APPLICATION OF SATELLITE REMOTE SENSING IN TERRAIN ANALYSIS AND FLOODPLAIN DELINEATION: A CASE STUDY OF THE SOKOTO-RIMA RIVER SYSTEM

By

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APPLICATION OF SATELLITE REMOTE SENSING IN TERRAIN ANALYSIS AND FLOODPLAIN DELINEATION: A CASE STUDY OF THE SOKOTO-RIMA RIVER SYSTEM

A Dissertation submitted to the Post-Graduate School, Federal University of Technology, Minna in partial fulfilment of the requirement for the award of the degree of M.Tech. in Remote Sensing Applications.

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DEDICATION

This Dissertation is humbly dedicated to the memory of my Late Aunt - Aishatu Abdulhadi Ladan (Yaya Shatu 'Mai Alale), who passed on, on the 10th January 1998 during the course of writing this thesis.

CERTIFICATION

This is to certify that this Dissertation entitled "Application of Satellite Remote Sensing in Terrain Analysis and Flood plain Delineation: A Case Study of the Sokoto-Rima River System", was undertaken by Ladan Baba (M. Tech/SSSE/085/96), in the Department of Geography of the School of Science and Science Education. Federal University of Technology, Minna and was approved for its contribution to knowledge under the supervision of:

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(Chief Examiner and HOD)

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LADAN, B.

ABSTRACT

Sokoto-Rima River Basin supports a significant number of farmers (cultivators and herders). Reduced rainfall in the area and the increase in population has placed increasing stress on the available land and water resources. Adequate knowledge which is fundamental for development planning is also scanty. furthermore, agriculture which is a vital component of the resource domain has received various innovations which have largely failed because various important physical and economic variables are less understood and are exacerbated by lack of relevant data. Consequently, agricultural agencies do not know the extent of land under cultivation in any season/year and size of holding/quantity and the crops grown.

The main aim of this project is to highlight the value of satellite remote sensing in mapping land systems and floodplain particularly important for dry season agriculture in the semi-arid area. A major data source for the study is LANDSAT multispectral data for both dry and wet seasons. The maps produced both visually and digitally (Computer assisted) are expected have immediate value for the Sokoto-Rima River Basin Development Authority and other relevant agencies.

The methodology, used and results will increase awareness of the vital roles that remote sensing can play in the study of environmental and resource problems, and also demonstrates its importance in areas where maps are either unobtainable or out-of-

date. At this level, satellite remote sensing has been proved to be the most cost effective tool for mapping terrain and floodplain areas. It has been seen that the system has self repetitive and synoptic coverage and has come between the laborious and time wasting land method and the highly costly air photographic systems. The results of the job done here could extend to other areas of the country.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

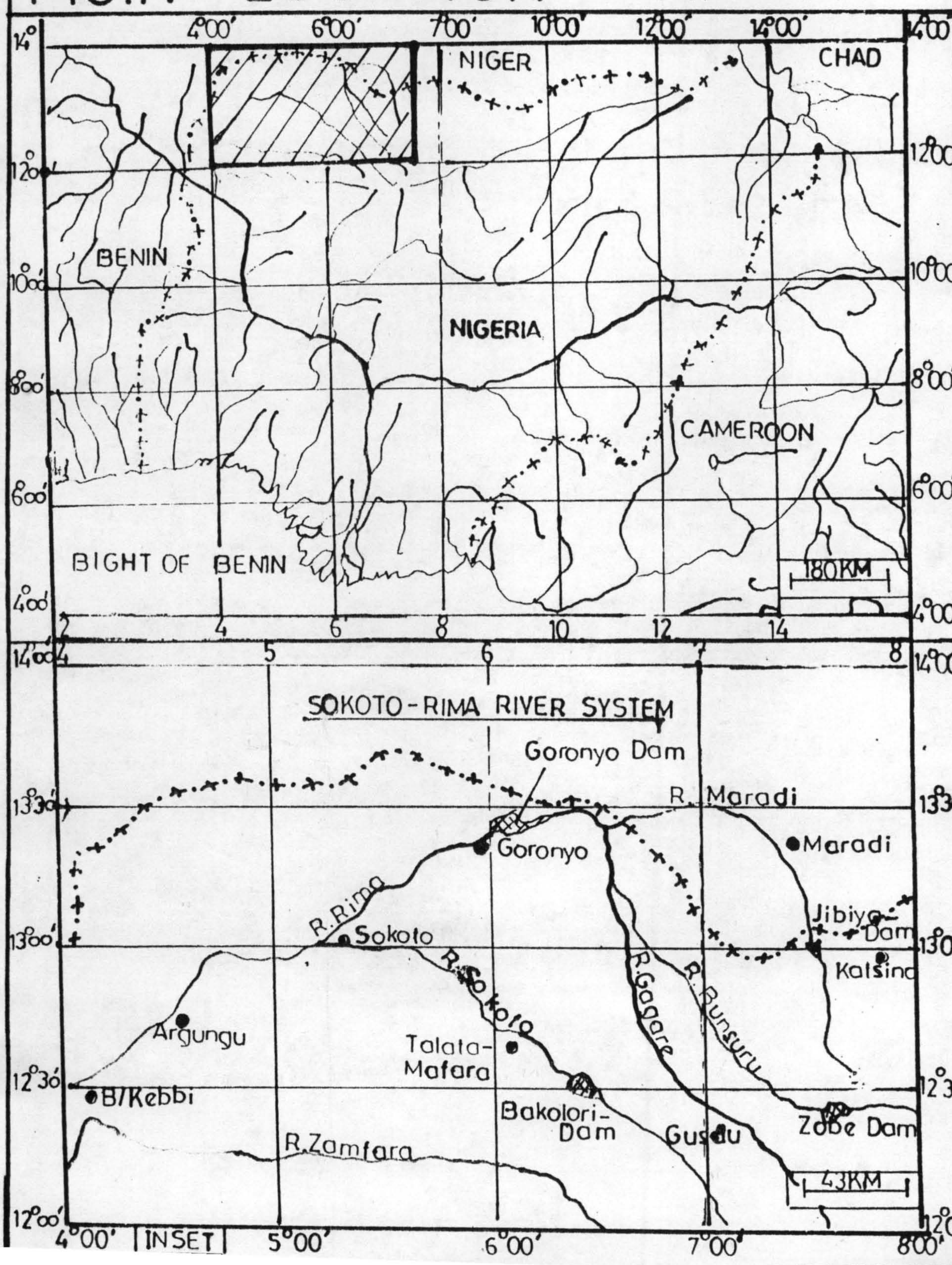
Land and water are ultimate sources of food and vital substance for human existence and indeed the major factors in commanding the progress of civilisations. Nigeria is experiencing a 'dramatic increase in population, rapid changes in social standards, in Agriculture, Urban, Industrial and other needs that make increasing demands on our land and water resources. The organisations concerned with defining developmental strategies and management of these resources must have access to a precise update inventory. At present, the basic source documents are topographic maps. Unfortunately, their accuracy depends on not only their scales but also dates of publication and constant review. Up-to date inventories and maps of rivers using satellite imageries will provide decision-makers with an effective and efficient means of management. Furthermore, information retrieval through computerised management techniques is possible since Earth Observation Satellite data enable fast inventories of the topography.

The use of satellite data involves image acquisition, image processing and image interpretation. Image start life as coded data and it is stored in digital form. A remote sensing image appears under the form of a radiometric sample of the observed scene, which is as a large number of digital informations are presented in line and columns. The digital information is usually given under the form of integer numbers (binary code), the data of which only computer compatible tapes (CCT) should be used, can be acquired from the archives or through special acquisition order placed with the operators of the satellite. This is what was used for landsystems mapping and floodplain delineation of the Sokoto-Rima River system. These Rivers are the main streams of agricultural production in Sokoto, Zamfara and Katsina States and of course the key source of economic growth of the semi-arid northern part of Nigeria.

1.2 The Study Area

The study area falls roughly between latitude 12^0 and 14° north and between longitude 5° 30 minutes and 7° 15 minutes East, in the extreme Northwest corner of the country (See figure 1: showing the location map). Sokoto basin according to Udo, R.K. (1970) has an area of about 36,000 square miles while that of Rima drainage basin is approximately 35,000 square miles. 65% of the entire area lies on the fringes of the desert. The Sokoto-Rima basin and its major tributaries (that is, river Ka, Zamfara, Bunsuru, Gagare, etc) constitute the major physical feature of the region. It is the main source of water for man, plants and animals. The Rima and its affluent are important factors in the location of economic activities as well as in the distribution of

FIG.1: LOCATION MAP



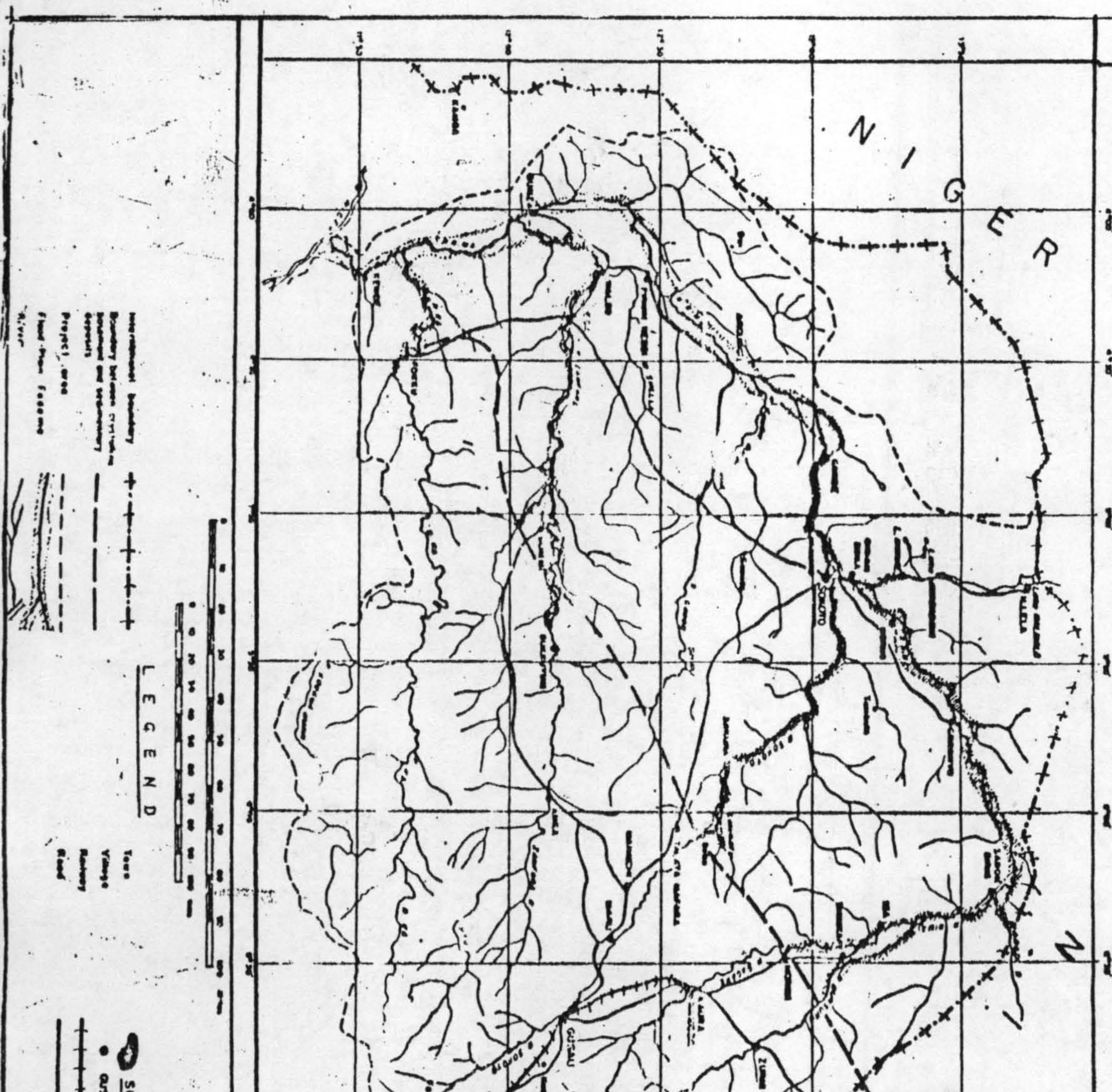


FIGURE 2: MAP OF THE STUDY AREA

population and settlements (see figure 2): Map of the Study Area, showing the Sokoto Rima River system. The exact area as imaged by the American Land Resources Satellite (LANDSAT) for this study coincide with the inset on the SPOT satellite Grid Reference System of Nigeria as contained in GRS sheet 2 for NW Africa on figure 3.

1.3 Geology and Physical Landscape

Two major geological regions may be recognised; that is, a region of pre-Cambrian rock in the Southeast and a region of young sedimentary rocks in the north and west (Udo,R.k. (1970), and See figure 4. All the main tributaries of the Rima rise from the region of the pre-Cambrian rocks which is characterised by broken plains from which rise steep sided granite, gneiss and quartzite inselbergs. The region of pre-Cambrian rocks is dissected by numerous shallow valleys, which form the drainage channels of streams flowing into the upper reaches of the Rima tributaries.

All the tributaries of the Rima flow in rather restricted and narrow valleys until they pass into the area of the younger sedimentary groups where they have developed broad valleys with extensive floodplain.

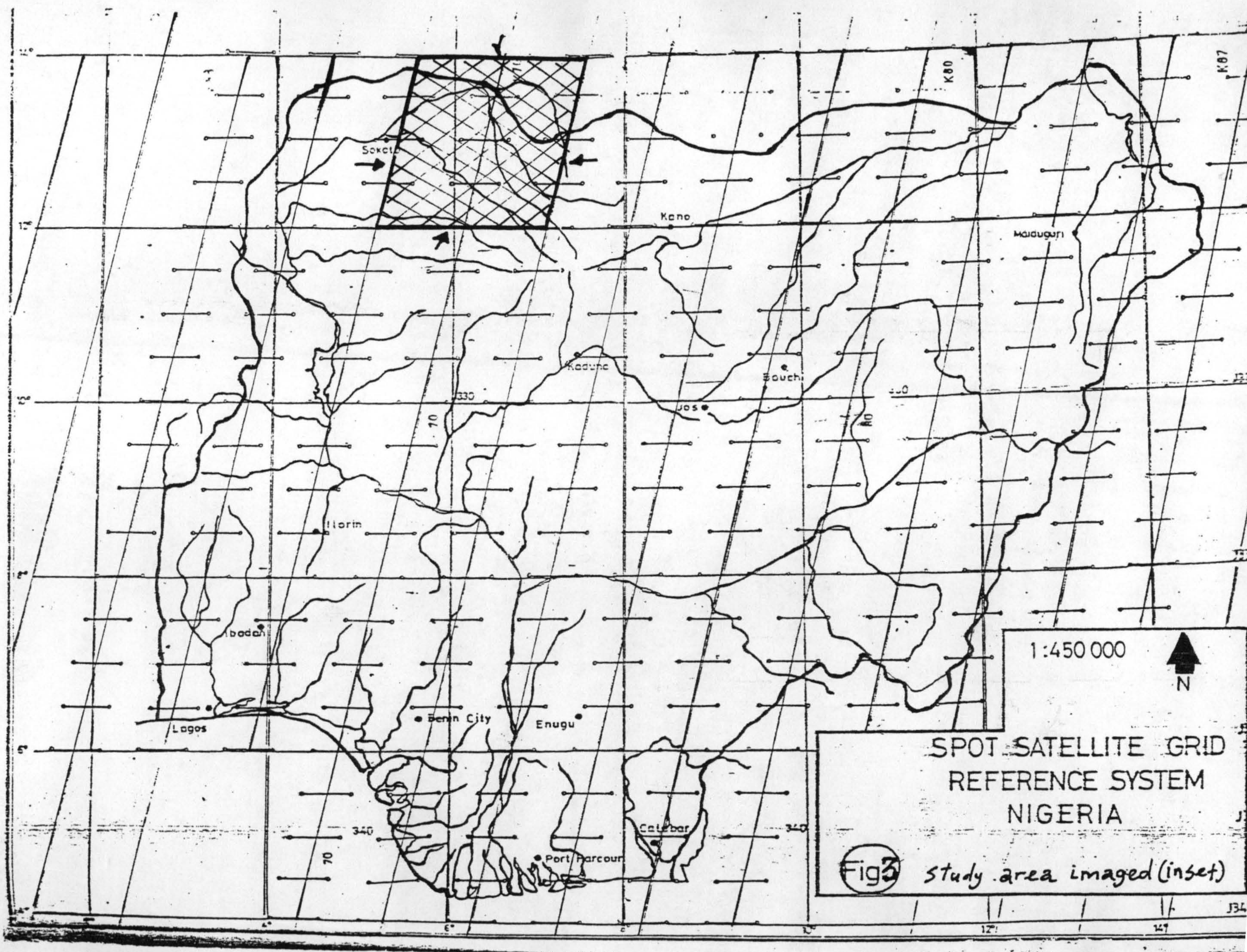
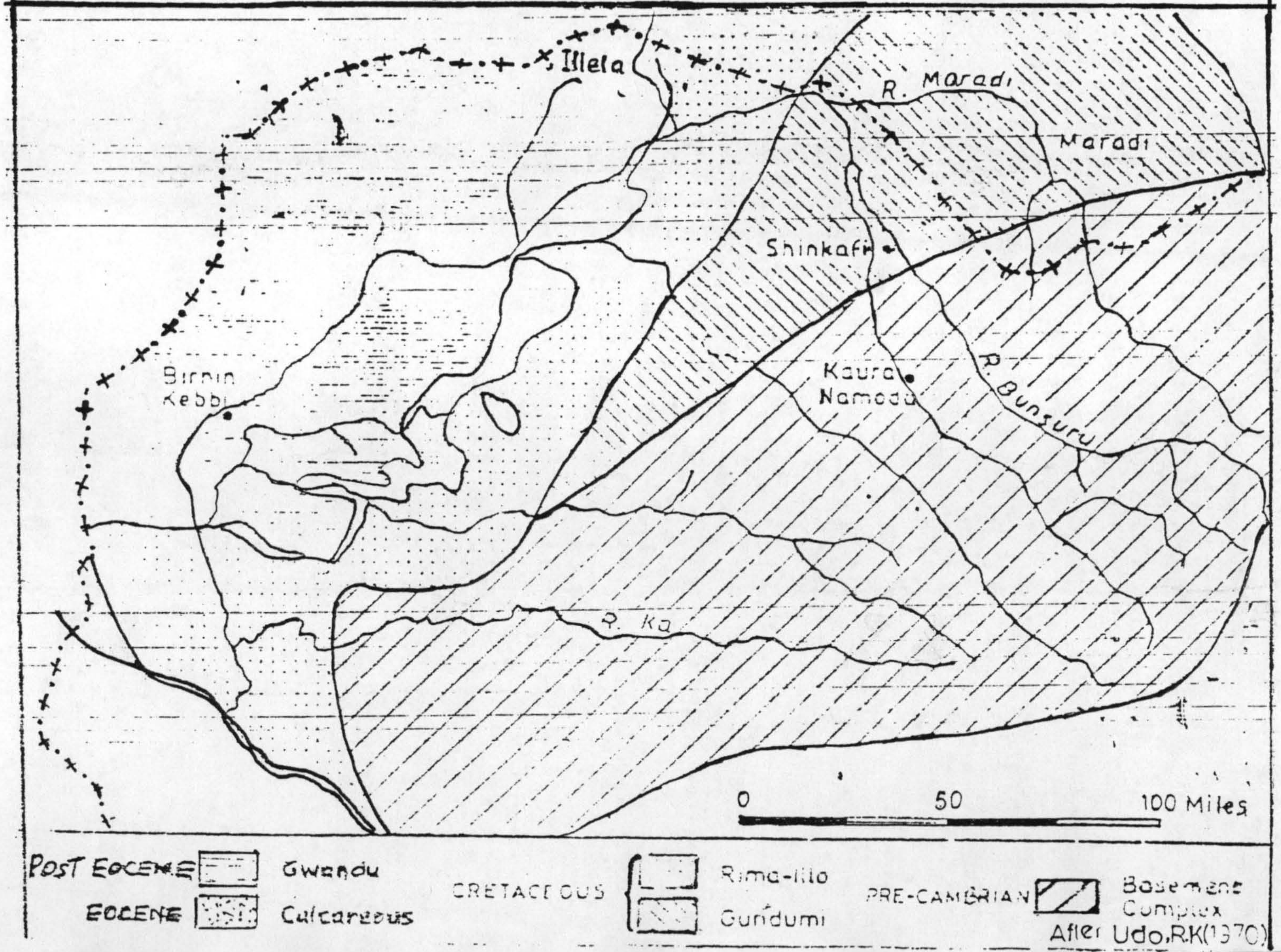


