APPLICATION OF GIS TECHNIQUES IN MAPPING LAND USE/LAND COVER FOR NATURAL RESOURCE MANAGEMENT:

A CASE STUDY OF THE UPPER UASO NYIRO RIVER CATCHMENT

BY

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DECLARATIONS

This thesis is my original work and has not been presented for a degree to any other University.

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This thesis has been submitted for examination with my approval as University Supervisor.

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ABSTRACT

As pressure on land and water resources continue to mount, the ability to accurately assess resource conditions and trends becomes even more essential. Hence there is need for integrated information which is computer amenable to facilitate effective and timely manipulation. Geoinformatics comprises all the fields that are related to the collection, processing, output and the use of land information e.g. Remote Sensing (including photogrammetry), GIS, Cartography etc. This study aimed at investigating the use of two tools of Geoinformatics, i.e. GIS and Remote Sensing in managing the natural resources of the *Upper Uaso Ny'iro river catchment.*

A user needs assessment was carried out to establish the desirable contents of a proposed GIS database. A Landsat MSS image was used to manually produce a land-use/land-cover map which was later digitized and combined with other data (such as the road network, drainage network, and major centres) in the database. GIS analysis was then performed on the database using Arc/Info and ArcView software packages. Various GIS products, which could be useful for various user needs, were output.

Results obtained revealed that tremendous savings in time and money can be achieved by using these Geoinformatics tools. The study has demonstrated that resource planners can now rapidly produce a combination of maps and tables that can be used for monitoring, modelling and management of natural resources in the Upper Uaso Ny'iro river basin, and other, similar regions.

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DEDICATION

This thesis is dedicated to my husband ***Dr. Anthony Karanja Wanyoro*** *for his patience, encouragement and for standing by me at the most trying moments. Thank you for having faith in me.*

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INTRODUCTION

1.1 GENERAL BACKGROUND

In 1984, the University of Nairobi in collaboration with the Rockefeller Foundation initiated a research project in Laikipia District with the following objectives:-

a) To develop management tools that can be used to evaluate:-
   - the interaction of highland-lowland production systems.
   - the effects of landuse and management changes on soil and vegetation resources.
   - the effects of land and water-use patterns on economic performance, environmental quality and human welfare.

b) To strengthen field research and modelling capacities of the partner institutions and improve collaboration among the institutions.

c) Application of the management tools as decision support system for resource management at district and or river basin level.

[Gichuki, 1993]

The research project focused on the Upper Uaso Ny'iro catchment area. This catchment area has been undergoing environmental changes as a result of:-

a) population dynamics,

b) land-use activities,

c) land subdivision, and

d) irrigation practices

[Taiti, 1992].

Population pressure in this region started building up after 1963, when former settler farmers and ranchers started selling their farms and ranches to indigeneous land buying companies. As a result of this, there has been a drastic increase in population due to immigration into the area by farming communities in the last two decades. Kohler (1987) reported that the population of Laikipia district has been growing at an annual rate of 7.3% due to immigration and natural increases.

Also there have been changes in land use practices from extensive grazing by the indigenous people of the area to small scale farming and irrigation by people who have immigrated into the area in recent times.

Approximately 25% of the district land area has been subdivided and is under small scale agriculture with family holdings of 1-4 hectares. The main subsistence crops include maize, beans, potatoes, peas and agricultural crops in irrigated areas.

Irrigation practices have caused a reduction of water in the lower parts of the river and consequently wild animals, e.g. elephants, antelopes, buffaloes, etc have had to move upwards along the river in search of water, in the process causing extensive damage to crops. This has had an adverse effect on the community at large, who now live in constant fear of the animals.

The need to carry out a detailed study of this area was necessitated by the following factors:-

a) it is one of the least studied river basins in Kenya;
b) it is the main source of water to the community surrounding it;
c) it has both highland and lowland regions, and there is need to study their interactions;
d) presence of agro-ecological zones, i.e. both high and low potential regions;
e) ethnic groups categorization of landusers, i.e. there are old settlers who are pastoralists and new settlers who are farmers;
f) the dynamic nature of landuse practices which includes agriculture, livestock and wildlife.

[Gichuki, 1993]

In order to address these issues, there is need for an update of spatial information which planners can rely on to make decisions on the resources allocation and management of the Upper Uaso Ny'iro catchment area. A lot of research is already being undertaken which includes extensive modelling of soil water balance, primary production, hydrology and water resource allocation. The kind of spatial information that would be necessary to carry out these studies includes landuse and landcover, soil types, vegetation, water sources, population distribution, infrastructure and the topography. This information will facilitate the comprehensive analysis of issues like, soil erosion, water resources allocation, food production and population distribution.

1.2 STATEMENT OF THE PROBLEM

A variety of spatial data for the Upper Uaso Ny'iro catchment area exists; these include topographic maps at varying scales, e.g. 1:50,000, 1:100,00, 1:250,000, aerial photographs, national water master plan, tabulated data, charts and field data. It is evident that the data available is from diverse sources in different formats and scales and is also static in nature. The use of such spatial information is encumbered by the following facts:-

a) The information is not in an integrated form which can be used effectively by planners to support environmental planning, resources management and policy decision making. In this case it is very difficult to accurately derive any information from the original datasets pertaining to, say, population versus water sources. Thus a planner who wishes to find solutions to the water allocation problem would have to go through a tedious process of trying to consolidate the data, before coming up with a solution. This entails a lot of effort and results in wastage of time.

b) Addition of any new information onto the already existing map, necessitates redrawing the whole map, resulting in duplication of effort and waste of funds. Land-use practises have been very dynamic in this region and hence there is need to update this information frequently. This is in connection with map revision and editing of information. For instance, further subdivisions could have taken place since the map was produced and there is need to reflect this on the map so that a planner using this map will have the true picture of the current situation, so that the decisions made will be based on up-to-date information.

c) It is difficult to establish the spatial relationship between the various thematic categories, for instance, which soil types support which kind of vegetation. By having this kind of information it is then possible to advise the community on what crops thrive best in what kind of soil. However this requires a lot of effort and time and in some cases is equivalent to drawing another map altogether.

d) Some information is more explicit at a given scale compared to others and with this kind of data it is not possible to change the scale at will to highlight a feature of interest. One may wish, for instance, to investigate the rate of deforestation, thus requiring that forest information be more highlighted as compared to other spatial data. This is essentially a function of the scale and if this is to be done then the scale should be varied accordingly. However with this kind of data in static mode using such data becomes a real handicap.

e) The map available for this area should be useable for a variety of applications and ought not to be tailored to specific applications only. This implies that on the same map for instance, are rivers, roads, ranches, vegetation, forests, topography, etc which might need to be represented differently at different times. Hence, if one be only interested in the topography, for instance, then all the other features need not be represented, in fact at times such other information hinders one from concentrating on the specific feature of interest.

As pressures on land and water resources continue to mount, the ability to accurately assess resource conditions and trends becomes ever more essential. Consequently, there is need for integrated information which is computer amenable to facilitate easy and effective manipulation.

In support of the above enumerated activities in this study, it is proposed to generate a land-use/land-cover map to support the main study by employing Geographic Information Systems (GIS) and Remote Sensing techniques. GIS is today the most effective technique for analyzing multi-layered georeferenced data in computer mode, as it provides a means of converting spatial data into digitized form that can be displayed, manipulated, modified and reproduced quickly in a new format as either a softcopy for visual display or hardcopy. With GIS it becomes therefore possible for the resource planner to rapidly produce a combination of maps and tables that show "where" and "what", and to answer questions such as:-

a) What is the present and potential fuelwood production within say X kilometres of Town A?

b) Where should a given food-processing facility be located? What raw materials or markets are within 300 km of the site? What and where are the available transport and power systems?

c) What are the locations and sizes of zones within a certain administrative unit that satisfy a given set of conditions, such as:

- soil type A or B;
- amount of rainfall between C and D mm;
- temperature between X and Y degrees;
- Population density and income distribution at E and F respectively; and
- distance to roads less than G km?

On the other hand, most geographic information system applications require the collection of data over large geographic areas for which remotely sensed data are ideal. Moreover, the ability to provide precise and reliable information lies in the fact that satellites provide frequent and repeatable coverage of the same area, for instance, Landsat registers the same area every 16 days whereas for Spot the repeatability is every 26 days; this ensures that information stored in the database is updated frequently. However, this still must be complimented by other data e.g. from plans, charts, tables and field data.

1.3 OBJECTIVES OF THE STUDY

The main objective of this study was to investigate the use of Geographic Information Systems (GIS) and Remote Sensing tools for natural resource management. The specific objectives were:-

a) Review of the state of art in mapping natural resources.

b) Formulation of mapping strategies based on user requirements.

c) Production of the required databases and maps.

d) Application of databases and maps to natural resource management.

1.4 ABOUT THE STUDY AREA

The study area is part of the Upper Uaso Ny'iro river basin. It is located to the East of Laikipia district and runs from the north of Mount Kenya to Archer's Post covering an area of approximately 3,500sq.Km. It is bounded approximately by longitudes 37° 00'E and 37° 45'E, and latitudes 0° 45'N and 0° 14'S. Fig 1.1 shows the location of the study area within the river basin as well as the main communication routes and the main centres, whereas Fig 1.2 shows the location of the study area within Kenya.

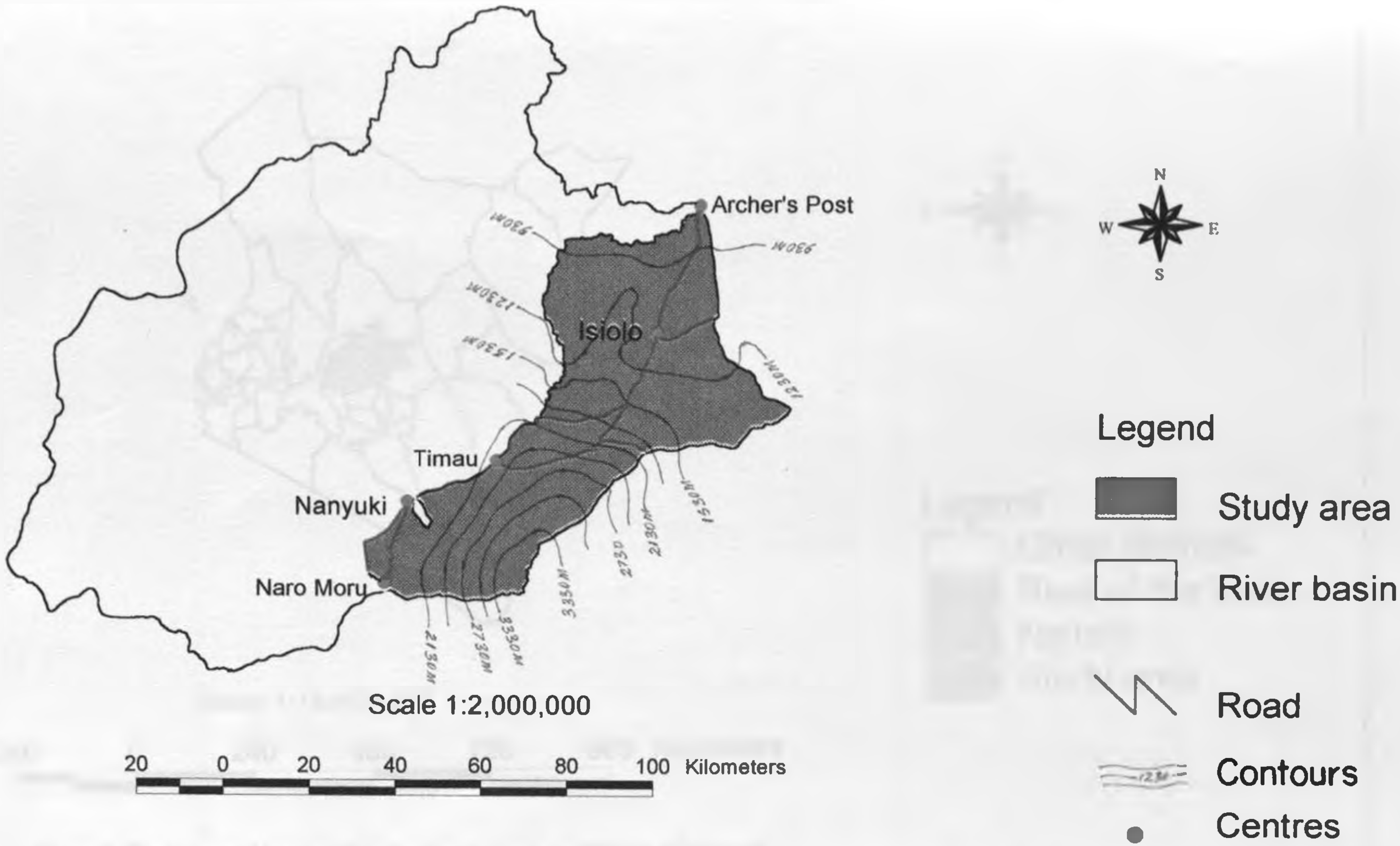


Fig 1.1: Location of study area within the Upper Uaso Nyiro river basin, main communication routes and centres

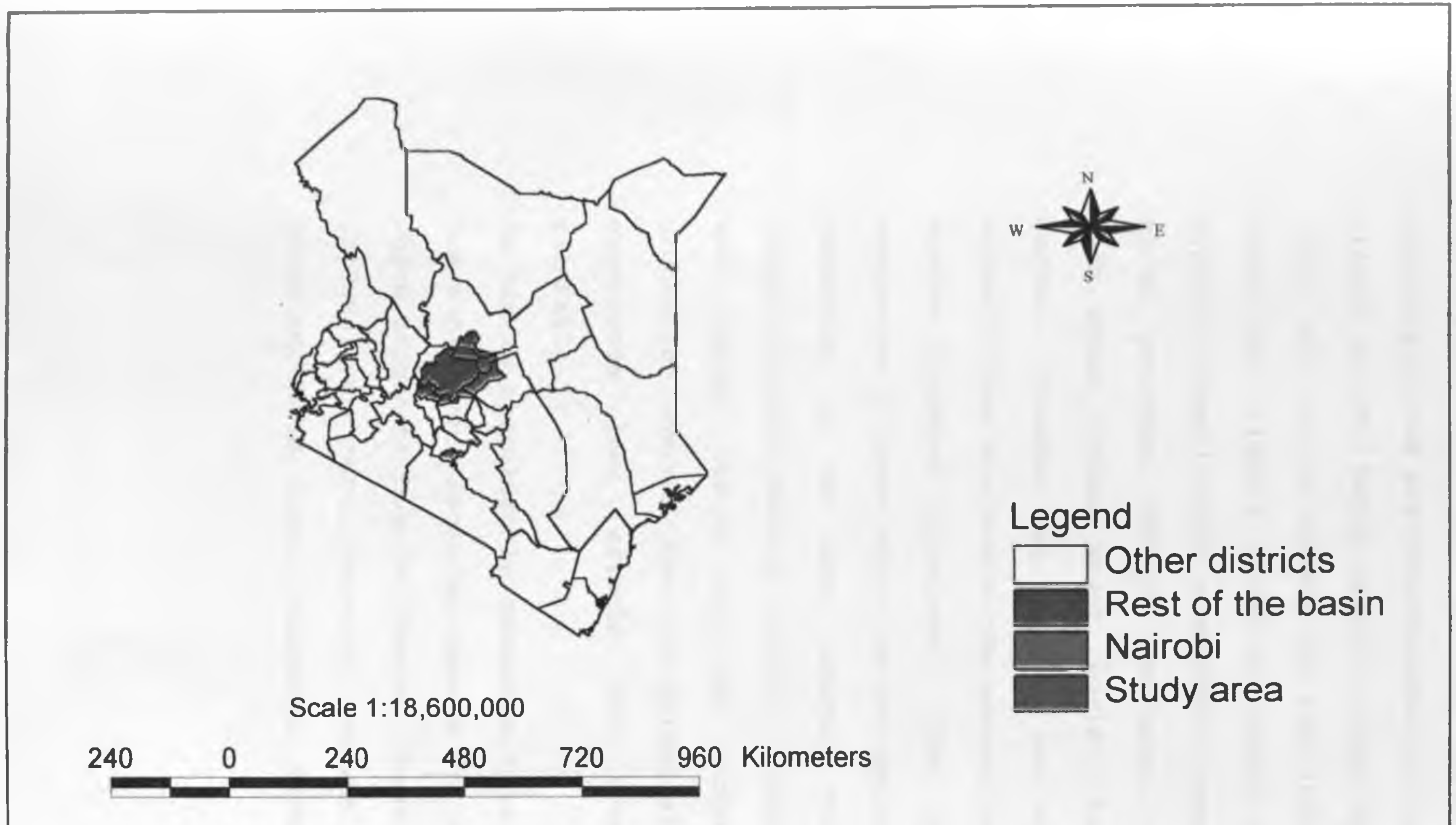


Fig 1.2: Location of study area within Kenya

F.N. KAMIRU, 1996

This region is characterized by:-

a) Presence of both high and low agricultural potential areas, where the high agricultural potential areas are concentrated in the south around the Mt. Kenya region, around Nyambene hills and in the middle of the study area below and slightly above the Ndare forest. Typical crops include subsistence crops e.g. maize, potatoes, cabbages and beans, whereas cash crops include wheat, barley, tea, and coffee. Towards the north as one moves to Archer's Post via Isiolo the general cover is sparse shrubbed grassland. The Rainfall regime has a direct effect on the agricultural potential in the area, whereby the high potential areas receive rainfall consistently and thereby result in high agricultural production whereas the low potential areas experience low, erratic and unreliable rainfall.

b) As far as hydrology is concerned this region has many rivers crossing through it, most of which originate from Mt. Kenya. These rivers include Naro Moru, Burguret, Nanyuki, Liki North and South, Timau, Teleswani, Western and

Eastern Marania, and Engare Ondare river. All these rivers drain their waters into the main Uaso Ny'iro river.

c) This region has been experiencing population increases due to immigration into the area by farming communities and as a result there are two categories of land-users, i.e. there are old settlers who are pastoralists and new settlers who are farmers. Also there has been a lot of subdivision of the former settler ranches which have been sold to indigeneous land buying companies. The land is now under small scale agriculture with family holdings of between 1 and 4 hectares [Taiti, 1992].

