identified for specific military operation. SPOT (XS) satellite image was used in the creation of contours and DTM of the study area. Conclusion reached by the researcher was the justification of the effectiveness of spatial features distribution to military requirement of accessibility, mobility, inter-visibility and security.

Considering the foregoing conceptualisation of the application of digital terrain model to military terrain evaluation, it is this researcher's view that concept of digital terrain model is an important factor in the analysis of terrain for military activities. Terrain greatly influence the success or failure of military battle field activities. It is the turning point in the course of military operational planning; a moment of success, failure or uncertainty, all culminating in serious consideration of terrain in all military activities.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Conceptual Approach

This chapter presents an outline of the methods applied in achieving the aim and objectives of the study. The workflow commenced with the collection of relevant data, delineation of the study area and analysis of the satellite image of the study area, to the classification of the land use/land cover, to the determination/generation of modelling the terrain of the study area and finally to the evaluation of terrain attributes relevant to military operations such as cover and concealment, identification of tactically important roads and determination of visibility/line of sight. In the generation of the DTM of the study area, graphic digitizing in conjunction with the draping of the satellite image of the study area methods were applied in the research methodology. Thus the methodology adopted in the study focused on the evaluation of military terrain attributes of the study area and analysis of the practicability of application of DTM to terrain evaluation for military operations using the study area as a case study.

3.2 Data Collection

The data for the study was acquired from various sources. These include materials from the internet, Library and Literature of past works in similar area of study. The primary data include ground field survey data, topographical map of Minna, Sheet 164 SW obtained from Niger State Ministry of Land and Survey and Landsat 7 ETM+ Satellite image from National Aeronautics and Space Administration (NASA) Landsat programme of the United States of America. The data collected were analysed using image processing techniques in remote sensing and Geographic Information System (GIS).

3.3 **Softwares Used**

The following softwares were used in image processing and digitizing of the Landsat 7 ETM+ image of the study area:

- ArcView 3.2 GIS Software.
- IDRISI 15 Andes Edition Image Processing Software.
- Franson CoordTrans v2.30.
- Golden Surfer Version 8.01 Surface Mapping System.

3.4 **Landsat Satellite Image**

Satellite image of the study area was acquired through Landsat (name indicating Land + Satellite) satellite for this research project. Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) was used for this research project. The image of the study area was acquired by NASA on 12 December, 2001 on its Earth satellite path 189 and row 054, which is sun-synchronous. This is the period of dry season in the study area. Landsat 7 ETM+ has 7 multispectral bands (colour) at 30m x 30m pixel resolution and a panchromatic band (black and white) at 15m x 15m pixel resolution. Landsat 7 ETM+

was chosen for the study due to its precise projection of land cover aspects as it has the latest and most advanced sensor. Equally, Landsat 7 ETM+ images allow terrain DEMs to be draped over for the creation and viewing of 3-D formats.

The satellite image for the study was acquired at an altitude of 705 km and at an inclination of 92.2^{o}. The ETM+ sensor of the satellite image of the study area has a spatial resolution of 30m and is a multi-spectral sensor with bands 1, 2, 3, 4, 5, and 7 representing blue, green, red, Near IR and Mid IR as follows:

Band 1 (Blue):	0.450 – 0.515 μm.
Band 2 (Green):	0.525 – 0.605 μm.
Band 3 (Red):	0.630 – 0.690 μm.
Band 4 (Near IR):	0.760 – 0.900 μm.
Band 5 (Mid IR):	1.550 – 1.750 μm.
Band 7 (Mid IR):	2.080 – 2.350 μm.

The image had already been geo-referenced by EROS Data Centre of the United States Geological Survey before being downloaded for this research project. Geo-referencing involves registration of the image to universally recognised coordinates such as longitude/latitude or Universal Transverse Mercator (UTM). Consequently, both geometric and radiometric corrections were applied to the image by the organisation/data providers. This is due to the fact that raw digital images often contain serious geometrical distortions that arise from earth curvature, platform motion, relief displacement and non-linearities in scanning motion. Equally, the radiometric corrections were carried out to correct errors in measured brightness values of the pixels as recorded by the satellite sensors. Fig. 3.1 is the orthographic preview multi-spectral bands 7, 4 and 2 of Landsat 7 ETM+ satellite image of the study area.

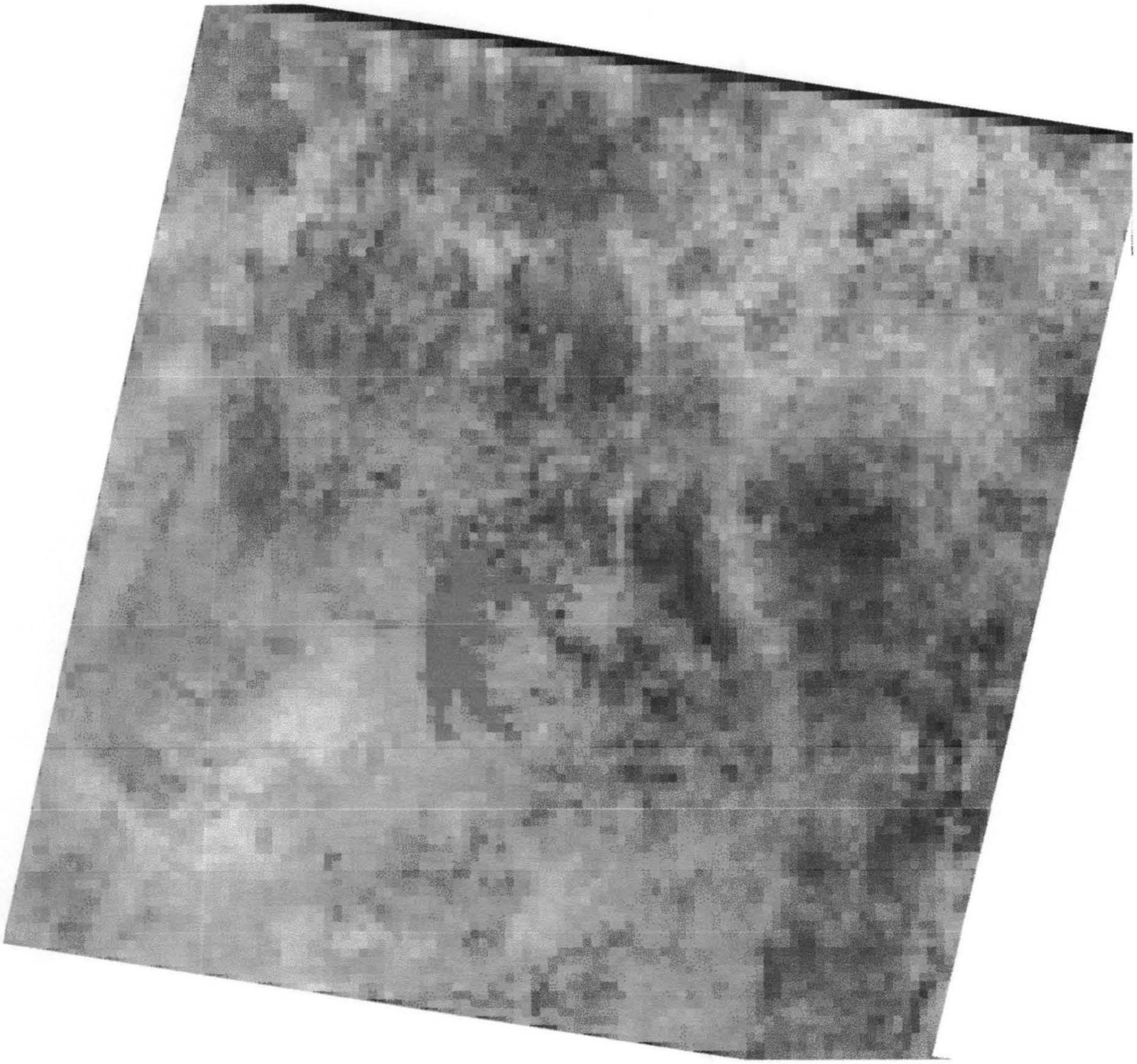

Fig. 3.1: Orthographic Preview Multi-Spectral Landsat 7 ETM+ Satellite Image of the Area of Study and its Environs.

Source: Global Land Cover Facility (www.landcover.org)

3.5 **Production of Sub Map of the Study Area**

The study area was carved out using IDRISI 15 Andes Edition image processing software package. The area covered Latitudes 9^{o} 30′ – 9^{o} 40′ North of Equator and Longitudes 6^{o} 30′ – 6^{o} 37′ East of Greenwich Meridian. The area includes metropolitan Minna in the centre; the mountain range to the north eastern part of Minna and the plains or low level areas in the southern part of Minna, which also has Rivers Chanchaga and Suka with their tributaries. The Latitude and Longitude coordinates of the study area were converted to UTM coordinates by the use of Franson CoordTrans v2.30 software in order for the coordinates to be applied to the IDRISI environment. The UTM coordinate for the study area was based on UTM 32N. Consequently, the image of the study area was georegistered to the UTM 32N reference system using the RESAMPLE module of IDRISI 15. Also using IDRISI 15 modules REFORMAT and WINDOW and through the application of WINDOW SPECIFIED existing geographical positions, the study area was carved out. The carved out area is made up of 444 columns and 715 rows. Fig. 3.2 is the orthographic band 4 view of the carved out study area.

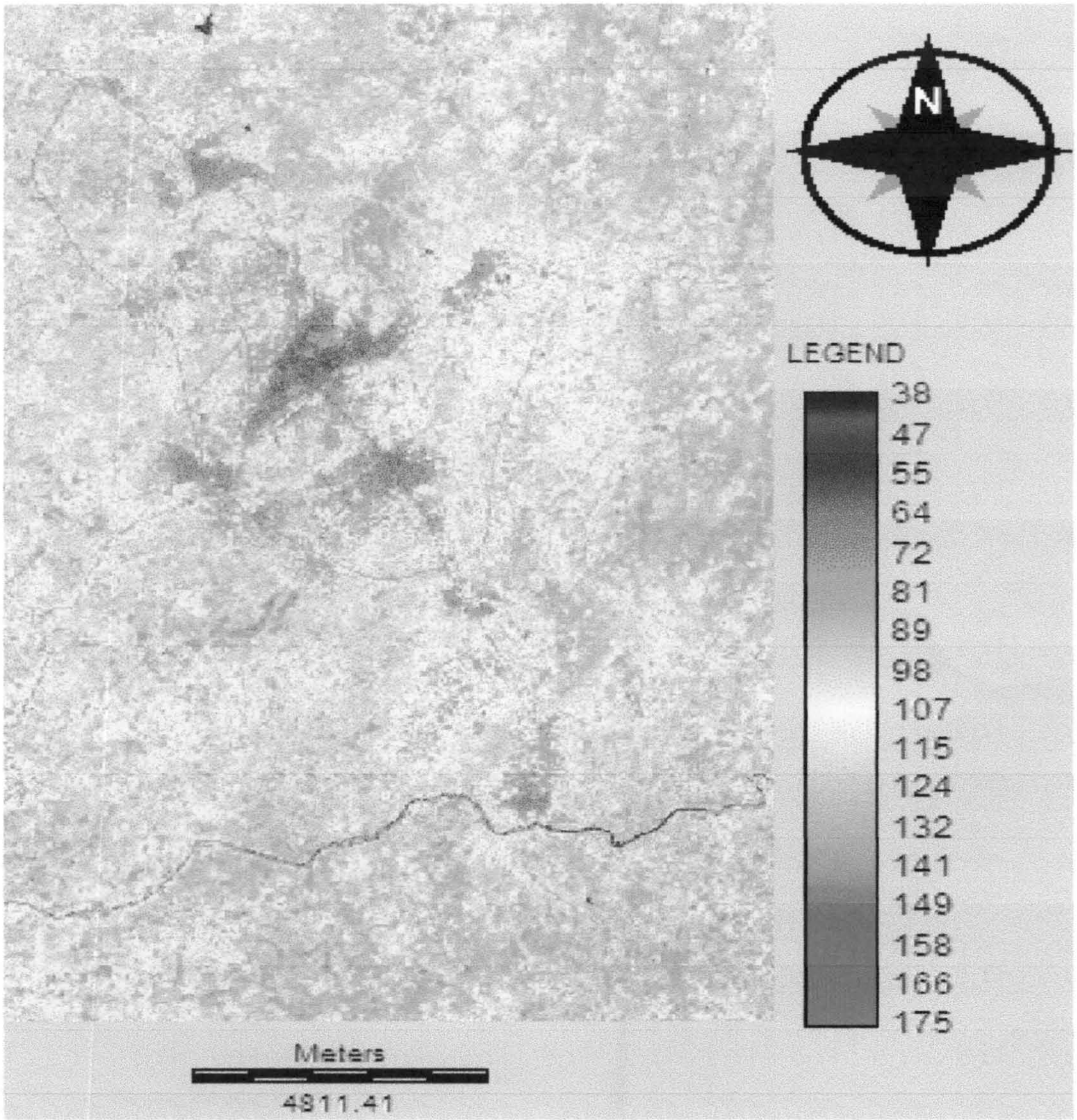

Fig. 3.2: Band 4 of Landsat 7 ETM+ Satellite Image View of the Carved out Study Area.