Fig3 Study area imaged (inset)

FIG.4 : THE GEOLOGY OF SOKOTO - RIMA BASIN

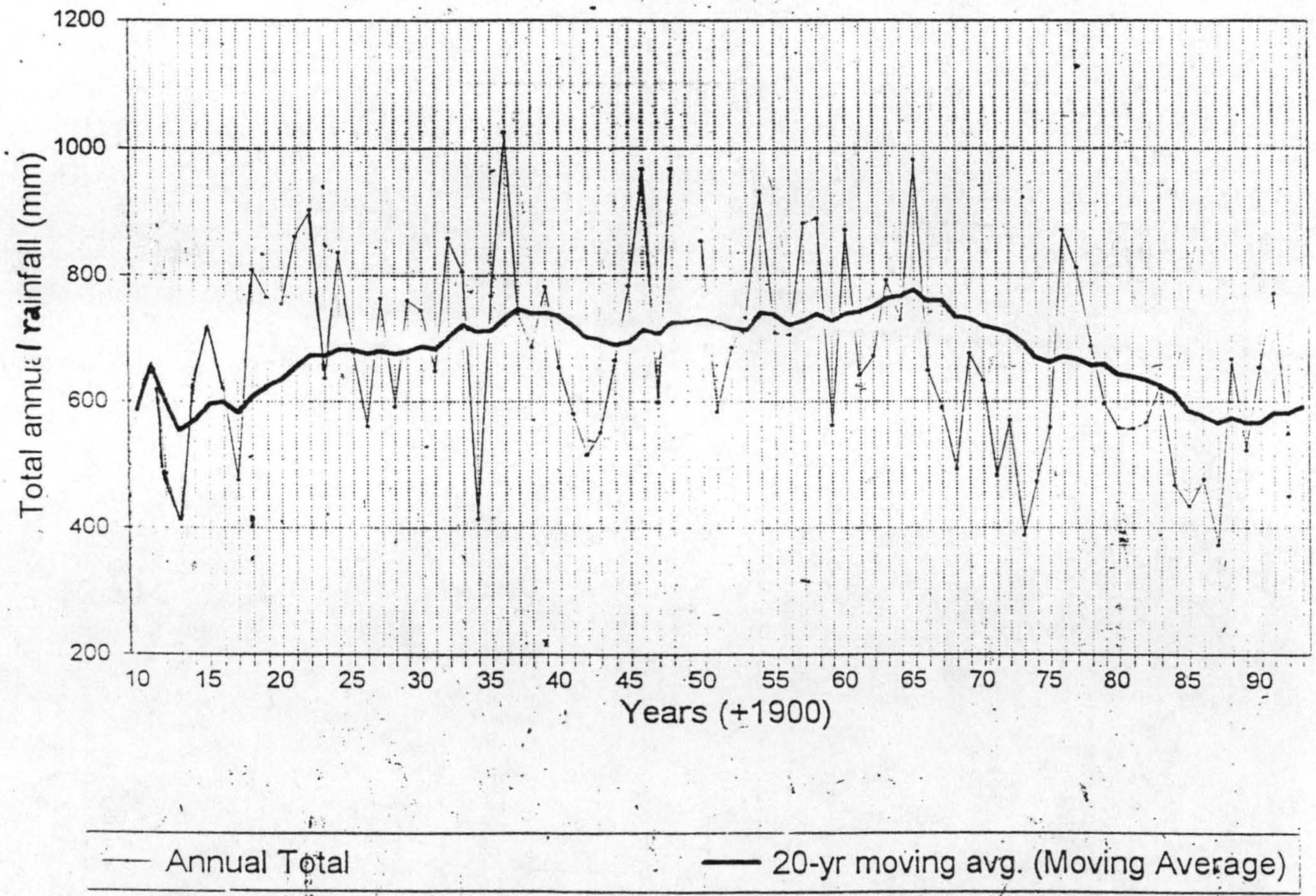


1.4 Climate, Vegetation and Soils

The climate of the area is typically that of the continental tropics with marked rainy and dry seasons. The climate is semi-arid with a prolonged and almost rainless dry season (Late October to early May) and a short wet season (Late May to early October). Over 75% of the total annual rainfall occur between July and September with maximum rainfall in August. Rainfall, which is usually stormy and of short spells ranges between 750mm-1000mm in the extreme west to between 250-750mm in the Northern parts. The monthly rainfall distribution and the total rainfall during wet season vary widely from year to year (Figure 5, shows the annual rainfall for Sokoto-Airport for 1910-1992). The variability of the rainfall regime imposes severe limitations on rainfed agriculture except in seasonally flooded Fadama areas downstream as highlighted by Adeniyi, F.A. (1985).

The geographical location of the area, that is, close to Saharan desert makes Sokoto generally very hot. However, the temperatures vary with season. The harmattan wind which is cold, dry and dusty lasts from November to February .In March, April and May, the weather is usually very hot (see figure 6 for Sokoto Meteorological data showing monthly rainfall totals, monthly average temperature, monthly average relative humidity and monthly average sunshine from January to December.

FIGURE 5: Sokoto airport
Annual rainfall 1910-1992



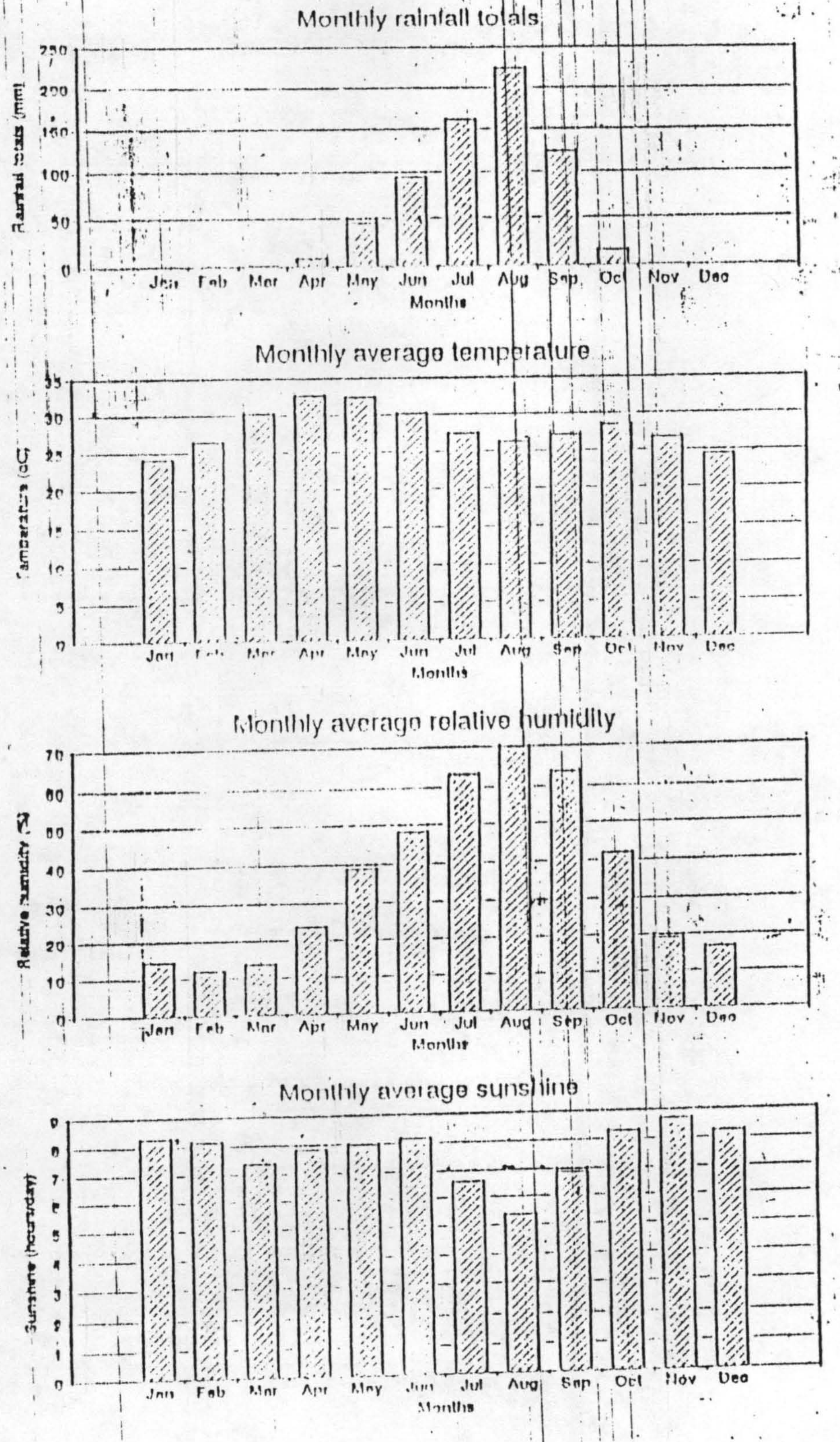


FIGURE 6 : SOKOTO AIRPORT METEOROLOGICAL DATA

Under natural condition as in the forest reserves, the forest is of a typical Sudan savannah biome, which consists of an almost continuous grass cover with scattered trees and shrubs. Vegetation has been greatly affected by various edaphic, climatic and biotic factors. The area has undergone drastic change following frequent bush burning, uncontrolled grassing, farming and overcutting of trees for fuel.

Soil types vary throughout the area but the soil profile is rather sandy topsoil and clayey subsoil. They are said to be low in organic matter content due to scanty vegetation cover, therefore, low infertility. Once the vegetative cover is removed through over cultivation, overgrazing and periodic burning, the topsoil are readily washed off by rainwater. The areas bordering the rivers are the most densely populated due to the need to establish settlements near water sources, although increasing height of flood waters in the basin has resulted in a retreat of settlements from the floodplain to the edges of the plateau surfaces.

1.4.1 Fadama

Fadama is a Hausa word for floodplain in a wide fairly flat river valley common in the savannah zones of Sudan and Guinea. It is the strip of land along rivers, which are subject to seasonal flooding, very fertile, and the focus of this study. The extensive floodplain differs from the general description of soil explain above. The fadamalands provide more fertile farmlands except where the drainage is very poor. The fadama are also very close to the sources of water for dry season irrigation. It should be noted also that these fadamalands account for less than 10% of the total land area in the Sudan savannah region but are considered very important dry season agricultural resources (Adams, W 1986). Consequently, the continued productivity of these floodplain areas is of vital importance in ensuring the agricultural viability of the region. The establishment of Sokoto-Rima River Basin Development Authority (SRRBDA) during the 1975-80 plan period was aimed at the accelerated resource development of the area.

1.5 The Sokoto-Rima River Basin Development Authority

The main functions of the authority include the following:

a. Water resource development

b. Construction and maintenance of dams.

C Irrigation/drainage works

d. Supply of irrigation water and land development for plantation, cattle ranches and livestock farms.

e. Land and water conservation including afforestation

f. Development of groundwater for human and livestock conservation

h. Settlement/resettlement of persons affected by construction, (SRRBDA, 1991).

As a first step towards implementing these programmes, the authority embarked on river basin planning with the following objectives among others: Optimum development of land and water potentials, maximising agriculture, livestock and fish production, developing small schemes such as small dams, boreholes for isolated areas, etc. And to achieve some of these objectives, the authority identified the following projects among others: Bakolori irrigation project (23,000 hectares net), Goronyo dam project area (40,000 ha.), Gagare-Bunsuru river project (to cover 15,450 ha.), Niger valley at Sokoto state (to cover 4,283 ha). The authority has not carried out any resource surveys of the basin. The authority lacked adequate information on the floodplain and agricultural activities downstream, and the success of the authority would have to depend on how well various development factors have been studied and integrated into their programmes.

1.6 Problem Statement

Besides its potentials for supplementing urban water supply, floodplain is also an important source of groundwater, which is extracted to reduce over dependence on rainfed agriculture and enhance cropping intensities during dry season, especially in drought prone areas like Sokoto, Zamfara, and Katsina States. Although, attempts have been made to improve on various irrigation techniques, less attention is given to the terrain characteristics and delineation of the potential agricultural land of the basin.

This research is an attempt to use Remote Sensing Techniques to map drainage patterns and delineate the floodplain areas of the Sokoto-Rima River System using terrain analysis.

Serious measures need to be taken in form of sound database in order to succeed in managing our water, agricultural and other earth resources, and to ensure adequate protection of our environment. It is believed that these tasks can be accomplished with the aid of data that can be obtained using existing generation satellite and airborne sensors supplemented with adequate ground truth data.

Satellite Remote Sensing has a unique characteristic whose benefits are not fully perceived. A large-scale uniformity of perspectives, a regularity of repetitive coverage, an extra ordinary facility, for visual presentation and communication. A capability to improve a comprehensive pattern on discrete elements of information and a potential catalytic impact on specialists, planners and decision-makers, impelling them to organise the gathering and application of resource information in a rational way. Moreover, the ability of Satellites to monitor and deliver resource data with uniform characteristics on a global basis may strengthen opportunities for international communication among resource scientists within and across disciplinary lines.

Efforts were made to assess whether Satellite Remote Sensing (using LANDSAT MSS data) is a reliable method of inventorying large scale terrain with emphasis on drainage mapping and floodplain delineation. Comparison was made between the use of satellite Remote Sensing and other methods of inventorying on one hand and visual interpretation with digital (computer-assisted) image processing on the other. Their relative importance and advantages were also assessed. It is expected that similar investigations could be used elsewhere both nationally and at international spheres using satellite imageries. This work will therefore provide a tool for evaluating cultivable land acreage in the Sokoto-Rima valley. Further research on suitability analysis for various agricultural crops will also enable the SRRBDA, ministries of agriculture, and other land developers to improve on their extension services and better the lots of the entire community in the region.

1.7 Aims and Objectives

The main aim of this research is to evaluate the potentialities of satellite Remote Sensing in Terrain analysis and mapping of drainage patterns and floodplain areas within the Sokoto-Rima Basin. Therefore, the specific objectives of the Dissertation are:

a. To identify terrain elements and drainage patterns necessary for determining the area that constitutes floodplain within the basin,

b. To evaluate the potentials of LANDSAT MSS data in terrain analysis and floodplain delineation,

c. To apply and compare visual interpretation with digital (Computer assisted) image analysis in mapping Land systems and floodplain areas.

d. To assess if remote sensing possesses advantages over conventional and contemporary visual (manual) methods.

1.8 Justification

The existing maps used for planning are often out of date. There is also generalisation of all features, lack of correct drainage information and lack of detailed information on the terrain and floodplain. Frequently, decisions on water resources planning and agricultural development are based on analysis of various sets of referenced data when earth resources surveys by remote sensing is more efficient and reliable. This research demonstrates the value of LANDSAT MSS data in terrain analysis and mapping of drainage patterns and floodplain. It will be beneficial for agricultural planning purposes, reduction of flood losses and possibility of flood insurance scheme.

Satellite Remote Sensing has been proposed for this study because it can offer a unique vantage point from which the entire environment can be observed so that prolonged, and rapid changes can be assessed with ease and with accuracy. Furthermore, the choice of the River basin in the savannah zone was based on the magnitude of environmental and resource problems in the area, and the need for greater resource information to serve as inputs into several land and water development projects being planned for the Sokoto-Rima River Basin.

1.9 Scope and Limitations

> "It has been very difficult to have reliable information on water resources potentials of rivers in Nigeria, despite the fact that Nigeria has a potential of irrigating a total of 972,867 hectares as agricultural land".
>
> Adeniyi, F. A. (1985)

Osot Associates (1984) in their report on River Rima Training, reported that:

> "As large as the Birnin-Kebbi catchment is, with an area of 58,150km square it has only Sokoto as the autograph rainfall recording station".

These indicate the inadequacy of data and of course there are still limited resources especially with respect to digital (Computer assisted) image processing and other facilities. Similarly, this research found it extremely difficult to obtain recent imageries and other remote sensing tools for the work. Hence, a relatively small area or catchment of the basin between Lugu dam at Wurno and Goronyo dam (Rima floodplain) was selected for digital image processing to serve as a demonstration in computer assisted analysis in floodplain delineation.

Another constraint in the research had to do with inadequate published literature especially using satellite Remote Sensing in both the field and the area of study. However, the LANDSAT MSS data for 1987 and 1989 on both CCT and Standard photographic prints; topographic sheets, aerial photographs and the computer facilities with IDRISI (for window) software package of Clark laboratory at the Federal University of Technology, Minna is adequate enough to accomplish the tasks of the study.

1.10 Assumptions

This study was based on the following assumptions:

a. LANDSAT MSS data has capabilities, and at the very least will provide a visual clue for identification of Landsystems for defining floodplain areas in the basin,

b. Satellite Remote Sensing provides the fastest and more accurate means for terrain analysis and floodplain delineation.

Despite the limited literature in the area of study and in the application of satellite remote sensing, attempts were made to review several work on drainage/floodplain and the use of remote sensing techniques in terrain evaluation, and floodplain delineation as reviewed in the following chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Terrain

Terrain is synonymous with land (Christian and Steward, 1968). The terrain which includes land surface, superficial geology, hydrology, vegetation, soil, etc was defined by FAO (1976) as:

> "An area of the earth's surface the characteristics of which embrace all reasonable cyclic attributes of the biosphere, the soil and underlying ecology, hydrology, the plant, and animal population, and extent that these attributes exert a significant influence on present and future uses of the land by man".

Essentially, terrain characteristics refer to directly observable properties of terrain, its productivity, ruggedness, erodibility, extent, etc. Terrain quality determines the degree to which the tract of land can be put to a certain use while land capability refers to the fitness of the terrain to perform a defined use (Townshend, 1981). Terrain evaluation is therefore required for various purposes among which are water supply, agriculture, mining, recreation, military activities, urban development, etc.

Rather than investigating its component parts, the terrain is often studied as an entity. And this holistic view of the terrain forms the basis for regionalization (physiographic or landscape approach) as was the case for the topographic subdivision of the United States of America by Bouman (1914) and Fenneman (1916). During the course of study, the varieties of classifications all based on the physiographic approach have led to the delineation of various sizes of regions among which are Bourne's (1931) site, Wooldridge's (1932) Facet, Veatch's (1933) natural land types and Milne's (1935) Catena.

2.2 Floodplain

Along side the channels of most rivers are a relatively flat surface extending to the base of the valley walls, it is periodically inundated (Selby, M. J. 1985). Floodplain of a river is therefore a valley floor adjacent to the incised channel which may be inundated during high water, they are essentially created by the processes of river meandering which is the result of a stream adjustments to its environment in order to carry its load most efficiently. According to Lillesand, et al (1987),

> "Meandering streams tends to follow certain Mathematical rules with regard to meander wavelength, amplitude, stream flow, volume, velocity, channel width, depth, floodplain

slope and river gradient".

Rivers tends to swing back and forth across the valley bottom reworking that floodplain deposits and eroding first one valley side and then the other. Floodplains are built primarily from deposition of sediments in the river channel and deposition of fine sediments on the floodplain when flooded. Sediment deposition in the channel plus natural levees on the bank can lead to a situation in which the stream floors at a higher elevation than in its floodplain. Floodplain tends to be flooded at fairly low recurrence intervals. Leopold et al (1964) reports numerous evaluations of flow magnitude required to over -flow the floodplain. Return periods generally range between 1-2 years and a general statement that floodplain of the Eastern and Central United States are inundated by flood waters in 2 out of 3 years is quite reasonable. Nixon (1959) made a similar analysis of British streams and found that flooding occurred on the average about twice each year. There is some difficulty in defining precisely what the floodplain is and a problem in defining precisely the bankfull stage. It is however clear that the floodplain is subject to frequent flooding and hence its use for building, agriculture and other purposes should be carefully regulated.

Floodplain terrain has an overall level relief with minor irregularities and a gentle downstream gradient. The texture of floodplain materials varies gently because they have slowly accumulated over years of shifting stream courses and overbank flooding. Therefore, the most important depositional feature is floodplain formed from a combination of within channel and overbank deposition, although many sedimentary forms are involved (Lewin, 1978). Over a long period of lateral and valley shifting, the channel may occupy all positions on the valley floor continually building the floodplain from within channel deposits. From measured rates of bank erosion and historical map information. Hooke (1980) estimated the time period required for a complete traverse of the 1.2km wide floodplain of the river in Devon to be about 1,300 years. Schumm and Lichty (1963) and Burkham (1972) described how new floodplains were built after destruction by major floods in as little as 20 and 50 years respectively.