1.5 ORGANIZATION OF THE REPORT

The report is organized into seven chapters. In the next chapter, a literature review related to the study is given. In Chapter 3, the technology of Geographical Information Systems is described and deals with the general overview of a GIS, the components of a GIS, common GIS packages, choosing a GIS, the status of GIS in Kenya at large and the general overview of Arc/Info the particular GIS software used in this study ; its features are highlighted and the suitability of the software for the study is also given. Chapter 4 deals with the process of developing a digital database for the Upper Uaso Ny'iro catchment area and the analysis of the study area. Chapter 5 gives the results and the analysis of the results. Chapter 6,discusses the results, whereas chapter 7, gives the summary, conclusions and recommendations of the study. Finally, there is a list of references and the appendices.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

Advances in computing technology in the last few years have been so rapid that it is difficult to evaluate the many alternatives offered today for high speed interactive computing. As a result of these developments in computing technology, electronic computers are today involved in almost every aspect of the map-making process which is mainly an interactive process. This involvement has become so extensive that it is practically impossible to find a recently developed process or device in the mapping field which does not employ digital processing in one form or another. This trend, which has been evolving over two decades, has been accelerated by the significant improvements in capability, reliability and cost-effectiveness of electronic devices [Elessal, 1985].

A major factor hindering research and application oriented studies of environmental issues for instance, biodiversity, population distribution, soil erosion, demography, deforestation, water resources allocation problems, food production, and land-use practices, etc for the Upper Uaso Ny'iro catchment area today, is that adequate data do not exist. An adequate map is characterized by three major factors, namely; scale, thematic content, and timeliness [Htun, 1993].

Some of the assumptions made about required maps are:-

a) it already exists;

b) it contains the information needed;

c) it is accurate; and

d) it is up-to-date.

However, it is important to note that the information is dated when it is collected and maps resulting from such information can have limited utility for certain types of studies. Some mapped information are more perishable than others, e.g. continental outlines are not as perishable as compared to deforestation. The case of Upper Uaso Ny'iro catchment area has been very dynamic due to immigrations, landuse activities, land subdivision, and irrigation practices. Kohler [1987], carried out a study on the population increases in this region and found out that the population of Laikipia district increased at an annual rate of 7.3% due to immigration and natural increases. A further study of the area on population and land-use changes for the period between 1960 and 1990 was conducted by Taiti [1992].

A lot of land subdivision has taken place in this region. It is reported that approximately 25% of the district land area has been subdivided and is under small scale agriculture with family holdings of 1-4 hectares [Taiti, 1992]. Therefore, frequent up-date of this spatial information is necessary so as to reflect the current situation. However, this has not been the case due to the fact that the time taken to produce a map can take 1-2 years. Since the value of data is related to its currency and timeliness, for purposes of monitoring landuse patterns such as for the Upper Uaso Ny'iro catchment area this map would not be adequate. The fundamental problem lies in the fact that mapping is a complex, expensive and time-consuming task.

The evolution of the map-making processes is outlined by Edward [1988]. During the 1960s and 1970s, new trends arose in the way maps were being used to assess resources and to plan land use. Realizing that different aspects of the earth's surface did not function independently of each other, people began to want to evaluate them in an integrated, multidisciplinary way. In the case of the Upper Uaso Ny'iro catchment area there is, for instance, the need to establish the relationship between land-use/land-cover and the drainage network. One way of doing this would be to simply overlay transparent copies of resource maps on light tables and look for places where the various attributes on the map coincided. This technique was adapted to emerging computer technology of making simple maps by printing statistical values on a grid plain paper, overlaying these grid values and using the overprinting of lineprinter characters to produce suitable grey scales representing the statistical values, in what was known as a grid-cell or raster system. The results of these early methods, however, were not refined enough to find acceptance among users.

These early methods of producing maps have a number of drawbacks:-

(a) The map is produced at one scale e.g. 1:50,000 and this implies that enlarging or reducing the scale must be achieved photographically at an extra cost and inconvenience.

(b) The map so generated can be used for a variety of applications for instance, the 1:50,000 series covering the Upper Uaso Ny'iro catchment area contains contours, rivers, roads, land-use patterns, forests and vegetation types, and therefore the static map can not be enhanced for special applications due to its' static nature.

(c) To be used in a Geographic Information System (GIS) it has to be converted into digital form.

(d) The process of producing this static map is labour intensive and time consuming.

By the late 1970s, the technology of computer map-making had advanced quite rapidly, with literally hundreds of computer systems and programs being developed for various cartographic applications. At the same time, advances were being made in a number of related fields, including soil science, surveying, photogrammetry and remote sensing. The rapid pace of this development initially resulted in much duplication of effort in the various related disciplines, but as systems multiplied and experience was gained, the potential for linking different kinds of spatial data processing together into truly general-purpose geographic systems emerged [Edward 1988].

By the late 1980s, as a result of computer technology becoming more sophisticated, less expensive and more widely adopted, GIS finally made its way through. Systems are rapidly being established by public agencies, research laboratories, academic institutions, private industries, the military and public utilities [Edouard,1988].

Consequently, the drawbacks encountered when using the conventional methods of producing maps for the Upper Uaso Ny'iro catchment area can be overcome through use of digital maps (softcopy maps) such that:-

(a) The scale can be adjusted or changed rapidly at will within the computer to suit users requirements.

(b) The information on the map can be categorized into different themes, e.g. in this particular study area the different themes will include land-use/land-cover types, main rivers, main roads, and main centres.

Spatial data for the Upper Uaso Ny'iro catchment area are available in different formats. The available data sources include, topographic maps at varying scales e.g. 1:50,000, 1:100,000, 1:250,000, aerial photographs, Landsat MSS data at a scale of 1:250,000, and field data. The technique of integrating several sources of data into one homogenous system have been developed and tested. Algorithms to accept topographic and thematic digitized data from a variety of sources, to permit the selection and amalgamation of the data in any arbitrary manner, and to map or quantify the desired thematic information have been developed [Collins 1981; Moon 1981]. To test these algorithms an area of size 31Km by 36Km with grid size 25m square in Guelph, Canada was used. The analyses performed included determining all road intersections and their orders and the number of gravel pits within 200m of a railway line.

Use of GIS and Remote Sensing techniques will be employed for the case of Upper Uaso Ny'iro catchment area. Related work on use of GIS and Remote Sensing techniques have been reported for instance by Adrea and Llyod [1993]. The study aimed at identifying potential nesting habitats of greater sandhill cranes in northwestern Minnesota. The modelling approach involved five fundamental steps namely, generating data layers, describing nest sites, testing for discrepancies between observed and expected distributions of nest sites, generation of the model and assessing the model. The results revealed that these two techniques can be used effectively for monitoring bird hazards.

Another example of the application of GIS and remote sensing technology was in the study of land resources in the arid zone of Australia [Zhou, Q., 1989]. In this case, the objective was to interface the two technologies in which the resulting system consisted of two interrelated subsystems: an image database which handles spatial data-sets, such as topography and Landsat imagery, using spatial modelling techniques, and a spatial database management which handles attribute data relating to these spatial data coverages. It was discovered that with these two technologies more useful information for the land manager can be obtained from the existing database to establish a real time land management system. Upper Uaso Ny'iro catchment area requires such a system which resource planners and policy makers can rely on to obtain real time information on the area and thereby make timely decisions. This will only be possible if all the necessary information is entered in a database which can be queried.

The environmental issues that need to be addressed for the case of the Upper Uaso Ny'iro catchment area include landuse and landcover, vegetation, soils, hydrology, population distribution and the topography. The difficulty in integrating these environmental issues for management purposes was realized for instance in Kathmandu, Nepal [Schmidt 1993]. There was growing concern by scientists, resource managers and policy makers over the world's environmental demands that required immediate and urgent attention. The case study of Lalitpur was chosen and five themes identified, namely; landuse, population, agro-ecological zonation, hydro-electricity potential and service centre locations. By using GIS it was possible to store, retrieve, analyze, manipulate, display and integrate environmental, economic and social data in a single system; in this way information became more accessible to planners and policy makers.

To help realise the objectives of the main study for the Upper Uaso Ny'iro catchment area, there is need for a land-use and land-cover map. It is proposed that available remotely sensed data from Landsat MSS will be used for this purpose. The results of a computer-based automated sample selection of the Tampa, Florida land-use and land-cover map produced by the U.S. Geological Survey at a scale of 1:250,000 from remotely sensed data were found to be more comprehensive than the results of a manual sample selection in estimating the accuracy of the land-use and land-cover map [Fitzpatrick-Lins 1981].

A pilot study on the use of GIS for landuse planning in the north-west coast of Egypt was conducted by Mathias [1993]. The results demonstrated further the effectiveness of GIS as a tool in the integration of remote sensing data and thematic maps, and yields data intersections and model development for alternative landuse, thereby promoting dialogue amongst interest groups in the process of landuse planning. This approach would be quite relevant for the case of Upper Uaso Ny'iro catchment area, in which a lot of modelling will have to be carried out, in order to come up with the best alternatives for resources management. Other modelling examples carried out to establish the best alternative, in different parts of the world are as follows:-

a) Digitally processed Landsat MSS data and GIS technology have been successfully applied to work out a land suitability classification for reforestation activities in Southern Sri Lanka. The methodology was designed to solve three main problems, namely to establish where forest cover exists, regions of reforestation and regions impossible for reforestation. The results demonstrated that about 17% of the total land area was classified as practically considerable for reforestation; more than 80% of this area was categorized as highly suitable for reforestation [Perera, Kajiwara and Tateishsi, 1993].

b) GIS approach was used by United States Development Authority (USDA) soil conservation service to develop agricultural land evaluation and site assessment system to determine the quality of land for agricultural uses and to assess agricultural land areas for their economic viability. The results demonstrated that this approach facilitates wide area modelling and allows a more flexible site analysis [Williams, 1985].

c) Another soil study was conducted using remotely sensed data. [Imhoff et al, 1982]. In this case cartographic soils data were digitized, spatially registered and merged with processed landsat data to produce image products useful for soil unit boundary delineation. The overlay of cartographic data on Landsat data facilitates comparisons between the various processing methods used for soil unit boundary determination, delineation and verification.

These examples, clearly illustrate that GIS and Remote Sensing have become very powerful tools for the resource planner. It is now possible to produce a combination of maps and tables that show "where" and "what" by simply querying the geographical database and extracting the information of interest. Areas whose environmental issues could not be addressed sufficiently e.g. the Upper Uaso Ny'iro catchment area for lack of adequate maps can now be addressed so long as the necessary databases have been created.

In recent years it has become apparent that the generation and maintenance of geographic databases is a major bottleneck and expense in the operational implementation of GIS [Aronoff, 1987; Ayabet 1990]. On the other hand, new sensors and progress in imaging technology have rapidly increased the capability of remote sensing to acquire digital spatial data at various levels of resolution. The advent of high resolution detectors intensified the interests of the GIS community in the potential of digital imagery as a source for geographic information. Growth in the GIS market, advances in hardware and software, and reductions in the cost of computer workstations have further stimulated these developments.

The fact that remotely sensed digital imagery has been widely used in raster-oriented GIS especially in environmental land resource and land-use analysis, its contribution to vector GIS remained limited. However, technological advances and the widening availability of high resolution satellite data, has begun to change this. Satellite data can now be integrated within vector-based GIS for applications such as topographic base map production and map revision, three-dimensional terrain analysis and visualization, change detection, environmental impact analysis and image segmentation [Ehlers, 1993].

Moreover, high resolution satellite data are a valuable source of global and regional environmental information and can be particularly useful in situations where no other or no reliable map information is available [Mather, 1990]. The combination of remote sensing with GIS is most promising. Earth observing satellites provide a new perspective of the world and they provide a powerful source of information for the management of our planets resources. Consequently, the use of data from satellite will play an increasing role for GIS as it will be capable of providing regular, reliable, timely and accurate geographic information at ever finer resolutions. Hence GIS technology is generally perceived as the most versatile, flexible and effective method for storage and interrogation of remotely sensed data for monitoring environmental resources [Sayn-Wittgenstein, 1993].

Remote sensing and GIS will not be fully appreciated until they are technically linked with the models used in process-oriented science. The immediate technical requirement is to facilitate the exchange of raster image data and other GIS data (raster and vector) in order to access the functionality already available in GIS [Dobson, 1993].

CHAPTER 3

GEOGRAPHIC INFORMATION SYSTEMS

3.1 GENERAL OVERVIEW

This chapter describes the nature of Geographic Information Systems in general.

The term *Geographic Information Systems* (GIS) is currently being applied to computerized information storage, processing and retrieval systems that have hardware and software specifically designed to cope with geographically referenced spatial data and the corresponding attribute information [Edward, 1988]. The spatial data are commonly in the form of maps, which may depict topography, water availability, soil types, vegetation, climate, geology, population, land ownership, administrative boundaries, infrastructure, etc . The capability of combining different data sets in an operation known as overlaying is one of the most important attributes of GIS.

Essentially, a GIS provides a means of taking a lot of different kinds of information, processing it into compatible data sets, combining it and displaying the results either in hardcopy or softcopy form. Some of the standard GIS capabilities include:-

a) integrating maps made at different scales, different projections, or different legends;

b) overlaying different types of maps of a particular area to make a new map that combines the attributes of the individual maps. For instance, a vegetation map could be overlaid on a soil map, and the resultant map could in turn be overlaid say, on a map showing the length of growing season, thereby producing a land-suitability map for a given crop;

c) generating buffer or proximity zones around lines or polygons on a map. This technique is used to find areas within a given distance from roads, rivers, etc., or from certain thematic conditions. These buffer zones can in turn be used as another layer in overlaying operations;

d) changes of scale, projections, legends, lettering, etc., on maps.

3.2 THE COMPONENTS OF A GIS

Geographic Information Systems have four important components, namely; the computer hardware, sets of application software modules, data, and a proper organizational context.