Source: Global Land Cover Facility (www.landcover.org)

3.6 **Image Processing**

The Landsat 7 ETM+ satellite image of the study area was analysed through two basic operations; colour composite and spectral image enhancement techniques.

3.6.1 **Image Enhancement**

Colour composite and spectral image enhancement techniques were carried out on the Landsat 7 ETM+ of the study area with the aim of improving the interpretability of the image by increasing apparent contrast among the various features of the image so as to enhance their visual appearance.

3.6.1.1 **Colour Composite Image Enhancement**

Colour Composite was used in the enhancement of the image. The IDRISI 15 module COMPOSITE was used to construct three-band 24-bit composite image of the study area for accurate visual analysis. These bands were band 3 – Red (0.630 – 0.690 μm), band 4 – Near Infrared (0.760 – 0.900 μm) and band 5 – Mid Infrared (1.550 – 1.750 μm).

3.6.1.2 **Spectral Image Enhancement**

Spectral image enhancement entails the enhancement of individual pixel brightness of the image of the study area. The aim was to clearly differentiate pixels having very close radiances. Linear with saturation point stretch technique was used in the spectral enhancement of the image of the study area. The Linear with Saturation Point stretch technique was chosen as it modifies the image such that pixels that are bright would appear brighter and dark pixels would appear darker. The procedure was applied in the IDRISI 15 software module COMPOSITE and Linear Saturation Point was selected.

3.6.2 **Normalized Difference Vegetation Index (NDVI) Image Extraction**

Vegetation overlay shows natural and cultivated vegetated areas, with information about type, size, and density. This factor overlay is one of the primary overlays used in determining the cross-country movement capability of troops and equipment, cover and concealment and line of sight. Thus application of the Normalized Difference Vegetation Index (NDVI) is important in the analysis of vegetation cover of the study area. NDVI was introduced by Rouse et al (1974) in order to produce a spectral vegetation index that separates green vegetation from its background soil brightness. Thus NDVI is expressed as the difference between the near infrared and red bands and normalized by the sum of those bands. That is;

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The measurement scale ranges from -1 to 1, with 0 representing the approximate value of no vegetation and negative values represent non-vegetated surfaces. The procedure using IDRISI 15 software module for NDVI extraction follows the selection of IMAGE PROCESSING, followed by TRANSFORMATION, and then VEGINDEX and finally NDVI.

Furthermore, the Tasseled Cap Transformation Vegetation Index (TCVI), which is one of the orthogonal transformation vegetation indices, was applied in the analysis of the vegetation cover of the study area. Orthogonal vegetation indices undertake a transformation of the available spectral bands to form a new set of uncorrelated bands within which a green vegetation band can be defined. In applying the TCVI, the six bands of the Landsat 7 ETM+ of the study area were used to produce three new images. The Green Vegetation Index (GVI) image represents vegetation. Other images produced represent Soil Brightness Index (SBI) and Moisture Vegetation Index (MVI).

TASSCAP was selected from the IDIRISI Image Processing/Transformation menu and thereafter, ETM+ was selected. The six bands of Landsat 7 ETM+ were selected and a file name for the transformed images was created.

3.7 **Topographic Map Data Extraction**

The topographic map of Minna, Sheet 164 SW, NIGERIA, 1: 50,000 was scanned with HP Design Jet scanner 4200 and then digitized to get the DTM to be used in conjunction with the Landsat 7 ETM+ satellite image of the study area. The map was georeferenced from the GPS coordinates collected from the field of the identifiable areas on the maps and the ground. Table 3.1 are the GPS coordinates used in the georeferencing of the topographic map.

Table 3.1: UTM Coordinate Projections of X, Y, and Z used for Georeferencing of Topographic Map of Minna SW Sheet 164, NIGERIA 1: 50,000.

X Coord	Y Coord	Z Value (Feet)	Description
0234323	1054919	730	Chanchaga Bridge
0234484	1056933	773	Kadna Junction
0234458	1057215	753	Bridge By FGC
0233583	1066630	986	Railway Culvert at Maitumbi
0232935	1065655	972	Rail-Road Bridge at Maitumbi
0230104	1067060	1029	Bahago Sec Sch
0225677.25	1071414.25	900	Lat $9^0\ 40'$ N Long $6^0\ 30'$ E

Source: Field Work.

Subsequently a sub map of the study area was carved out of the topographic map of Minna SW, Sheet 164, NIGERIA 1: 50, 000. Fig. 3.3 is the sub map of the study area showing the Latitude and Longitude boundaries.

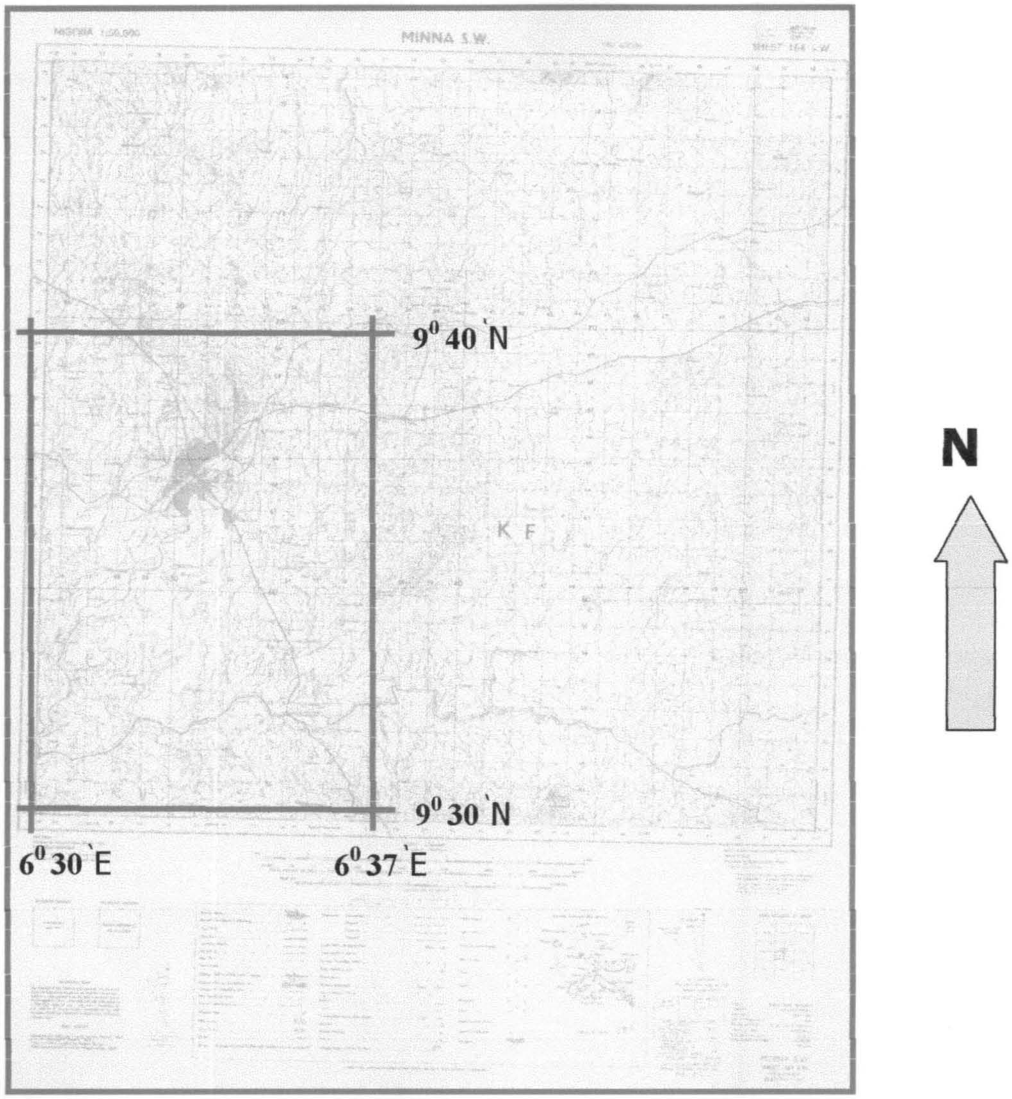

Fig. 3.3: Sub map of the Study Area in Topographical Map of Minna SW, Sheet 164, NIGERIA, 1:50, 000.
Source: Ministry of Lands and Survey, Niger State.

The following data layers were digitized on screen from the topographic map by on-screen digitizing of the scanned topographic map in ArcView 3.2 GIS software.

a. Water Bodies.

b. Road Network.

c. Built up Areas.

d. Contours.

e. Vegetation and Cultivations.

3.8 **Contours and Slopes Creation**

In order to determine the impact of terrain on mobility aspect of military operations, a contour map of the study area was created from the acquired Shuttle Radar Topographic Mission (SRTM) image of the study area. This was subsequently employed in the analysis of the slope aspect of terrain in terms of vehicular movement of military vehicles, both tracked and wheeled. GIS ANALYSIS was selected in the IDIRISI 15 module, SURFACE ANALYSIS was thereafter chosen. This prompted a dialog box for the selection of TOPOGRAPHIC VARIABLES and then SLOPE. Carved out SRTM image of the study area was inserted and finally output slope with degree values was created. Fig. 3.4 is the SRTM image of the study area.

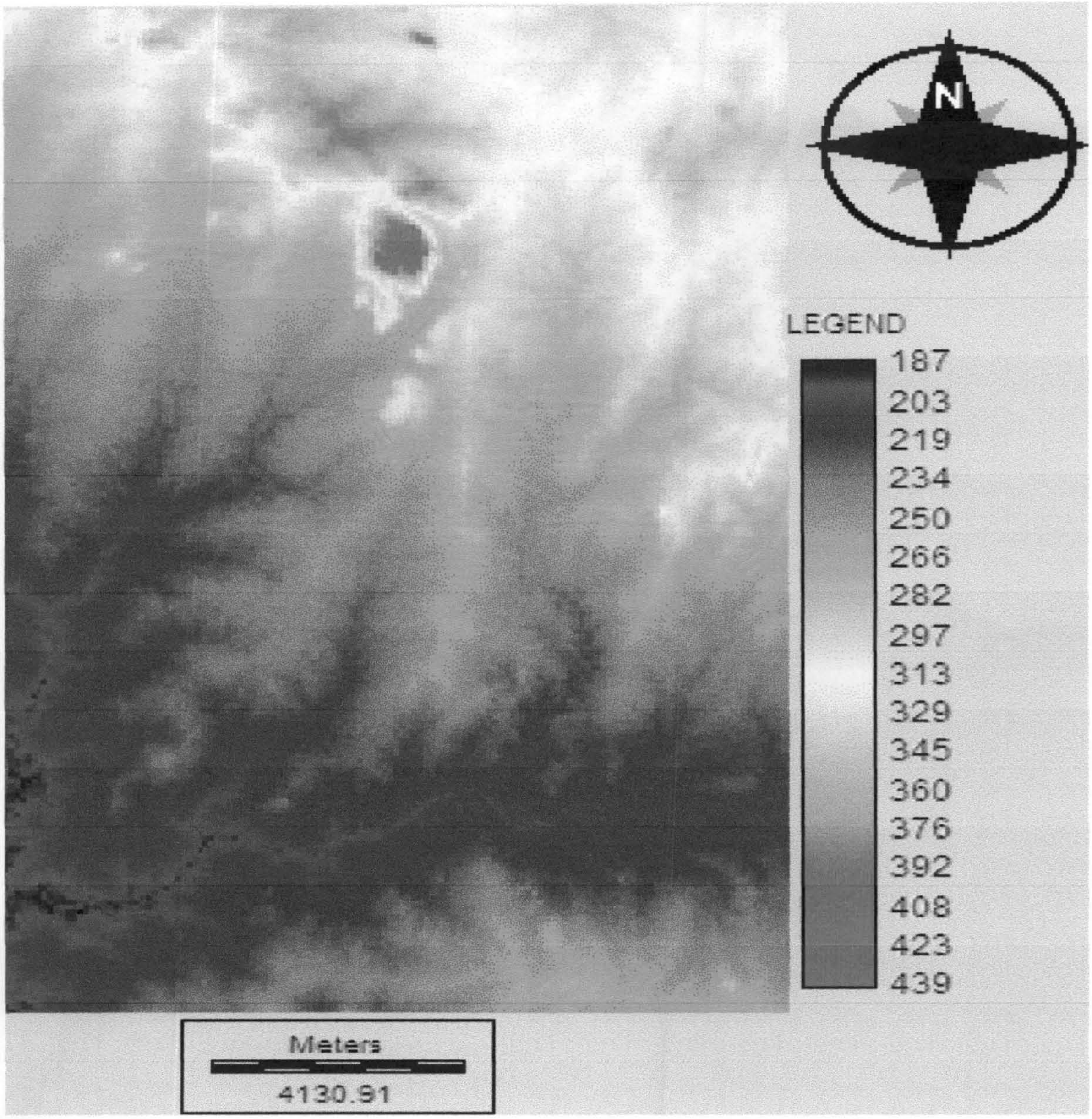

Fig. 3.4: SRTM image of the Study Area.