Vertical accretion takes several forms:

(i) formation of natural levees

(ii) direct deposition in extra channel areas, and

(iii) development of Channel Islands which subsequently became attached to one bank - a process which has been observed elsewhere (Knighton, 1972). In a similar study, Wolman and Leopold (1957) concluded that lateral accretions within channel depositions are the dominant processes in floodplain formation accounting for up to 90% of the deposition.

Floodplain is important to environmental planners concerned with reducing risk due to floods for many densely populated areas are concentrated on floodplain. Mapping of floodplain for development planning especially agricultural production, flood insurance purposes has received major emphasis in United States and other developed countries. In this process, the floodwall (area covered by a flood) is delineated for floods occurring with a given probability.

> "The determination of the limits of a given flood often incorporates floodplain terrain evaluation, topographic mapping through photographic techniques and hydrologic modelling".
>
> (Lillesand, et al, 1987).

In studies for which the floodplain are important, such as this, one must have adequately detailed maps or special field surveys and now better with satellite imageries which will satisfactorily define the information needed for drainage mapping over extensive areas and delineation of floodplain.

2.3 <u>Floodplain Mapping</u>

Floodplain management is becoming an acceptable part of flood damage mitigation. The hydrologic problems are to define the area, which will be flooded during the occurrence of a flood of specified period. The standard procedure for this in the United States is to find the 100 years flood at a key point and use a back water computation to determine the stages up-stream. The 100 years flood is usually estimated from a stream gage record, if available or by regional frequency methods or by loss rate and unit hydrograph applied to the 100 years rainfall, (Linsley, R. K. 1988). If no record exists, it is probably better to develop a synthetic record by simulation with a deterministic model. The model should employ a routing technique to construct hydrography. This permits the calculation of peak floors at the end of each reach. Thus, a frequency curve can be constructed for each point and the 100 years flood peak determined at that point. However, floodplain have been delineated using remotely sensed data to infer the extent of the floodplain from vegetation changes, soils or some other cultural features commonly associated with floodplain, (Rango et al, 1974). Sollers et al (1978) produced flood and flood prone maps at 1:24,000 and 1:62,500 scales using digital LANDSAT data. "One can reasonably expect better results and more accurate delineation of flood prone areas with Landsat Thematic Mapper (TM) and SPOT data, although for many legal requirement, it is necessary to map flood prone areas from high-resolution aerial photography" (Maidment, 1993).

2.4 Remote sensing as a Tool

In 1960 when the term remote sensing was first coined (Fischer, 1975), it simply referred to the observation and measurement of an object without touching it. Since that date, remote sensing has taken discipline dependent meanings in the environmental sciences of geography, geology, engineering, forestry, agriculture, etc. It is usually referred to as:

> "the use of electromagnetic radiation sensors to record images of the environment which can be interpreted to yield useful information". (Curran, 1985).

Short (1982) also defines it as:

> "the acquisition of data and derivative information about objects or materials located at the earths surface or its atmosphere by a device separated from it".

Information about the earth's surface is obtained from satellite orbiting the earth at an altitude 917.8km, later lowered to about 705km. These satellites carry sensors, which scan or image the object (target) through electromagnetic waves and they eventually convey information in form of photographic imageries. Interest in remote sensing from space has been greatly heightened by the launching in July, 1972 of the first Earth Resources Technology Satellite (ERTS-1) renamed LANDSAT-1 and the ensuring diversity of assessment about the utility of LANDSAT data for various earth applications. The availability of LANDSAT-1 through 5 which has two different sensors on board (see figure 7: showing observation configuration of Landsat 4 and 5) with the multispectral scanner (MSS) Sensor, a resolution of 56x79 meters in four spectral bands modified to yield 82 x 82 Instantaneous Field of View (IFOV). And thematic mapper (TM) sensors with a resolution of 30m and seven spectral bands (one is in the thermal band with a resolution of 120m acquired areas covering 185x185km) It provides prospects of better imagery with fine resolution, more frequent coverage, faster processing, etc. It has also presented developing nations like Nigeria with an opportunity that was not there before. Estes, et al (1980) states that:

> ".... remote sensing is a reality ... whose time has come. It is too powerful a tool to be ignored in terms of both its information potential and the logic implicit in the reasoning processes employed to analyse the data. We predict it could change our perception, our methods of data analysis, our models and our paradigms".

Sensing from space platforms has three unique characteristics, viz.:

1. Synoptic View: - LANDSAT scenes cover 185x185km in size at a resolution of 82 meters. A simple view of such a large area under fixed solar illumination and from near vertical (orthography) perspectum (see figure 8, showing the spacing between adjacent Landsat orbit tracks at the equator). It makes the

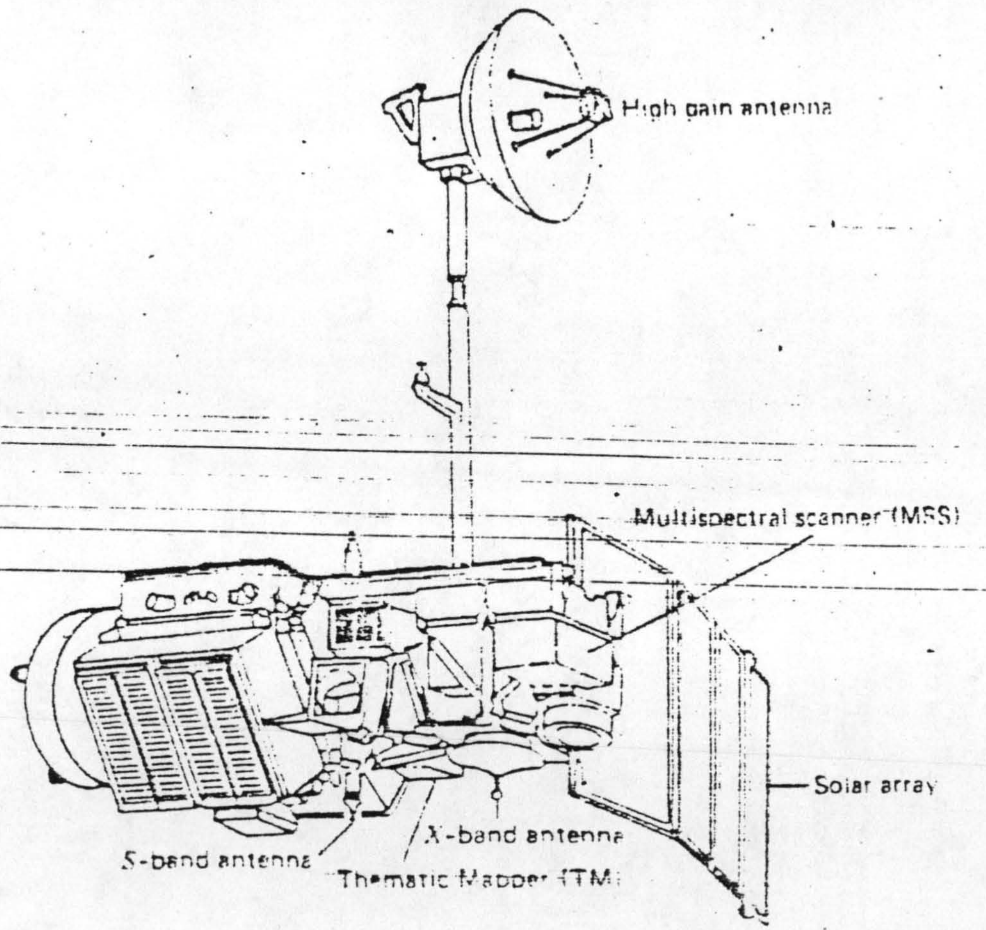


FIGURE 7: Landsat-4 and -5 observatory configuration. (Adapted from NASA diagram.)

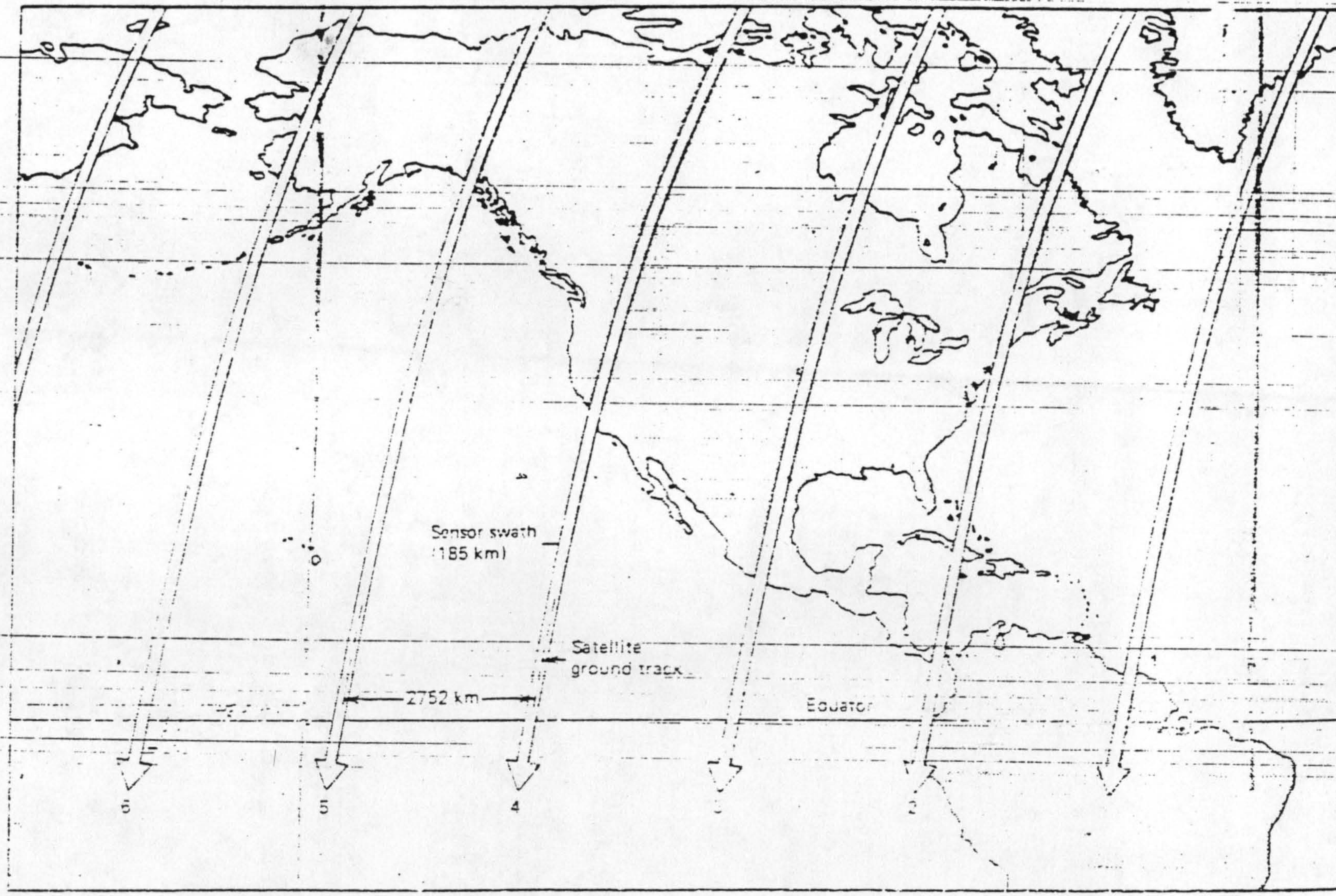


FIGURE 8: Spacing between adjacent Landsat-4 or -5 orbit tracks at the equator. The earth revolves 2752 km to the east at the equator between passes. (Adapted from NASA diagram.)

Landsat particularly valuable for cartographic purposes and for recognising indicators of large-scale geologic features and vegetation patterns difficult to detect by other means.

2. Repetitive Coverage: - The repeated coverage every seven (7) or nine (9) days at worst of each same part of the earth's surface (see figure 9: Timing of adjacent Landsat-4 or -5 coverage tracks). It therefore provides an unequalled opportunity to monitor dynamic phenomena such as changes in vegetation cover and hydrology.

3. Uniformity: - LANDSAT orbits are synchronous with the sun, each scene is scanned at approximately 9:45AM local sun time throughout the world. As shown in figure 10. Landsat-4 and -5 have an inclination angle of 98.2° (8.2° from normal) with respect to the equator and uniform by vertical perspectives make possible image mosaic on a continental scale and the overlay of scenes taken on different dates to permit precise comparison.

The choice of LANDSAT MSS data as a proper tool for the preliminary assessment of the terrain, drainage mapping and floodplain delineation stemmed from the above characteristics, its relatively easy accessibility and generalisation to other parts of the world.

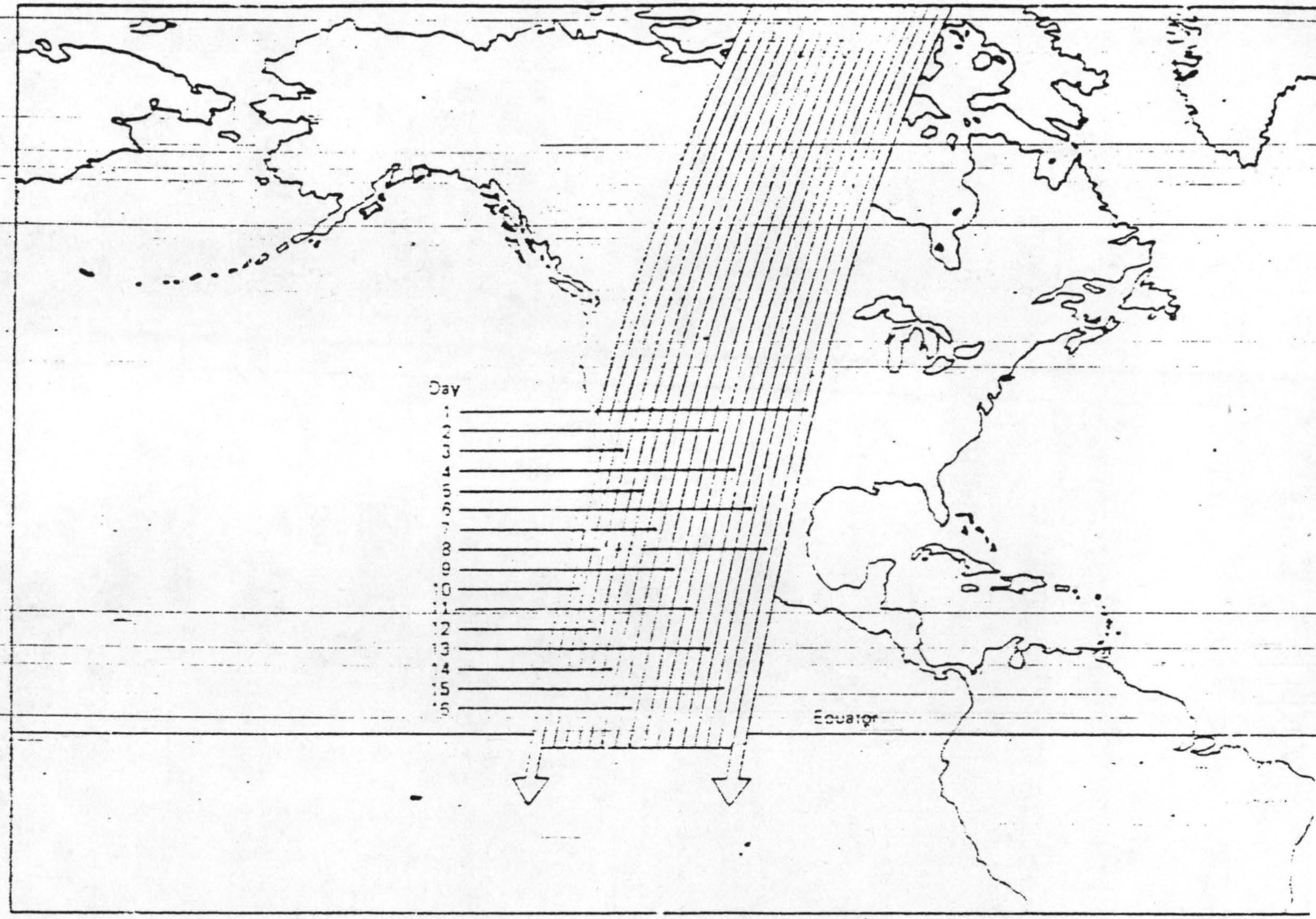


FIGURE 9 : Timing of adjacent Landsat-4 or -5 coverage tracks. Adjacent swaths are imaged 7 days apart. (Adapted from N
diagram.)

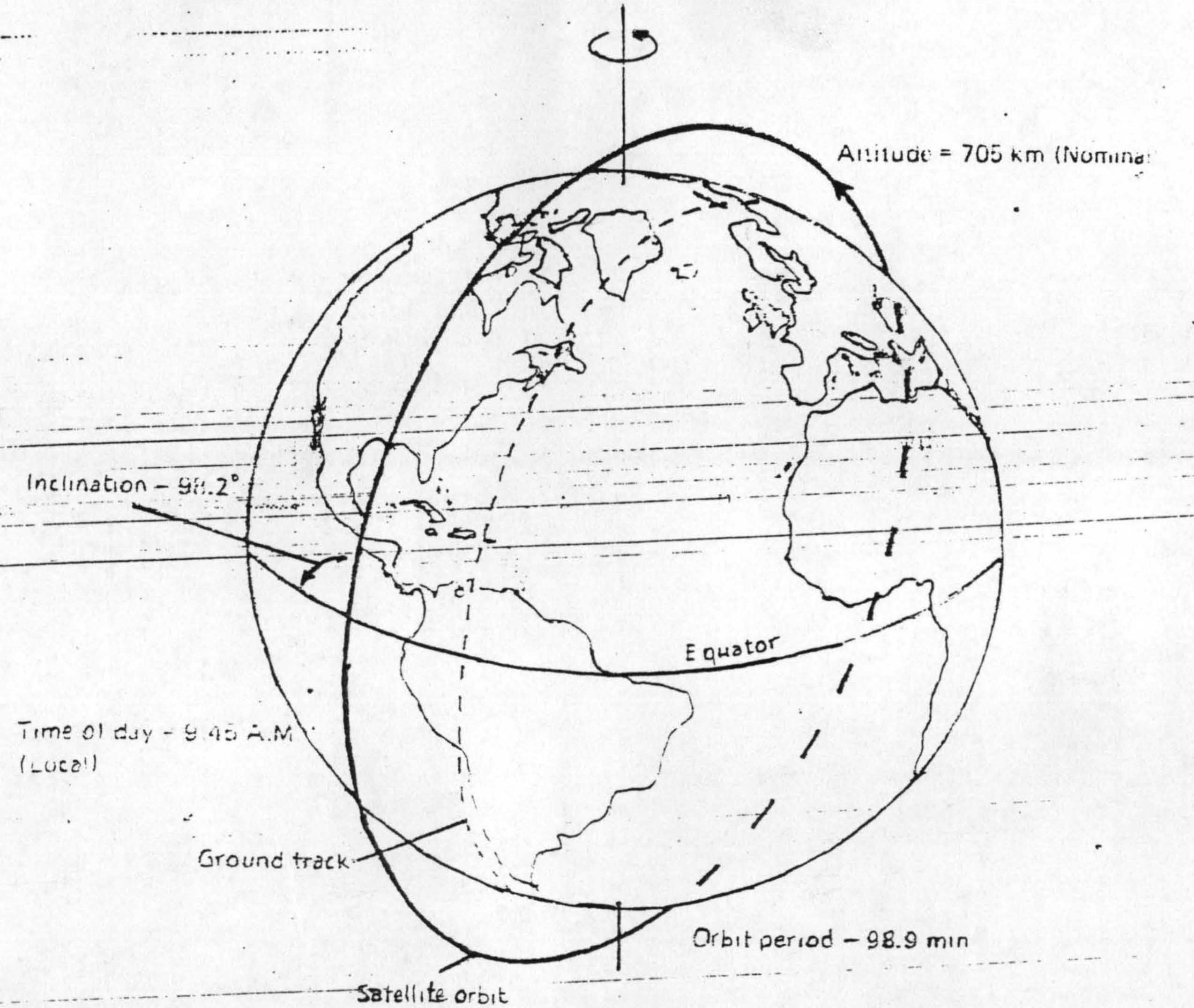


FIGURE 10 : Sun-synchronous orbit of Landsat-4 and -5. (Adapted from NASA diagram)

2.5 Floodplain Mapping Using Remote Sensing Techniques

As noted by Howard (1992), floodplain topography is poorly analysed and could be investigated profitably by using remote sensing techniques. The power of remote sensing for detailed analysis of low relief floodplain topography is enormous, but little studied, allowing classification of lake form, district topographic features and possibly mapping of spatial concentration of suspended solids and flow lines over inundated areas. Hamilton et al (1992) demonstrates this potential using Radar Imagery on the Amazon and Orinoco floodplain. Their measurements indicate that flooded topographic cons have statistical self-similarity with respect to area, implying that relief on the floodplain displays fractal characteristics. Such a result if of general application would have implications for modelling spatial variation in floodplain deposition.