3.2.1 COMPUTER HARDWARE

The general hardware configuration for a geographic informationm system is as shown in Fig. 3.1

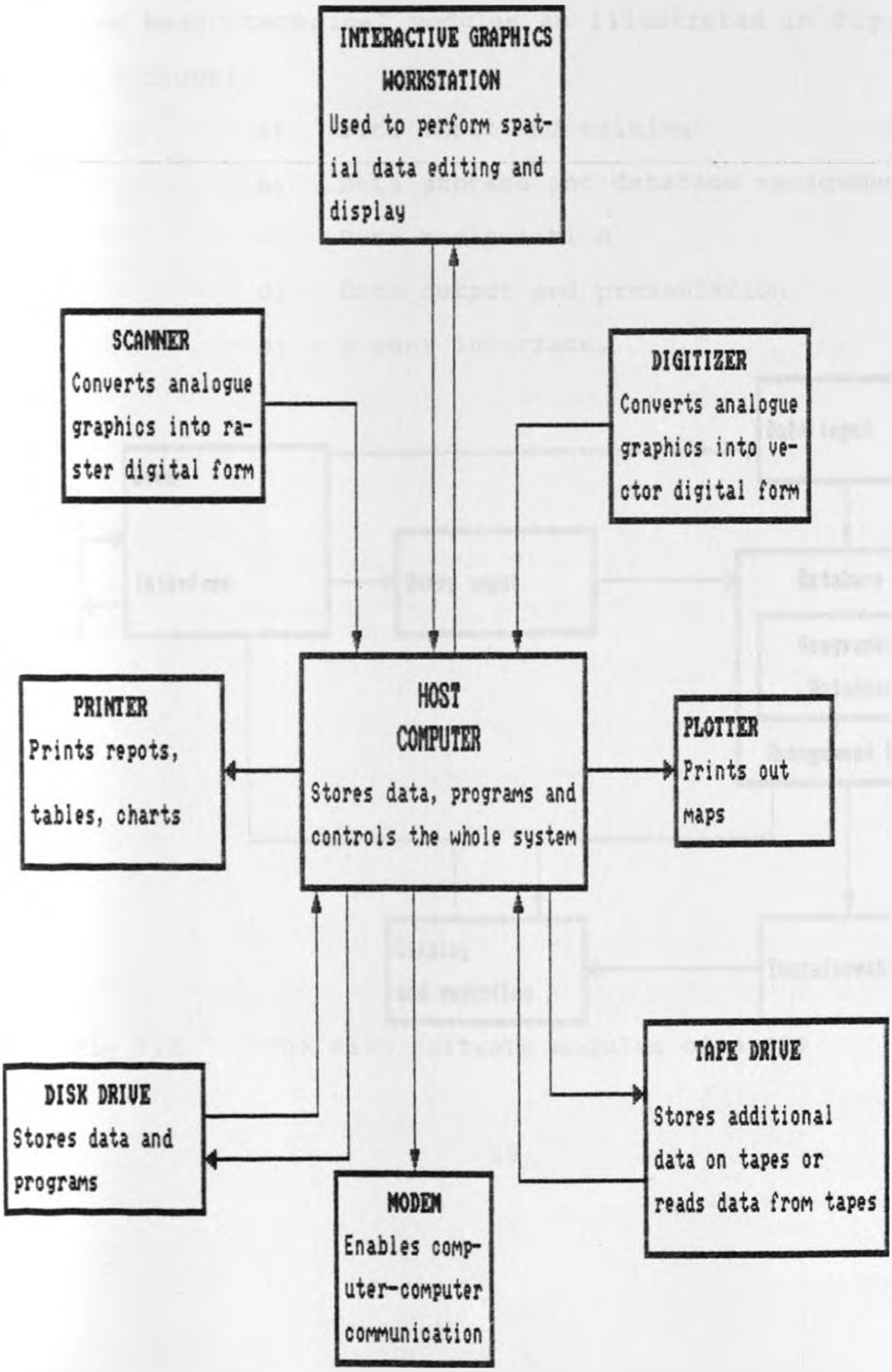


Fig. 3.1: *The major hardware components of a GIS*

These four components need to be in balance if the system is to function satisfactorily.

3.2.2 GIS SOFTWARE MODULES

The software for a geographic information system consists of five basic technical modules as illustrated in Fig. 3.2. These include:

a) Data input and editing

b) Data storage and database management

c) Data manipulation

d) Data output and presentation

e) A user interface.

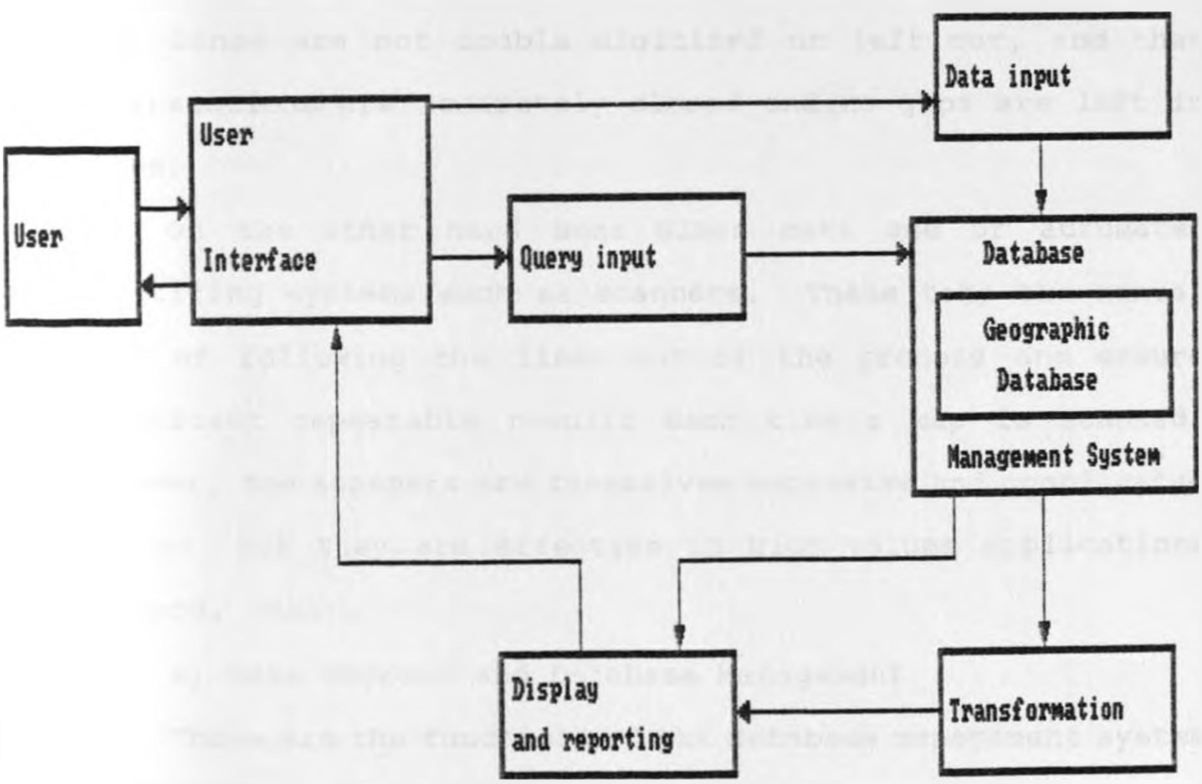


Fig 3.2 The main software modules of a GIS

a) Data input and editing

This module is concerned with the conversion of data from maps, field observation, processed satellite images and aerial photographs into digital form while at the same time ensuring that the integrity of the data entered in the database is maintained [Burrough, 1986].

Most GISes today utilize a manual digitizing approach to convert spatial features from maps into digital form. This requires that a map be placed on a flat digitizing table and all the lines that make up the map are followed by using a cursor pad, keeping the cross hair on the lines and ensuring that lines are not double digitized or left out, and that intersections are accurately closed and no gaps are left in lines.

On the other hand some GISes make use of automated digitizing systems such as scanners. These take the manual work of following the lines out of the process and ensure consistent repeatable results each time a map is scanned. However, the scanners are themselves expensive and complicated to use, but they are effective in high volume applications [Edward, 1988].

b) Data Storage and Database Management

These are the functions of the database management system of the GIS. They are concerned with the way in which the data about the position, topology, and attributes of geographical elements (points, lines, and areas) representing objects on the earth's surface are structured and handled in the computer [Edward 1988]. They are also concerned with how the data is accessed and perceived by the user of the system.

c) Data Manipulation

This module is concerned with analyzing data to provide answers to the questions the user puts to the GIS [Aronoff, 1987, Edward, 1988]. Processing may involve both the spatial and non-spatial aspects of the data. Typical operations include overlaying different thematic maps, creating buffer zones, computing areas and distances, acquiring statistical information about the attributes, changing legend, scale and projection of maps and plotting them, and making three-dimensional perspective view plots using elevation data.

d) Data Output and Presentation

This module deals with the way the information is displayed to the user. This can either be as a visual display (soft copy) or printed map (hard copy) drawn by a plotter or as magnetically recorded or printed information in digital form. The plotter is to GIS graphics what a printer is to the standard word processor.

Some common GIS capabilities for data output include:

- windowing to select area of output;
- scale change,e.g. in zooming;
- color change;

- modifications to text and line fonts, colors, dimensions, etc;
- three-dimensional display;
- selection of data using layers, overlays or attributes.

e) User interface

The user interface is basically a set of modules with the following characteristics:-

i) It shields the user from the system details, such that the user need not know how the various system components interact to yield the results.

ii) If user friendly, it is very easy to learn and use thus enabling even people who have little knowledge of computing to perform an unlimited number of operations by using certain combinations of data retrieval and transformation options.

iii) It may also enable an end user to obtain a certain product based on the user's specified requirements with ease.

3.2.3 DATA

Data here refers to geographic data. These data represent the real-world location of features, where these features describe objects commonly seen in the:-

a) natural environment, and

b) man-made environment.

Traditionally geographic features have been displayed on a map as:-

a) points,

b) lines, and

c) areas.

These features are differentiated by colors, symbols and annotations, all of which are explained by legends (keys) and description text.

On the other hand representing real-world data in a digital format requires:-

a) abstracting common objects, and

b) converting all analogue data into digital form.

A GIS can handle two kinds of data namely spatial and attribute data. Spatial data are usually translated into simple objects namely points, lines, and areas, whereas attribute data are usually recorded as simple descriptions.

3.2.4 THE ORGANIZATIONAL ASPECTS OF GIS

In order for GIS to be used effectively, it should be placed in an appropriate organizational context. There is need to properly integrate GIS into the whole work process of an organization [Burrough, 1986]. This requires:-

a) Investing in the necessary hardware and software.

b) Retraining of personnel and managers to use the new technology in the proper organizational context.

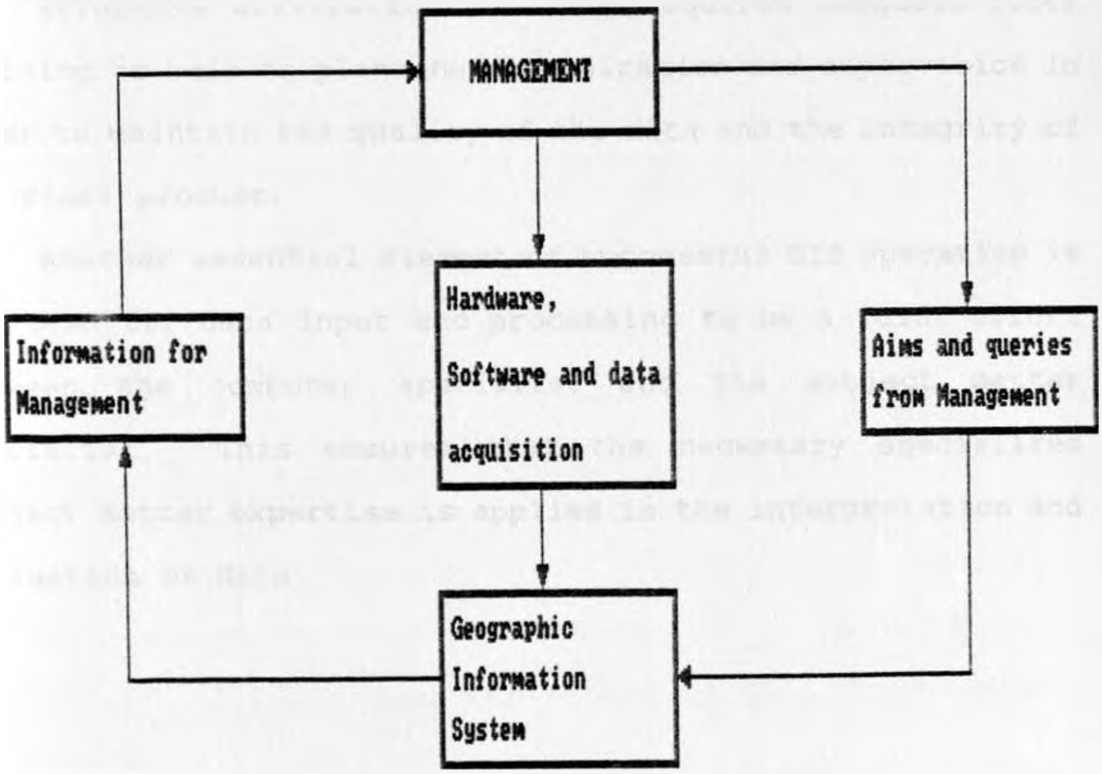


Fig. 3.3 The organizational aspects of GIS

3.2.5 PEOPLE IN GIS

When describing a GIS there is a tendency to think in terms of hardware, software and data as the entire system thus overlooking the most important component: the people needed to make the whole system function effectively [Edouard, 1988]. These people include GIS analysts, database managers, data entry operators and users.

The people who design the system, must know and understand both the information needs of the users and the data required to meet these needs, and be able to identify the hardware and software needed to produce the desired results.

Effective utilization of a GIS requires adequate staff training as well as planning, organization and supervision in order to maintain the quality of the data and the integrity of the final product.

Another essential element of successful GIS operation is the need for data input and processing to be a joint effort between the computer specialist and the subject matter specialist. This ensures that the necessary specialized subject matter expertise is applied in the interpretation and evaluation of data.

3.3 COMMON GIS PACKAGES

Map data may be represented in a GIS in either raster or vector format.

In a raster or cell-based system, the map is represented by a geometric array of rectangular or square cells, each with an assigned value. On the other hand, in the vector based system, the line work is represented by a set of straight-line segments called vectors. The x,y coordinates at the end of each vector segment are digitized and explicitly stored and the connectedness implied through organization of the points in the data base. Each system has its own advantages and disadvantages.

However most of the popular GIS packages have a data conversion module which enables one to convert from one data format to another. Examples of raster based systems are, IDRISI, ERDAS, SPANS, ILWIS and GRID, whereas an example of a vector based system is ARC/INFO. These are the most commonly used GIS packages locally.

3.4 CHOOSING A GIS

The implementation of a GIS is a costly, long term undertaking [Burrough 1986, Aronoff 1987]. Consequently, acquisition of GIS facilities should be done after serious consideration. A serious commitment to GIS implies a major impact on the whole organization. It must be geared to different methods of data collection, processing and different kinds of products.

Aronoff [1989] subdivides the process of GIS implementation into six phases namely:-

a) Creating awareness of the existence of GIS by reading journals, books, or attending conferences and special courses on the subject of GIS. Also a vendor can carry out a demonstration that is relevant to the users.

b) System requirements analysis involves establishing the users' requirements and thereafter preparing a Request For Proposal(RPF) document which is sent to different vendors that would have products likely to meet the most of the requirements and are interested in implementing the sytem.

c) System evaluation involves comparing the different vendors that were approached in order to establish who will implement the system.

d) Development of an implementation plan involves setting out a plan for implementing the system, ensuring that all the requirements are met.

e) System acquisition and start-up involves acquiring all the necessary hardware and software, testing the system, training of personnel, and contract negotiation.

f) Operational phase involves the actual use of the system in the organization and constant evaluation of the system to ensure that changing user needs are met satisfactorily. For a smooth operation of GIS, co-operation of management, users, data suppliers, and system vendors is of utmost importance.

Fig 3.4 illustrates this process.