Source: Global Land Cover Facility (www.landcover.org)

3.9 **Determination of Military Terrain Attributes of the Study Area**

Assessment of terrain by the military at the strategic level is concerned with the gross spatial distribution of economically important areas with their cities and associated transportation lines and also with the mountains, seas, and rivers barriers that divide them. At the tactical level, the terrain is considered in more detail; the focus being on visibility, cross country mobility, the reaction of terrain to deformation and the availability of water and constructional materials. Consequently, terrain of the study area was classified and analysed through the use of satellite image of Landsat 7 ETM+ in conjunction with the topographical map of the study area. The terrain was thus classified into differing land use patterns relevant to military operations by the use of IDRISI 15 Andes Edition image processing software. Landforms influence movement, observation and efficient use of military equipment. Both the topographic map and the Landsat 7 ETM+ of the study area were used in the determination and interpretation of terrain attributes relevant to successful conduct of military operations.

3.10 **Application of Digital Terrain Model (DTM) to Terrain Evaluation**

DTM is basically developed on the basis of selected data of the topography which is represented in digital format. The DTM generated for the study were through the digitizing of contour lines of the topographic map of Minna and environs. The method applied in the generation of DTM of the study area was the graphic digitizing method in conjunction with the Landsat 7 ETM+ of the study area using IDRISI 15 Andes Edition image processing software.

3.10.1 **Graphic Digitizing Method**

The graphic digitizing method involved the use of topographic map of the study area that was converted to digital format through scanning and digitized using ArcView 3.2 software. Thus the digital data generally occur as series of strings of X, Y coordinates with an associated Z value of the contour level. A total of 260 of 2cm x 2cm grids (13 rows and 20 columns) of the topographic map of the study area were utilized to form a raster square grids for the area covering Latitudes 9° 30′ – 9° 40′ North of Equator and Longitudes 6° 30′ – 6° 37′ East of Greenwich Meridian. About 1, 040 elevation points (in feet) were extracted at the grid intersections. The UTM coordinates of the intersections were also determined. These form the discrete data for the digital elevation model of the study area. Appendix I are the surface interpolation coordinates of the study area.

3.10.2 **Orthomap Generation with Landsat 7 ETM+ Image**

Orthomap generation creates orthographic perspective (3-D) display of digital elevation models (DEMs). The process of the generation of orthomap involved the following stages:

Stage 1: ASCII File Generation of XYZ Positional Data. The series of X, Y coordinates with an associated Z values earlier created in Section 3.10.1 were converted to American Standard Code for Information Interchange (ASCII) file.

This was carried out through manual data creation using Microsoft windows excel and then entered into the EDIT mode of the modelling option of IDRISI 15 operations menu. In this operation, the row values (lines) are transposed and entered as column values. The process involves joining of the row values one after the other (i.e from the first top row to the last bottom row), to form a continuous one column data. Subsequently, the X data of the UTM coordinate are entered for the first column, followed by the Y data in the second column and Z data in the third column.

Stage 2: Conversion of ASCII File to IDRISI Vector File. The conversion of ASCII file earlier created to an IDRISI vector file is necessary before it could be handled by IDRISI 15 Andes Edition software. This was done through the selection of IMPORT option of IDRISI module and followed by the GENERAL CONVERSION tools option of XYZ – Idrisi operation. The input data for the operation was the ASCII file which also included other necessary reference parameters. The output data is a vector file containing colours assigned to points at some regular intervals of height (Z component data).

Stage 3: Surface Interpolation. The vector file earlier created was converted to a raster image. Surface raster image is a two-dimensional image created with the use of height colour information from vector file to produce a colour map. Each colour represents a particular height for a particular pixel. Surface interpolation is important for the creation of orthomap. The process involved the selection of GIS ANALYSIS, followed by SURFACE ANALYISIS, then INTERPOLATION and finally INTERPOL. Input image was the vector file and an output file name was created.

Stage 4: Orthomap Generation. ORTHO was selected from DISPLAY in the main menu of IDIRISI 15 module, which prompts a dialog for surface input image and in this case, the surface image created in stage 3. Thereafter, drape image was selected which was the composite image of the study area. Output image was the orthographic perspective display (3-D) image of the study area at 640 x 480 resolution.

3.11 **Hill shade Image Generation**

Hill shade image indicate the illumination of slopes in relation to the incident low angle illumination from the sun. Outcome of hill shade generation is an image with different shades of gray colours showing varying forms of relief. In the operation of its creation, GIS ANALYSIS was selected and was followed by SURFACE ANALYSIS. TOPOGRAPHIC VARIABLES and HILLSHADE were finally selected. Input image for this operation was surface interpolation image created in Section 3.9.2; stage 3. Golden Surfer Version 8.01 Surface Mapping System software was further used to create an enhanced hill shade view of the study area.

The methodology outlined the processes that were carried out in order to achieve the aim and objectives of the study. The results obtained are presented in the next chapter.

CHAPTER FOUR

RESULTS

The research work was undertaken in order to evaluate the application of digital terrain modelling for military operations using Minna and environs as case study. This chapter presents the results of the study which includes images, figures and tables.

4.1 Landsat 7 ETM+ Satellite Image

In the general classification of the terrain features of the study area, a combination of bands 3, 4, and 5 of Landsat 7 ETM+ of the study area were used. On the image water reflectance was absorbed and it appeared black and the built up areas appeared in magenta. Vegetation appeared in their natural colour of green and the open spaces/bare land appeared brown. Consequently, the following terrain features were identified on the satellite image of the study area and confirmed to be true during field work:

a. **Water Bodies.** The spectral reflectance of water made it most distinctive in the near-infrared wavelength. Thus the application of band 4 which is in the near-infrared region has made the delineation of water bodies easy due the absorption properties of water. Consequently, in the study area, one major river, River Chanchaga flows from west to east with tributaries such as River

Suka. Small lakes are found around some villages and Bosso dam is noticeable in the northern part of the study area.

b. **Road Network.** Existing roads and tracks are important aspects as these ensure the smooth movement of military convoys and logistical supplies. Roads and tracks criss-cross the study area. Major roads are the Minna – Suleja road; Minna – Zungeru; Minna – Bida; and the East and Western bypasses. Band 3 of the wavelength region of the satellite image was applied in the identification of road network of the study area.

c. **Built up Areas.** Man-made features such as buildings are identifiable in the band 3 wavelength region of Landsat 7ETM+ of the study area. Cosmopolitan Minna township forms part of the study area. Other built up areas are sparsely found in the environs of Minna township.

d. **Open Spaces/Bare Grounds.** Spectral reflectance of soil is captured in the bands 3 and 4 of the wavelength region of the applied satellite image for this study. Some of the factors affecting soil reflectance are moisture content, soil texture, presence of iron oxide and organic matter content. Open spaces are noticeable in the various parts of the study area. Existence of these open spaces/bare grounds was confirmed through field work.

e. **Vegetation and Cultivations.** Chlorophyll is a major constituent of leaves which strongly absorbs energy in the band 3 wavelength region of the satellite image of the study area. Thus the high absorption of blue and red energy by plant leaves and the high reflection of green energy, presented the green colour vegetation seen on the image. Vegetation is noticeable in some parts of the study area, especially along water courses. Cultivated areas are sparsely found in environs of Minna, though most of the cultivation is more prominent during the rainy season. Fig. 4.1 is the colour composite image of the study area after processing.

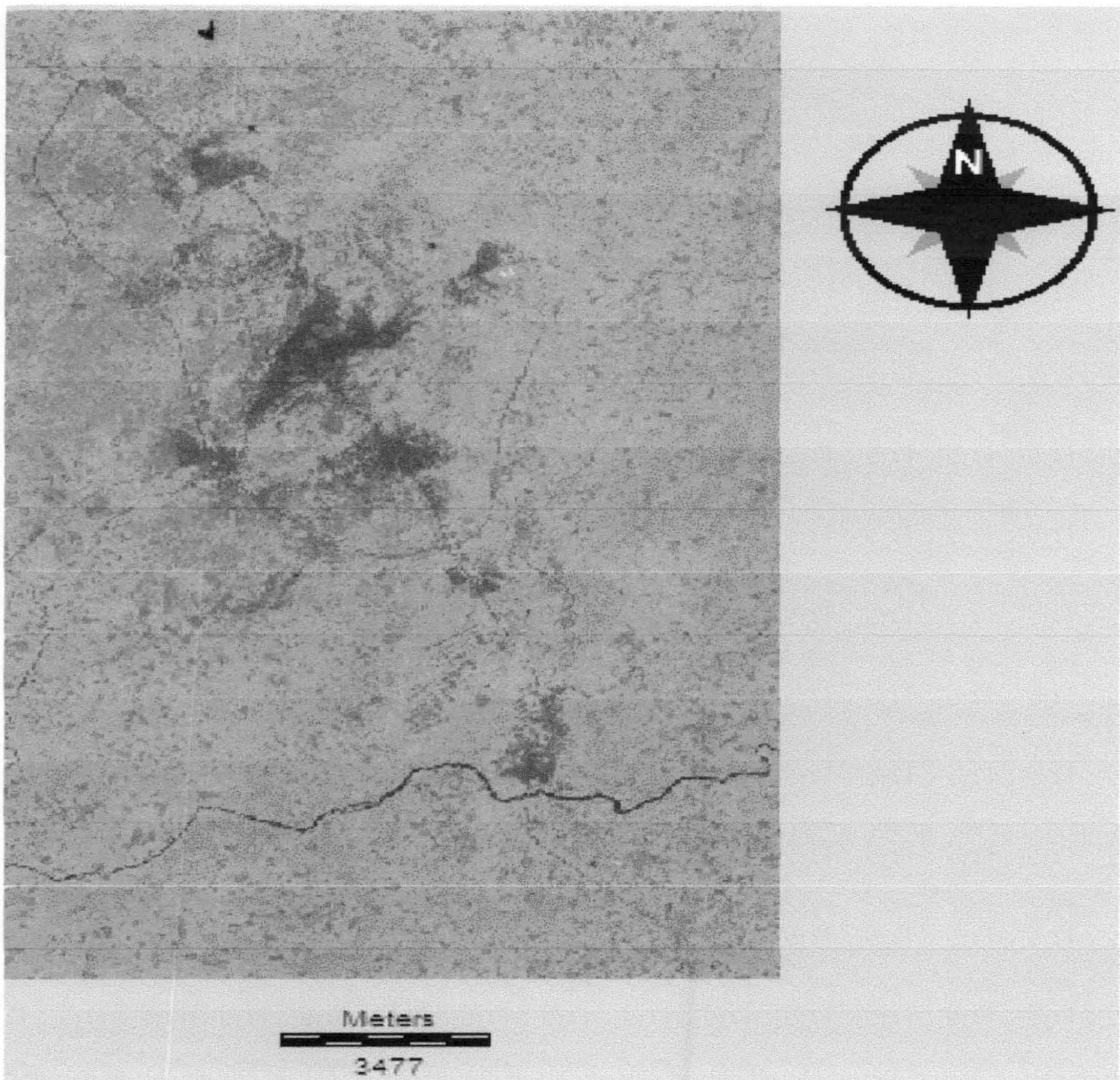

Fig. 4.1: Colour Composite Bands 3, 4, and 5 Image of Landsat 7 ETM+ of the Study Area after processing.

4.2 Normalized Difference Vegetation Index (NDVI) Image

The Normalized Difference Vegetation Index (NDVI) is expressed as the difference between the near infrared and red bands and normalized by the sum of those bands. Fig. 4.2 is the NDVI extracted from bands 3 and 4 of the Landsat 7 ETM+ of the study area. The measurement scale which ranges from -1 to 1, and 0 represents the approximate value of no vegetation while negative values represent non-vegetated surfaces.