Studies have also been conducted to determine the possible value of LANDSAT data for environmental monitoring. The LANDSAT capabilities to recognise discontinuities of coloration in water and to distinguish differences in Landcover over large areas have proved of value in identifying land systems. LANDSAT imagery is increasingly being employed in assessing major watershed characteristics that affect runoff and erosion, assessment of grazing and farming conditions of land, monitoring and mapping. Remote Sensing Imagery makes possible the delineation of floodplain and in combination with landuse maps, permits the

Identification of flood prone lands and the estimating of economic consequences of flooding, particularly with respect to agricultural experimental results evacuated in United States, by Geological Survey.

Robinove in 1975, indicated that LANDSAT images have value for mapping and or warming and assessing certain types of disasters throughout the world.

Comparative analysis of two sets of LANDSAT scenes convering the state of Orissa in India (dry season, 1973 and monsoon, 1973) has yielded a substantial volume of Land information of direct value to the resource managers and agricultural planners. The two scenes highlighted the difference between dry season and wet season agricultural patterns and identified promising areas for conventional irrigated crop production. The data also indicated areas suitable for dams, it showed extent of forest cutting in the high lands and coastal regions. It also provided a new base for checking the accuracy of crop acreage and estimates done by conventional means showed the changing of the Mahadi river and its tributaries as well as changes in sandbars, spite and Islands along the coast, (Weismulter, 1976).

Flood mapping with LANDSAT imagery was demonstrated with conspicuous success in the case of Mississippi River and Indus River (Pakistan) flood both in 1973 (IBRD, 1973) coastal flooding caused by hurricanes and typhoons, as well as erosion and deposition along the affected coasts were mapped and monitored after the storms.

As noted above, several studies have been conducted on floodplain not only using conventional techniques but also through the use of remotely sensed data on the international scene, and studies have attained high level of sophistication which is yet to be matched by local studies. Nigeria has a complete national coverage of aerial photography obtained in the past 50 years. Having different acquisition dates and scales but nowadays space sensing permit an adequate triplet data using satellite images, air photographs and ground control. It makes this research relevant in bridging gaps in floodplain and drainage mapping.

Some other closely related studies include the following: The use of false colour Near Infrared film in a variety of applications, which include mapping of soil (Frenzee, et al, 1973). In recent years too, this kind of film has been applied to mapping the relatively inaccessible wetland zone with great successes by (Gammon and Carter, 1979) and (Stewards, 1980).

Patrick and Abdulhamid (1989) made use of photographs and questionnaire method to access the impact of dam construction on the downstream morphology and agricultural productivity in Kano State. They used aerial photographs to map and predict floods water-logging and erosion.

Adeniyi et al (1988) employed the capabilities of digital and visual analysis of LANDSAT MSS for identifying and monitoring the impact of dam construction in the Sokoto - Rima Basin. Landuse and Landcover types were classified using maximum likelihood procedure to investigate the chances, LANDSAT MSS was found suitable for rapid classification and monitoring of the agriculture resources of the area, and landuse was identified especially in the floodplain downstream of the dam. It was concluded that the combined use of digital and visual analysis of a higher resolution data of SPOT (HRV) would provide baseline data for detailed agricultural resources planning and management.

A study of fadama shallow ground water of Sokoto State by Odusanya, B. O. (1987) delineated about 170,800 hectares of fadama lands with adequate ground water potential for irrigated agriculture. The report divided the fadama lands into major, intermediate and minor fadama. Furthermore, the individual yields obtained from boreholes drilled in River Sokoto floodplain were high (400m3/day) while the average among the five (5) successful boreholes tapping water in the River Sokoto alluvium at Tundafia yielded 1090^{3}_{m}/day with only 0.76m of draw down below a static water level of 2m below land surface, (Anderson and Ogilbe, 1973). The aquifer storage in the floodplain is increased when recharge occurs during the rainy season by infiltration of floodwater following periods of heavy rainfall or by perennial streams flowing over it.

Floodplain areas are regarded as having natural functions and it has economic values. The hydrological and ecological values of these wet lands have been summarised to function as groundwater recharge and discharge, flood control, nutrient retention and microclimate stabilisation. It produces forest resources, wildlife, fisheries and forage, etc. And a sound database is greatly needed if we need to successfully manage these resources. The problems plaguing the use of maps to describe geographic phenomena led to the development of Geographic Information Systems (GIs) which is the Geographic system of capturing, storing, checking, integrating, manipulating, analysing and displaying of data which are spatially referenced to the earth. This is normally considered to involve spatially referenced computer data base and appropriate application software (Chorley, 1987). The advent of satellite remote sensing has therefore brought a new line of research integrating GIs into remote sensing, since satellite images have become valuable. Integration of some up-to-date information is useful in monitoring and mapping of earth phenomena, as will be applied in this study using both visual techniques and computer-assisted methods. This will absolutely fill the gabs created by the lack of temporal/remotely sensed data with the use of methods of the Geographical Information Systems.

2.6 River Basin as a Planning Unit

Integrated or multi-purpose river basin development is comparatively old. Most of such projects having developed from the lessons and experience of the Tennesse Valley project (Chapp, 1965). Nevertheless, many schemes are already in existence in different parts of the world, for instance in the United States (Smith, 1958). The most important river basin development projects in Africa have been described by Lowe McConnell (1966) while the Mekong Valley project described by (White (1965) typifies the south-east Asian situation. Similarly, the efforts to develop Australian's greatest river system - the Murray-Darling System in the overall interest of the nation, Rutherford, (1968) is praiseworthy, just as the efforts to develop smaller catchment basins for example the Hunter river valley in New South Wales (McMalon, 1969). Finally, the Plate River Basin Project, involving a number of Latin American Nations like Uruguay, Argentina, Paraguay, Brazil and Bolivia - is one of the latest in this series, arising from world-wide consciousness of the benefits derivable from the properly planned development of river basin (Fifer, 1970).

The establishment of River Basin Development Authorities in Nigeria within the 1975-80 plan period was also a step in that direction, where the country was divided into definable and unequivocal drainage basin units as shown in figure 11. According to the map, the country was conveniently considered as comprising hierarchical areas which are further divided into several River Basin Development Authorities for purposes of convenience in

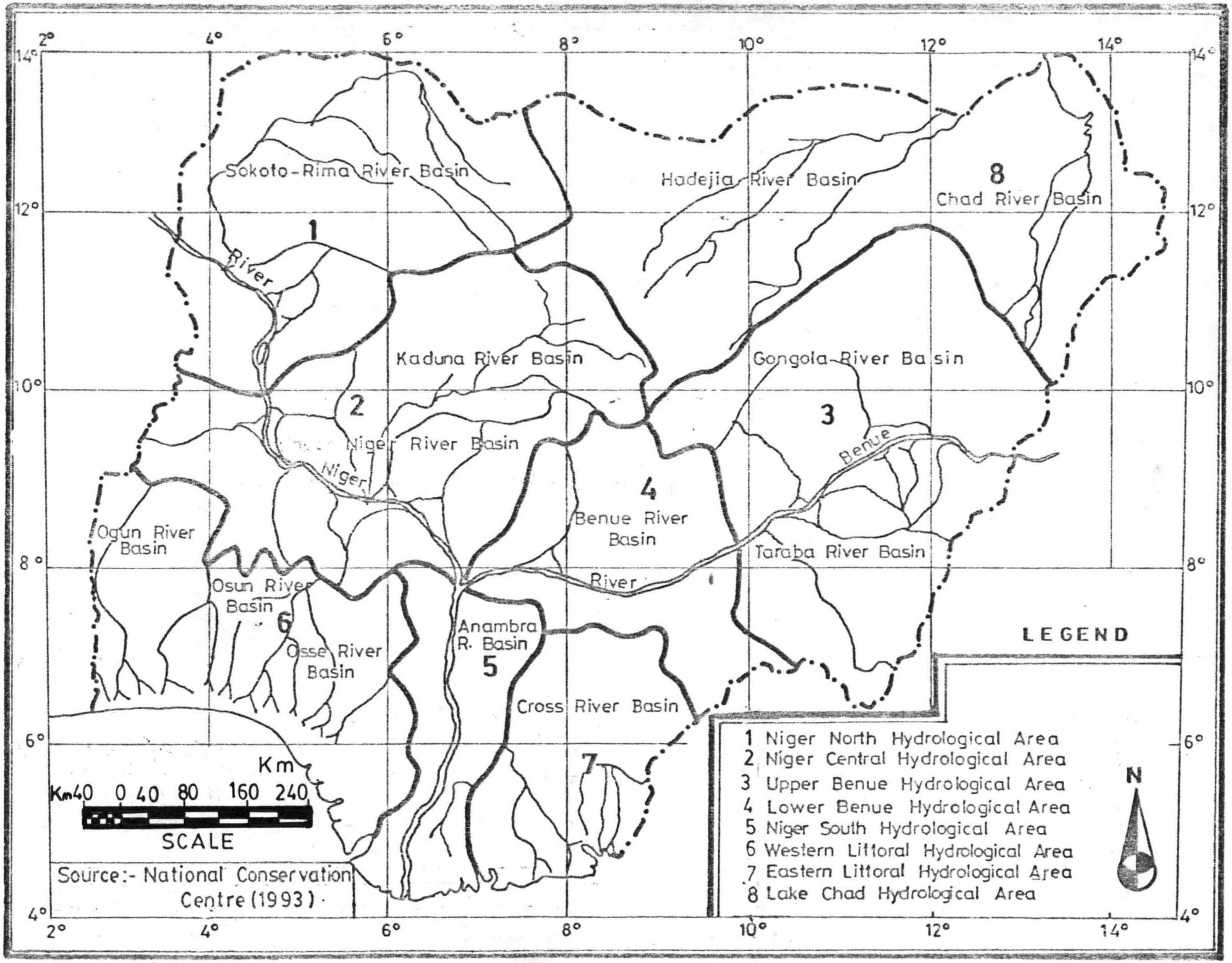


Figure 11 : CATCHMENT BASINS OF MAJOR RIVERS IN NIGERIA

handling development projects. It may also interest the reader to note that Sokoto-Rima River Basin Development Authority is not only one of the earliest in the country but one of the most successful in terms of execution of projects and programmes of the mother ministry - the Ministry of Water Resources and Rural Development.

Summarily, it is very clear that the use of manual methods in terrain evaluation and floodplain delineation is fast becoming out of use following improvement in Technology. Therefore, it is pertinent to briefly highlight here that terrain in this study will be considered as land, and its analysis will follow the pattern demonstrated by Christian and Steward (1968) to include land surface, superficial geology, hydrology, vegetation and soil. The terrain quality will take the form determined by Townshend (1987) while classification will be based on physiographic approach as considered by Veatch (1933) and Jeje's (1986) Landsystems.

Remotely sensed data will be employed for the study as done by Sollers, et. al (1978), Travett, J. W. (1986) and Hamilton et. al (1992) using radio detection and ranging (RADAR). Specifically LANDSAT MSS data will be assessed as investigated by IBRD (1973); Robinove (1975) and Weismulter (1976) that used two images (wet and dry seasons) as will be conducted here.

Both visual interpretation and digital (Computer-assisted) Image processing techniques will be employed as studied somewhere by Chorley (1987) and Adeniyi et al (1988).

Other closely related studies involves the use of false colour Near Infrared (NIR) film in mapping soils, Franzee, et al (1973); wetland, Gammon and Carter (1979), and Steward, et al (1980); Aerial photographs and interviews, Patrick and Abdulhamid (1989). These studies revealed a variety of and different sources of data and methodology, some of which will be applied with modifications in order to fill gaps created in the study of terrain and the use of remote sensing techniques.

CHAPTER THREE

METHODOLOGY

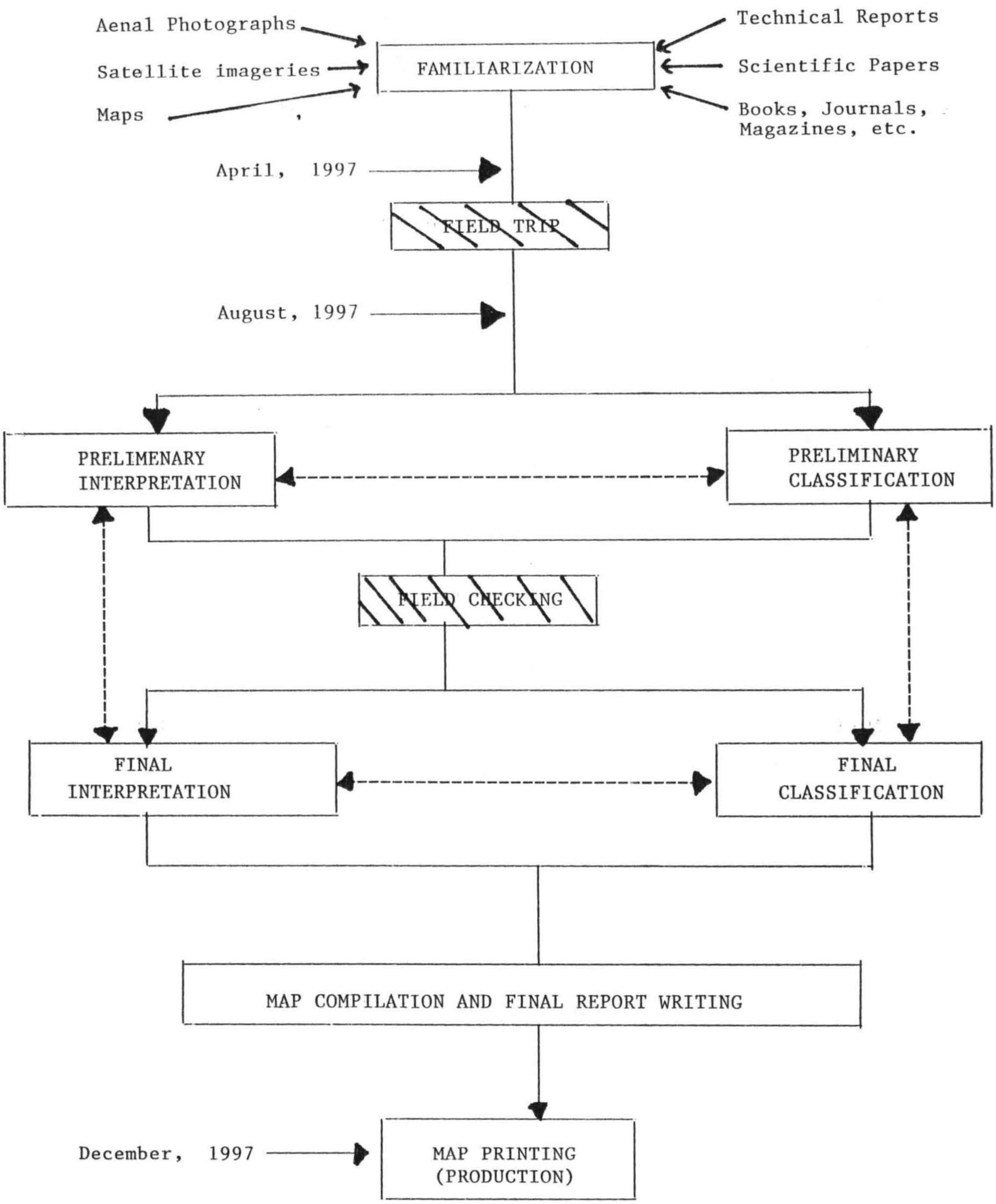
This research is concerned with the application of Remote Sensing Techniques in Terrain analysis (drainage mapping and floodplain delineation). The work relied on visual interpretation and digital (computer-assisted) image processing.

3.1 Data Collection and Procedure

There is a tendency, particularly in remote sensing applications to ignore the potentials of other contemporary data sources, and to carry out interpretation using only satellite imagery obtained. Figure 12 is a block chart of a typical Radar survey by Travett, J. W (1986) which will be adopted in this studies and the basic characteristics of the data sources are also illustrated on table 1. First and foremost, every available data whether they are maps, reports, statistics or other imagery bases were obtained and examined in order to acquaint one with area. Any information even if old may still yield valuable information about the area, the vegetation types, soils, settlement patterns, drainage, etc. This was possible using the university library, state and National library, all in Minna.

Throughout the interpretation, recourse will be made to these databases in order to clarify points of doubts or to

FIGURE 12: RESEARCH OPERATIONAL FLOW DIAGRAM



AFTER TREVIETT, J.W. (1986)

help in the interpretation. The flow diagram also shows that pre-interpretation field reconnaissance was carried out and study of the available data sources enabled survey journeys to be planned to the best advantage and identification of areas where supplementary field studies may be required was done.

Table 1: Data Source and their Characteristics

S/No	Type of Data	Date	Scale	Identification	Acquisition source
1	Aerial Photographs	May, 196[illegible]	1:10,000	9307-9311 0071-0075	Sokoto-Rima River Basin Dev. Auth. (SARBDA)
2.	Aerial Photographs	1976	1:[illegible],500	Semi-Controlled Mosaic for Bakolori Project	-do-
3.	LANDSAT MSS (CCT)	11 Mar. 1985	-	808-ESA/ACS LANDSAT E V05-04	Climate Change FEPA, FUT, MINNA
4.	LANDSAT MSS STANDARD PHOTOGRAPHIC PRINTS	18 NOV. 1987 22 OCT. 1989	1:250,000 1:250,000	1023-1800 A (16-11-91) 1023-1800 A (17-11-91)	-do- -do-
5.	TOPOGRAPHICAL MAP SHEETS	1975 1974 1968 1968 1965	1:100,000 1:100,000 1:50,000 1:50,000 1:250,000	Sabon Birni (Sheet [illegible]) Isa (Sheet 12) Sokoto NE (Sheet 10) Gusau SE (Sheet 10) Sokoto (Sheet 2)	Fed. Surveys " SRRBDA " "
6	Field Checking and completion exercise	10-18/11/97	-	Verbal information acquired through discussions	SRRBDA and Residents at Wurno, Goronyo and Talata Mafara.

3.2 Remote Sensing Data

Landsat Mss data constitute the primary data source for the research. The decision to use Landsat data is based on the synoptic coverage of the LANDSAT vis-à-vis the size of the basin, the possibility for combined application of visual and digital image analysis techniques and temporal suitability of the data over the project area.

Computer-Compatible tapes (CCT) that is, magnetic tape acquired at the Climate Change Outreach Station of the Federal Environmental Protection Agency, (FEPA), at University of Technology, (FUT) Minna, was converted to floppy diskettes after down loading into hard-disk using disk-drive of the National Water Resources Institute, Kaduna. While the Standard Contact (photographic) prints of the Satellite Imageries - LANDSAT MSS data of both dry season: 18th November 1987, S-190-15 (1023-1800) of 16th November 1991 and wet season: 22nd October 1989, S-190-51 (1023-1800) of 17th November 1991 (See plates 1 and 2 respectively) will be used for visual interpretation. The imageries covered a significant part of the Sokoto-Rima River Basin Area, and is cloud free and of high quality. It was important to obtain good quality and cloud free imagery for the study of the terrain.

Photographs (Plates)

Plate 1: Satellite view of Sokoto-Rima River System LANDSAT MSS (dry season) 18th November, 1987 Number: 18 NOV 87 5-190-51 12 4 01 1023-1800 A (16/11/91).