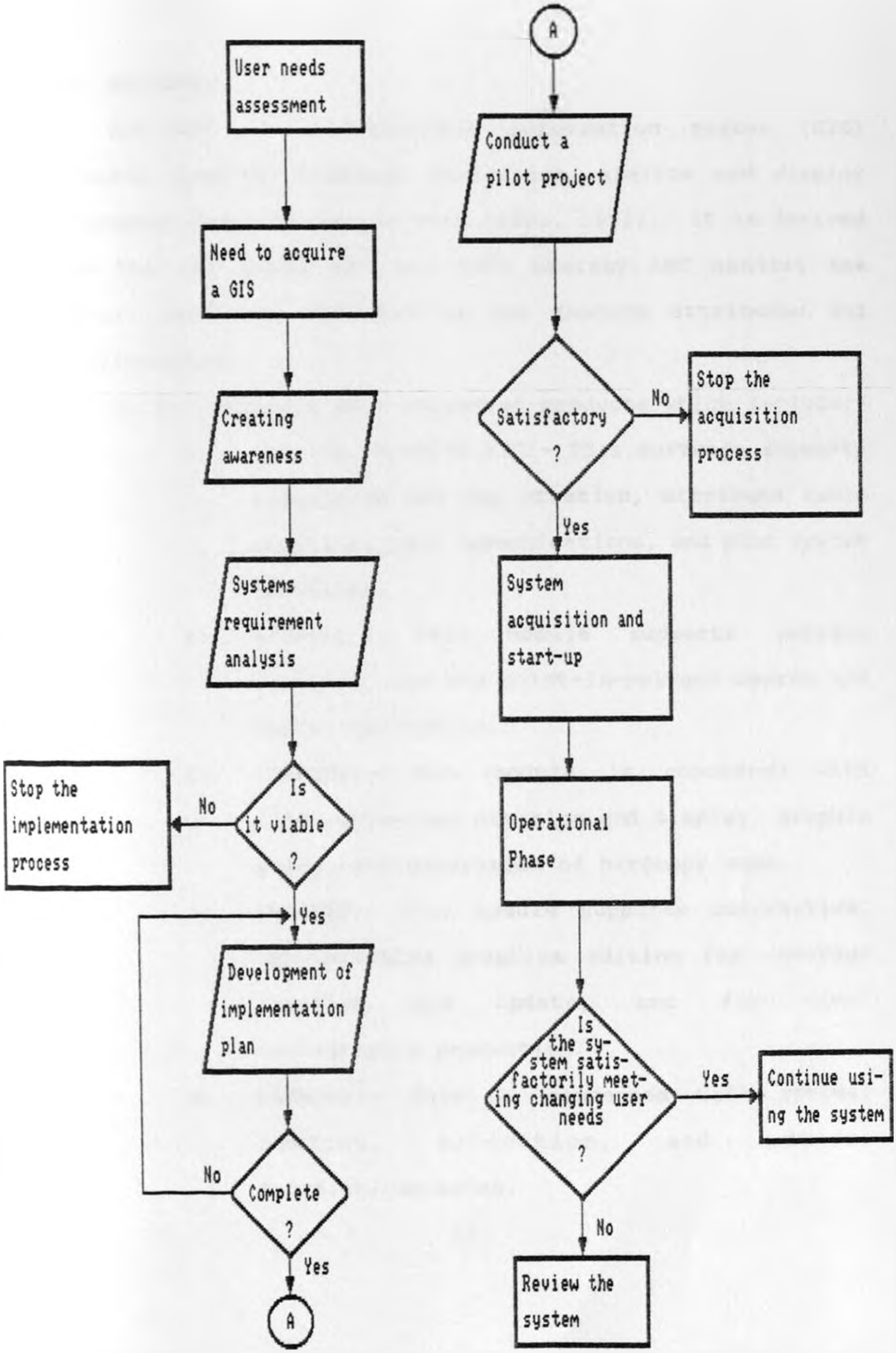


Fig. 3.4: The GIS implementation Process

3.5 ARC/INFO

ARC/INFO is a geographic information system (GIS) software used to automate, manipulate, analyze and display geographic data in digital form [ESRI, 1992]. It is derived from the two words ARC and INFO whereby ARC handles the spatial data and INFO handles the feature attributes and relationships.

It is available as a series of products which include:-

a) ARC/INFO STARTER KIT:- This software supports digitizing and map creation, attribute table creation, host communications, and plot system functions.

b) OVERLAY:- This module supports polygon overlay, line and point-in-polygon search and buffer generation.

c) ARCPLOT:- This module is concerned with interactive map creation and display, graphic query, and generation of hardcopy maps.

d) ARCEDIT:- This module supports interactive, sophisticated graphics editing for coverage creation and update, and for final cartographic production.

e) NETWORK:- This is concerned with optimal routing, allocation, and address matching/geocoding.

f) DATA CONVERSION:- This module supports transfer between the Arc/Info data format and other data formats.

This software can run on IBM PC/AT class machines and other compatible 286/386/486/Pentium computers. These computers must be 100% DOS compatible [ESRI, 1990]. The minimum hardware configuration for ARC/INFO to run are:-

a) IBM PC/AT or compatible
b) High-density floppy disk drive
c) PC-DOS or MS-DOS version 3.1 or higher
d) 640KB of RAM
e) 40MB hard disk drive
f) Maths co-processor
g) One parallel port for PC Arc/Info hardware key and, optionally a printer
h) Hardware key - Arc/Info products can not run without this key. Its purpose is to protect against unauthorized use of ESRI software.

It is also compatible with a number of peripheral hardware devices which e.g. graphic hard copy device (graphics printer or a pen plotter), mouse, digitizer, and modem.

Arc/Info contains about 1,000 commands that support various functions e.g. data transfer, data entry and editing, disk storage management commands, topology creation, etc.

a) Data storage commands:- Arc/Info is distributed in a compressed file format so that they take up 40 to 50 percent less storage space on the hard disk [Pfanffenberger, 1991]. The programs are automatically uncompressed when required for use and then recompressed once execution is completed [ESRI, 1992].

b) Data entry and editing:- It has full digitizing capabilities, which facilitate the creation of new map coverages and editing of the existing ones [ESRI, 1994].

c) Topology creation:- Topology is the mathematical study of the geometrical properties of objects that are invariant under distortions in the shapes and sizes of those objects. These properties include connectivity, adjacency and inlusion [Mulaku, 1987]. In Arc/Info the CLEAN and BUILD commands are used to generate and update correct topology for new map coverages and to create the feature attribute tables which store thematic data about coverage features [ESRI, 1994].

However Arc/Info has both software and hardware limitations. The number of features supported by Arc/Info commands is dependent on the version of the graphic modules in use, for instance, the 386 versions of ARCEDIT, ARCPLOT, and

NETWORK support more features than their corresponding 286 versions. On the other hand, some processes of Arc/Info e.g. CLEAN require that at least 480 kilobytes of RAM be available to complete successfully. If more than 640 kilobytes of RAM is available on the system, a disk cache system could be installed which takes advantage of extended memory.

As far as this study is concerned, a comparison of the three available GIS packages namely; ARC/INFO, ILWIS, and IDRISI was made and the results are presented in Table 3.1.

FEATURES	ARC/INFO	ILWIS	IDRISI
TYPE	Vector GIS	Raster GIS	Raster GIS
DATA FORMATS SUPPORTED	Vector and Raster	Raster and Vector	Raster and Vector
PROGRAM MODULES	Arc/Info Starter Kit, Overlay, Arcplot, Arcedit, Network, Data Conversion	Digitizing, Conversion, Network analysis, Modelling, Image processing	Core modules, Geographic Analysis ring modules, Statistical Analysis, Image processing, Ring modules, peripheral, Time series analysis.
COST	High	Low	Low
DATA ORGANIZATION	Relational & topological	Relational & topological	Relational & topological
SECURITY OF DATA	High	Low	Low

Table 3.1. Comparison of the available GIS packages: ARC/INFO, ILWIS, and IDRISI

Consequently, the choice to use Arc/Info was necessitated by the fact that the data available for the study area was in vector format, as well as the existing data which included main rivers, roads and major town centres. On the other hand, in order to use either IDRISI or ILWIS the data would have to be converted to raster format which could in the process result in data loss. Moreover, studies being conducted for this region for instance, by the Laikipia Research Project are also using Arc/Info. Generally, Arc/Info is a very powerful tool for data capture in vector format as well as an analysis tool. It was therefore desirable to use a software that is compatible with the data formats already in existence.

3.6 GIS IN KENYA

Many organizations now are spending large amounts of money on Geographic Information Systems (GIS) and geographic databases. An interview with some organizations revealed that, initially when the technology was introduced, the large amounts of money involved in implementing the system was a drawback. However, regardless of the high costs, they were quick to point out that, there are reasons as to why they are increasingly adopting the technology:-

a) The cost of the computer hardware needed for the task is dropping rapidly and thus is affordable to an increasingly wider audience.

b) Geography and the data describing it are part of our everyday world, almost every decision that is made is constrained, influenced or dictated by some fact of geography.

c) The traditional methods of handling spatial data are time consuming and are not able to cope with the pressure and trends of assessing resource conditions on land and water resources which continue to mount. As a result, there is need for integrated information which is computer compatible to facilitate easy and effective manipulation.

d) Some organizations which rely on donors, e.g. research institutions and government ministries, had the systems introduced and installed for them and they have come to appreciate the power of GIS. Some tasks which were either impossible or very tedious to perform are now feasible.

Table 3.2 shows a list of the various organizations,the corresponding GIS software, and the main applications.

ORGANIZATION	GIS SOFTWARE	MAIN APPLICATION
Regional Centre for Services in Surveying, Mapping and Remote Sensing.	IDRISI, ARC/INFO.	Research, Training and Mapping natural resources.
Department of Resource Surveys and Remote Sensing.	ARC/INFO, IDRISI, SPANS.	Research and Mapping natural resources.
United Nations Environmental Programme	GRID, IDRISI, ARC/INFO.	Global and regional environmental monitoring
Kenya Agricultural Research Institute	IDRISI, ARC/INFO, ILWIS	Agricultural applications (e.g. weed and pests control)
Laikipia Research Programme	ARC/INFO, ARCVIEW	Research on the natural resources of the Upper Uaso Ny'iro basin
International Centre for Research in Agro-forestry	ARC/INFO	Forestry and Agricultural applications
Survey of Kenya	ARC/INFO	Mapping natural resources
Ministry of Water	ILWIS, SPANS	Hydrological modelling and management
Kenya Medical Research Institute	ATLAS	Medical applications (e.g. disease control)
Thunder International	ARC/INFO, ARCVIEW	Training
Geomaps	ARC/INFO	Mapping natural resources
Kenya Forest Research Institute	IDRISI, ARC/INFO	Forest application (e.g. monitoring)

Table 3.2 Some Kenyan organizations with GIS

CHAPTER 4

RESEARCH MATERIALS AND METHODOLOGY

This chapter is concerned with the various stages involved in developing the database. In particular, it focuses on the user needs assessment study carried out so as to establish the contents of the GIS database and its implementation for the Upper Uaso Ny'iro river basin.

4.1 USER NEEDS ASSESSMENT

A user needs assessment was carried out in order to establish the desirable contents of a GIS database for the Upper Uaso Ny'iro river basin. A sample of the questionnaire as well as a list of the interviewees are contained in Appendix A1 and A2 respectively. It aimed at investigating the following:-

a) Which tasks involving spatial data are currently being performed in the area?

b) Which data are currently being used?

c) How are data currently being used?

d) Who uses the data?

e) Are there any problems with the current procedures or systems?

f) What are the scales and accuracy requirements?

g) What is the level of awareness of GIS?

h) What are the future possibilities?

The results of the interviews are summarized in Table 4.1

USER	SPATIAL DATA	SCALES EMPLOYED	ACCURACY REQUIREMENT
Surveyor	Topography,land-use, land-cover, land-ownership	1:500 - 1:1000000	<=2m
Planner	Drainage network, topography, communication network, land-use/land-cover, soil types and land-ownership	1:50,000, 1:250,000	<=10m
Administrator	Drainage and communication network, topography, land-use/land-cover, soil types, land-ownership	1:50,000-1:250,000	<=10m
Engineer	Drainage network, and abstractions	1:50,000	>10m
Farmer	Indirectly(through various professionals)	N/A	N/A
Businessmen	Indirectly(through various professionals)	N/A	N/A
Soil scientist	Drainage network, topography, land-use/land-cover, soil types	1:50,000, 1:100,000	<=10m
Hydrologist	Drainage network, topography, land-use/land-cover, soil types, and climatological data	1:50,000-1:250,000	<=10m

Table 4.1 Interview results.

From Table 4.1, the following conclusions can be drawn:-

a) There are a lot of tasks involving spatial data being performed in the area which include extensive modelling of soil water balance, primary production, hydrology and water resource allocation. However, the data required by users exists in different formats and scales and is static in nature. This causes a lot of problems in the handling of these data by different users who have different interests. For instance, on the same map there are rivers, roads, land-use/land-cover, topography, etc which might need to be represented differently at different times. Hence, if one is only interested in rivers, then all the other features need not be represented. Consequently there is need to have a multi-layered map for this region to facilitate resources management. This entails developing a digital database which will contain all the spatial data required.

b) The most important spatial information required for natural resource management as expressed by the users included:-

1) Land-use/land-cover types
2) An analysis of percentage cover of each land-use/land-cover types.
3) Relationship between land-use/land-cover types with the drainage network.
4) Relationship between land-use/land-cover types with main communication network and major centers.
5) Relationship between soil types and land-use/land-cover types.
6) Relationship between the topography, rainfall regime, and the agro-ecological zones.
7) Assessment of parcel sizes and ownership.
8) Soil erosion modelling.
9) Relationship between rainfall distribution and land-use/land-cover types.
10) Population distribution in the various major centres.

However, not all the expressed needs could be addressed due to time and financial constraints. Consequently this study aimed at providing for the first four expressed user needs.

4.2 DATA COLLECTION

This stage was the most involving and time consuming. It involved identifying the sources of data in respect of the user needs.

4.3.1 DATA SOURCES

The data sources available for this study included:-

a) A Landsat MSS image at a scale of 1:250,000.

b) Topographic sheets at scales of 1:50,000 and 1:250,000.

c) Sample aerial photographs, of scales 1:10,000, 1:12,500, and 1:50,000.

d) Available field data which included rainfall data and vegetation maps. The vegetation maps were of some small catchments within the basin and the ones that covered the area of study included Embori, Ituri, Logilandu, and Teleswani at a scale of 1:20,000. The rainfall data included monthly and annual (from January to December) values as well as trend analysis. The available data for the

Meteorology stations that were within the area of study included:

i) Archer's Post station from 1957 to 1995.

ii) Naro Moru forest station from 1978 to 1995

iii) Ontulili station from 1957 to 1992

iv) Meru Forest station from 1957 to 1992

v) Nanyuki forest from 1969 to 1992

vi) Marania forest station from 1982 to 1992

vii) Gathiuru forest station from 1959 to 1992.