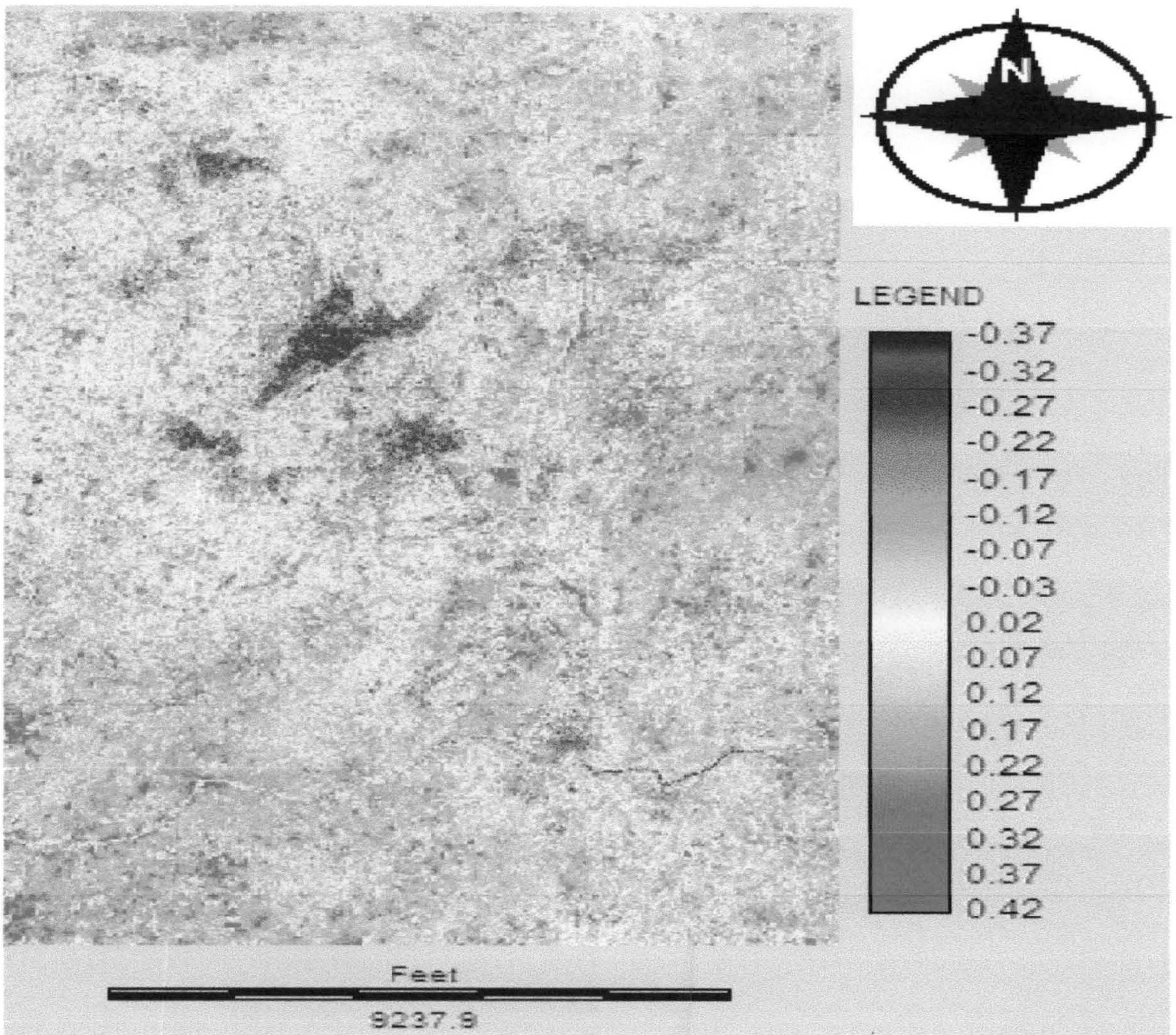

Fig. 4.2: NDVI Image of the Study Area.

The NDVI image of the study area was further reclassified to deduce the distribution of vegetation in the study area. The vegetation reclassified image is in Fig.4.3

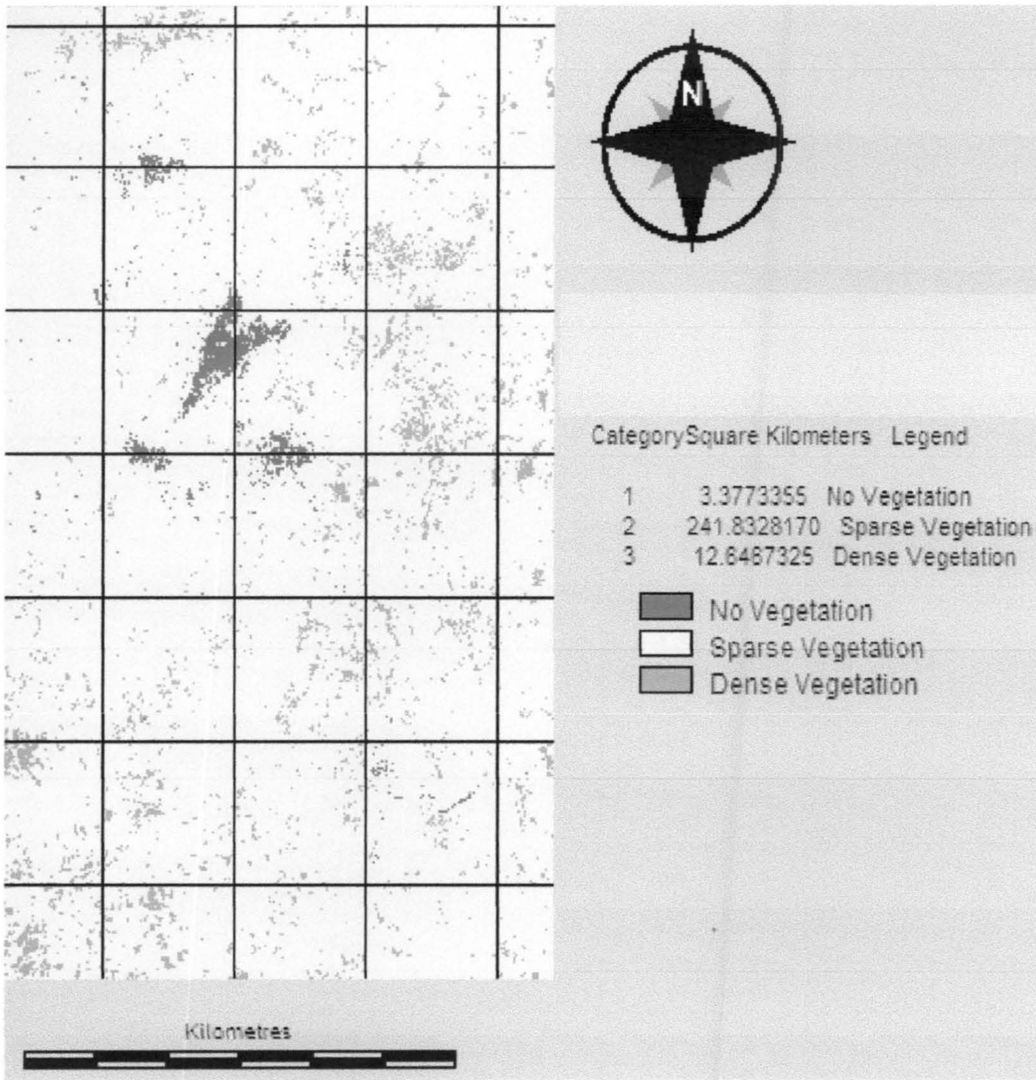

Fig. 4.3: Vegetation Cover in Square Kilometers in a Reclassified NDVI Image of the Study Area.

4.3 **Topographic Data of the Study Area**

The aim of application of the topographic map of the study area was to use the topographic data to complement the satellite image of the study area in the analysis and interpretation of results of the study. This was achieved through the display of a 3-D perspective image of the study area. Equally, the on-screen digitizing of features of the topographic map of the study area brought about the creation of composite map of the study area. The map was georeferenced from the GPS coordinates collected from the field of the identifiable areas on the map and the ground.

4.3.1 **Composite Map of the Study Area**

Topographic map features such as built up areas, settlements, rivers, roads and elevations in the form of contours were digitized on-screen for the area covering Latitudes $9^0\ 30'$ and $9^0\ 40'$ North of Equator and Longitudes $6^0\ 30'$ and $6^0\ 37'$ East of Equator using Arc View 3.2 software. The digitized composite map of the study area in Fig. 4.4 indicated existing environmental features of the study area such as the range of hills in the North Eastern area of the study area which is represented by the close nature of the contours.

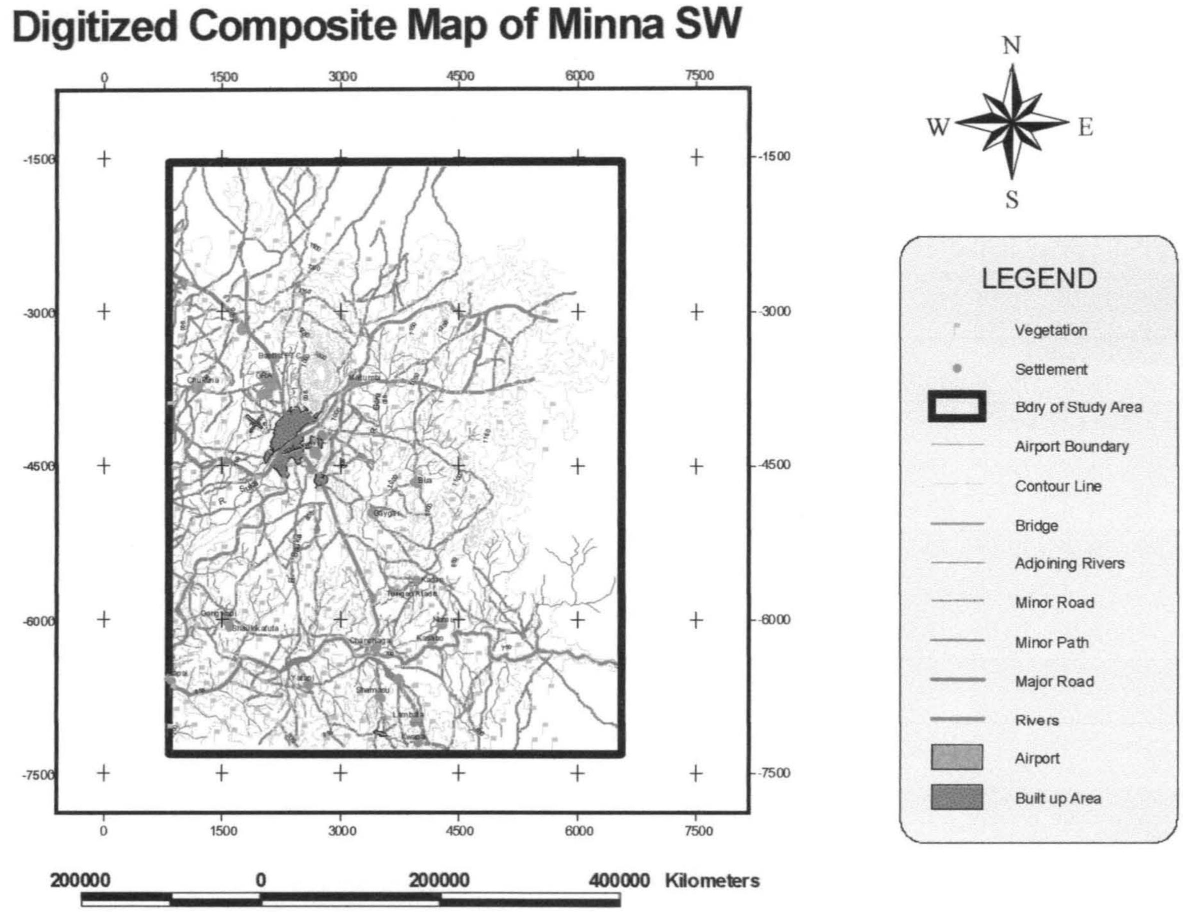

Fig. 4.4: Terrain Features in a Digitized Composite Map of the Study Area.

4.3.2 **Rasterized Digitized Contours of the Study Area**

Rasterised digital contours of the study area were created through the surface interpolation of the topographic map of the study area in Fig.4.5.

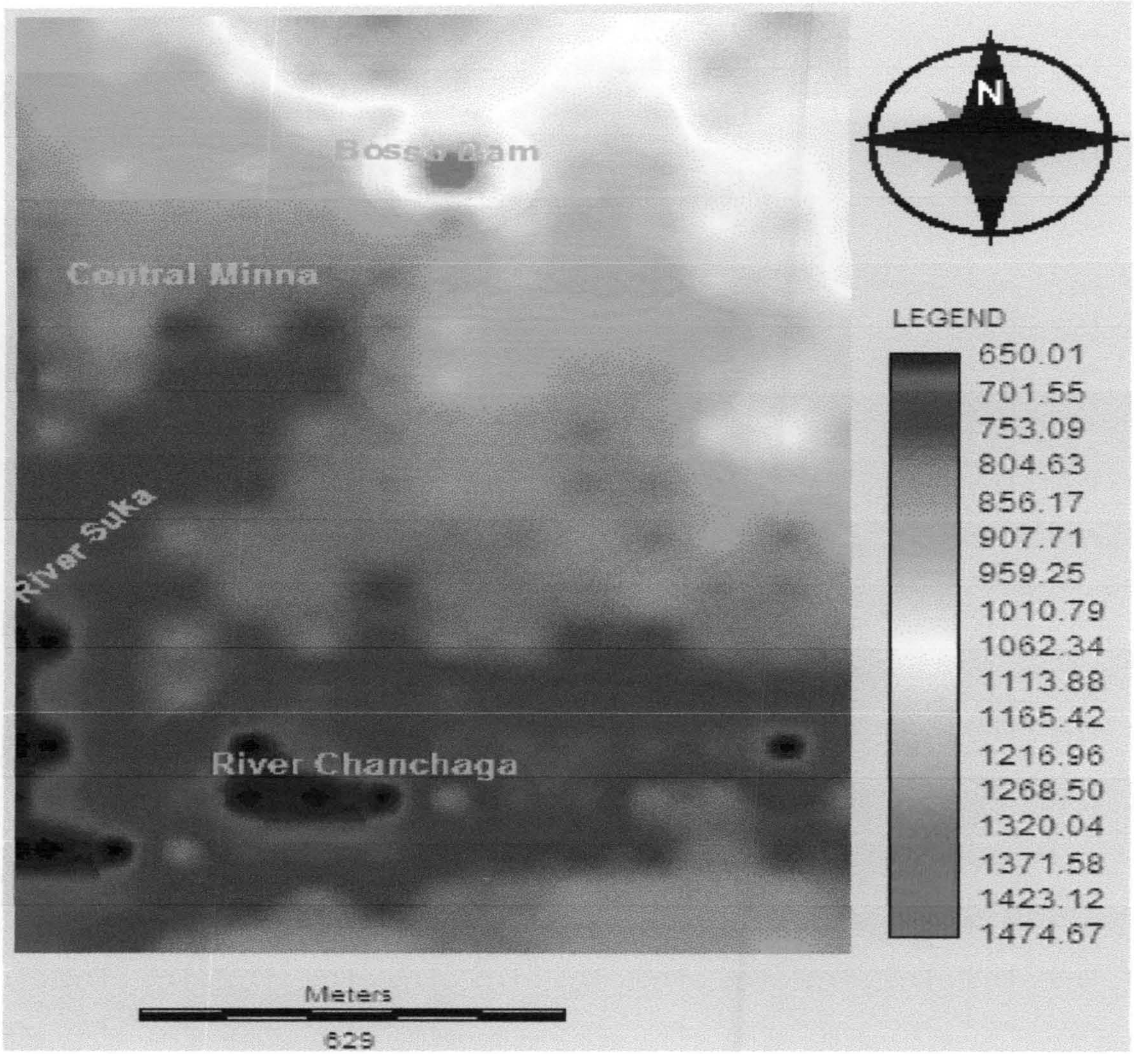

Fig. 4.5: Surface Interpolations in Feet of the Topographic Map of the Study Area.