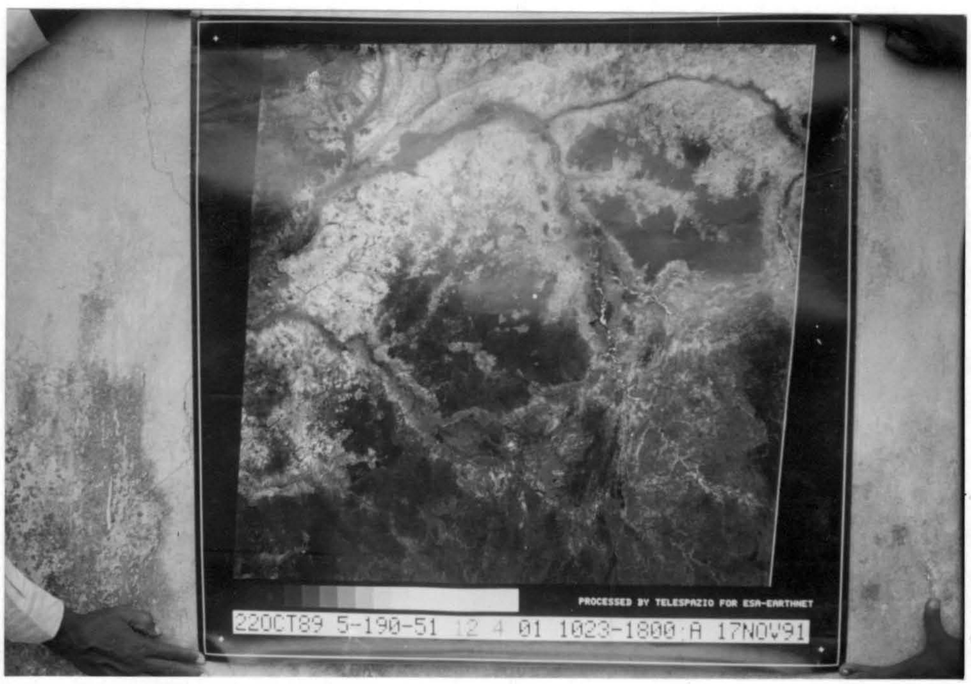


Plate 2: Satellite view of Sokoto-Rima River System LANDSAT MSS (Wet season) 22nd Oct. 1989 Number: 22 Oct 89 5-190-51 12 4 01 1023-1800 A (12/11/91).

In addition to the Landsat imageries, a substantial number of 1:40,000 sequential black and white aerial photographs flown in 1962 and 1:2,500 semi-controlled mosaic for the Bakolori project flown in 1976 will be used as reference data. And supported by field data collection in 1997 (during both dry and wet seasons.)

3.3 Instrumentation

Remote sensing applications are instrument dependent. The nature, type and accuracy of the interpreted data depend to some extent on the type of instrument used. In this project, the instruments to be used include:

(i) IBM-Personal Computer (IBM-PC) with IDRISI (for windows) software package of the Clark Laboratory of the Department of Geography, Federal University of Technology, Minna which has digital image analysis, statistical analysis and automatic cartographic components. A small sampled area between Lugu dam and the Goronyo dam project on the image will be utilised.

(ii) Visual interpretation of the entire Landsat imageries and other remotely sensed data will be done using sets of mirror stereoscopes, magnifying glasses, etc. available at the Federal University of Technology, Minna.

(iii) Various and complementary cartographic facilities at the Niger State Ministry of Works, National Directorate of employment and the Federal University of Technology, Minna will be used for the research.

While the interpretation of the aerial photographs will be carried out with the aid of mirror stereoscopes with 3X magnification, the Landsat digital analysis will be performed on the IBM-PC Computer hardware using the IDRISI software system. The Pre-processing of the data will be limited to image to image registration for overlay purposes, and preliminary evaluations will involve visual analysis. However, in addition to the image data, other sources of data e.g. maps, published records/research documents and field studies will be employed.

3.4 Field Data

Since the availability of ground information for this area is limited, extensive efforts were made to collect data through field observations (supported by ground photographs and interviews/discussions. Systematic field sampling was difficult to perform due to problems of access and accurate geo-positioning; attempts were made to determine the nature of the terrain in selected areas. Identified changes were in most instances corroborated by the discussions with local farmers. Of particular significance were their responses on floodplain situated more distant from the river course and downstream of the dams.

3.5 Procedure for Terrain Analysis

Terrain as used here refers to the portion of the region that is characterised by a particular combination of landform, geologic deposits, soils, vegetation, and water, (Townshend, 1981). In this research, the main emphasis is on the development of an efficient classification, compilation and mapping of the terrain components. The mapping will be based essentially on visual interpretation of the enhanced LANDSAT MSS imagery for dry season, aerial photographs and topographical sheets to complement the visual analysis.

The procedure to be followed here include the following:

a. Documentation of available terrain classification scheme for similar environment.

b. Compilation of a preliminary terrain classification scheme.

c. Creation of base map from topographic maps sheets.

d. Interpretation of Landsat and other image data.

e. Transfer of interpreted terrain data

f. Field checking of preliminary landsystems mapped from Landsat imagery

g. Adjustments of the classification scheme and final interpretation/mapping

h. Cartographic activities (e.g. map composition, printing, reduction, etc.)

i. Brief analysis of the terrain types.

3.6 General Procedural Tasks

Based on the available sources of information and data collected, the following tasks are to be accomplished:

a. Identification/recognition of Features

The first step in the research is to identify terrain types; drainage patterns, and determines floodplain areas within the basin. Here, the terrain analysis, drainage patterns and floodplain areas will be identified. As in aerial photography, the basic element in interpretation of features from imageries of Landsat MSS data includes photo-elements. (Tonal contrast, size, shadow, site, association and resolution) The relevance of these elements to interpretation from conventional aerial photographs is well-documented (Avery, 1977; Barret and Curtis, 1976; Verstappen, 1977, etc.). Magnifying glasses will be used to aid in the analysis. The choice of wet and dry season imageries is to enhance discrimination between features such as soils, vegetation, agricultural land, lakes, etc. for easier visual analysis and interpretation.

b. Interpretation

The second phase of the study is to analyse the

potentials of Landsat 5 (MSS) data in mapping of drainage and floodplain. The various types of map details identified on the image in task (a) above will be manually taken on a transparent overlay. And replaced on the two imageries one after the other to check the information content of the dry season image from that of the wet season in order to make comparison and take details. A thorough study of the drainage conditions and floodplain areas will be done, and all identified features will be mapped.

c. **Digital (Computer assisted) Procedure**

The computer compatible tapes (CCT) obtained was down-loaded and transferred by bands into computer hard disk then into floppy diskettes using the magnetic disk-drive of the National Water Resource Institute at Kaduna.

The IDRISI algorithm (Software package of the Clerk Laboratory) has capabilities for processing the data, as such it will be used for image processing. Some of the basic techniques to be employed include the following: Density slicing, Supervised classification and reclassification of spectral signatures and maximum likelihood classification The classification key to be employed for both visual and digital analysis is illustrated on table 2. it includes subdivisions of water bodies, wetland, non-agricultural bare surfaces, settlements,natural fadama (floodplain) and rainfed cultivation.

d. **Field Checking**

Apart from the initial field trip embarked upon in the area of study, it will be necessary to repeat a visit in order to conduct field check to identify features that did not appear very clear during visual interpretation and image processing for features verification. Ground photographs of most of the features will be taken, and as earlier noted, attempt will be made at systematic random sampling during the ground truthing.

Table 2 : Classification for Terrain Analysis.

S/N	Class	S/C	Sub-Classification
1	Water bodies	1.1	Reservoir
		1.2	Dam
		1.3	Small dam
		1.4	River and Tributaries
2.	Wet Land	2.1	Vegetated wetland
		2.2	Non-vegetated wetland
3.	non-agricultural Bare Surfaces	3.1	Sandy and Bare surfaces
		3.2	Laterite slopes and rocky surfaces
		3.3	Shrubland and grasses
4.	Settlement	4.1	Villages and Towns
		4.2	Roads and Bridges
5.	Rainfed cultivation	5.1	Rainfed cultivation (Wet)
		5.2	Rainfed cultivation (dry)
6.	Natural Fadama (Floodplain)	6.1	Stream flow
		6.2	Sandbars
		6.3	Backswamp on floodplain
		6.4	Non-swampy part of floodplain

Sources: Survey data (1997).

e. **Discussions**

In the final phase, for each of the tasks undertaken from (a) through (d), observations noted would be summarised and a short discussion will be made in the following chapter. Experiences and findings concerning both the visual and computer-assisted image processing will be made and supported by ground photographs where necessary. The potentialities of and limitations of Landsat mss data will also be presented which will enable recommendations to be presented regarding the entire study area.

Having discussed the methodology (i.e. data types, collection methods, instrumentation and general procedure for terrain analysis and visual/computer assisted image processing to be employed. It is also vital to follow these methods logically in order to bring out results obtained from the procedure tasks embarked upon in the study. Detailed discussions on the findings and the implications of the research are all shown in the following chapter.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Descriptions/Identification

Looking at the two Landsat Mss data on plates one and two, it is clear that the major physical feature in the region is the drainage system. It encompasses the Sokoto-Rima River system and the tributaries of Gagare-Bunsuru and Maradi rivers. The conspicuous appearance of two reservoirs - the Goronyo Lake and Bakolori dam can be visualised. Some few other small lakes like the Lugu dam at Wurno, Zurmi, Kaya dams and several other lakes and ponds can all be easily identified. While stream channels could be noticed easily on plate two (dry season image). The stream flow and flood plain areas appear glaringly due to soil moisture, because the grey tone of the soil reflects its water content (as the water content increases, the spectral reflectance is reduced.) In clay deposits, the reduction extends over a range of wavelengths from 0.4-1.0µm whereas for sandy deposits this reduction occurs in the range of red light (0.6-0,7µm) and near infrared (NIR): 0.7-1.0µm. Plants are good indicators of groundwater occurrence in connection with floodplain delineation. Vegetation appears red on the image while stream flow on light blue tone. Areas of sand-dunes, dry grasses and bare surfaces is in distinct contrast with light tones.

Looking further inwards to the middle of the image lying above the river plain areas and a view on the extreme Northeast corner are areas of plinthites or laterite surfaces and rocky outcrops rising prominently. The Landscape here consists of dissected masses of level bedded serrated outlines while the southern corner shows the appreciably higher crystalline rocks of the basement complex which form part of what is termed the high plains of the hausaland (that is, the Sokoto plains).

The open-water (reservoirs/lakes and ponds) produce blue tone and the banks of white shingle that appear inside most of the river bends is the patches of sandbars. The dark colour on the image represents the laterite slopes and rocky surface, while shrubland exhibit greenish colour and forest reserves appear dark green. The white/light tone, which is distinct on the image, represents sandy and bare surfaces with dry grasses. The reddish colour traced all over on the field must especially in the southern part of the wet season image along the floodplain areas are the vegetated wetland.

The description of agricultural land as given by local farmers will be discussed later as it has assisted adequately in the interpretation of the Landsat mss data.

4.2 Interpretation of the Landsat MSS data

The interpretation of the Landsat prints is hardly different from that of any small scale high altitude aerial photography, as in the terrain analysis, the most important element in the interpretation of the land resources satellite remote sensing data are texture, pattern, shape and tone.

Texture is produced by the frequency of tonal change within the image due to aggregate of features too small to be clearly discerned individually on the imageries. Thus, landsurface features such as series of ridges, hills, depressions, etc. which can be individually identified on large-scale conventional imageries will be visible only on texture.

Pattern is the spatial arrangement of terrain features throughout a region. As the imageries have relatively small scale, many terrain elements that could form a distinctive pattern at larger scales comprise the component of a distinctive image texture. Patterns resulting from particular distributions of certain lineaments in most terrain configurations are usually related to geologic structures such as faults, joints, etc. Drainage lines, which form destructive patterns, are also important with regards to their underlying structure and lithology.

Shape is the spatial form with respect to a relatively constant boundary. Shape has been useful in terrain analysis at small scale of the Landsat imageries, as several geologic structures and individual features can be easily identified based on their ground plans. Such natural elements of the landscape have irregular shapes, but some landforms such as lakes have regular outlines. Cultural features proved difficult to interpret because of the scale factor.

Shadows do not exist in the imageries, where it seems so, for example in depressions; their important is indeed invaluable.

In agricultural areas, the field pattern did not stand out clearly and differences in crop types could not be distinguished by tones/texture values, while in the non-agricultural areas, it was possible to use the same basis of tone/texture to delineate different zones. However, contextual information and local field data helped their classification. Urban areas on the other hand demonstrated a high return signal with some evidence of patterns. The hydrology on the image was readily interpreted and it helped to relate to landuse. Still for all, accurate interpretation will require' local knowledge, adequate field data and subsequent checking. The accuracy of classification will be related to the ancillary data available.

Interpretation key (a set of images against which each part of the image being analysed, its matched and allocated to the class whose image in the key it most resembles is shown on table 3. Deductions were made in some cases on the basis of evidence from the image along with ground truth. Some of the problems in using the key related to its flexibility, as it may be area specific. Same key will however, be used for other images to be used in the study area or other semi-arid environment but certainly not in other regions.

4.3 Terrain Analysis

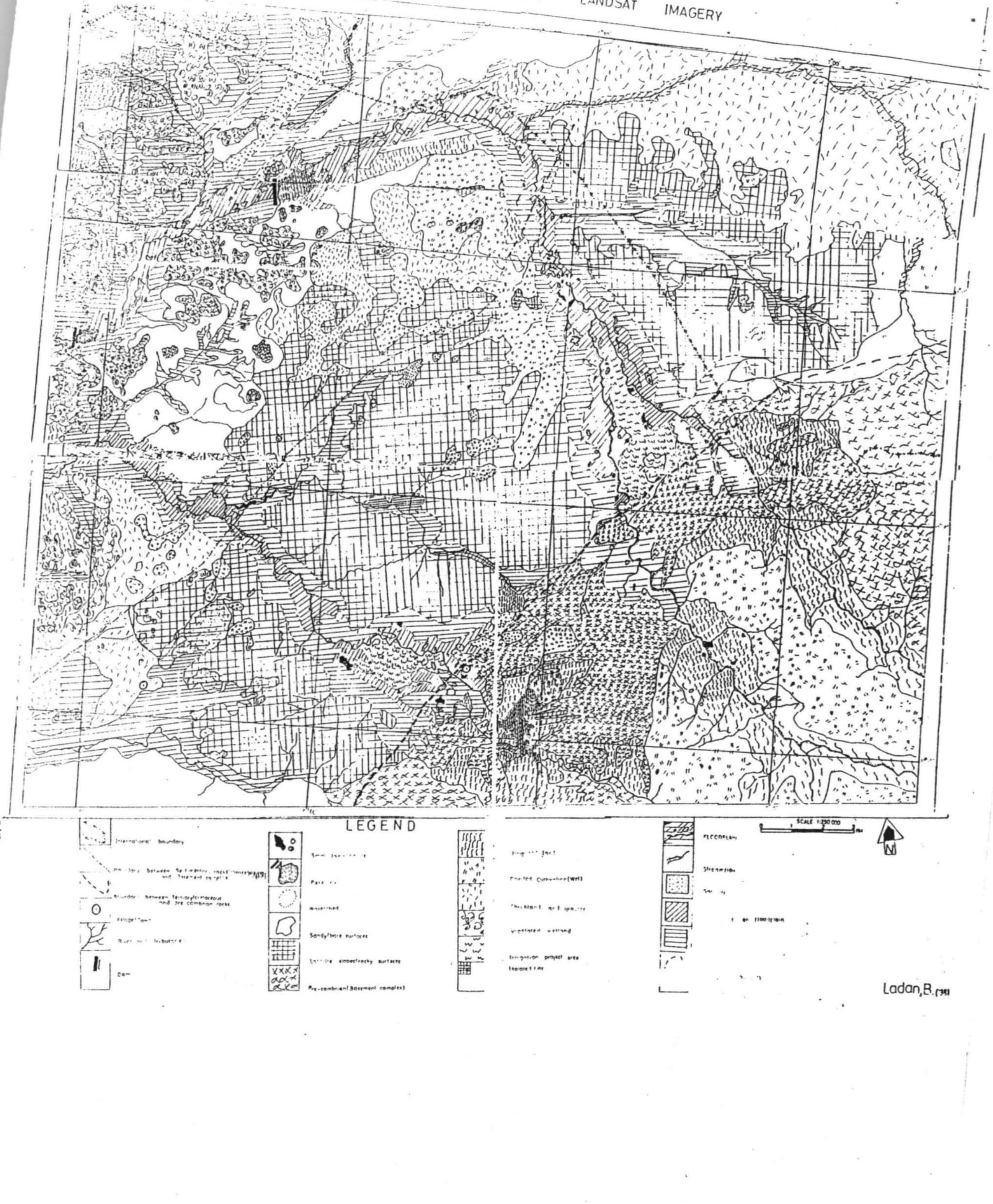
Essentially terrain analysis is a study of the inter-relationship among the various elements of the

Table 3: Interpretation Units of the Landsystems Classification scheme used for visual interpretation in Terrain Analysis and floodplain delineation.

Unit No.	Sub No.	Landuse/cover class	Grey tone on image		Texture	Boundary
			Dry	Wet		
1.0		Water Bodies				
	1.1	Reservoir	Blue	Blue	Strong	Distinct
	1.2	Small ponds / lakes	"	"	Moderate	Not very clear Spots
	1.3	Ponds or pools	"	"	"	
2.0		Wetland Areas				
	2.1	Vegetated wetland	Green	Dark green	rough	Distinct
	2.2	Non Vegetated wetland	light	light	light	clear
3.0		non-agricultural Bare Surfaces				
	3.1	Sandy and Bare	purple	white	faint	Distinct
	3.2	laterite slopes	Brown	Dark brown	Coarse	"
	3.3	Basement complex rocky surfaces				
	3.4	Shrubland and grasses	Dark Olive	Pink Olive	rough faint	Clear Spots
4.0		Rainfed Cultivation(RFC				
	4.1	RFC (Wet)	Yellow /brown	Red	Moderate	Distinct
	4.2	RFC (Dry)	Brown	brown	faint	Not very clear
5.0		Natural fadama (Floodplain)				
	5.1	Stream flow	Light blue	blue	moderate	clear
	5.2	Sand bars	White	white	"	"
	5.3	Backswamp on floodplain	Dark red	pinkie yellow & red	Faint	"
	5.4	Non-swampy part of floodplain	red	red	Medium	"
6.0		Settlement				
	6.1	Village/Town	White	white	light	Distinct
	6.2	Roads	Brown	Brown	faint	not clear

Terrain. It is an integral part of geography and is the focus of various regional surveys now being carried out. It is for this that, in this study, land systems (that is, an area or group of areas throughout which there is a recurring pattern of topography, soil, and vegetation, Christian and Steward (1968) was mapped. This analysis was done manually and the landsystems were mapped. Topographical map sheets aided the interpretation on 1:250,000 same as the imageries while those on other scales were reduced to same scale. Air- photographs were also used to aid in the mapping, and ground checking became necessary for verification of some features. Other equipment used included magnifying glasses, stereoscopes and various cartographic materials available at Federal University of Technology, Minna. The imagery used for terrain analysis was the dry season image while the wet season image was used for inference and it enhanced discrimination between different land facets. Such features like vegetation, water bodies, rocky and bare surfaces, agricultural and non-agricultural lands etc. Figure 13 on appendix 1 shows the landsystems of the area mapped from the 1:250,000 as printed using plan printer and reproduced at a reduced scale see fig. 13 with a brief interpretation of the Landcover so designated.