Image interpretation of the satellite imagery was carried out and the main data extracted was land-use/land-cover. Consequently the satallite imagery was the main data source whereas the rest of the data sources were used as aids in the interpretation. The data collection process is summarized in Fig 4.1

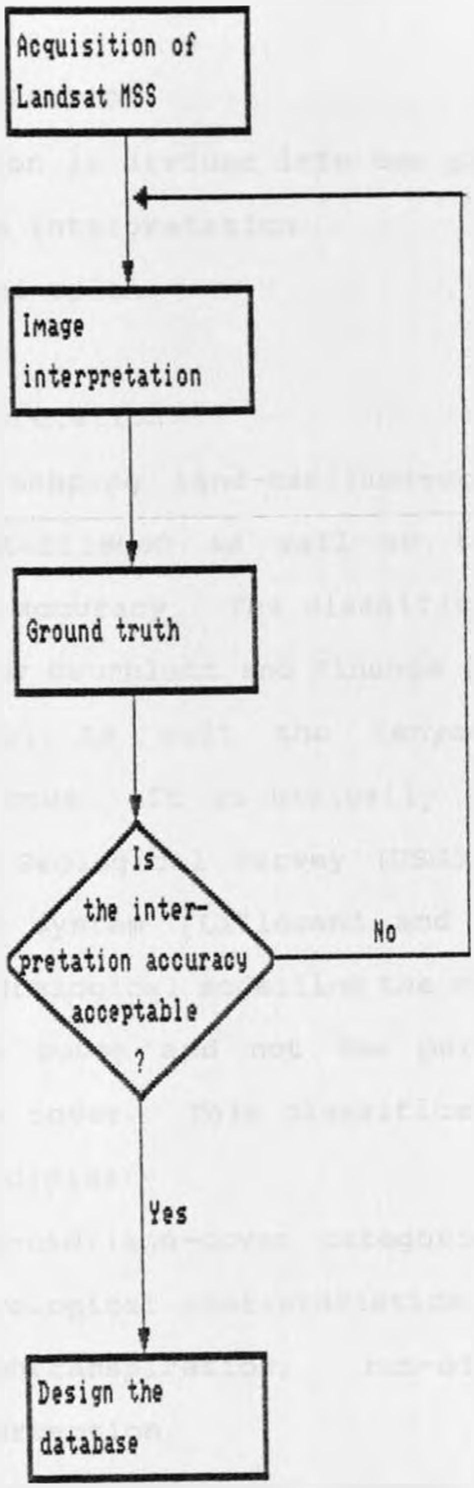


Fig. 4.1: The data collection procedure

4.2.2 DATA EXTRACTION

This section is divided into two parts namely:-

a) Image interpretation

b) Ground truth

a) Image Interpretation

Prior to mapping land-use/land-cover a classification system was established as well as the desired level of interpretation accuracy. The classification system used was one suggested by Grunblatt and Sinange [1989] and tailored by Linniger [1990] to suit the Kenyan situation with a hydrological focus. It is basically a modification of the United States Geological Survey (USGS) land-use/land-cover classification system [Lillesand and Kiefer, 1979]. For purposes of hydrological modelling the most significant factor is the canopy cover and not the particular species that constitute the cover. This classification was based on the following principles:-

a) Land-use/land-cover categories are based on the hydrological characteristics of the land-use e.g. evapotranspiration, run-off potential, and interception.

b) Land-use/land-cover categories can easily be identified using satellite imagery, maps, aerial photographs, and ground surveys.

c) Land-use/land-cover categories can provide an inventory of vegetation or crop types, management conditions, and conservation practises to monitor changes that affect the hydrological behaviour of land-use/land-cover.

As a result of the scale and the resolution of the satellite image, upto third level interpretation was adopted and the Table 4.2 contains a listing of the various classes and the codes adopted.

LEVEL I		LEVEL II
1. Urban(U)	11	Residential areas
	12	Airfield
	13	Communication network
2. Cropland(C)	21	Large scale
		211 Cropland
		212 Ploughed land
		213 Fallow land
	22	Small scale cropland
3. Grassland(G)	31	Treed grassland(tG) (2-20% tree cover & >50% grass cover)

	32 Treed grassland/ cropland	
	33 Sparse shrubbed grassland (2-20% soil cover)	
4. Treeland(T)	41 >50% Dense treeland(Td)	
		411 Indigeneous treeland
		412 Plantation treeland
	42 20-50% Mixed treeland	
		421 Treed cropland(TC)
		422 Treed grassland(TG)
	43 0-10% Riverine trees	
	44 Shrub forest (moorland)	
5. Open Water/Aquatic vegetation(S)	51 Rivers	
	52 Lakes	
	53 Permanent swamps	

6.	Bare/Rock (R)	61	Exposed rock
7.	Ice/Snow(I)	71	Glaciers

Table 4.2 Land-use/Land-cover classification system (After Grunblatt and Sinange, 1989; Linniger, 1990)

The image available for this area was a hardcopy Landsat MSS at a scale of 1:250,000 taken on 30th January 1973 and therefore interpretation was done manually. It involved mounting the image on a light table and overlaying a transparencey on the image on to which all the land-use/land-cover categories were delineated and coded using the classification code already established as shown in Table 4.2.

The level of interpretation accuracy desired was 85% [Lillesand and Kiefer 1979].

b) Ground truth

A ground truth exercise was conducted to verify the correctness of the interpretation and to make corrections where necessary. Since it was not possible to carry out the exercise for the whole study area due to cost and time constraints, sample areas were selected based on the following criteria:-

a) They should be representative of the area around them

b) They should have key terrain features for control purposes.

c) Areas that were difficult or confusing to classify.

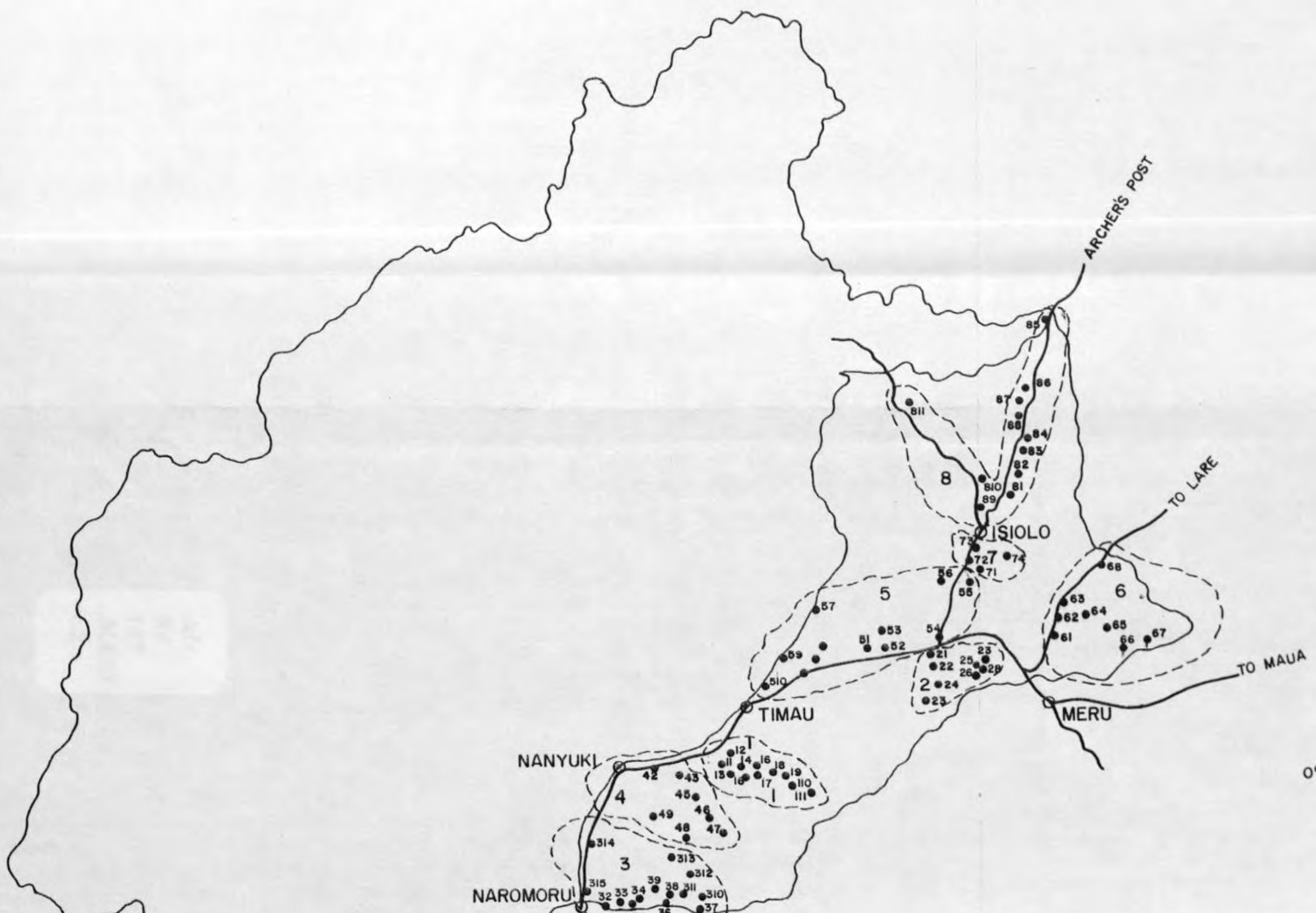
d) They should be accessible.

[Fitzpatrick-Lins, 1981; Hay, 1979]

A sketch showing these sample areas and the control points is shown in Fig 4.2

37°00'E 37°30'E

FIG. 4·2 : GROUND TRUTH SAMPLE AREAS AND CONTROL POINTS



KEY

SAMPLE AREA ---------------

NUMBER OF THE SAMPLE AREA ------ 1,2,3,4,6...

CONTROL POINTS --------------- •22

TOWN CENTRE --------------- O TIMAU

MAIN ROAD ---------------

F. N. KAMIRU, 1996

GPS trimble navigation system was used to control the area. For each control point an area of at least 200m square was covered and the percentage cover of each land-use/land-cover was established. The booking sheet format used for the field data collection is contained in Appendix A3. Tables 4.3 to 4.10 summarize the results obtained. The general surface cover for this study area consists of treeland, grassland, and cropland hence the ground truth exercise zeroed in on these categories of land-use/land-cover. It was particularly difficult to classify where there was a mixture of two or all of these categories and hence the ground truth exercise aimed at sorting out this problem.

For each sample area, a comparison was made between what was found on the ground and how it was classified on the image. For instance, at sample area 1, there were four classes of Treeland identified on the image, whereas ground truthing revealed only two classes of Treeland for the same area. Therefore, to get the percentage level of interpretation accuracy, the following expression was used;

$$\frac{GC}{IC} \times 100 = L$$

where,

GC - is the Ground truth Class

IC - is the Image interpretation Class

L - is the Level of interpretation accuracy.

[Aronoff, 1982; Hord and Brooner, 1976]

If the level of interpretation accuracy was less than the desired 85%, then an investigation was carried out to establish whether the discrepancy was either due to misclassification in which case a correction was effected or new developments in which case this was noted.

Table 4.3 Sample area 1

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	4	2	50	Yes	No
Cropland	7	5	70	Yes	No
Grassland	-	-	-		

Table 4.4 Sample area 2

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	4	3	75	Yes	No
Cropland	3	3	100		
Grassland	2	1	50	Yes	No

Table 4.5 Sample area 3

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	9	6	67	Yes	No
Cropland	6	4	67	Yes	No
Grassland	6	4	67	Yes	No

Table 4.6 Sample area 4

Land-use/ land-cover category	Image classification	Ground truth classification	% level of intepretation accuracy	Change due to	
				New developments	Misclassification
Treeland	6	6	100		
Cropland	1	1	100		
Grassland	2	2	100		

Table 4.7 Sample area 5

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	2	2	100		
Cropland	6	5	83	Yes	No
Grassland	4	3	75	Yes	No

Table 4.8 Sample area 6

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	2	2	100		
Cropland	-	-	-	-	-
Grassland	6	6	100		

Table 4.9 Sample area 7

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	-	-	-	-	-
Cropland	-	-	-	-	-
Grassland	8	6	78	No	Yes

Table 4.10 Sample area 8

Land-use/ land-cover category	Image classification	Ground truth classification	% level of interpretation accuracy	Change due to	
				New developments	Misclassification
Treeland	1	0.25	40	No	Yes
Cropland	-	-	-	-	-
Grassland	9	6	67	No	Yes

In general the overall interpretation accuracy is about 78%. The possible reasons as to why the level of interpretation accuracy was less than the desired 85% are:-

a) Age of data:- An investigation carried out to establish which satellite scenes covered the area of interest revealed that for this particular area, the image available was a Landsat MSS which was acquired on 30th January 1973. This therefore means that it is about 23 years old. A lot of developments have taken place, especially around the mountain region; for example areas that were covered by trees in 1973 have been cleared and are now under crops. However, in the northern part where it is basically grassland little has changed and therefore the two classifications agree quite well.

b) Image resolution:- The pixel size on the Landsat MSS is approximately 79m * 79m. This affects the amount of information that can be extracted. For instance, a region could appear to be dense treeland, and yet there could be some cover of say crop and grass which is only visible on the ground or on a larger scale image. Furthermore, only sample aerial photographs could be obtained to support the interpretation.

c) Data format:- The image available for this area is in hardcopy format which makes the interpretation subjective. This is due to the fact that the information extracted entirely depends on the interpretor's visual capability, i.e. how well one is able to distinguish between the different tones and patterns on the image.

Hence in the circumstances, the level of interpretation accuracy attained was considered to be satisfactory and accepted. Hord and Brooner [1976] observed that the time dimension is a very important aspect in image interpreation as this has a direct effect on the level of interpretation accuracy. Similar studies carried out in Tanzania reveal that visual interpretation of remotely sensed data yielded about 80% accuracy, whereas data after Larsson et al. (1991) give 85% [Kinabo, 1996].

4.3 DATABASE DESIGN

A database is a collection of related data, where data here means recorded facts. It represents some aspect of the real world and is used for specific purposes by one or more groups of users.

Database design consists of three major steps: the conceptual design, which involves identifying entities, attributes, and relationship between entities; logical design involves mapping the conceptual model onto a DBMS i.e the logical organization of the entities, attributes and relationships in the database; and the Physical design is concerned with mapping the data structures onto a computer medium i.e. it is concerned with the way data is physically organized and accessed from disk [Date, 1990].

These steps are summarized in Fig 4.3

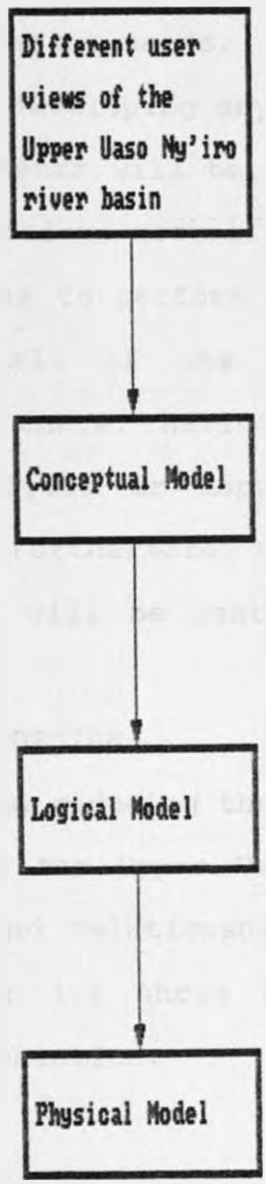


Fig 4.3 Database design

Different users exist, as established by the user needs assesment and they include hydrologists, surveyors, engineers, planners, administrators, farmers and businessmen. The study further revealed that these users view the basin differently and therefore have different needs.

The first step in developing any digital database is to determine what the contents will be. Spending some time in designing the database before actually automating it, ensures that when the time comes to perform the analysis and create the final products, all of the coverage features and attributes required are there. Having to modify a database in the middle of an analysis or mapping procedure is time consuming and costly. Furthermore, a well designed database ensures that the data will be usable for future projects [ESRI, 1994].

4.3.1 CONCEPTUAL DESIGN

This stage involved reducing the user views to a set of concepts that modelled the Upper Uaso Ny'iro river basin. Entities, attributes and relationship between the entities were identified. Fig 4.4 shows the Entity-Relationship diagram used for documentation.