4.4 Contour Map of Minna and Environs

Contour map is a vector map which presents the height information about any surface of the earth. This otherwise provides information on the elevation ranges of the study area. The slope image displayed in Fig. 4.6 was extracted from the slope surface analysis of Shuttle Radar Topographic Mission (SRTM) image in Fig. 3.4 with a resolution of 90m. The slope surface analysis was subsequently used in the analysis of the effects of gradient on military vehicular movement.

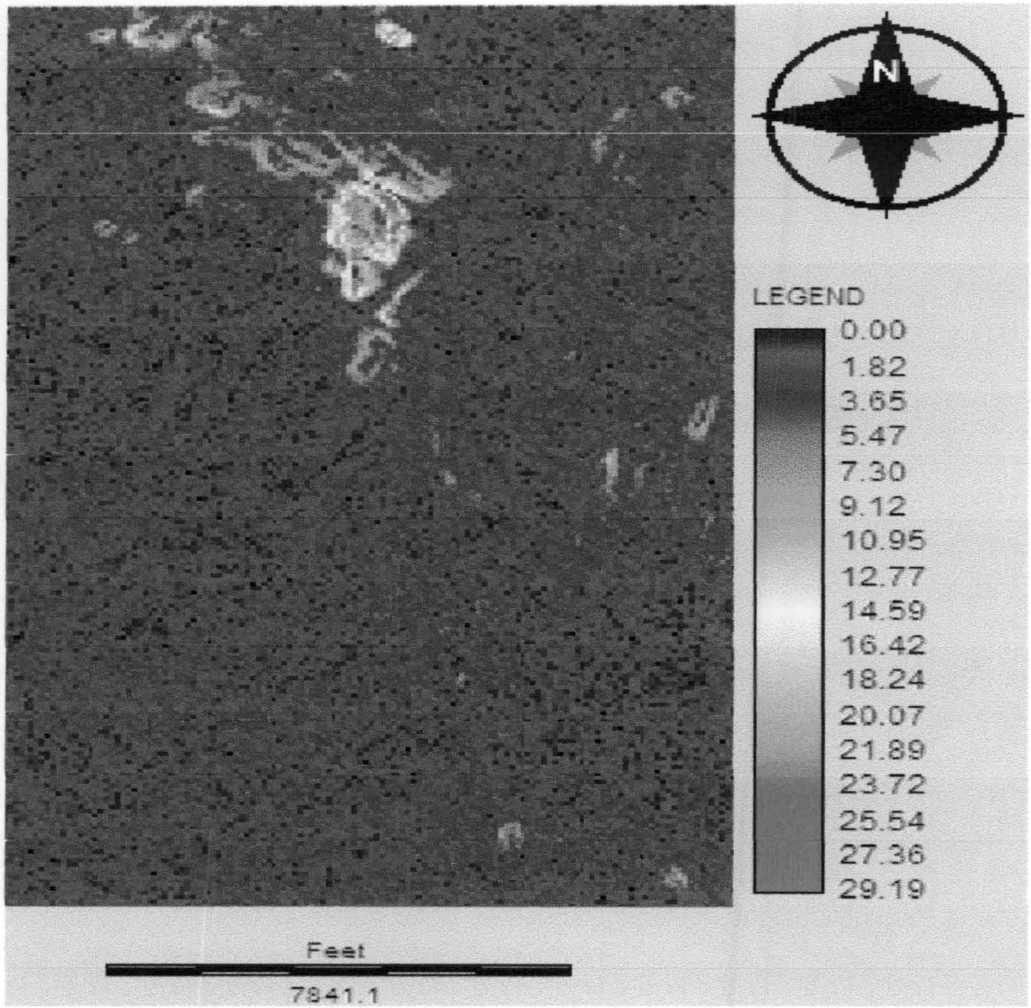

Fig.4.6: Slope in Degrees Image of the Study Area.

4.5 **Orthomap Image**

Production of Orthomap image of the study area was achieved through the draping of a vector image of the study area at Fig. 4.5 with the composite image of the study area at Fig. 4.1. The result of this process is a three dimensional image of the study area at Fig. 4.7. The 3-D image in Fig. 4.7 portrays a 3-D perspective view of the study area.

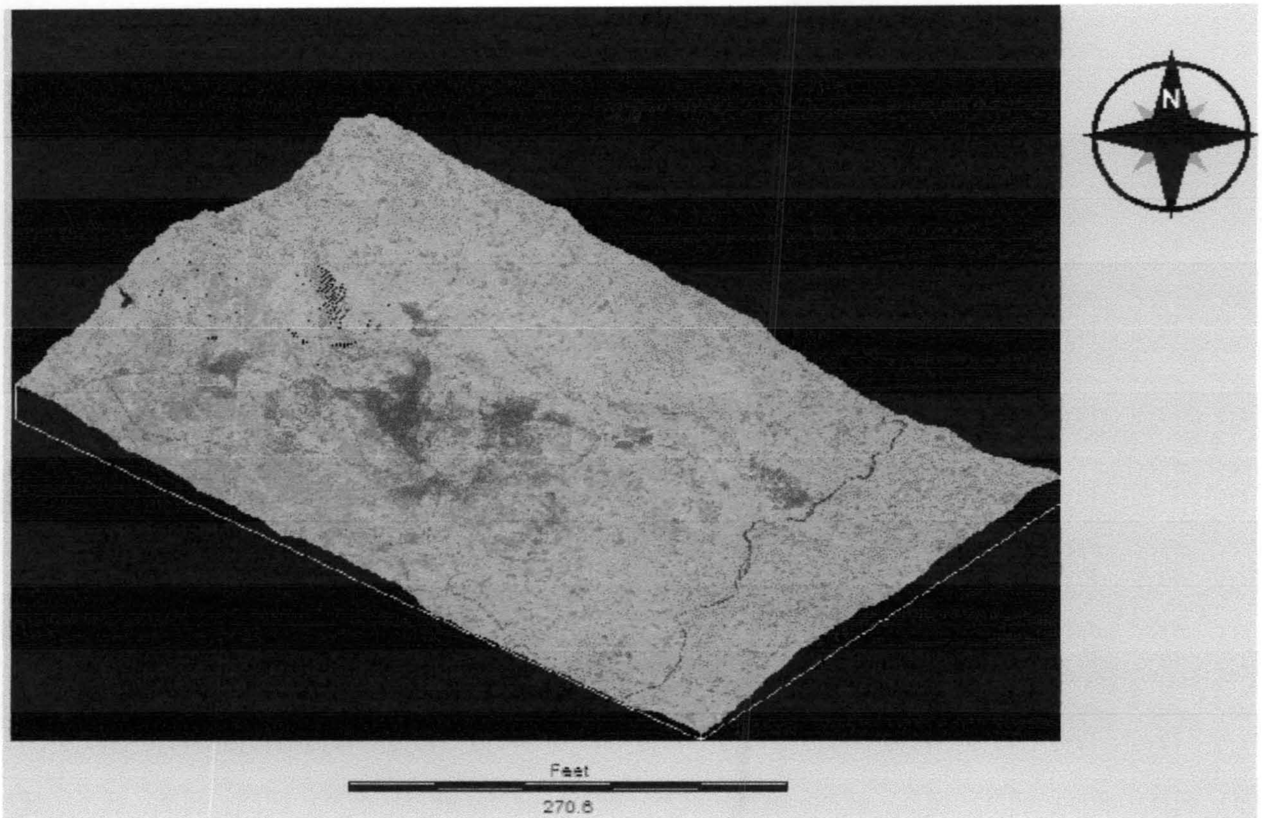

Fig. 4.7: Landsat 7 ETM+ and DEM Drape 3-D Perspective View of the Study Area.

However, an enhanced view of 3-D perspective of the study area was created through the application of Golden Surfer 8.01 Surface Mapping System software. Fig. 4.8 is the 3-D surface DTM view of the study area which greatly enhanced the interpretation of the terrain under consideration for various military operations.

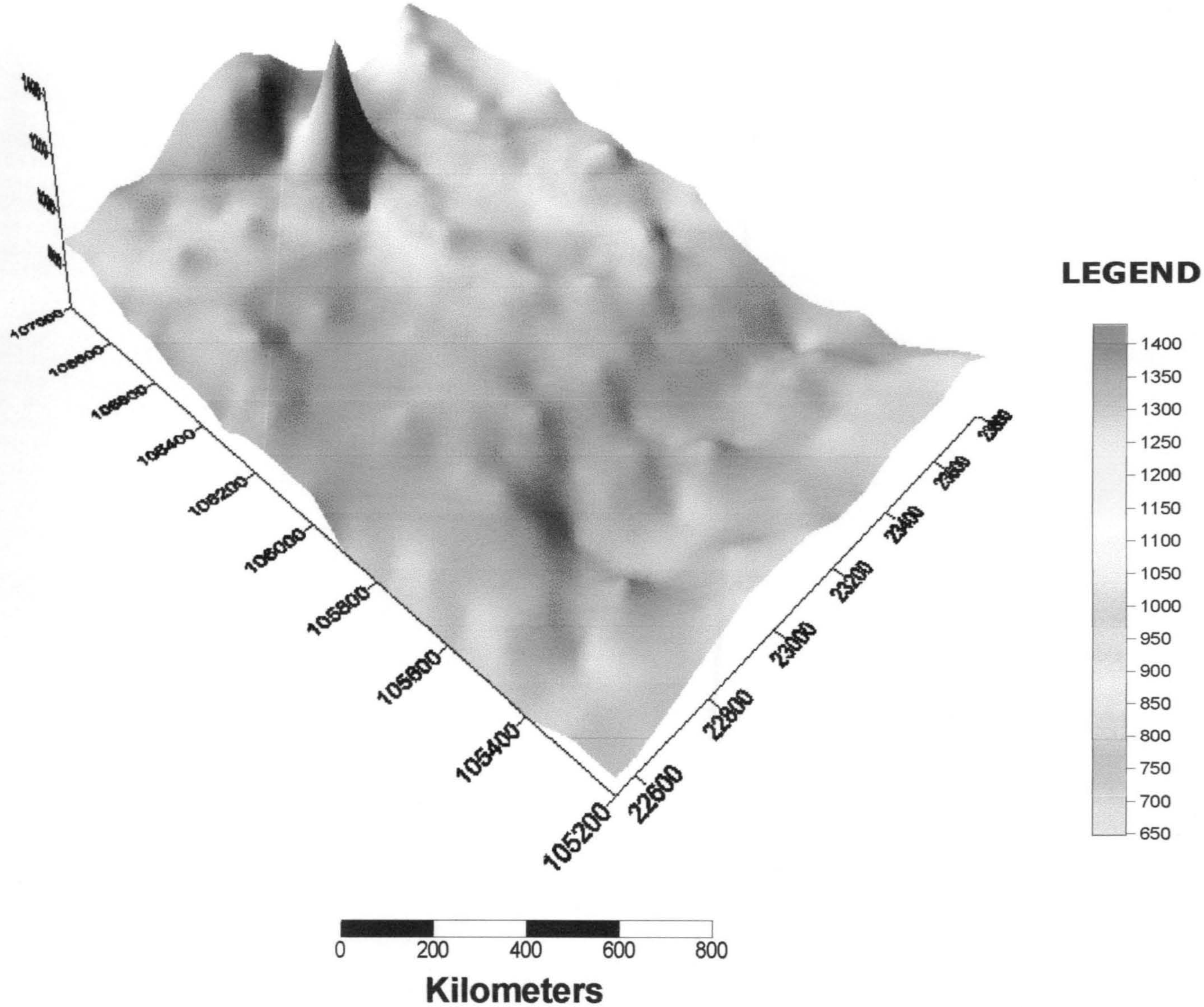

Fig. 4.8: 3-D Surface DTM Perspective View of the Study Area.