FIGURE 13.1 (Appendix 1): SOKOTO - RIMA BASIN LAND SYSTEMS MAPPED FROM LANDSAT IMAGERY



Ladan, B. (38)

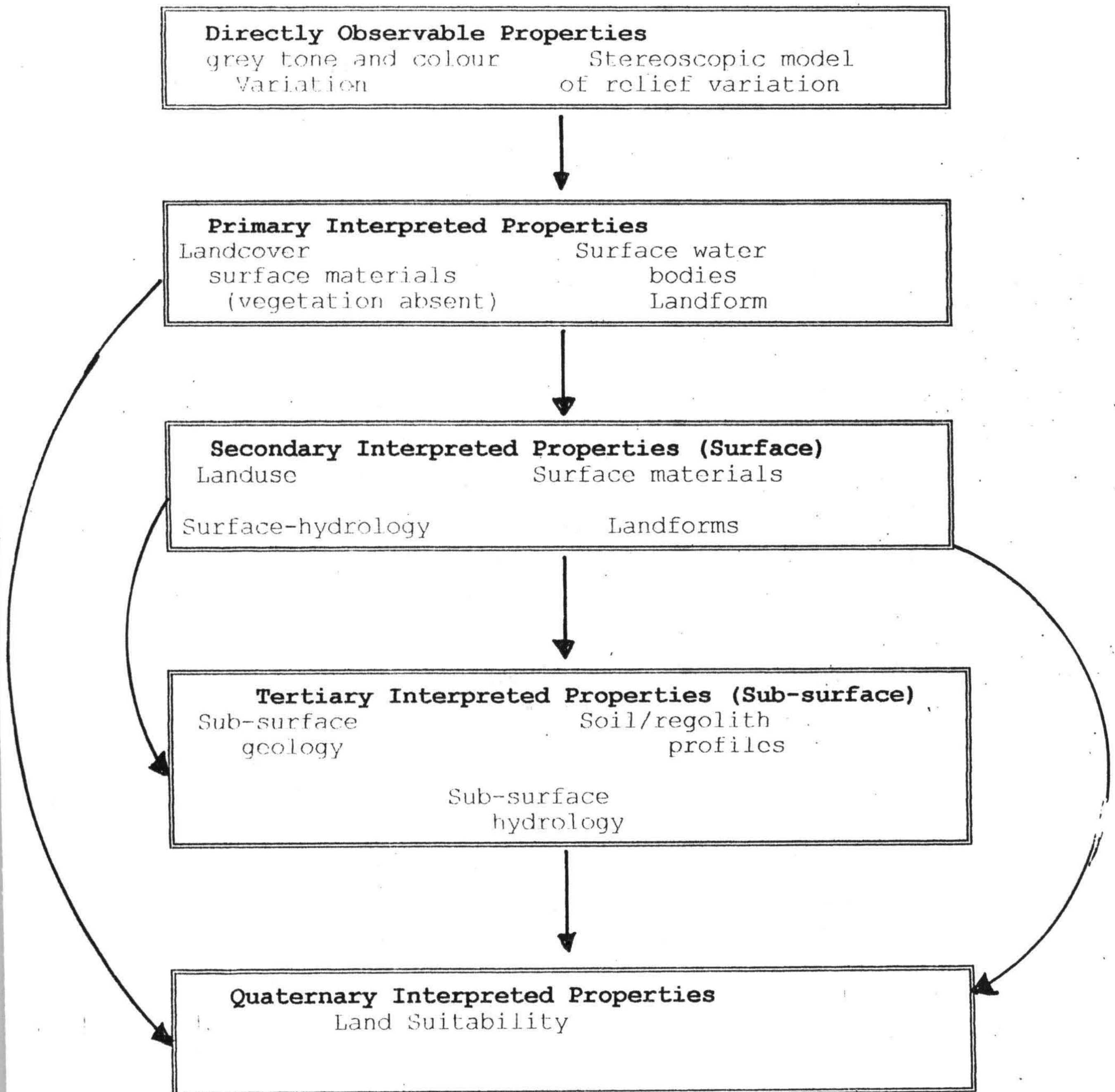
4.4 Land system Delineation from LANDSAT Imageries

As observed by Verstappen (1977), the interrelationship between various landscape ecological factors which are collectively considered in land system mapping are best reflected in the geology and geomorphology, so that the correct interpretation of the visible landform has proved valuable in revealing the other aspects of the land.

The first step in delineating the landsystems was the mapping of the diagnostic characteristics as discussed in some texts such as Allum (1966) and Jeje (1986). This is then followed by delineation of different morphogenic zones on the various broad geological units. The case with which these regions were recognised varies seriously with different terrain types. The boundaries are self-evident in this case, however, where land is widely cultivated, the resultant field pattern dominated the general appearance of the area that the terrain regions are very difficult to recognise for mapping purposes.

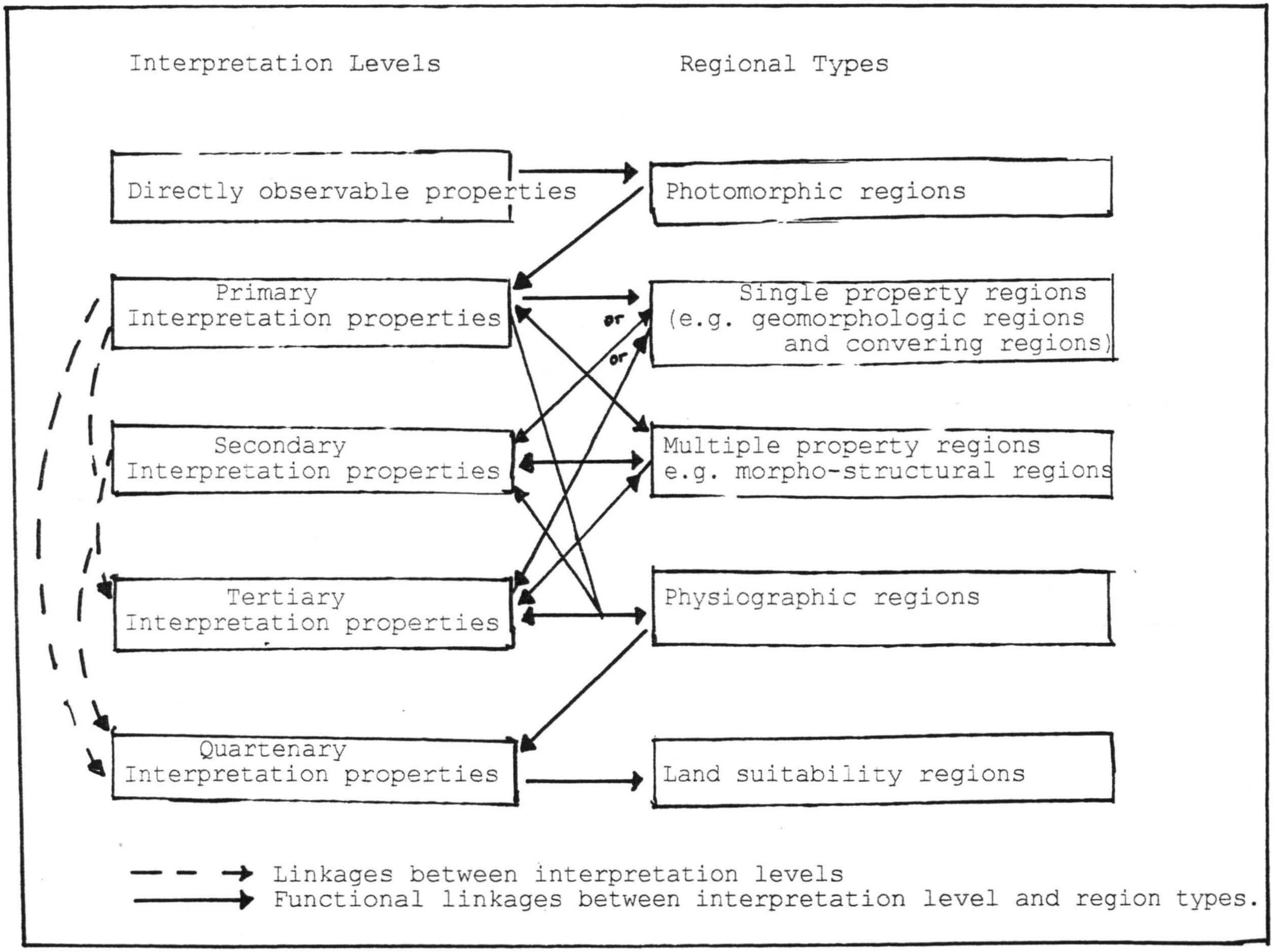
As Townshend (1981) recognises 4 hierarchical interpretation properties in delineating land systems was used for this study and it is illustrated in figure 14. Thus using either primary, secondary or tertiary interpreted properties, a single or multi-property regions can be derived, Jeje (1986). For instance, if the landform are recognised, it can help in locating both surface and subsurface hydrological characteristics as demonstrated and shown on figure 15.

Fig. 14: Hierarchical Structure of human Interpretation In Land systems mapping.



AFTER TOWNSHEND (1987)

Fig. 15: Relationship between interpretation levels and regionalisation (After Townshend, 1987).



The Landsat image appears to be very useful for the mapping purposes. The wet season image appears particularly valuable for interpreting vegetation, landuse and hydrological details while dry season image appear more suited for geological and geomorphologic and hydrological mapping.

As already indicated, an important aspect of terrain analysis is identification and mapping of the geology. Three geological suites were recognised in the area from both imageries. These comprise: the Holocene and Pleistocene with river deposits, ancient sand dunes and cover sands in the North; tertiary and cretaceous rocks constituting of silt-stones, sandstone's, clayey, grits, shale's and limestone in the middle; and pre-Cambrian rocks with igneous and metamorphic rocks in the south. The boundaries between the sedimentary rocks and the crystalline rocks of the basement complex are clearly demarcated on figure 13 .

It was based on the geology, the dominant geomorphologic processes and the superficial configurations were mapped. The following landsystems were mapped from the imageries: Drainage pattern, floodplain, landform, Agricultural and non-agricultural land.

Not all the landsystems could however be recognised fully from the imagery, and it was not easy to establish a clear distinction between the exact boundaries of some terrain features. The various landsystems are briefly described below:

a. Drainage Pattern

The drainage patterns are indicators of landform and bedrock type, and also suggests soil characteristics and site drainage conditions. The drainage pattern shows an east-west zonation reflecting the geology and relief. The Sokoto high plains characterised by the pre-Cambrian rocks of the basement complex rocks in the southeast. It has broken plains from which steep sided granite, gneiss, and quartzite inselbergs. Extensive belts of phyllite occur along the Ka River between Bukuyum and Anka as well as in the East of Maradi. The region is dissected by numerous shallow valleys, which form the drainage channels of streams flowing into the upper reaches of the Rima tributaries. The badlands topography is a result of the rapid headward erosion of the streams, which in turn is caused by the rapid and high rate of surface run off. Conditions, which encourage this rapid and high rate of surface runoff, include: the broken nature of the landscape, which creates considerable slopes, the low permeability of the rocks and the character of the dendritic drainage pattern, formed by the main streams Their tributaries branching and re-branching freely in all directions. It occurs because of the relatively homogenous materials of the horizontally bedded granite and the sedimentary rocks of the Gundumi and Rima Illo series and the younger series of Eocene and post Eocene age known as the

Calcareous and Gwandu groups - all covering the western and northern part of Sokoto. The Sokoto River for instance flows through a broad flat-bottomed trench-like valley between two steep and worn escarpments. Generally, the drainage density decreases South to North.

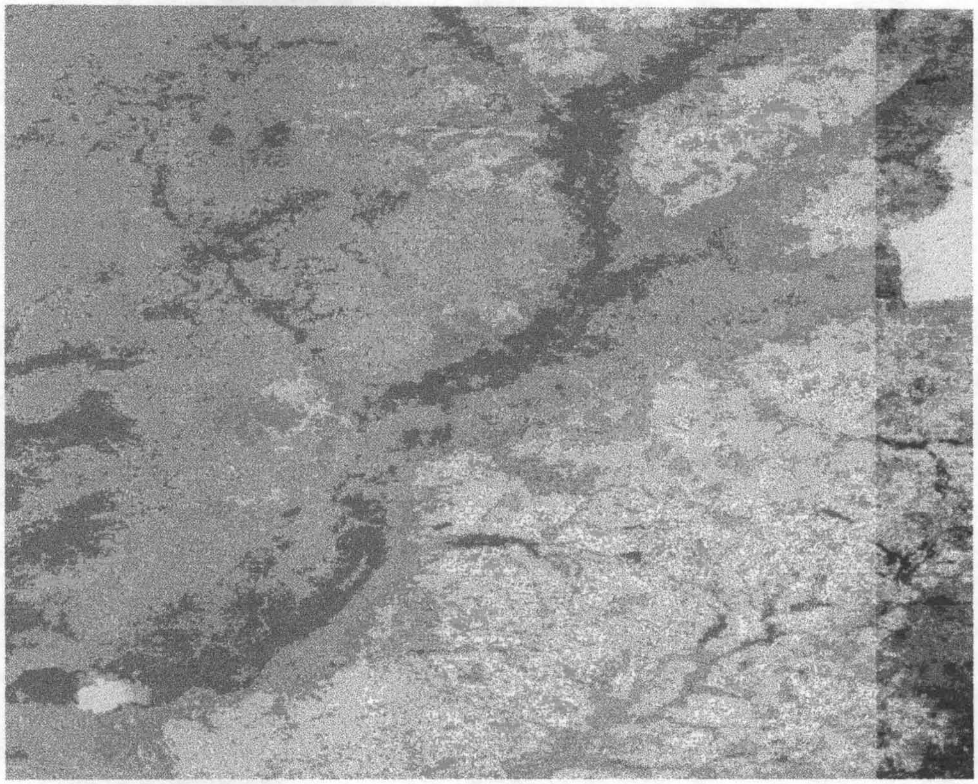
b Floodplain

These are readily recognised on the two imageries. Infilled lakes, ponds, meander traces, lakes/reservoirs, differed junctions, etc. As water bodies absorb infrared radiation, they always appear dark on infrared positive prints. But on the false colour composite (FCC), as on computer print out on figure 16, it clearly appears Ash in colour. Remarkably vegetation tones appear reddish in colour with forest reserves and vegetated wetland appearing dark and greenish respectively. The floodplain will be explained in details later. Some of the inundated land, (floodplain) are displaced on plates 3 and 4.

c. Landform

Lying above the river- plains are areas of plinthites, (or laterite) highly infertile and most commonly covered by bush or forest reserves. This area may be used for grasing

Fig : 16 colour composite



PART OF RIMA FLOODPLAIN
(LANDSAT MSS, 1987

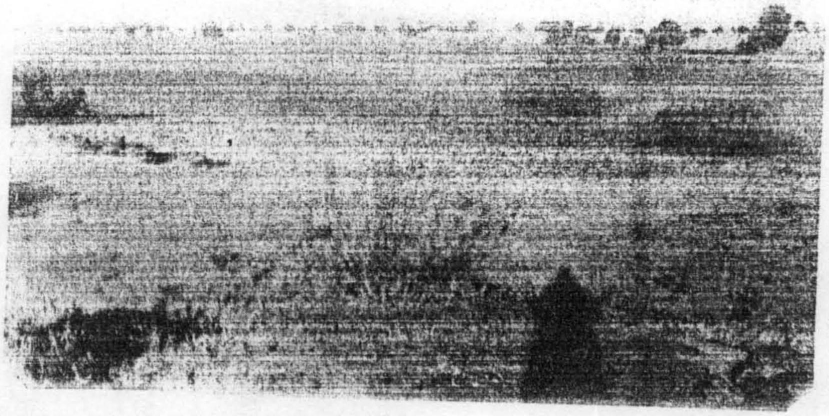


Plate 3: Inundated wetland on Sokoto River

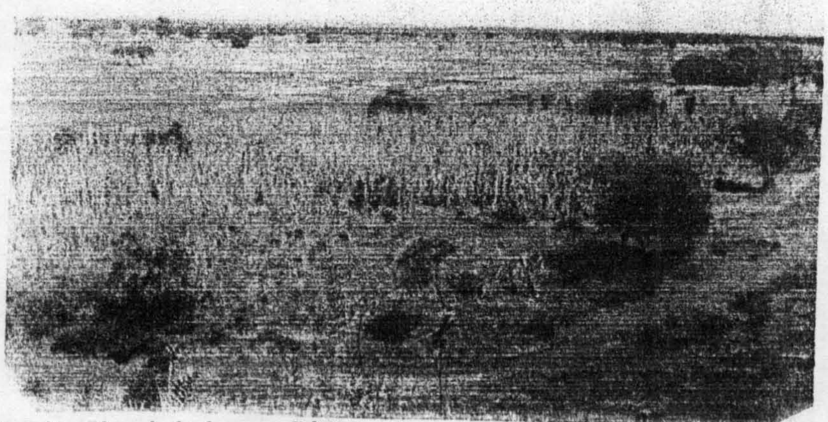


Plate 4: Gandi floodplain on River Rima Inundated

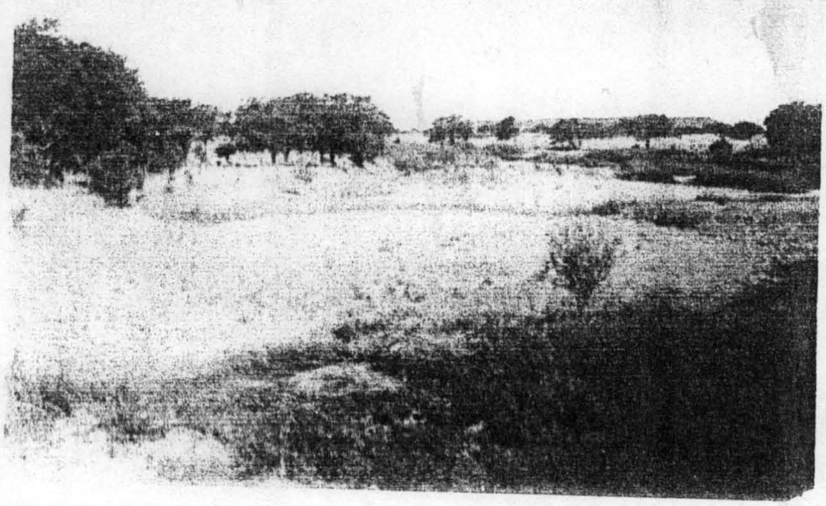


Plate 5: A sharp ridge of rocky hill with sharp crest around Moriki with an altered vegetation

~~used for grazing~~ purposes. The plain display little relief and are traversed by shallow but broad valleys separated by inconspicuous watersheds. Other landforms are explained with the aid of ground photographs obtained during field checking.

(i) Sharp ridge - the ridges consists of quartzite which has restricted erosion and now forms a series of virtually bare rocky hills with sharp crests standing well above the present relief (see plate 5).

(ii) Scarps - Scarps are formed at the edges of laterite caps as a result of lateral slope retreat as on plate 6.

(iii) Rock outcrop - This is in form of inselbergs consisting of granite and gneiss which are the most prominent features of the area (see plate 7).