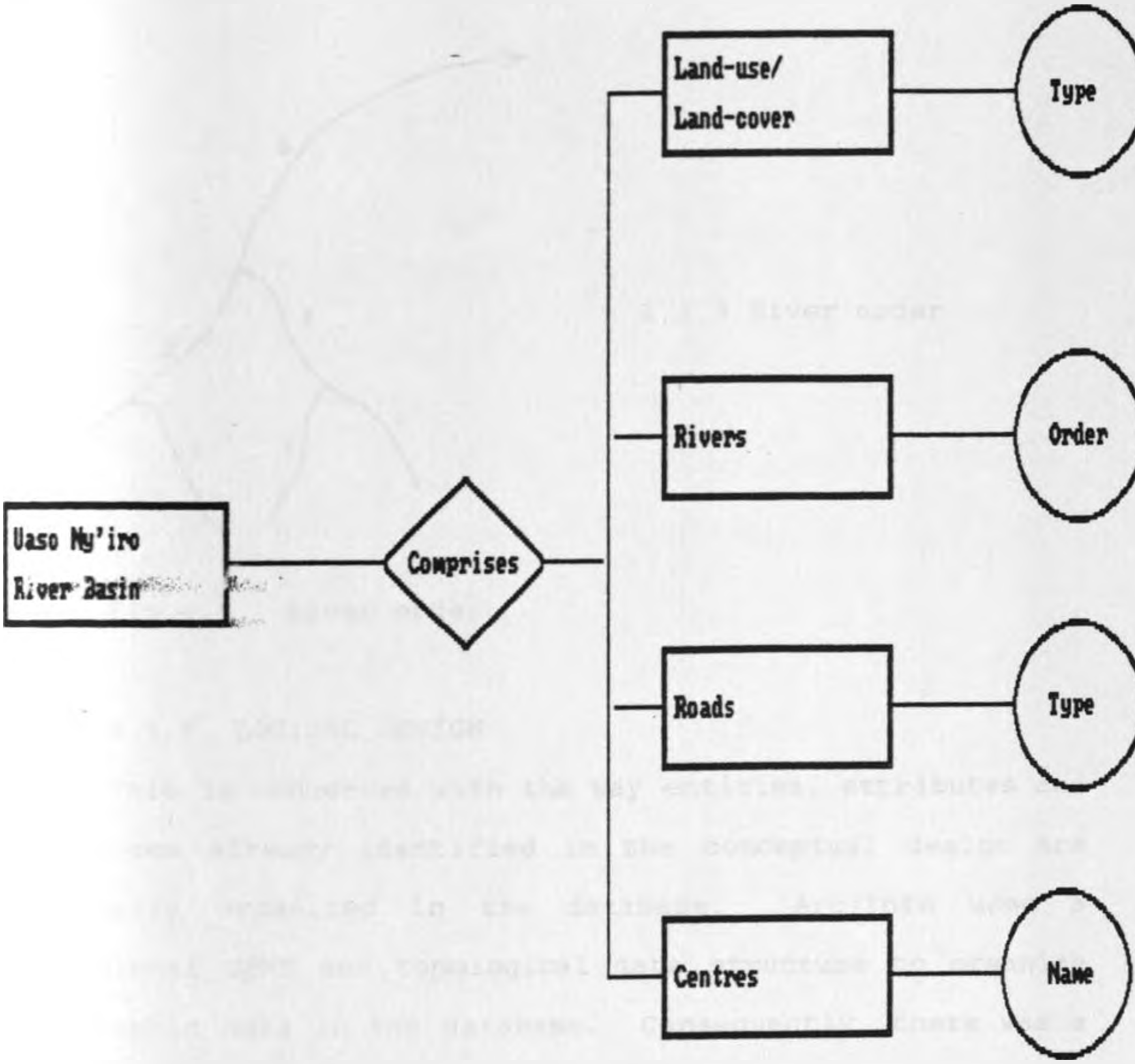
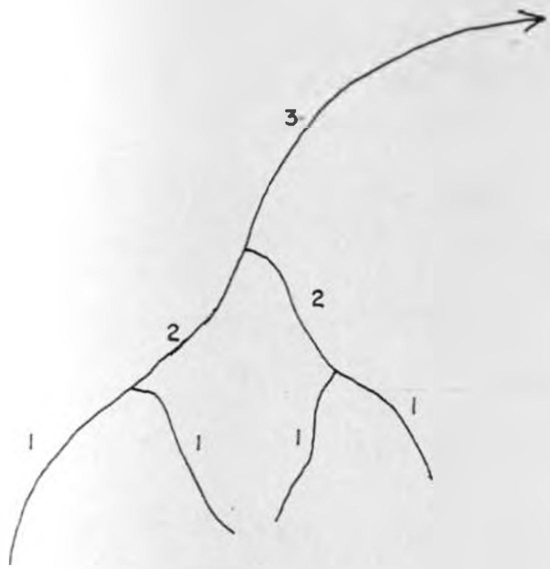


Fig 4.4 E-R diagram for the proposed database

The order of a river is defined by the number of tributaries joining to make a river. This is illustrated in figure 4.5



1,2,3 River order

Fig 4.5 River order

4.3.2 LOGICAL DESIGN

This is concerned with the way entities, attributes and relations already identified in the conceptual design are logically organized in the database. Arc/Info uses a relational DBMS and topological data structure to organize geographic data in the database. Consequently, there was a canned solution for the logical design.

4.3.3 PHYSICAL DESIGN

This stage is concerned with the way data is actuallly organized on disk and how it is accessed. The DBMS like in the logical design takes care of this and the user/GIS analyst is shielded from these details.

4.4 DATABASE IMPLEMENTATION

This stage involved digitizing and editing the land-use/land-cover map, and thereafter attributes were added to the Polygon Attribute Table (PAT).

4.4.1 DATA CAPTURE AND EDITING

Data input and editing was done in three steps:-

a) Digitizing arcs using *ARCEDIT* module.

b) Editing using *ARCEDIT* module.

c) Adding attribute data using the *TABLES* module.

a) Digitizing arcs involved:-

i) Mounting the manuscript on the digitizing table.

ii) Establishing a minimum of four tics and digitizing them. This was a two step process and it involved:-

- Entering the Tic-ID with the numeric buttons on the keypad e.g. for Tic-ID 82, this was simply typed in from the keypad and acceptance signalled by typing A or *.
- Once the Tic-ID has been entered, the next step was to digitize the location of the TIC by positioning the keypad crosshairs on the point

and pressing A or * to accept. When all the tic locations were digitized a Root Mean Square (RMS) was calculated and displayed in the dialog area. This error exists because a transformation can not just stretch the tics to fit. The tics are therefore transformed by using the affine transformation which involves translation, rotation and scaling, to the new coordinate system. A rule of the thumb is to keep the RMS error less than 0.0000762m, which is based on the resolution of most digitizers. In this case it was 0.0000508m and therefore accepted. A boundary was then established slightly larger than the area to be digitized so as to ensure that all the features are digitized.

iii) Setting the tolerances for digitizing which included, the snap distance, weed distance, snaptype closest. Snap distance is the minimum distance within which nodes snap to other existing nodes, thus avoiding arcs that are not connected which would otherwise result in unclosed polygons. Weed distance is the minimum distance desired between vertices of an arc. They are used to avoid the creation of small accidental polygons and to capture data at the appropriate resolution of the source material. Snaptype specifies how node snapping will occur. There are three options to node snapping; First when a node will snap to the first node it finds within the snap distance; Closest, when node snapping will search the entire area inside the snap distance for the closest node and this is the default; and Off, when no node snapping will occur [ESRI, 1994].

v) Once the environment was set then the arcs were added ensuring that arcs longer than 0.1m were split using a slash(/). This slash was also used to mark the beginning and the end of a node. Pressing a 2 marks the beginning of an arc i.e. a node and the arcs were digitized by pressing a 1 which enters the vertices along the line and the end was signalled by pressing a 2.

vi) Each polygon was marked with a small cross (+) as a location for the label. Then by using the label option, the location and assigning of a unique ID was effected. The label say 422 would be entered from the keypad buttons, after which the location of this label point was digitized by positioning the keypad crosshairs over the desired location.

b) Data editing was done in order to correct for any spatial errors. This was a four step process and involved:-

i) Constructing topology: Until topology is created, no polygons exist and arcs that cross each other are not connected at a node since there is no intersection. Thus topology makes explicit the relationships between geographic features, which eventually facilitates the identification of some common errors which include; arcs that do not connect to other arcs, polygons that are not closed, polygons that have no label point or too many label points, and User-IDs that are not unique. CLEAN and BUILD [ESRI, 1994] are the two ARC/INFO commands used for topology creation. CLEAN constructs topology for polygons and lines, but not for points and creates the corresponding Polygon Attribute Table (PAT) and Arc Attribute Table (AAT). On the other hand, BUILD constructs topology for polygons, lines and points and creates the corresponding attribute tables. The main difference between these two operations is that CLEAN uses a fuzzy tolerance when processing coverages while BUILD does not, which implies that CLEAN can detect and create intersections, and on the other hand since BUILD does not use a fuzzy tolerance, coordinates will not be adjusted while topology is being built. The standard arc attributes include

- FNode - the internal number of the node where the arc begins.
- TNode - the internal number of the node where the arc ends.
- LPoly - the internal number of the polygon on the left side of the arc.
- RPoly - the internal number of the polygon on the right side of the arc.
- Length - the length of the arc
- Cover_ - internal feature number (system

defined)

Cover_ID User defined feature identifier.

The standard polygon attributes include:

Area - area of each polygon

Perimeter - perimeter of each polygon

Cover_ - internal feature number

Cover_ID - user defined feature identifier.

The standard point attributes are the same as for the polygon except that the values for area and perimeter are equal to zero but these fields still appear in a Point Attribute Table.

ii) Identifying digitized errors was done in three ways:

a) Using the *Arcedit* module to display node errors e.g. pseudo and dangling nodes;

b) Using the *Arcplot* module to display label errors which consisted of either missing labels or two labels assigned to one polygon;

c) Finally by comparing the plot and source map to identify any other missing information that could not be detected by the above modules, e.g assigning wrong labels, missing arcs etc.

iii) Correcting errors involved adding missing data and removing bad data and replacing it with the correct data. Corrected errors included for instance; adding missing arcs and labels, identifying and deleting a label point where two existed in one polygon, closing gaps between two arcs, deleting overshoots, and marking the correct value where an incorrect User-ID was entered.

iv) Once all the errors were corrected, topology was reconstructed to re-establish the spatial relationships since editing alters the coverage topology. At this stage also, any additional errors were checked for; in this case there were none and hence attribute data were added.

This process is summarized in Fig 4.6

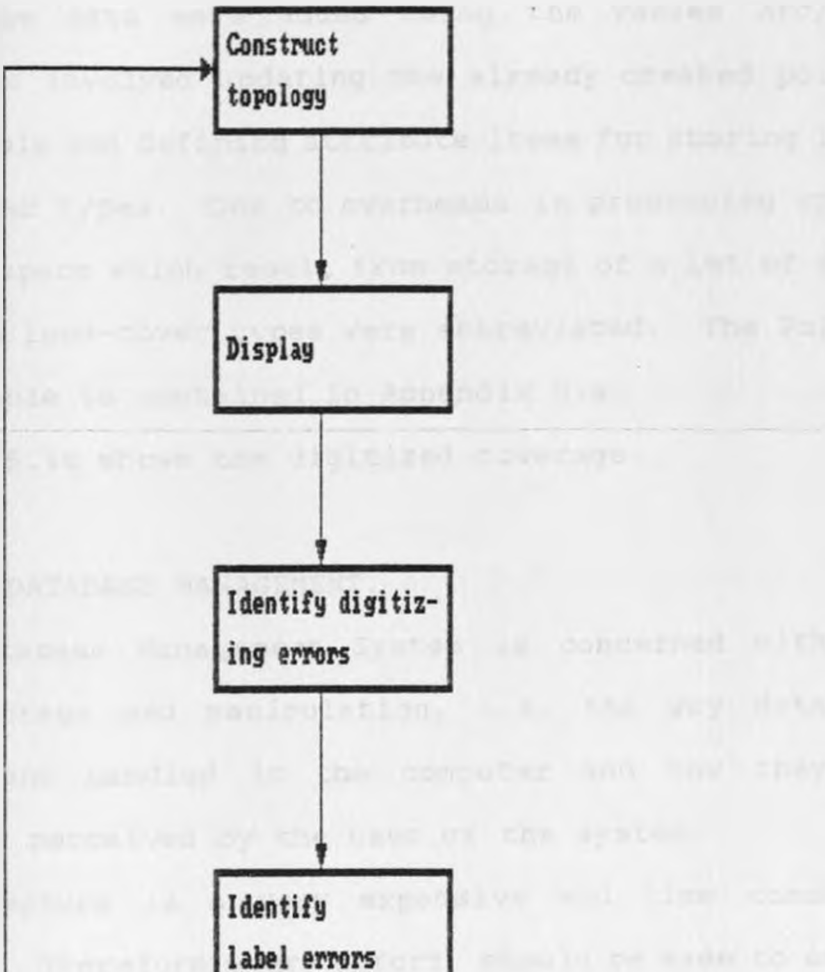


Fig. 4.6: Data editing in Arc/Info

Attribute data were added using the *Tables Arc/Info module*. This involved updating the already created polygon attribute table and defining attribute items for storing land-use/land-cover types. Due to overheads in processing speeds and storage space which result from storage of a lot of data, the land-use/land-cover types were abbreviated. The Polygon Attribute Table is contained in Appendix B1a.

Figure 5.1a shows the digitized coverage.

4.5.3 DATABASE MANAGEMENT.

The Database Management System is concerned with the database storage and manipulation, i.e. the way data are structured and handled in the computer and how they are accessed and perceived by the user of the system.

Data capture is a very expensive and time consuming undertaking. Therefore every effort, should be made to ensure that these data are safeguarded to avoid losses or destruction. Data management consists of measures taken to ensure that the integrity of the database is maintained. For the purpose of this study the measures taken included:

a) Backing up data to avoid losses.
b) Organizing the data in one workspace to facilitate efficient access and manipulation of data.
c) Adopting some naming conventions so that the

name is descriptive of what the coverage contains and at what stage it is in, e.g.

LulcvDG - is the digitized land-use/land-cover coverage

LulcvED - is the edited land-use/land-cover coverage

Lulcvcl - is the coverage with topology created (i.e, it has been cleaned).

d) Deleting older versions of the data and retaining the usable data, so as to free up memory and to ensure that only the usable coverage is accessed.

4.5 GIS DATA ANALYSIS

4.5.1 KINDS OF GIS ANALYSIS

A broad range of analytical operations can be undertaken, however most of them fall into one of the three basic groups namely simple query (database query), complex query and derivative mapping.

Simple query involves extracting only that information of interest from the database for further analysis, for instance, in a database containg soil types, land use/land cover, vegetation, infrastructure, etc.one may be interested in say soil types only and these can easily be retrieved using database query tools. Complex query involves setting certain constraint, for instance, extracting all land use /land cover types within say 2Km from the main road. Derivative mapping involves combining components (data layers) of the database to yield new derivative layers, thus adding new data in the databaase which could be used for further analysis. For instance, several criteria for analysis may be set as, say, soil type A, area within 5Km from the main road, area within 2Km from the main rivers and non-forested area may extracted from the database to yield suitable regions for growing horticultural products.

4.5.2 OBJECTIVES OF THE ANALYSIS

Prior to performing geographic analysis, the problems to be solved were defined after which a sequence of operations was identified to produce meaningful results. These problems were identified during the user needs assessment out of which four formed the basis for analysis. They included:-

a) Providing a land-use/land-cover map;

b) An assessment of the area covered by each land-use/land-cover category;

c) Providing a map showing the spatial relationship between land-use/land-cover types and the main rivers;

d) Providing a map showing the spatial relationship between land-use/land-cover types, the main roads as well as the main centres.

In addition to the outlined needs, this study further wished to demonstrate the following:

a) An assessment of the extent of the indigenous treeland in this study area, which is an endangered species (simple query);

b) An assessment of the land-use/land-cover within 10km of the main road (complex query);

c) An assessment of land-use/land-cover within 5km of the main road and more than 1km from the rivers (derivative mapping).

4.5.3 THE ANALYSIS

ArcView goes beyond desktop mapping by providing a fully functional GIS. It supports analytical tools that create spatial data and define spatial relationships among multiple sets of data.

The land-use/land-cover map (Fig 5.1a) is the basic output from where the area covered by each land-use/land-cover type is generated. ArcView makes use of charts to summarize tabular data. In order to provide information on the area cover for each land-use/land-cover type it was found desirable to use the charts facility for this purpose. This is due to the fact that charts quickly convey information that might otherwise require a long time to summarize and synthesize. ArcView supports six types of charts namely; Pie, Bar, Area, Column, Line, and xy scatter charts [ESRI,1994]. For this particular case a Column chart was used since it is good for comparing individual data because of their horizontal nature.

The procedure for creating a chart involves opening the table from which the chart is to be created in this case the land-use/land-cover polygon attribute table and make it active. Then one chooses the chart type from the charts gallery and by using the create chart command, the properties are displayed on a sheet using some default colours. The appearance of the chart can then be modified by applying user defined colours, adding a title, and adding text on the x and y axes. Fig 5.1a shows this chart.