The percentage ration of the vegetation cover in the study area was further calculated so as to determine the distribution of vegetation cover in the study area. Table 4.1 indicates the percentage ration of the vegetation cover in the study area.

Table 4.1: Percentage Ratio of Vegetation Cover in the Study Area.

Vegetation Classification	Area Coverage (Km^2)	Percentage
No Vegetation	3.377	1.31%
Sparse Vegetation	241.833	93.79%
Dense Vegetation	12.647	4.90%
TOTAL	257.857	100%

Additionally, an orthomap of NDVI of the study area as indicated in Fig. 4.9 was used to further analyse and buttress the relationship between vegetation and provision of cover and concealment in a 3-D perspective.

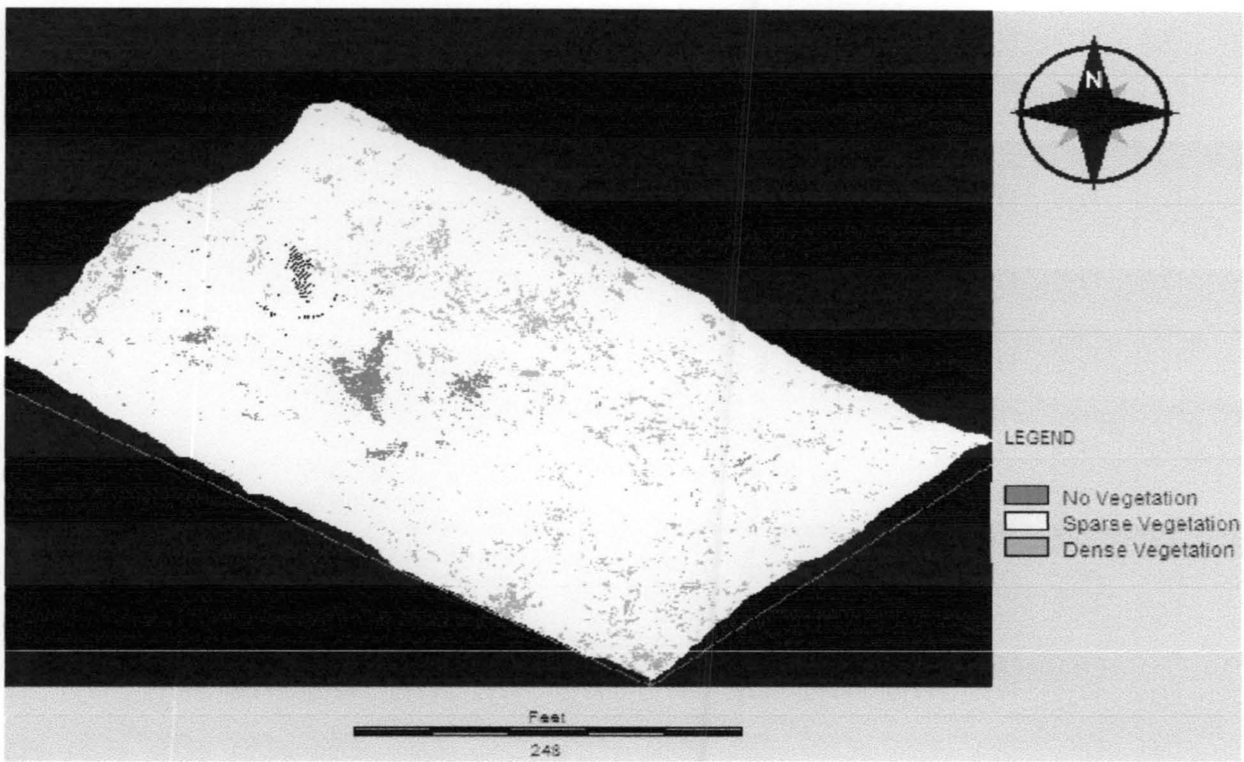

Fig. 4.9: NDVI 3-D Perspective View of the Study Area.

In the determination of inter-visibility between pairs of points in the study area, a hill shade showing nature of inter-visibility as indicated in Fig. 4.10 was used. Consequently, the analysis of inter-visibility/line of sight was conducted based on the nature of hill shade of the study area.

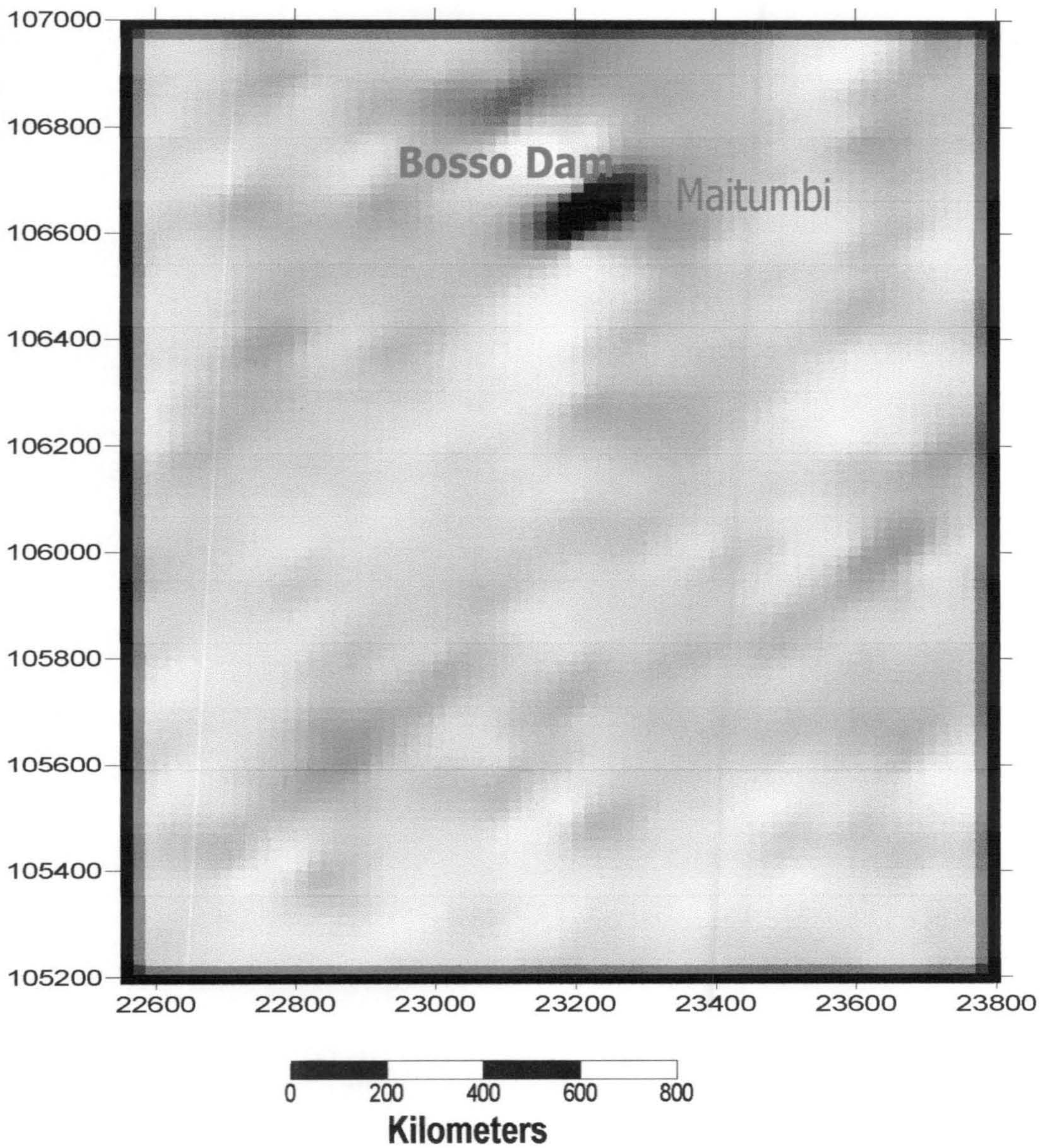

Fig. 4.10: Hill Shade of the study Area Indicating Inter-visibility.

In the realm of the assessment of the mobility and accessibility of vehicular and troop's movement in the study area, a digitized road network of the study area was applied in conjunction with an adopted data on some military vehicles which indicates their speed and maximum slope ascend. Fig.4.11 is the digitized road network of the study area, while Table 4.2 indicates some military vehicles, their speed and maximum slope ascend.

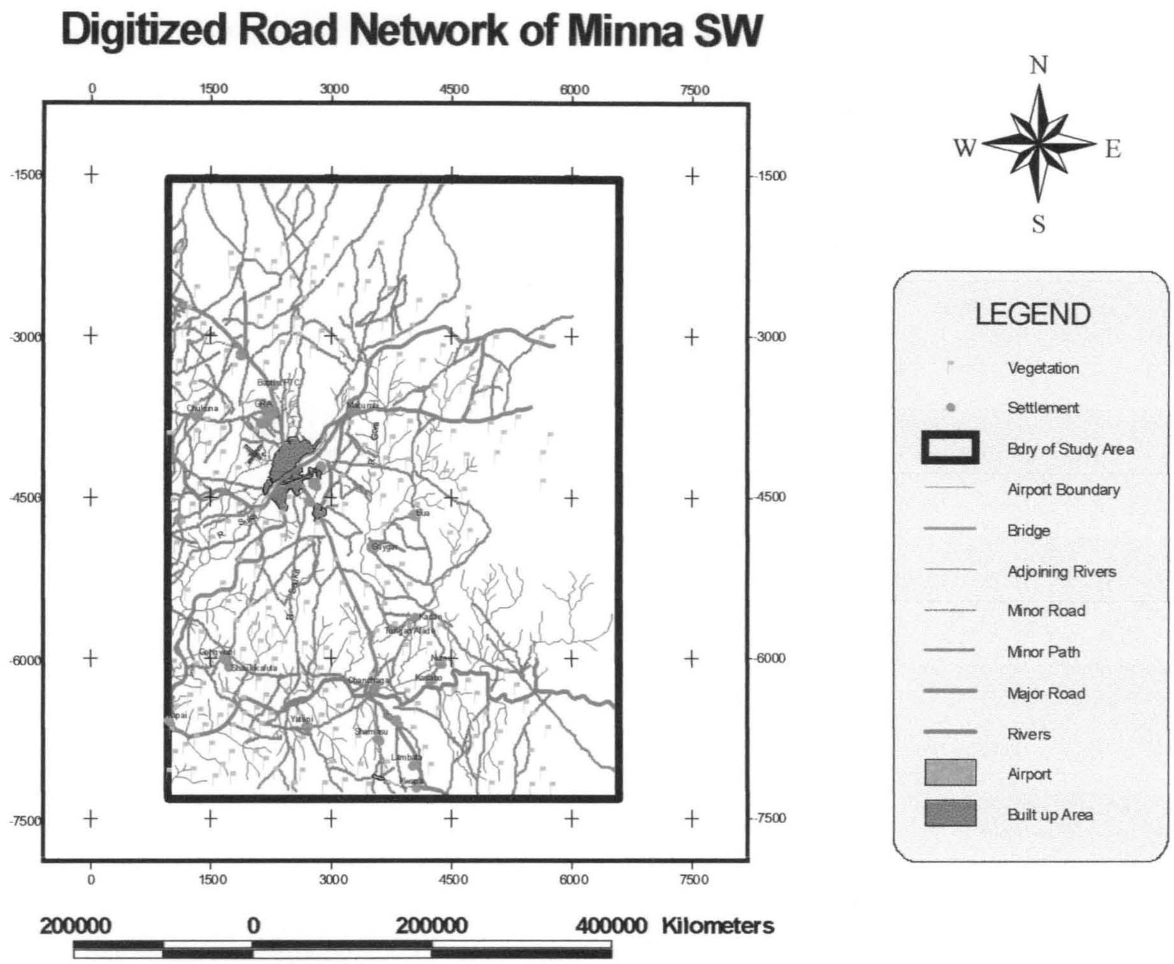

Fig. 4.11: Digitized Road Network of the Study Area.

Table 4.2: Some Military Vehicles, their Speed and Maximum Slope Ascend.

Type of Vehicle	Cross Country Speed (Km/h)	Max Slope Ascend	Weight	Function
155 Self Propelled (Tracked)	20 – 25	25^0	25.9 ton	Combat
Foxton (Tracked)	25 – 35	30^0		Combat
APC Mizz (Tracked)	30 – 45	35^0	4880 Kg	Movement of troops
Unimog (Tracked)	30 – 45	45^0	3 – 5 ton	Towing of guns
T55 Tank (Tracked)	20 – 27	32^0	36 ton	Combat
Land Rover	45 - 55	45^0	¾ ton	Command and Comms
Mercedes Benz Truck (Wheeled)	30 – 45	40^0	5 ton	Movement of troops, stores and supplies

Source: Adopted from Curt (1975) Modern Military Series; Artillery Data.

The mobility or accessibility of troops and vehicles in the military is also being affected by how firm a ground is to withstand the heavy weight of military vehicles. Firmness of a ground is affected by the soil moisture of the soil of an area. Consequently, a wet area mapping which is an indicator of moisture content of the soil of an area was achieved through the creation of Tasseled Cap transformation moisture image of the study area in Fig. 4.12.