(iv) Dunes - Cover sands still preserved fairly well. They often overlie an indurate laterite. The dunes of Sokoto generally cover sands vary in length from 1500-2000 ft. and width from 600-1,500 ft . They are 31-60ft and occur in isolated and scattered expanses.

d. **Vegetation**

The vegetation reflected forest reserves, vegetated wetland and Shrubland. The woodland is much altered by persistent human activity (see plate 5 and 8). New land is usually cleared for agriculture by **slash and born**

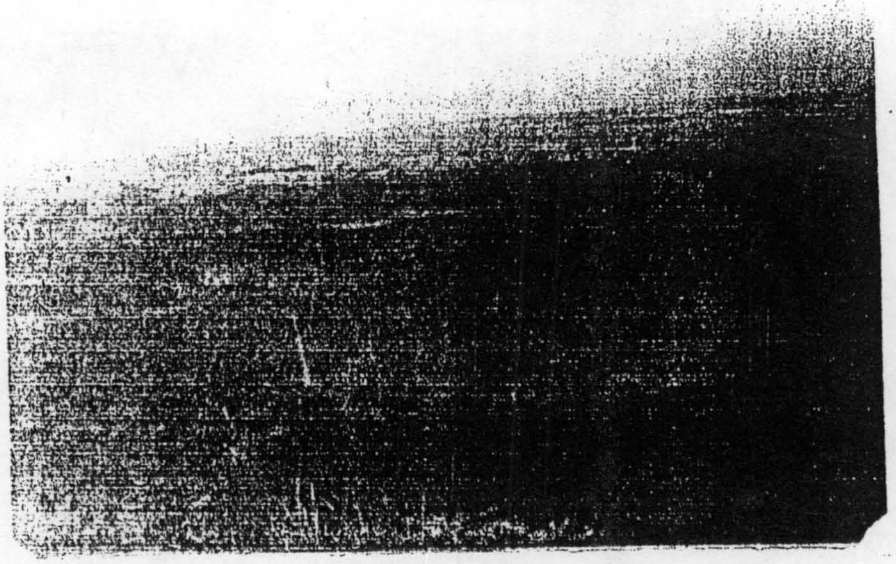


Plate 6: Scarps at edges of laterite capped hills/slopes

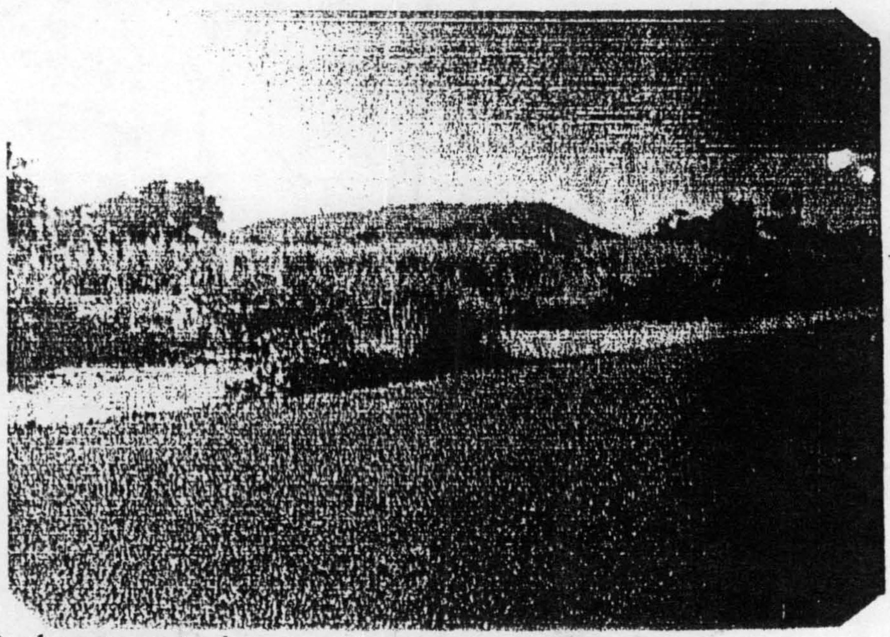
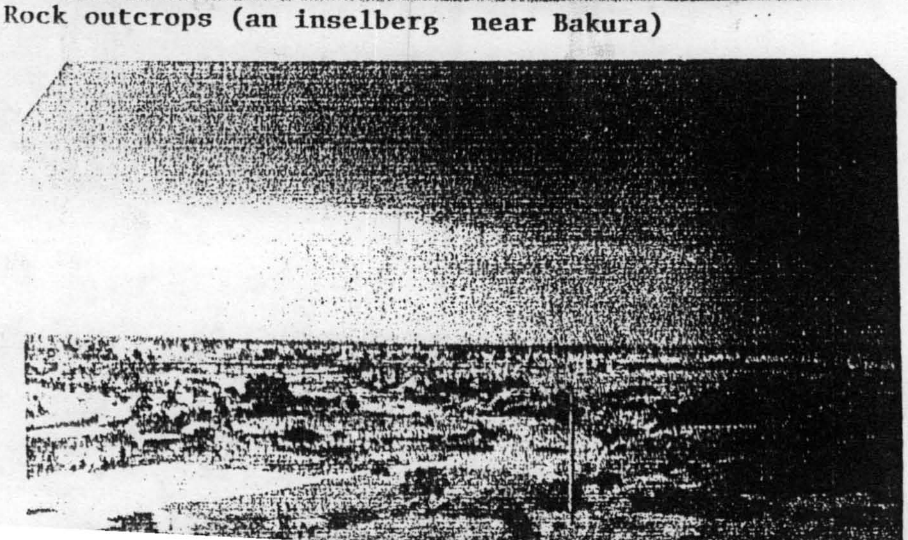


plate 7: Rock outcrops (an inselberg near Bakura)



Slash and burn method and bush fires as reported by local farmers during field checking. What woodland remains is extensively exploited for fuel (wood) with very few dispersed large trees left - a dangerous trends that need to be checked, as the resultant opening-up of the canopy increased widespread and leads to increase desiccation, Agyepong, (1984).

e. **Agricultural Land**

The agricultural land resources is divided into two categories by the Hausa farmers (see land classification of Hausa farmers on table 4). These categories are referred to as fadama and Tudu (land which does not flood). The fadama is found principally in the floodplain of the rivers, but may also occur in enclosed depressions away from river courses. Such areas usually present the farmer with a variety of depth and duration of inundation offer a diversity of resources suitable for a range of crops of particular importance are rice, vegetables, maize, sugar-cane, etc. (See table 5 for the crops, fadama cultivation). The moisture trapped in such areas provided the capacity also to grow crops during dry season. Again rice, vegetables, may be grown together with wheat, cassava, tobacco etc. as shown on table 6: Crops irrigated cultivation.

Prior to the construction of the dams, fadama land was used for rice cultivation or for recession cropping after floods had receded. Recession crops included pulses groundnuts and cassava), vegetables (sweet and hot

Table 4: Land Classification of Hausa Farmers

S/No.	Sub/Class	Hausa Name	English meaning
1.0	-	Fadama	Land which floods
	1.1	Yashi/rairai	Wet/dry coarse sand Dark coloured mud
	1.2	Laka	Light coloured mud
	1.3	Tabo	Well mixed mud &
	1.4	Bangarji	sand
2.0	-	Tudu (Cultivated)	Land which does not flood
	2.1	Jigawa	Sand with organic material
	2.2	Baringo	Red, Silty rather than sandy
	2.3	Jangarigari	Red clay
	2.4	Yashi/rairai	River Sand
3.0	-	Tudu (uncultivated) Daji	Land which does not flood
	3.1	Dabaji	Wooded, potential crop land
	3.2	Fako	Stony, used for grazing
	3.3		Hard, barren ground

Source: Field Interviews (1997).

red and green pepper, Okra, tomatoes, onion and garlic) and pumpkins (calabash and water melon) with the control of the Rima and Sokoto rivers by dams, flooding is reduced and the traditional fadama cropping area is limited. On the other hand farmers in the area reported that before the construction of the dams, there was considerable flooding which ceased after the dams were completed. There is change as where there is no longer natural wet season flooding of the valley, which was a prominent feature of the natural regime and where dry season is now sustained by release of water from the dams. Adams, W. M. (1986) has shown the strong relationship between duration of inundation and distribution of crops in the fadama and from this, it is clear that any modification of the natural flood regime will have profound impact on landuse in areas outside the irrigation scheme. Effects are experienced in upland areas also, particularly where farmers who where displaced by flooding of the reservoirs have been resettled. It was reported that floodplain areas had become increasingly less productive since the flow of the river Sokoto and Rima river had been restricted following the construction of Bakolori and Goronyo on the two rivers respectively. Rice is still the most important crop in the present fadama cropping area with recession cropping of cassava, sweet potatoes and beans. Previous fadama are presently not flooded any more it is intensively used for the growth of sorghum, millet and pulses with some maize and sugar cane cultivation. The remaining Tudu-land far exceeds the floodplain. Agriculture on Tudu land is totally rainfed, although, the Tudu land is at present still subject to inundating because of heavy rainfall during rainy season and insufficient drainage discharges from the Goronyo reservoir which has caused some flooding incidents in the past few years. The crops here include various millet, sorghum, legumes, peanuts, cotton, cassava,

TABLE 5: CROPS, FADAMA CULTIVATION

CROPS	PLANTING	HARVEST
Rice	May/June	September/October
Sweet potato	October/November	March/April
Cassava	September	February/March
Sorghum (white and red)	June	October/November
Pulses	October/November	March/April
(Cowpeas, beans, groundnuts)	July/August	November
Millet	May/June	September/October
Sugarcane	November/December	August/September (next cropping season)
Maize	June	September/October

TABLE 6: CROPS, IRRIGATION CULTIVATION

CROPS	PLANTING	HARVEST
Wheat	November	April
Onions	October	February
	December	April
Pepper	October	February
(red/green)	November	April
Garlic	October	February
	December	April
Tomato	October	February/March
Okro	November	March

TABLE 7: CROPS TUDU (UPLAND) CULTIVATION

CROPS	PLANTING	HARVEST
Millet	May/June	September/October
Sorghum	May/June	October/November
Pulses (Cowpeas, groundnuts)	July/August	November
Cassava	May/June	December/January
Calabash	June/July	December/January

SOURCE: HASKONING FINAL REPORT (1995)

calabash, etc. (See table 7: Crops, upland cultivation). Finally, it should be noted that part of this land is reserved as grazing area or remains fallow.

The way the people perceived their land and their environment has permitted the evaluation of the capability of the various land types explained above. These aspects essentially based on fieldwork, documentary evidence and the results obtained in the terrain analysis. The primary objective of which is to enhance delineation of floodplain areas as well as the development of a survey technique that could be used for future programmes in the basin.

4.5 Floodplain delineation

This study is characterised by deductive approach, which infers the occurrence of features through an interpretation of land systems. In floodplain delineation, the purpose is primarily to detect the flood and flood prone area. The floodplain areas were delineated in four ways according to: topography, soils, vegetation and the extent of flood-flows.

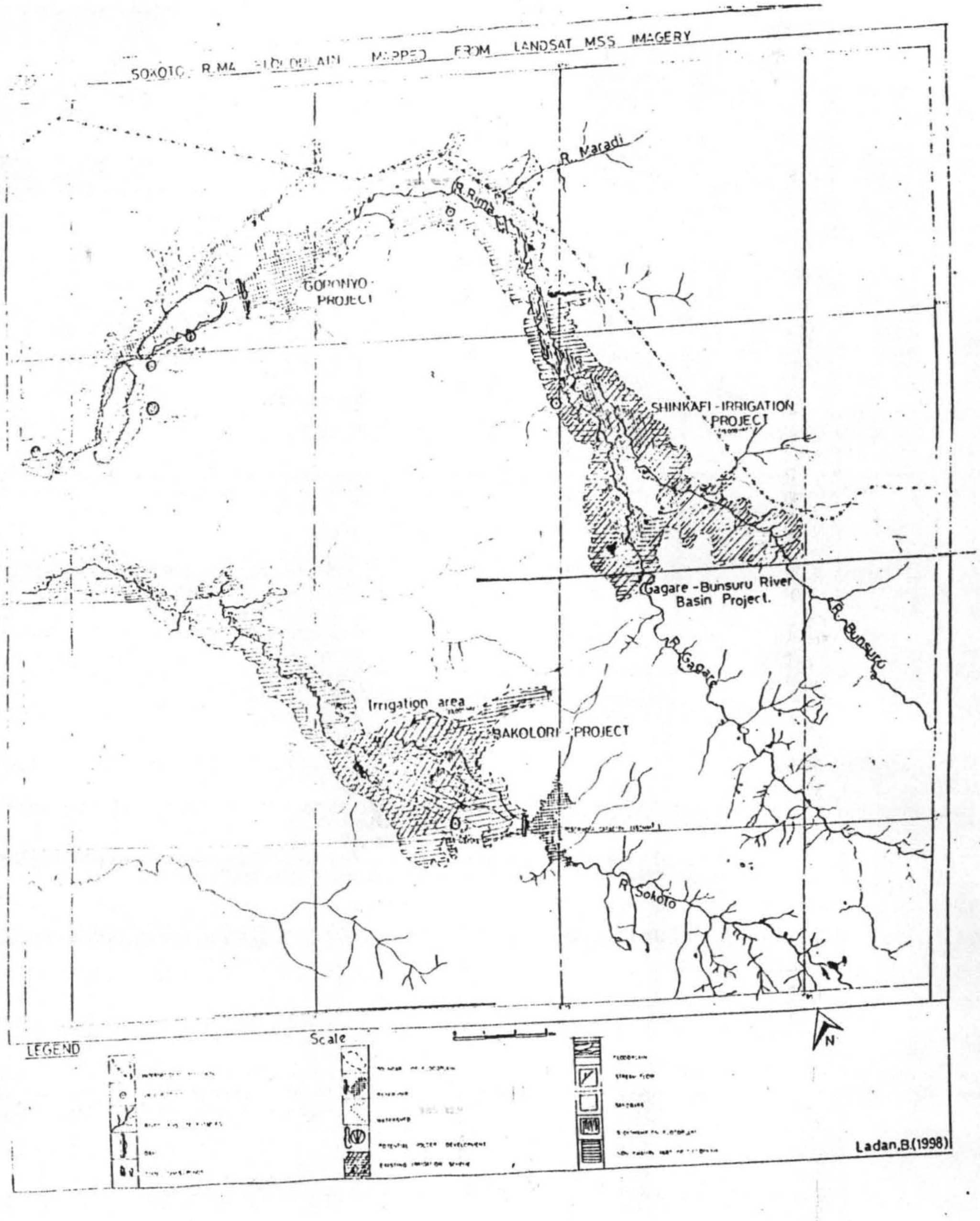
Topography - The Landsat mss data is helpful in mapping floodplain as the topographic features appear very distinct, and when aerial photographs were viewed with standard stereoscopes, topographic features appear exaggerated thereby making identification of valley features a relatively easy task in many instances.

Soils - Because river floodplain are built from river deposits, the soils of floodplain proves characteristics distinctively different from those of the neighbouring uplands

Vegetation - One other indicator of floodplain is the vigour or health of the vegetation, which serves as surrogate to the underlying soil and surface morphology. This in turn is also related to the groundwater situation. As the water table is high in the floodplain, one can expect the occurrence of more healthy plants and a high foliage density shown even on the dry season image. This explains why colour infrared image is normally preferred in this study because the NIR is highly reflected by the spongy mesophyll of the leaves of healthy plants, the vigour was revealed by Varying degrees of red colour, which facilitated the precise delineation of the floodplain.

Finally, floodplain was also defined according to the extent of part of flood flows. However, only some few evidence of past flows was gained from first hand observers who were able to pinpoint the position of the water surface in the landscape and from features such as organic debris on fences and deposits that were tied to the past floods. This method proved very difficult, as it demanded extensive fieldwork and interviews with local residents. Therefore, there was little practical success using this method.

Using the four indices above, the image overlay technique was employed in synthesising the 2 images and a standard project floodplain was mapped as shown on Figure 17a (Appendix 2) and a reduced version on figure 17' . Floodplain are here defined according to geomorphic criteria, the **floodplain**...


SOKOTO RIMA FLOODPLAIN MAPPED FROM LANDSAT MSS IMAGERY
R. Maradi
R. Rima
GORONYO PROJECT
SHINKAFI IRRIGATION PROJECT
Gagare-Bunsuru River Basin Project.
R. Bunsuru
R. Gagare
Irrigation area
BAKOLORI PROJECT
R. Sokoto
N
LEGEND
Scale
Ladan,B.(1998)

~~Floodplain~~ appears as the low lying land along the rivers with the outer limits marked by steep slopes, the valley walls. A total of over 62,000 Hectares of the floodplain areas have been delineated using visual interpretation of the entire area of the Landsat MSS data. A preliminary breakdown based on the existing schemes and potential polder development in the Basin is given on table 8 as clearly shown on the floodplain map produced by this research.

Table 8: <u>Irrigation Project Areas Mapped</u>

Project	Total Area Mapped
1. Bakolori Irrigation Area	23,000 Ha
2. Shinkafi Irrigation Project	15,000 Ha
3. Kagar- Rima Polder	2,081 Ha
4. Takakurma	1,074 Ha
5. Wurno	1,200 Ha
6. Others (including part of Tangwali)	20,000 Ha
	Σ = 62,355 Ha

Excluding the stream channel itself, the floodplain is generally the lowest part of the stream valley and thus is most prone to flooding. Secondly, floodplain soils are poorly drained because of the nearness of the water table to surface and saturation by flood waters and thirdly, the floodplain must have been formed by incremental erosion and deposition associated with lateral migration of streams in their valleys. Therefore, the borders of the floodplain served as good indicators for the floodplain mapping. A good illustration of the abrupt change in topography, soil, drainage and vegetation from floodplain to the valley walls is shown on the floodplain areas mapped with various classes or units.

4.6 Hypothetical cross-section of the Sokoto-Rima Floodplain

The cross-section of the floodplain drawn on figure 18 is hypothetical, and it indicate the relationship between various units and gives additional information on the floodplain. Legend group L refers to the low terrace which occur like floe-like patches within the main floodplain. They usually have rather dense woody vegetation. Group F (Floe) is levee like parts with dense woody cover, tufted grasses characteristically high active termite mounds. Group T is the unit with sediments at top layers that are a mixture of floe, park and central deposits thicker than T_2. The sedimentary composition and also liability to flooding with accumulation in the subsurface layer Group C (central) occur in the central parts of the main floodplain. The soil seems to be the most important agriculturally because tall termites mounts, trees, shrubs, herbs, etc. are absent here. Group M (Micaceous) is flaked of mica and is abundant in recent sediments. It is relatively high textured.

Seven land irrigation classes have been suggested for a possible estimate of total land acreage and suitability analysis as some of the classes are likely to be (very suitable, moderately suited or suitable with some limitations) arising from flooding, uncontrolled flooding, unfavourable high alkalinity, excess moisture, poor drainage, difficulty in reclamation, etc.

4.7 Present Situation of the Floodplain

The main drainage is everywhere aggrading. Outcrops of rock are extremely rare in the floodplain. The main channels are flanked by floodplain between 80-120m wide, which extends for long distances up the main tributaries. In general, an upper and a lower floodplain can be distinguished, the former being the more extensive, particularly along the Sokoto river. The two floodplain elements are normally separated by a distinct step of about 3-8m but the vertical separation may increase to between 7-11m along the main channels (See plate 10 for a floodplain on Sokoto River around Bakura Village). The upper floodplain is generally or near high flood levels with surface apparently fairly stable while the lower floodplain is much less regular. It is traversed by the channel or braids of the main river and by numerous minor flood channels. Low sand bars alluvial flats and gravel mounds and spreads make up its surface. The main channels are up to 30-50m wide typically braided trench like in cross-section and with steep banks up to 7m high. The beds are flattish and sandy, except where subject to scour which produces irregular minor channels with deep holes, and intervening bars of unsorted boulder gravel.

The floodplain in its natural state (that is, before the construction of dams and reservoirs) the fadama received every year fine deposits of fertile alluvium. This is no longer the case, although flooding still occurs whenever large flows are released from Goronyo and Bakolori dams which act as gigantic silt trap. Despite the almost complete termination of this automatic topsoil renewal process, the agricultural potential of the fadama is high. Soils are generally good, water is available for most of the year and terrace and surface irrigation systems are relatively easy to construct.

The floodplain did have a significant influence on the hydrological features by de-silting, retaining and retarding floodwater. And it is important to have an idea about the expected return period of various floods downstream of the Goronyo-Reservoir.Floods is characterised by the peaks and volumes. In the case of the Rima at Goronyo, sudden flood peaks do not occur due to the size of the catchment approximately 80,000 km^2 net. Peak flows can last for two weeks; moreover since 1988 flows are regulated by the operation of the reservoir. Such that sudden peak releases are avoided. In the 1988 wet season volume of 1347mm^3 is less than the 1994 volume of 188mm^3. Nevertheless, daily total releases in 1988 of 350m^3/5 lasted for 30 days, while 1994 maximum of 352m^3/5 lasted for 26 days. Thus it is extremely difficult to estimate return periods for the downstream floods. Inundations were experienced in the floodplain downstream of Goronyo reservoir during the 1988, 1992 and 1994 wet seasons. These floods damaged parts of the emergency spillway and caused considerable erosion in the outlet-stilling basin. Although improving reservoir operation may reduce the damage, limited damage is unavoidable in the case of low probability floods. It is therefore important to know the frequency of floods to be expected at the reservoirs in order to take appropriate measures to protect the downstream irrigation infrastructures.

On the ground water potentials of the floodplain, the individual yields obtained from boreholes drilled in River Sokoto fadama were high ($400m^3$/day). The average among five successful borehole tapping, water in the alluvium at Tundafia yielded (by Suction pump) $1090m^3$/day with only 0.76m of drawdown below a static water level of 2m, (Anderson and Ogilbe 1973).

The aquifer storage in the fadama is increased when recharge occurs during the rainy season by infiltration of floodwater following periods of heavy rainfall or by perennial streams flowing over it. Therefore, the floodplain in the basin is clearly a source of water supply in the region and all crops especially vegetables need water to survive and prosper. And most of the uncertainty associated with rainfall can be eliminated through irrigation which is basically an artificial way of supplying water to the crops when nature herself does not provide it, the fadama can be an important source of irrigation water.

4.8 Digital Image Processing (Computer-Aided Analysis)

4.8.1 Preamble

Satellite remote sensing data are on the whole not acquired as pictures. Majority of satellite image data is transmitted to earth as digital values of the response of each pixel in the wavelength employed in the sensor. Only at a later stage are the digital value forms and plotted as pictures. Therefore, once an image is produced, then it is in digital form, further manipulations of data can readily be performed by computer to extract useful information from the data.

The four main components used for the analysis using both hardware and 'software includes:

a. Input of digital data using magnetic tape drive of the water Resources Institute, Kaduna High Density Digital Tape (HDDT) was converted to CCT.

b. Storage of the data on a hard disk of an IBM-PC and then on floppy diskettes.

c. Processing of the pixel data using the IDRISI software package of the Clark Laboratory.

d. Display of the data and of the analysis performed on the data using a colour monitor and printer.

4.8.2 Pattern Recognition

Various features on the image data were categorised into identifiable classes via extraction of significant attributes of the data from a background of details.

As our eyes perceive more colours than shades of grey, the use of coloured images on the IBM-PC (ACER view model 54 el.) has dramatically increased the amount of information that was visualised earlier on the normal/false colour composite on the image (see figure 16).