One of the spatial analysis aspects is the creation new relationships in data. User needs (c) and (d) (see section 4.2) are good examples whereby different thematic information are combined to reveal the relationship between these categories of information which would otherwise be difficult to decipher. The process for generating this output is summarized in Fig 4.7

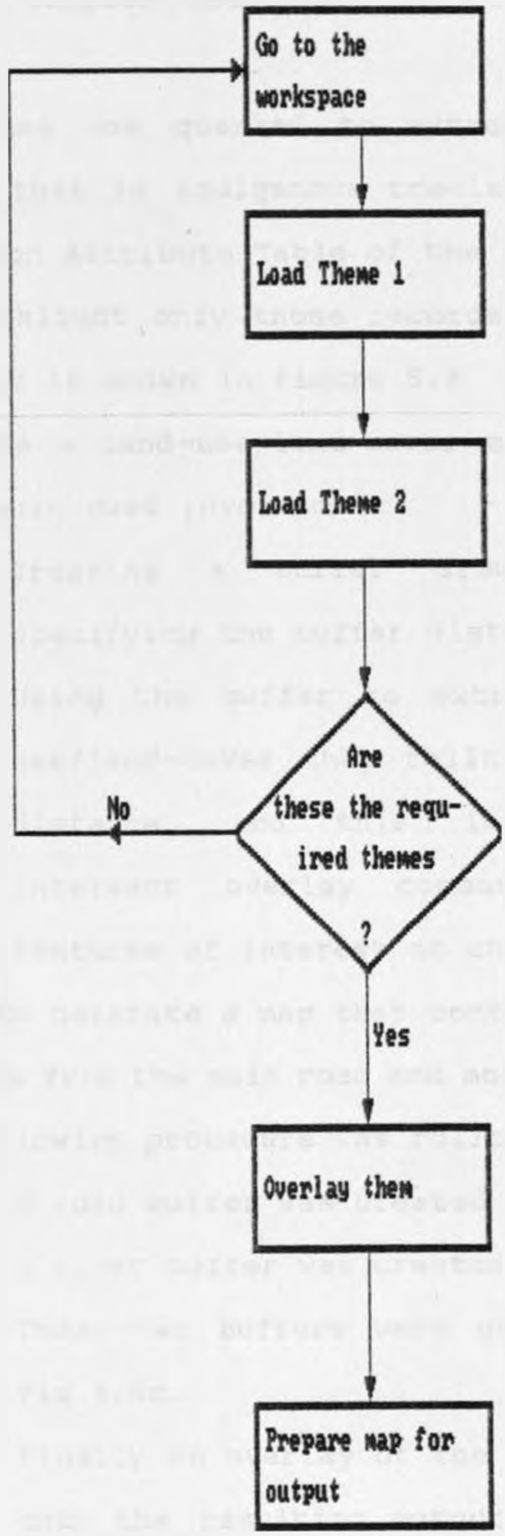


Fig. 4.7: Spatial relationship analysis

The consequent outputs are shown in figures 5.2 and 5.3 respectively.

The database was queried to extract only the land-use/land-cover that is indigenous treeland. This involved using the Polygon Attribute Table of the land-use/land-cover coverage to highlight only those records of interest. The resulting output is shown in Figure 5.4

To generate a land-use/land-cover map which is within 10km from the main road involved:

a) Creating a buffer around the road by specifying the buffer distance;

b) Using the buffer to extract all the land-use/land-cover that falls within the buffer distance, and this involved using the intersect overlay command to retain the features of interest as shown in Fig 5.5

In order to generate a map that contains land-use/land-cover within 5km from the main road and more than 1km from the rivers, the following procedure was followed:

a) A road buffer was created [see Fig 5.6a];

b) A river buffer was created [see Fig 5.6b];

c) These two buffers were overlaid to generate Fig 5.6c.

d) Finally an overlay of the land-use/land-cover onto the resulting output from (c) Fig 5.6c generated Fig 5.6

To establish the relationship between the output from Fig 5.6 and the original main rivers and roads, these thematic data were overlaid to generate Fig 5.7.

CHAPTER 5

RESULTS

5.1 RESULTS

The output device available for this purpose was the Epson Stylus Colour Ink Jet Printer. This device supports only A4 size paper and hence the scale of the output had to be reduced to conform to this specification.

Figure 5.1a shows the digitized land-use/land-cover map, whereas its Polygon Attribute Table is contained in appendix B1. This table contains 5 fields namely:

a) Area of each polygon in square metres;

b) Perimeter of each polygon in metres;

c) Lulcov5_ which is an internal ID defined by the system;

d) Lulcov_ID which is defined by the user;

e) Lulcov-typ which is the descriptive information of each land-use/land-cover type abbreviated to reduce on memory storage e.g. SSC stands for Small Scale Cropland. The legend contains the full names and abbreviations of each land-use/land-cover type.

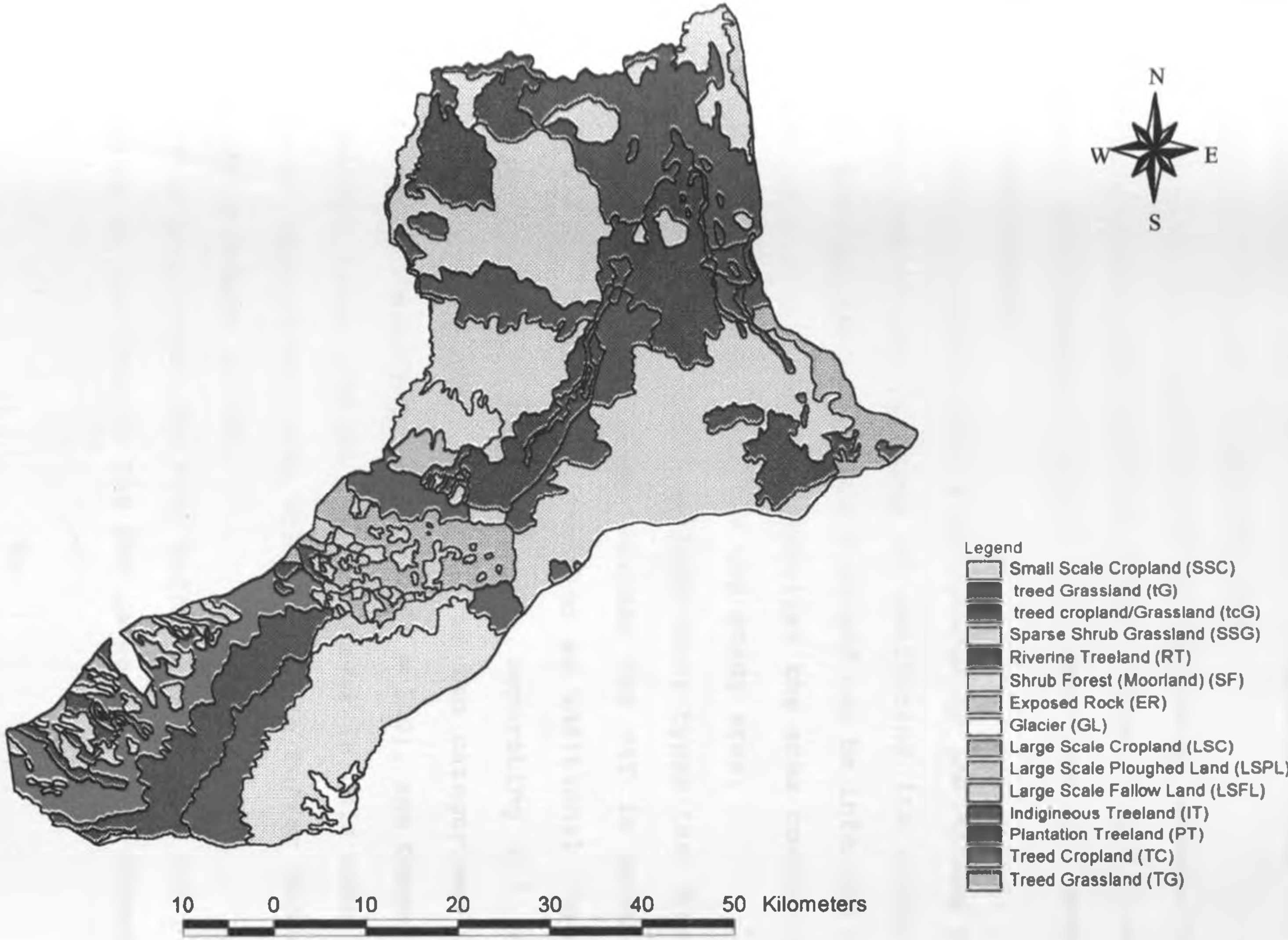


Fig. 5.1a: Land-use/land-cover map

F.N. KAMIRU, 1996

Fig 5.1b shows the chart which summarizes the area covered by each land-use/land-cover type. The land-use/land-cover PAT was summarized by summing up the area of each land-use/land-cover type and a chart generated using this table which is contained in appendix B1a.

Fig 5.2 shows the spatial relationship between the land-use/land-cover with the main rivers whereas Fig 5.3 shows the spatial relationship between the land-use/land-cover, main road and centres.

Fig 5.4 depicts the area covered by indigenous treeland in the region for purposes of monitoring its extent. The total area of the indigenous treeland can be inferred from the chart in Fig 5.1b, which summarizes the area covered by each land-use/land-cover type for the study area.

Fig 5.5 shows land-use/land-cover types that are within 10 km from the main road, whereas the PAT is contained in appendix B2. This table contains an additional item called "inside" which is a coded value separating all polygons created by the buffer command into two categories; i.e the area inside the buffer zones (INSIDE = 100), and those outside the buffer zones (INSIDE = 1). However in this case all the land-use/land-cover types are within the buffer zone, hence the whole column is 100.

Fig 5.6a shows the road buffer map created for a buffer distance of 5km whereas the PAT is contained in appendix B3.

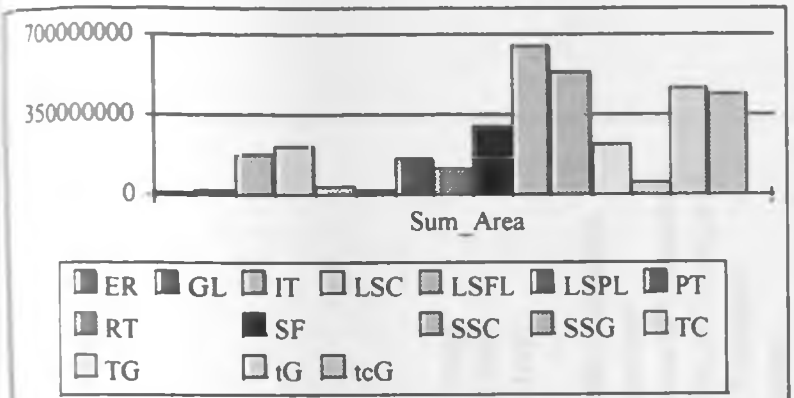
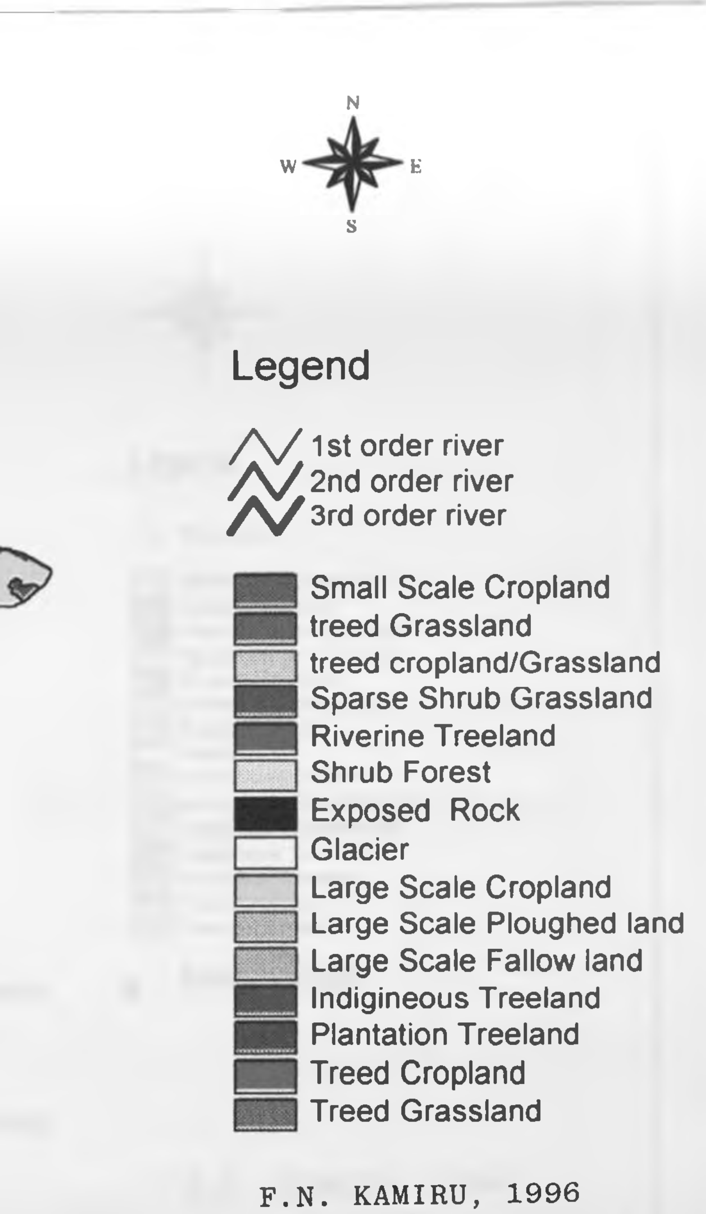


Fig 5 1b: Area coverage summary of land-use/land-cover types

Fig. 5.2: Land-use/land-cover and main rivers overlay map


N
W
E
S
Legend
1st order river
2nd order river
3rd order river
Small Scale Cropland
treed Grassland
treed cropland/Grassland
Sparse Shrub Grassland
Riverine Treeland
Shrub Forest
Exposed Rock
Glacier
Large Scale Cropland
Large Scale Ploughed land
Large Scale Fallow land
Indigineous Treeland
Plantation Treeland
Treed Cropland
Treed Grassland
F.N. KAMIRU, 1996