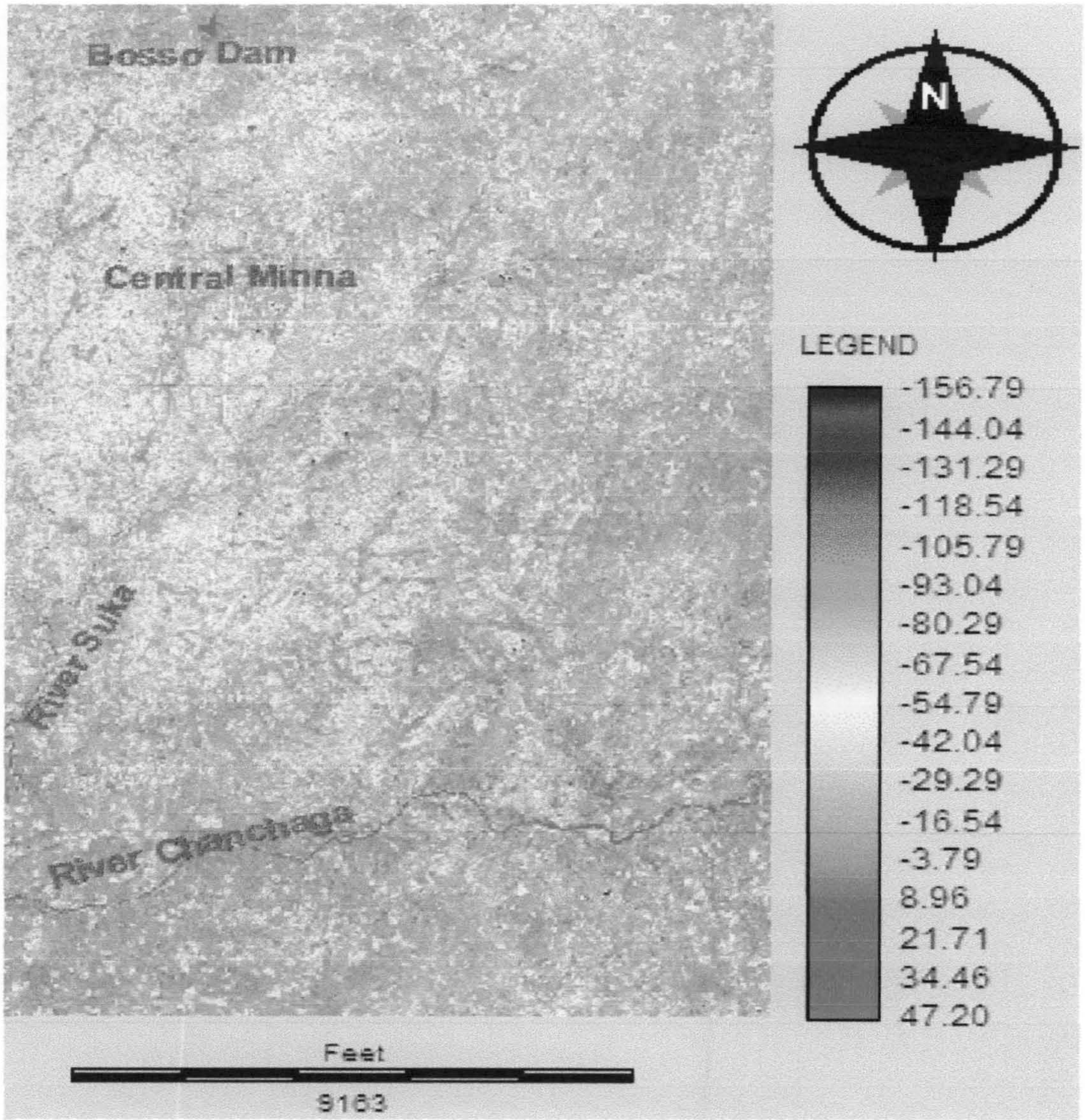

Fig. 4.12: Tasseled Cap Transformation Moisture Image Indicating Soil Moisture Content of the study Area.

CHAPTER FIVE

DISCUSSION, SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

The discussion of the results of the study entails the interpretation and analysis of the terrain features of the study area in relation to their effects on the conduct of military operations and the practicability of the application of DTM to terrain evaluation for military operations. This was achieved through the interpretation and analysis of the earlier presented images, figures and tables in the previous chapter.

5.1.1 Normalized Difference Vegetation Index (NDVI) Image Analysis

The Normalized Difference Vegetation Index (NDVI) indicated the spatial distribution of vegetation in the study area. Fig. 4.2 is the NDVI image of the study area in which high values indicate thick healthy vegetation, while low values indicate absence or near absence of vegetation in an area. Therefore, areas with positive vegetation index values located in the North Eastern and Southern parts of the study area are more vegetated than areas in the North Western areas of the study area.

5.1.2 Analysis of the Rasterized Digitized Contours of the Study Area

An analysis of the surface interpolation of the study area as shown in Fig. 4.5 indicated that, the North Eastern part is an elevated terrain with associated hills and mountain range (the Bosso dam area having the highest elevation range with a range of 1470 feet). Areas of low elevations are found in the built up central Minna area and along river courses of Rivers Chanchaga and Suka with their associated tributaries. The elevation ranges of built up areas and rivers spanned 650 - 960 feet and in some associated areas up to 1000 feet. Therefore military tactical operational requirements such as vehicular and troop mobility, inter-visibility or line of sight were analysed through slope analysis of the study area.

5.1.3 **Orthomap Image Interpretation and Analysis**

Terrain elevation modelling and rapid assessment of terrain conditions at relatively high resolutions remains a vital part of tactical military planning for terrain analysis and mobility corridor determination. A commander must be able to defeat or avoid obstacles at various occasions as necessary in order to achieve success in tactical manoeuvre operations. Strategies for the defeat of such obstacles include engineering capabilities such as earth-moving systems as well as line-of-communications bridging. Avoidance requires advance knowledge of the terrain between the unit's location and the objective. Knowledge about the locations and attributes of obstacles and the ability to disseminate this information directly to commanders in a geospatial context improves situational understanding and decision-making capabilities for ground operations. Operational attributes that affect the successful conduct of military operations includes; cover and concealment, inter-visibility and mobility/accessibility.

5.1.3.1 **Cover and Concealment**

The vegetation indices as indicated in Figs. 4.2 and 4.3 show natural and cultivated vegetation with information on size, and density in the study area. Vegetation index is one of the primary factors used in determining the cross-country movement capability of troops and equipment, cover and concealment and line of sight. Plant cover can affect military tactics, decisions, and operations. Perhaps the most important is concealment. To make reliable evaluations when preparing vegetation overlays, analysts must collect data on the potential effects of vegetation on vehicular and foot movement concealment and observation. Consequently, NDVI is an important tool in the evaluation of the application of digital terrain model for military operations. Equally, vegetation may provide cover and concealment, but may also interfere with movement and land navigation. Figs. 4.2 and 4.3 are the NDVI Image and reclassified NDVI images of the study area respectively. Areas with no vegetation would provide no cover and concealment, while areas with sparse vegetation would provide some form of cover and concealment. Densely vegetated areas would provide better cover and concealment to military personnel during an operation or field training exercise. Equally, Fig.4.3 indicated the vegetation cover in the study area by which no vegetation areas covered 3.377 km^2; while sparsely vegetated areas covered 241.833 km^2 and densely vegetated areas take up 12.647 km^2. Also, Table 4.1 indicated the percentage ratio of vegetation distribution in the study area. Therefore built up areas in the cosmopolitan Minna and surrounding areas that appear in red colour, indicating lack of vegetation would not provide any vegetation driven cover and concealment for the military. The sparsely vegetated areas in light yellow colour occupied 93.79% of the landmass of the study area. This area would provide some form of vegetation driven cover and concealment to the military. On the other hand, densely vegetated areas that occupied 4.9% of the study area and which appeared in green would provide an excellent cover and concealment to the military for both ground and aerial observations.

In the light of this therefore, the study area would generally provide partial cover and concealment from both ground and aerial observations to the military. However the provision of the partial vegetation driven cover and concealment does not guarantee military personnel immunity from hostile fire or bombardment, unless some form of protection is provided such as construction of trenches.

5.1.3.2 **Inter-visibility/Line of Sight**

Determination of the existence of inter-visibility between pairs of points above undulating terrain is a fundamental operation within land-based military operations. Plains or low level areas generally favour movement or trafficability, except where traffic may be impeded by dense vegetation or hydrologic features such as lakes, marshes or estuaries. Also, plain areas provide optimum observation conditions, if vegetation or man made structures do not interfere; but provide little cover or concealment. A hilly or mountainous area restricts observation. Thus, the range of horizontal visibility varies inversely with relief. Therefore surface observation depends directly upon the amount of irregularity of the landscape. Thus the Line of Site (LOS) is an unobstructed view from point A to point B. The study area is composed of some hills especially in the North Eastern part of Minna. Other man made elevated features such as buildings equally present an obstruction to line of sight during military operations. Fig. 4.10 is a hill shade of the study area as regards inter-visibility. Gray areas indicate the areas that are inter-visible, while the dark and light dark tone areas are places that are not inter-visible. Thus the hilly areas around Bosso Dam and Maitumbi are not inter-visible. Generally, the study area has been found to provide good inter-visibility for military operations especially LOS and in the use of flat trajectory weapons such as rifles.

5.1.3.3 **Mobility/Accessibility**

Assured land mobility of military forces may be adversely impacted upon by unexpected discontinuities in terrain that fall within the relative vertical limits or gaps of the terrain. Terrain gaps are areas consisting of such anomalies, within the context of military manoeuvre, having characteristic dimensions on the order of ten meters or more and minimum slope of approximately 40 degrees, which may impede or constrain the movement of wheeled or tracked military vehicles. Also Gaps in military context may be natural or man-made, wet or dry, permanent or transient. They may include irrigation ditches, stream banks, short but steep escarpments, canals, excavations and other micro-terrain features with a positive or negative elevation differences from immediately surrounding terrain. Fig. 4.6 is the slope in degrees analysis of the study area indicating the distribution and nature of slope in degrees. Thus 0 degrees indicating plain areas, and the highest point being 29.19 degrees in height, while Fig. 4.11 is the digitized road network of the study area indicating roads and foot paths that criss-crossed the study area. However In comparison with the maximum slope ascend for military vehicles as indicated in Table 4.2, the study area in general would provide excellent mobility for military vehicles with the exception of the T55 self propelled armour tank whose mobility is restricted in the hilly North Eastern part of the study area.

The mobility or accessibility of troops and vehicles in the military is also being affected by how firm a ground is to withstand the heavy weight of military vehicles. Firmness of a ground is affected by the soil moisture of the soil of an area. Consequently, a wet area mapping which is an indicator of moisture content of the soil of an area was achieved through the creation of Tasseled Cap Transformation Moisture image of the study area in Fig. 4.12. It could therefore be noticed that the higher the numerical values of the pixels of the image the more moisture content of the area. Thus soils of areas in and around Bosso Dam and Rivers Chanchaga and Suka have higher soil moisture ranging from 8.96 to 21.71. Equally, built up areas in central Minna and surrounding areas that appear brighter with numerical values of between -54.79 to -29.29 have less moisture content than their surroundings that are dark brown in colour and within the numerical ranges of -16.54 to -3.79. The import of this analysis is that military vehicular mobility especially those with high tonnage of 20 tons and above would encounter serious difficulties in areas of high soil moisture which would require some form of military engineer support for successful cross country mobility. In general however, the study area would provide a firm ground for the smooth military vehicular mobility especially in areas with less soil moisture that are within the numerical ranges of -157.79 to -3.79 that make up more than 90% of the landmass of the study area.

Generally, military commanders must have accurate intelligence on the surface configuration of the terrain in order to achieve success in a military campaign. Ravines, embankments, ditches, plowed fields, boulder fields, and rice-field dikes are typical surface configurations that influence military activities. Terrain elevations, depressions, vegetation, artificial landmarks such as buildings and hydrologic features which abound in the study area are some of the terrain factors that would affect movement of troops, equipment, and materials.

In summary therefore, the interpretation and analysis of the data presented in this Chapter of the thesis report have uniquely demonstrated the potentials of application of digital terrain modelling and remote sensing and GIS in the analysis of terrain features both natural and artificial for the conduct of military operations. Critical terrain features such as hills, vegetation, hydrology and built up areas were analysed in relation to their effects on the conduct of military operations.

5.2 **Summary**

Terrain analysis which is an integral part of the intelligence preparation of the battlefield (IPB) plays a key role in any military operation. During peacetime, terrain analysts build extensive data bases for each potential area of operations. They provide a base for all intelligence operations and tactical decisions/operations. They also support the planning and execution of most other battlefield functions such as supply and logistics. Because terrain features continually undergo change on the earth's surface, data bases must be continuously revised and updated. These assertions aptly captured the aim and objectives of the research project and hence the reasons behind the conduct of the research work. Thus accurate and timely terrain analysis is the key for today's fast paced mobile battlefield. Therefore, conventional techniques of terrain analysis in the military need to be updated due to availability of data products like maps in digital form and high resolution imageries. Hence terrain elevation modelling and rapid assessment of terrain conditions through the application of relatively high resolutions images remains a vital part of tactical military planning.