4.8.3 Image Classification

The geographical region convering Lugu dam at Wurno (near Sokoto) see plate 11 showing part of the dam and the irrigation area. It extends through River Rima to a small portion of Goronyo Lake was classified using the initial classification key applied for visual terrain analysis and floodplain delineation. However, the classification here was characterised qualitatively by the features remotely sensed spectral response.

First and foremost, Density Slicing was used which involves the grouping of image Digital numbers (DN), interactively. The effect of automatic thresholding is shown on table 9 where the 255 grey levels of the original images have been divided into several classes.

Contrary to the popular believe that computer classification of remotely sensed images is not a difficult part of image classification procedure, but in order to obtain

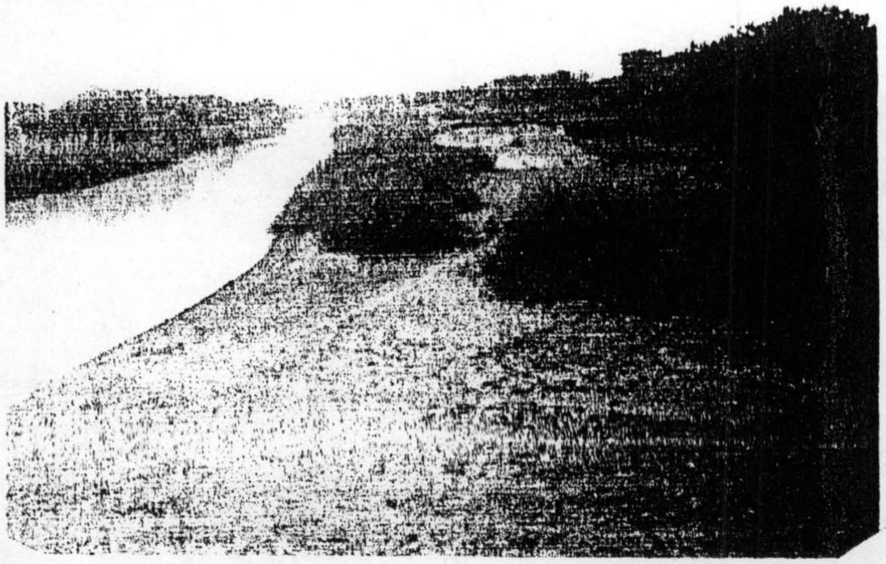


plate 9: Vegetated and non-vegetated wetland along Rima River

plate 10: Floodplain Area along Sokoto River at Bakura

obtain meaningful and accurate classification, there was also the need to interact with the image data on computer by supervising the classification in order to

Table 9: Image Classification/Reclassification using maximum Likelihood and qualitative (16)

Category	Colour	Landuse/Cover Class	Acres	Cell (pixel)	Percentage of Total
1.	Ash	Reservoir(s)	3.52278	14256	2.49%
2.	Light blue	Stream flow	0.09464	383	0.07%
3.	Greenish blue	Sediments	0.04571	185	0.03%
4.	Dark-grey	Vegetated wetland	6.4695	26181	4.58%
5.	Dark spots on flood-plains	Ditches/Ponds	1.75076	7085	1.24%
6.	Red	Floodplain	10.5241	42589	7.44%
7.	Pink	Rainfed cultivation	17.2996	70008	12.24%
8.	Light Pink	Laterite surface	26.8429	108628	18.99%
9.	Green	Shrubland	1.45628	5869	1.03%
10.	Yellowish/white	Sand-dunes with dry grasses	5.42774	21965	3.84%
11.	-	Unclassified	-	-	-
12.	Brown	Non-vegetated wetland	12.7772	51707	9.04%
13.	Light Green	Forest Reserves	10.1134	40927	7.15%
14.	Cyan/Blue	Bare Surfaces	45.0435	182282	31.86%
			163-166		Σ=572065

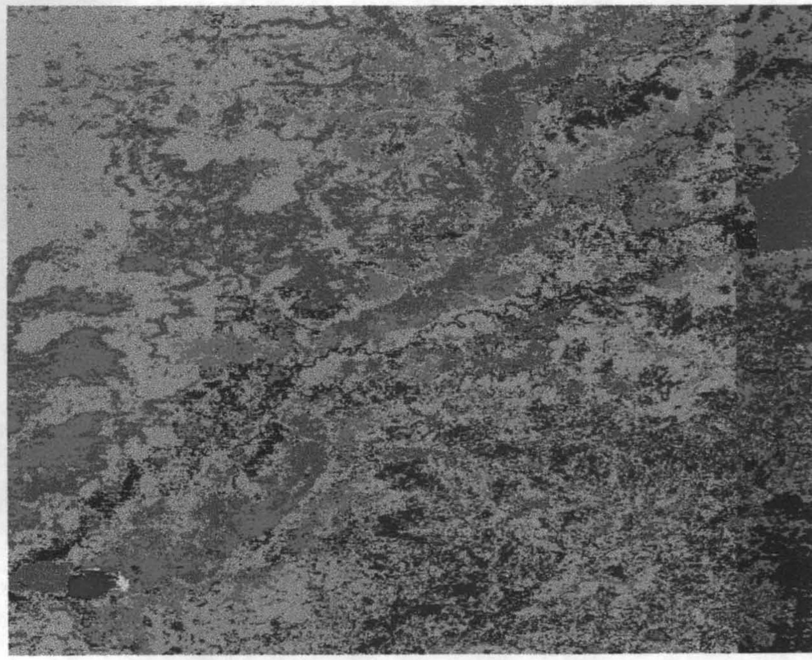
* Based on Landsat MSS Pixel dimensions of 57 x 79 meters

* Identified on 1987 Imagery only (1:250,000).

extrapolate and relate the results of the field check for the accurate assessment of the resultant image as displayed on figure 19.

The maximum likelihood model applied in the work determines the probability of all points in the feature space

Fig 19: PART OF RIMA FLOOD PLAIN
(COMPUTER AIDED CLASSIFICATION)



LEGEND

- RESERVIOR
- STREAM FLOW
- SEDIMENTS
- VEGETATED WETLAND
- DITCHES/PONDS
- FLOODPLAIN
- RAINFED CULTIVATED
- LATERITE SURFACE
- SHRUB LAND
- SAND DUNES
- UNCLASSIFIED
- NON VEGETATED WETLAND
- FOREST RESERVE
- BARE SURFACE

belonging to a particular class, so that each point has a probability of belonging to each class identified. The class for which any given point belongs is the class for which it has the highest probability, that is, the maximum likelihood of belonging to that class. The unclassified pixel on legend 11 was a result of the reclassification done to obtain a more reliable and accurate classification. From the general classification made, it is clear that the bare surface account for over 31% followed by laterite surfaces accounting for about 19%. The floodplains account for over 7% of the area.

4.8.4Area Quantification

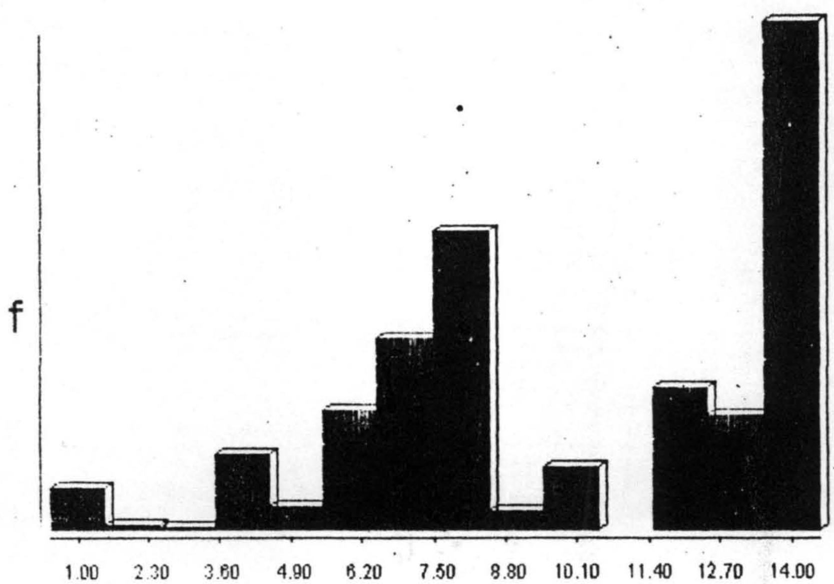
The area covered by each potential class was quantified to yield the results on table 9. Only the percentage coverage and acreages were computed, and a histograph is presented on figure 20.

Finally, it should be noted that the digital analysis does not suggest that visual interpretation of satellite imagery is not useful. It is, and using conventional procedures of interpretation, image tone, colour, size, shape, texture, etc. useful analysis can be obtained, but computer aided analysis is by far easier, faster, more accurate or reliable and indeed cost effective. However, in our case access to computer and appropriate algorithm i.e. software package makes visual interpretation still very relevant despite its time consumption, difficulties and other inadequacies. A brief comparative analysis between

Fig. 20

Histogram of Rima general classification
baba3r

Class width	-	1.0
Display minimum	-	1.0
Display maximum	-	14.0
Actual minimum	-	1.0
Actual maximum	-	14.0
Mean	-	10.0466
Stand. Deviation	-	3.6329
df	-	57.2064



Visual interpretation and digital image processing is given on table 10. It is clear that remote sensing posses greater advantages over the conventional methods of mapping.

Table 10: Comparison between Visual Analysis and Computer Aided Processing in Mapping Landsystems and Floodplain of Sokoto-Rima Basin.

Terrain Features	Major Indicators	
	Visual Interpretation Landsat MSS 1:250,00	Digital Analysis Landsat MSS 1:250,000
Geology	The major geological structures were readily identified and fully delineated using field check and the assistance of topographical map sheets	All features were easily depicted and they show up better
Geomorphology	Closely related to geology- similar difficulties were encountered as in geological mapping of the area. Relief impression were identified but not mappable	A better identification aided by the Digital values with good details
Floodplain	Delineated using contextual information and with great success	Floodplain and other fluvial terraces could easily be recognised without extensive use of contextual information, although not Mapbase in detail
Topography	Difficult to clearly depict escarpments with steep slopes	Escarpments and steep slopes were clearly depicted because of the terrain impression
Hydrology	Major streams are readily depicted and mappable in flatland but can be missed in highly cultivated areas	Major streams readily depicted and can be differentiated from surrounding landuse on flatland
Soils	It was impossible to delineate soil units even with local knowledge	Some inferences could be possible regarding boundaries due to soil moisture content
Landuse/cover	Colour and tonal	General classes of

	variation help in the delineation of vegetation cover. Although, urban settlements were detectable, but not Mapbase, the rural settlements were difficult to be identified	vegetation cover can be delineated. Differentiation can be made between various landuse classes and settlements are readily depicted using background knowledge
Infrastructure	Road network and railways are only perceived but not readily mappable. Paths and tracks are perceived within un-vegetated areas	The Road network and railways can be mapped th ough with very little detail. In un-vegetated area, path, and tracks could be mapped.

These results demonstrate that Landsat MSS can provide useful data for terrain analysis in mapping Landsystems drainage pattern, and floodplain delineation of the Sokoto-Rima River Basin Area. It should be noted however, that such analysis also has certain inherent limitations probably attributable to the resolution of the data. For instance, where traditional agriculture is practiced, only a general information regarding the type of agriculture (that is, fadama or Tudu) can be identified. Such baseline information can be useful in identifying location and extent of critical areas. Therefore, further detailed analysis utilising better resolution of Landsat TM and SPOT (HRV) with aerial photographs and a more detailed field surveys can be carried out in the area.

It is based on the work done here that a summary is given, and recommendations forwarded to different relevant organisations on how the research could be utilised to improve land and water resources development in the area for the over all benefit of the host community.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

The research, the aim of which has been to show some of the contributions satellite remote sensing can make to the study of large area, cost effectively. The way in which Sokoto-Rima River System could be mapped from satellite data - the only practical technique, by which this type of information can be provided, giving varied advantages.

The capabilities of LANDSAT MSS data in terrain analysis and map of drainage and floodplain areas in the semi-arid environment has been introduced. Its application in the northwestern region of Nigeria has demonstrated its ability to provide comprehensive information on the nature of the landscape, drainage patterns and the extent of floodplain areas. It has been demonstrated that satellite remote sensing can provide accurate and comprehensive information for such purposes. The results confirm that floodplain area downstream of Bakolori and Goronyo irrigation projects and within Gagare and Bunsuru rivers all support fadama cultivation and other dry season farming. However, there will be the need for continuous mapping of the Landsystems in the area. This is necessary for the protection of the land resources, and it will help to determine the extent of changes on the fadamaland for better utilisation of the agricultural potentials of the region.

Remote Sensing is indeed a highly effective method of conducting resource surveys, monitoring the natural and cultural environment and mapping. Both general and detailed investigations can be made accurately, quickly and at a fraction of the cost of the conventional survey methods. The developed world is now placing emphasis on the use of data derived from satellites including the use of multispectral and thermal Infrared sensing, Radar and other data acquisition techniques. Many of the most successful applications of Remote Sensing have been achieved through interpreting satellite imagery in conjunction with existing maps, and historical data. The wide scope of use for satellite data in many field of applications is mainly due to the fact that they can be processed by computers which was exploited. The software used to process the remote sensing data in this study is IDRISI whose capabilities proved effective in terrain evaluation and floodplain delineation using maximum likelihood classification and reclassification of signatures. From the foregoing, it is very clear that the ability of satellites to monitor and deliver resource data with uniform characteristics on global basis may strengthen opportunities for international communication among resource scientists within and across disciplinary lines.

5.2 Uses of the Maps produced

The maps produced gives a general picture of the terrain within the Sokoto Rima River system, and the floodplain areas of the basin with a preliminary cross-section of the floodplain. These maps and the report are useful for future decision on landuse in the area. These include the possibility of detailed soil analysis, suitability analysis; water quality, physical properties, etc. In fact Landsat imagery provides a valuable tool and could be used by various disciplines repeatedly at various times as a source of data for small-scale analysis and planning in the future. There is a need for further work in this project area especially on the optimum utilisation of the floodplain delineation for agricultural production (that is, detailed planning of irrigation schemes).

Depending on technical and financial resources that will be made available for agricultural development in the future, coupled with good management and skilful farming within the floodplain areas, large proportion of the fadama land could be improved using the various maps produced. The floodplain could be utilised properly, and other areas could be reclaimed by construction of polders. The maps will prove useful in floodplain management and detailed floodplain zoning in the future. It will also help in the establishment of areas susceptible to floods of various magnitude .It will help in the establishment of criteria for use of the floodplain areas. And provide information aimed at reducing flood hazards .It will also provide improvements during emergency operations, and above all pave way for flood insurance scheme within the basin. Other multiplier benefit exists from the study.

5.3 Other Benefits of the Research

The project will provide a unique source of information of direct value to the Sokoto-Rima River Basin Authority. And other relevant agencies and perhaps the National Fadama Development Project (NFDP), National Agricultural Land Development Authority (NALDA), Agricultural Development Authority (ADP) and others who may wish to adopt remote sensing strategies for their own purposes. It is also anticipated that other River Basin Development Authorities, will appreciate the benefit of acquiring resource information from Remote Sensing data and will therefore, commit themselves to the extended use of remote sensing data and cartographic techniques in their respective areas of jurisdiction in the future.

The fundamental significance of land and water in the development process will make the project methodology and result is of considerable assistance to various government organisations and private land developers.

It is also envisaged that the project will be of direct assistance to National Planning and Agricultural and Water Resource Institutes, as it will increase awareness of the value of Satellite remote sensing in National development efforts and help in solving various environmental resource problems. Its utility should not be lost on similar areas (that is, semi-arid environment in West Africa) that have similarity of environmental problems and the need to try the technique where current information is either non-existent or severally dated.

5.4 **Achievements**

The major achievement of this work is its ability to successfully use a reliable, cost effective, timely- and reliable tool (i.e., Land resources satellite data) to attempt a terrain analysis by mapping Land systems and delineating floodplain areas .The study also uses both visual interpretation and digital (Computer-Assisted) analysis. This project will provide a yardstick for further developmental purposes in the area. It is also clear that the research has been able to address in part, the Food and Agricultural Organisation's (FAO's) recommendations .In its assessment of the country's food situation for its improvement in Nigeria, the objectives of which are yet to be achieved. This is due in large part to the lack of relevant resource information. The recommendations includes:

1. The need to identify and map the riverine areas capable of development for increasing agriculture
2. The needs to identify and map areas suitable for dry season farming

3. The importance of establishing a system of permanent farming

4. The need for adequate agricultural and related statistics.

5.5 Recommendations

Planning for agricultural development at a national scale requires knowledge about changes in agricultural landuse pattern over a very large area. Such information would help to identify regions where agricultural lands are being depleted or are under environmental stress, as well as suggest areas suitable for agricultural expansion. The most reliable and cost effective method will involve the use of remote sensing techniques using multi-temporal aerial photographs coverage of a region and the use of satellite monitoring approach as adopted in this study.

The repetitive and extensive coverage of satellite remote sensing systems, particularly the Landsat-series are capable of imaging an identical 34,225 Sq.km area on the earth every 16 days, can provide a primary source of information for monitoring change in areas where traditional data sources do not exist. Changes can be identified comparing two sets of Landsat imageries taken from the same area at different dates.

It is also recommended that enhanced techniques such as overlay methods of vegetation indexing be used to identify sensitive to the types of change characteristics of the floodplain in the downstream areas of the reservoirs. Classification techniques on the other hand are able to generate valuable information about the types of change that has occurred. A procedure incorporating both techniques will not only allow phenological (natural) and human induced changes to be separated but also allow the precise dynamics of change to be determined.

The result of this study suggests the need for more or widespread use of satellite remote sensing not only in the basin but also in others as it will help to establish the present state of the country's agricultural resource base and provide valuable information for its future development.

Intergreted river basin development has obvious advantages in terms of convenience, practical planning in handling development projects and to some extent socio-economic considerations. This recommends it for adoption and continuous sustenance by way of adequate funding, infrastructures and staffing.

Development on floodplain must proceed with extreme caution as annual losses of life and property are staggering. In addition the danger of flooding and serious limitations are imposed by variable soils and high ground water table. If development is to take place on floodplain, it must be preceded by a careful study of the soil; internal drainage, groundwater conditions and the frequency or severity of flooding that can be expected. Floodplains are infact better flooding that can be expected. Floodplains are infact better suited for agricultural uses that can withstand periodic flooding with comparatively low losses.

Mapping floodplain for developmental planning and flood insurance purposes has received major emphasis in United States of America. It is also my candid suggestion that flood insurance programme be established within the basin to serve as one of the controls to limit development in floodplain.

The Sokoto-Rima River Basin Development Authority should consider adopting gate operation table in Goronyo and Bakolori Lakes as soon as possible. In such a way that the beginning of the wet season when there are only small demands on the reservoirs, to create storage to accommodate the wet season floods. While at the end of the wet season floods before the onset of the dry season, the level should be raised.

The hydrological department should be equipped to collect accurate information on reservoir H_2O levels, gate settings, releases and most importantly in and outflows in order to be able to apply statistical techniques with respect to inflow in any year.

Finally, as the most obvious threat to stable ecological stability in Sudan Sahel belt is the emergence of sahel type shrub vegetation due to deforestation, the problem is imminent to an extent that areas north of latitude 10°N may become proper sahel if no immediate action is taken

(Adefolalu, 1990). Since lack of vision about how to develop Nigeria without disturbing the environment to the point of destruction is one ultimate cause for recurrence of drought and desertification. Then the vision 2010 Committee and its subsequent implementation has a task of considering some of the inputs made in order to ameliorate the climatic scourge (drought and flooding) in the study area.

5.6 Conclusion

This work suggests that the lack of relevant information on the increasing, rates of destruction of floodplain is partially responsible for the food production problems presently experienced by Nigeria. Consequently, the implementation of River Basin Development Authority's large scale agricultural projects such as the Bakolori and Goronyo irrigation projects must be preceded by adequate funding/implementation and monitoring. Above all the continued assessment of predicted impacts and beneficial or harmful side effects, especially in the fadamaland downstream of the developments. To accomplish these, information on changes that have occurred in the floodplain and other land areas is indeed essential. It has been shown that satellite remote sensing provide baseline information for mapping the entire terrain.

Finally, it should be noted that the study area has some serious complexities of terrain, which may hamper change detection using Landsat mss data. Therefore, with the advent of Landsat thematic mapper (Tm) and SPOT (HRV) imagery with higher resolution, its use in conjunction with other remotely sensed data will enhanced results. This could be used for other investigations in the area.

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