The Normalised Difference Vegetation Index (NDVI) images in Figs. 4.2, 4.3 and 4.11 further indicated the spatial distribution of vegetation of the study area. The resulting images indicated that the North Eastern part of the study area is more sparsely vegetated as against other areas and also thick vegetations are found along hydrologic features such Rivers Chanchaga and Suka and their distributaries. The import of the analysis of the NDVI is that vegetation plays a vital role in the provision of cover and concealment during military operations.

Finally, a three-dimensional perspective view of the study area as created in Figs. 4.7, 4.8 and 4.9 highlighted and portrayed the terrain model of the study area which paved the way for the eventual analysis of terrain features of the area for various military operations such as provision of cover and concealment, inter-visibility and mobility corridors.

The results of the research work on the application of digital terrain modelling in terrain analysis for military operations indicated that only 4.9% of the terrain of the study area would provide adequate vegetation derived cover and concealment from both air and ground observation during military operation, while 93.79% would only provide partial cover and concealment. It has also been shown that the study area would provide excellent mobility routes to the military with however the exception of hilly areas in the North eastern part of the study area. Equally the study area has been found to provide good inter-visibility with the exception of the hilly Bosso Dam area for military operations especially in the use of flat trajectory weapons such as rifles.

5.3 Conclusion

On the backdrop of conduct of the research project, the research has demonstrated the practicability of the application of digital terrain modeling in terrain evaluation for military operations. Thus digital terrain modeling for terrain analysis has been found to be a viable tool in military operations as it is timely and accurate as compared to other traditional methods of terrain evaluation through the use of sand models, card board or plastic models to depict terrain features in the military. Equally, remotely-sensed data makes it possible for accuracy in definition and quantification of features on the ground which leads to accuracy in their classification.

Consequent upon the findings of the research work, one could conclude that, the terrain features which include hydrologic features such as rivers, streams and dams, vegetation, hills and built up areas found in Minna and its environs could prove to be difficult in some areas or easy terrain in some other areas for military operations as noticed in the data presentation and analysis part of the thesis.

5.4 **Recommendations**

The study was undertaken to analyse the application of digital terrain model in terrain evaluation for military operations, using Minna and environs as case study; it then becomes pertinent to make the following recommendations:

- There is the growing need for the Nigerian Military to establish a terrain evaluation unit for the acquisition of terrain data at the operational, tactical and strategic levels for different military operations.

- Adequately equipped remote sensing/GIS laboratories should be established by the military in order to take advantage of the inherent capabilities of remote sensing and GIS in terrain analysis especially in view of the present battlefield military manoeuvres.

- The Nigerian military should commence as a matter of importance the training of its personnel in the acquisition of remote sensing and GIS knowledge.

- Deliberate effort should be made by the Nigerian Military to encourage its personnel to have a pre-knowledge of the terrain they are to operate upon through the application of remote sensing and GIS approach especially the Niger Delta region and Nigeria's international borders.

- Further research should be carried out to determine the practicability of application of digital terrain model for military operations in other environments such as the semi arid areas of the extreme Northern parts of Nigeria and the thickly forested Southern parts of Nigeria.

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Appendix I

Surface Interpolation Coordinates of the Study Area

X Coordinates	Y Coordinates	Z Values (Feet)
(a)	(b)	(c)
22550	107000	900
22550	106900	900
22550	106800	850
22550	106700	800
22550	106600	800
22550	106500	750
22550	106400	750
22550	106300	700
22550	106200	750
22550	106100	750
22550	106000	750
22550	105900	650
22550	105800	650
22550	105700	650
22550	105600	650
22550	105500	650
22550	105400	650
22550	105300	700
22550	105200	700
22600	107000	900
22600	106900	900
22600	106800	900
22600	106700	850
22600	106600	800
22600	106500	800
22600	106400	800
22600	106300	800
22600	106200	800
22600	106100	750
22600	106000	750
22600	105900	700
22600	105800	650
22600	105700	700
22600	105600	650
22600	105500	700

(a)	(b)	(c)
22600	105400	650
22600	105300	700
22600	105200	700
22700	107000	1000
22700	106900	950
22700	106800	900
22700	106700	950
22700	106600	850
22700	106500	850
22700	106400	850
22700	106300	800
22700	106200	750
22700	106100	750
22700	106000	750
22700	105900	750
22700	105800	750
22700	105700	750
22700	105600	750
22700	105500	750
22700	105400	650
22700	105300	700
22700	105200	750
22800	107000	1000
22800	106900	900
22800	106800	900
22800	106700	900
22800	106600	850
22800	106500	800
22800	106400	750
22800	106300	750
22800	106200	750
22800	106100	750
22800	106000	800
22800	105900	750
22800	105800	800
22800	105700	800
22800	105600	750
22800	105500	700
22800	105400	800
22800	105300	750

(a)	(b)	(c)
22800	105200	800
22900	107000	1150
22900	106900	1050
22900	106800	900
22900	106700	950
22900	106600	850
22900	106500	800
22900	106400	800
22900	106300	750
22900	106200	750
22900	106100	750
22900	106000	800
22900	105900	800
22900	105800	750
22900	105700	750
22900	105600	650
22900	105500	650
22900	105400	700
22900	105300	750
22900	105200	850
23000	107000	1250
23000	106900	1200
23000	106800	1000
23000	106700	900
23000	106600	850
23000	106500	800
23000	106400	750
23000	106300	750
23000	106200	800
23000	106100	800
23000	106000	800
23000	105900	800
23000	105800	800
23000	105700	700
23000	105600	700
23000	105500	650
23000	105400	700
23000	105300	800
23000	105200	850
23100	107000	1300

(a)	(b)	(c)
23100	106900	1250
23100	106800	1000
23100	106700	1050
23100	106600	900
23100	106500	800
23100	106400	800
23100	106300	800
23100	106200	800
23100	106100	800
23100	106000	800
23100	105900	750
23100	105800	750
23100	105700	750
23100	105600	750
23100	105500	650
23100	105400	700
23100	105300	750
23100	105200	850
23200	107000	1250
23200	106900	1150
23200	106800	1100
23200	106700	1475
23200	106600	850
23200	106500	900
23200	106400	950
23200	106300	950
23200	106200	850
23200	106100	850
23200	106000	800
23200	105900	800
23200	105800	800
23200	105700	700
23200	105600	700
23200	105500	800
23200	105400	750
23200	105300	800
23200	105200	800
23300	107000	1150
23300	106900	1100
23300	106800	1050

(a)	(b)	(c)
23300	106700	1050
23300	106600	1000
23300	106500	950
23300	106400	900
23300	106300	900
23300	106200	850
23300	106100	850
23300	106000	800
23300	105900	800
23300	105800	800
23300	105700	750
23300	105600	700
23300	105500	700
23300	105400	750
23300	105300	800
23300	105200	800
23400	107000	1100
23400	106900	1050
23400	106800	1000
23400	106700	950
23400	106600	900
23400	106500	900
23400	106400	900
23400	106300	850
23400	106200	800
23400	106100	800
23400	106000	850
23400	105900	800
23400	105800	750
23400	105700	750
23400	105600	700
23400	105500	700
23400	105400	750
23400	105300	850
23400	105200	850
23500	107000	1050
23500	106900	1050
23500	106800	1000
23500	106700	950
23500	106600	950

(a)	(b)	(c)
23500	106500	900
23500	106400	900
23500	106300	850
23500	106200	850
23500	106100	800
23500	106000	800
23500	105900	850
23500	105800	750
23500	105700	750
23500	105600	700
23500	105500	800
23500	105400	750
23500	105300	850
23500	105200	850
23600	107000	1100
23600	106900	1200
23600	106800	1150
23600	106700	1050
23600	106600	1050
23600	106500	1000
23600	106400	900
23600	106300	950
23600	106200	1000
23600	106100	900
23600	106000	900
23600	105900	800
23600	105800	800
23600	105700	750
23600	105600	700
23600	105500	800
23600	105400	800
23600	105300	850
23600	105200	850
23700	107000	1250
23700	106900	1150
23700	106800	1100
23700	106700	1050
23700	106600	1000
23700	106500	1000
23700	106400	950

(a)	(b)	(c)
23700	106300	1000
23700	106200	1050
22600	106600	800
22600	106500	800
22600	106400	800
22600	106300	800
22600	106200	800
22600	106100	750
22600	106000	750
22600	105900	700
22600	105800	650
22600	105700	700
22600	105600	650
22600	105500	700
22600	105400	650
22600	105300	700
22600	105200	700
22700	107000	1000
22700	106900	950
22700	106800	900
22700	106700	950
22700	106600	850
22700	106500	850
22700	106400	850
22700	106300	800
22700	106200	750
22700	106100	750
22700	106000	750
22700	105900	750
22700	105800	750
22700	105700	750
22700	105600	750
22700	105500	750
22700	105400	650
22700	105300	700
22700	105200	750
22800	107000	1000
22800	106900	900
22800	106800	900
22800	106700	900

(a)	(b)	(c)
22800	106600	850
22800	106500	800
22800	106400	750
22800	106300	750
22800	106200	750
22800	106100	750
22800	106000	800
22800	105900	750
22800	105800	800
22800	105700	800
22800	105600	750
22800	105500	700
22800	105400	800
22800	105300	750
22800	105200	800
22900	107000	1150
22900	106900	1050
22900	106800	900
22900	106700	950
22900	106600	850
22900	106500	800
22900	106400	800
22900	106300	750
22900	106200	750
22900	106100	750
22900	106000	800
22900	105900	800
22900	105800	750
22900	105700	750
22900	105600	650
22900	105500	650
22900	105400	700
22900	105300	750
22900	105200	850
23000	107000	1250
23000	106900	1200
23000	106800	1000
23000	106700	900
23000	106600	850
23000	106500	800

(a)	(b)	(c)
23000	106400	750
23000	106300	750
23000	106200	800
23000	106100	800
23000	106000	800
23000	105900	800
23000	105800	800
23000	105700	700
23000	105600	700
23000	105500	650
23000	105400	700
23000	105300	800
23000	105200	850
23100	107000	1300
23100	106900	1250
23100	106800	1000
23100	106700	1050
23100	106600	900
23100	106500	800
23100	106400	800
23100	106300	800
23100	106200	800
23100	106100	800
23100	106000	800
23100	105900	750
23100	105800	750
23100	105700	750
23100	105600	750
23100	105500	650
23100	105400	700
23100	105300	750
23100	105200	850
23200	107000	1250
23200	106900	1150
23200	106800	1100
23200	106700	1475
23200	106600	850
23200	106500	900
23200	106400	950
23200	106300	950

(a)	(b)	(c)
23200	106200	850
23200	106100	850
23200	106000	800
23200	105900	800
23200	105800	800
23200	105700	700
23200	105600	700
23200	105500	800
23200	105400	750
23200	105300	800
23200	105200	800
23300	107000	1150
23300	106900	1100
23300	106800	1050
23300	106700	1050
23300	106600	1000
23300	106500	950
23300	106400	900
23300	106300	900
23300	106200	850
23300	106100	850
23300	106000	800
23300	105900	800
23300	105800	800
23300	105700	750
23300	105600	700
23300	105500	700
23300	105400	750
23300	105300	800
23300	105200	800
23400	107000	1100
23400	106900	1050
23400	106800	1000
23400	106700	950
23400	106600	900
23400	106500	900
23400	106400	900
23400	106300	850
23400	106200	800
23400	106100	800

(a)	(b)	(c)
23400	106000	850
23400	105900	800
23400	105800	750
23400	105700	750
23400	105600	700
23400	105500	700
23400	105400	750
23400	105300	850
23400	105200	850
23500	107000	1050
23500	106900	1050
23500	106800	1000
23500	106700	950
23500	106600	950
23500	106500	900
23500	106400	900
23500	106300	850
23500	106200	850
23500	106100	800
23500	106000	800
23500	105900	850
23500	105800	750
23500	105700	750
23500	105600	700
23500	105500	800
23500	105400	750
23500	105300	850
23500	105200	850
23600	107000	1100
23600	106900	1200
23600	106800	1150
23600	106700	1050
23600	106600	1050
23600	106500	1000
23600	106400	900
23600	106300	950
23600	106200	1000
23600	106100	900
23600	106000	900
23600	105900	800

(a)	(b)	(c)
23600	105800	800
23600	105700	750
23600	105600	700
23600	105500	800
23600	105400	800
23600	105300	850
23600	105200	850
23700	107000	1250
23700	106900	1150
23700	106800	1100
23700	106700	1050
23700	106600	1000
23700	106500	1000
23700	106400	950
23700	106300	1000
23700	106200	1050
23700	106100	950
23700	106000	800
23700	105900	800
23700	105800	800
23700	105700	750
23700	105600	650
23700	105500	750
23700	105400	750
23700	105300	850
23700	105200	900
23800	107000	1150
23800	106900	1150
23800	106800	1100
23800	106700	1100
23800	106600	1100
23800	106500	1100
23800	106400	1000
23800	106300	1000
23800	106200	950
23800	106100	950
23800	106000	950
23800	105900	850
23800	105800	800
23800	105700	750

(a)	(b)	(c)
23800	105600	[illegible]50
23800	105500	[illegible]00
23800	105400	750
23800	105300	800
23800	105200	850

Source: Field work.