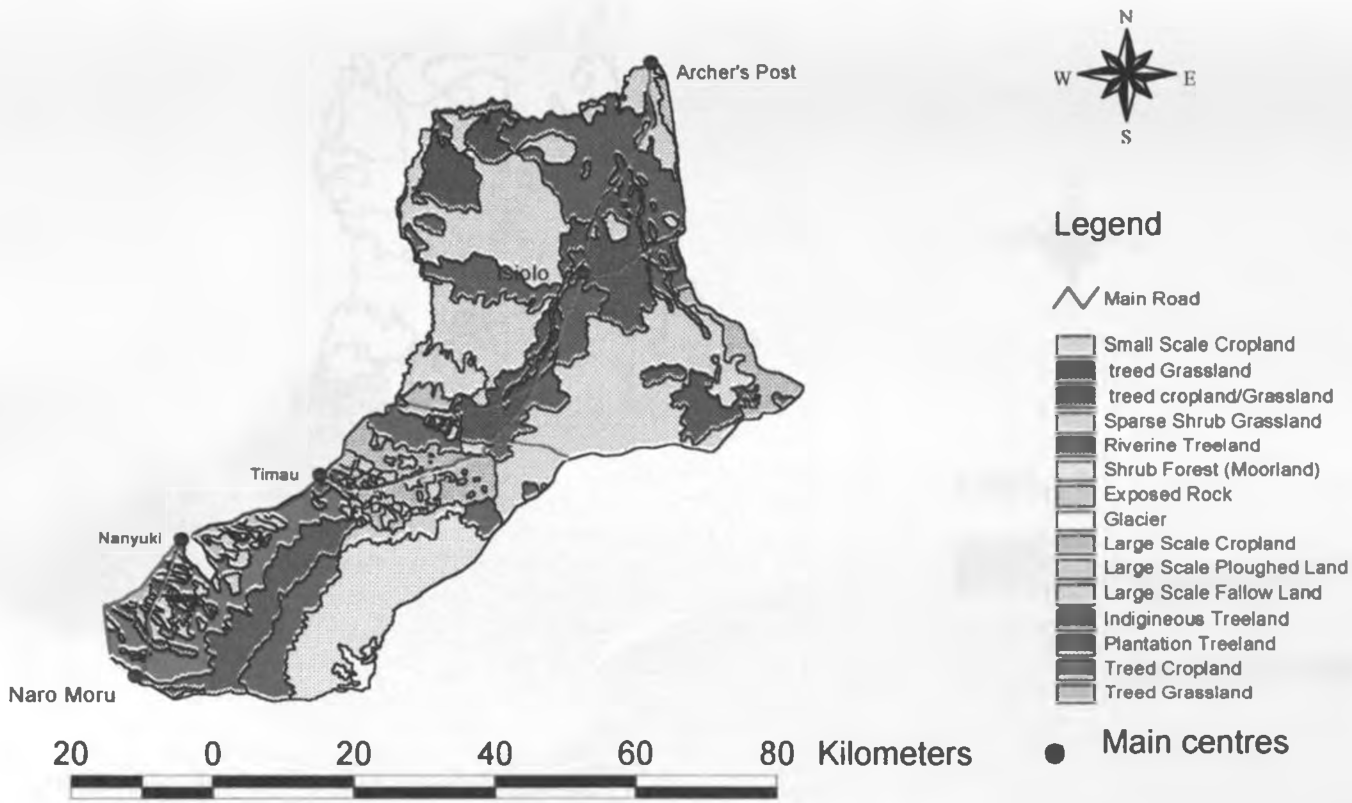


Fig 5.3: Land-use/land-cover, main roads and centres overlay map

F.N. KAMIRU, 1996

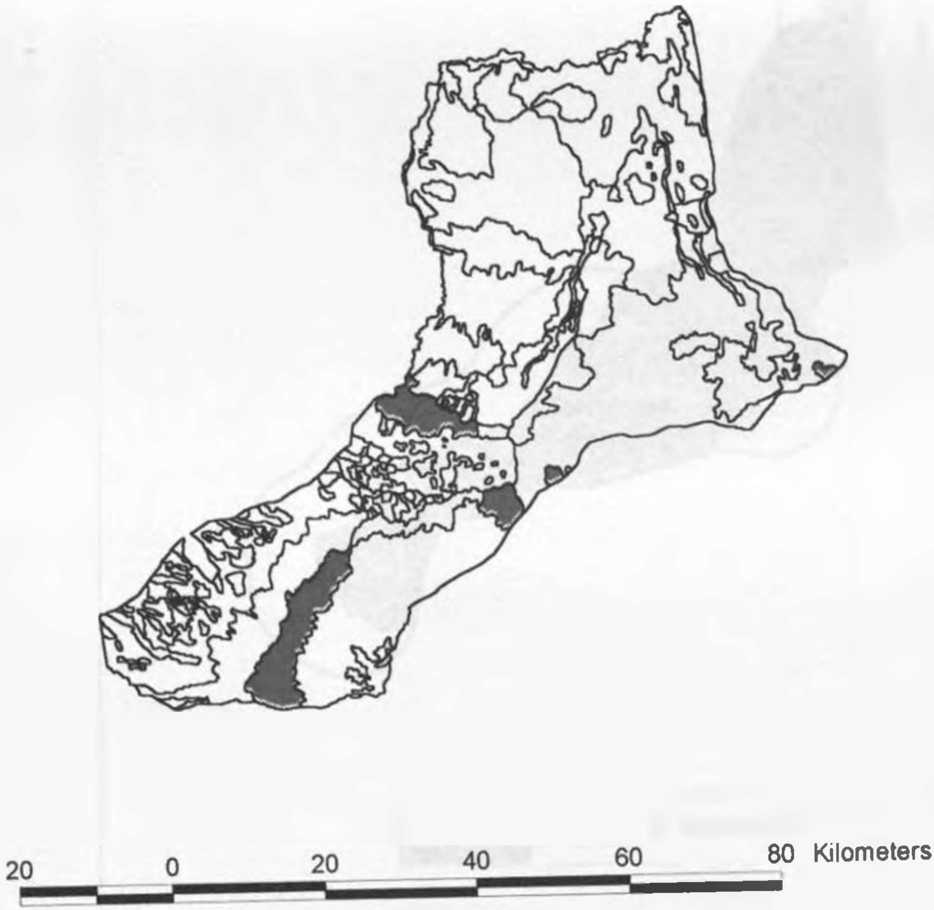
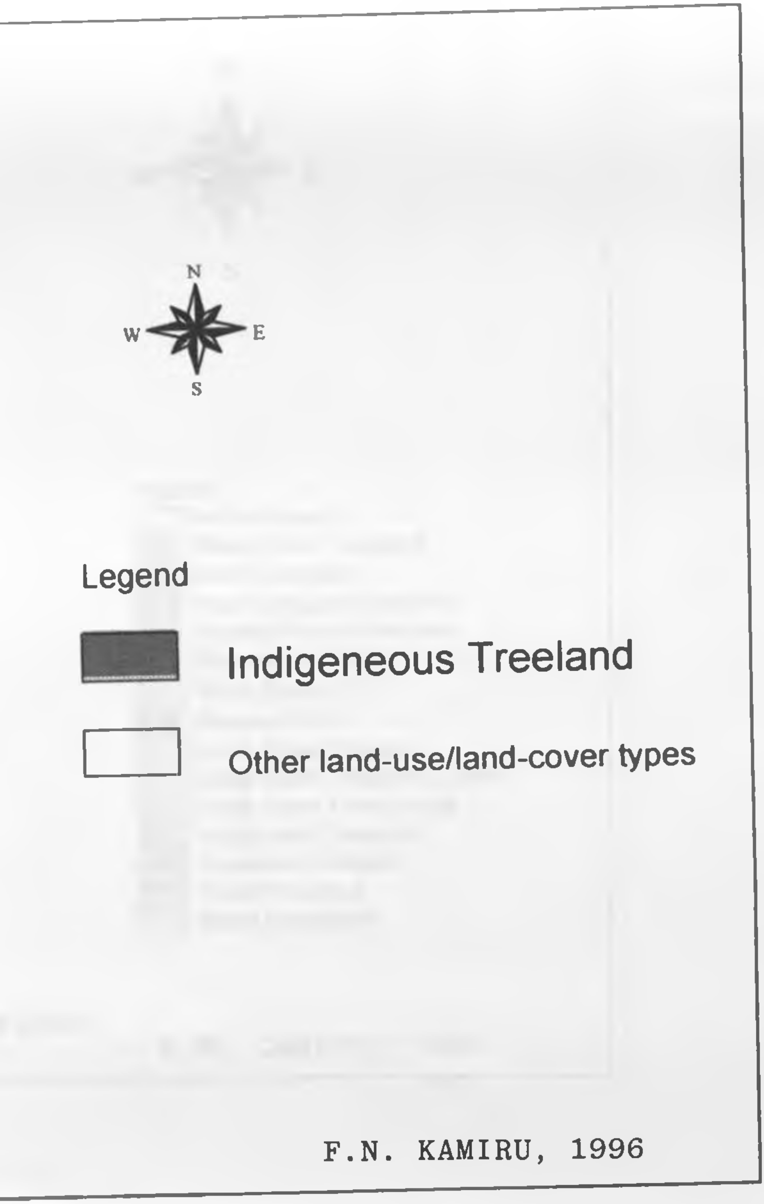


Fig 5.4: Area under Indigeneous Treeland


N
W
E
S
Legend
Indigeneous Treeland
Other land-use/land-cover types
F.N. KAMIRU, 1996

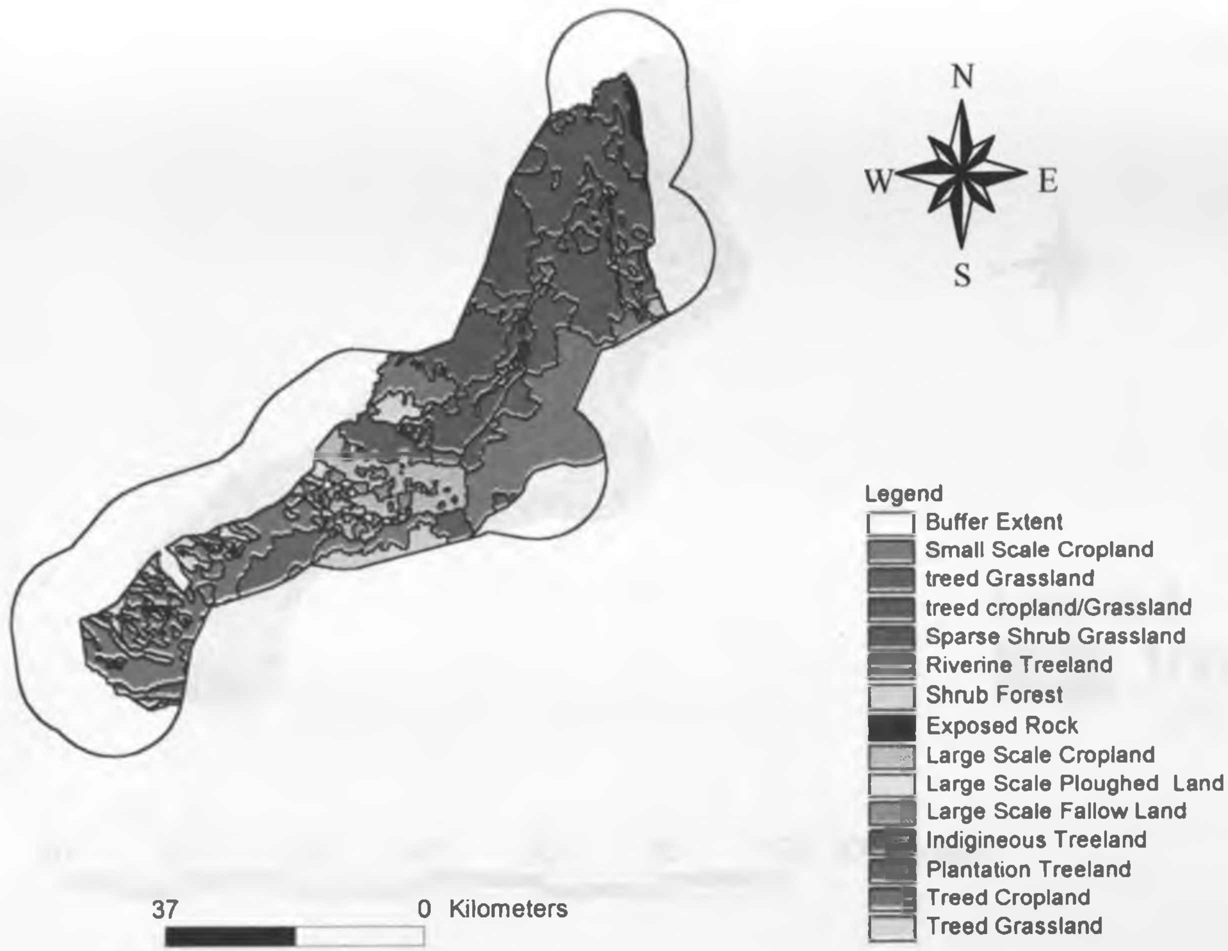


Fig 5.5: Land-use/land-cover within 10Km of the main road

F.N. KAMIRU, 1996

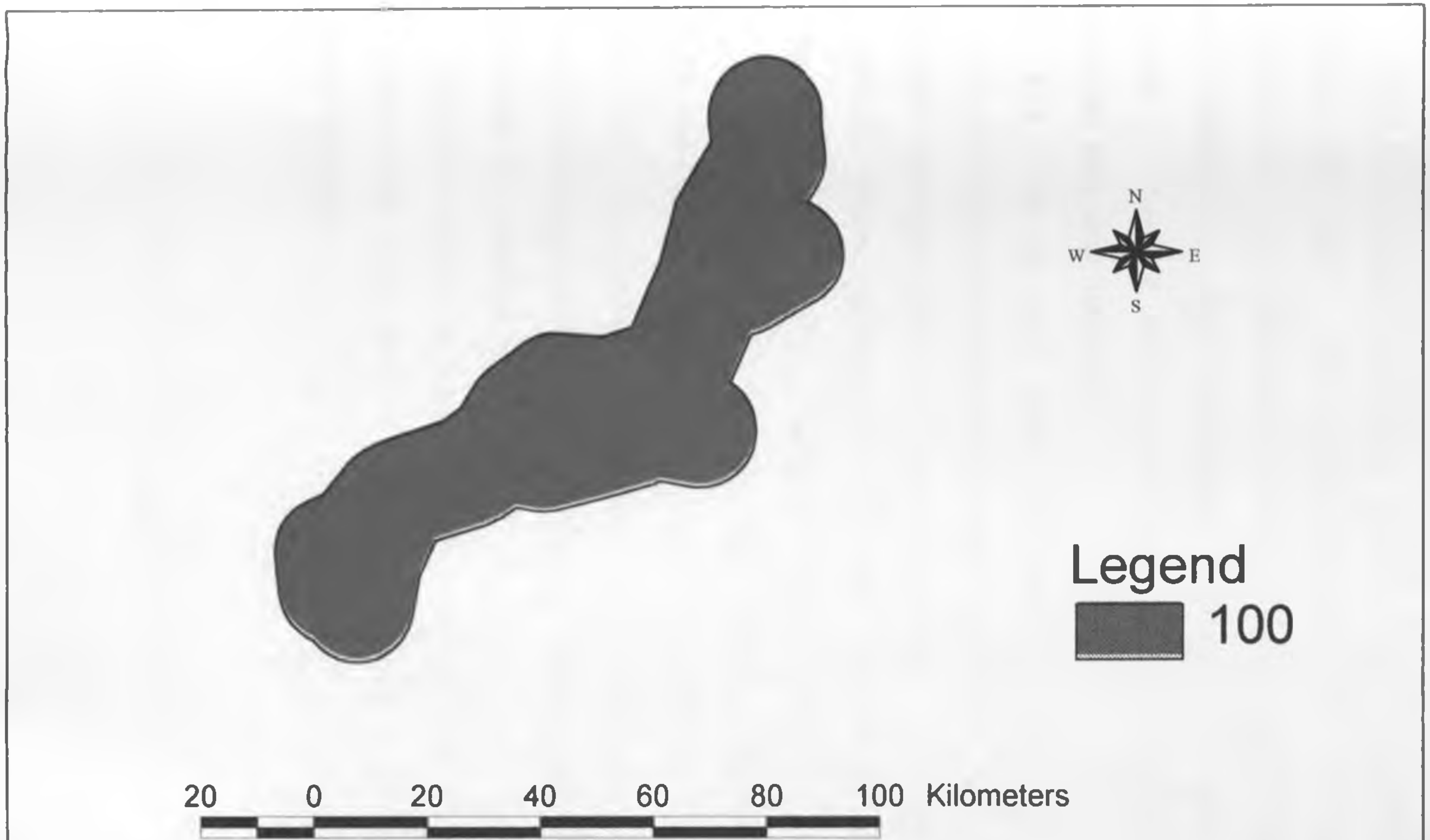


Fig 5.6a: Main road buffer coverage

F.N. KAMIRU, 1996

This table contains only one record having fields that give the, shape, area, perimeter, system defined fields strtbuf_ and strtbuf_id and inside=100 to indicate that all the study area is inside the buffer zone.

Fig 5.6b shows the river buffer map created for a buffer distance of 1km. The corresponding PAT is contained in appendix B4. In this case we have two different Inside values i.e. (INSIDE = 100) for areas inside the buffer zone, and (INSIDE = 1), for areas outside. These areas are shown in both the map and the PAT.

Fig 5.6c is as a result of overlaying Fig 5.6a and Fig 5.6b to satisfy the condition that the area should be within 5km from the road and >1km from the river. Therefore the area is within these specifications and hence the field inside contains values of 100. The PAT is contained in appendix B5.

Finally, Fig 5.6 shows the land-use/land-cover types within 5km from the road and >1km from the river. This as a result of an overlay of figures 5.6c and 5.1 to give only areas within the specified criteria. The corresponding PAT is contained in appendix B6.

Fig 5.7 shows the land-use/land-cover within 5km from the road and >1km from the river against the original river and road coverages.

Fig 5.6b: River buffer coverage

F.N. KAMIRU, 1996

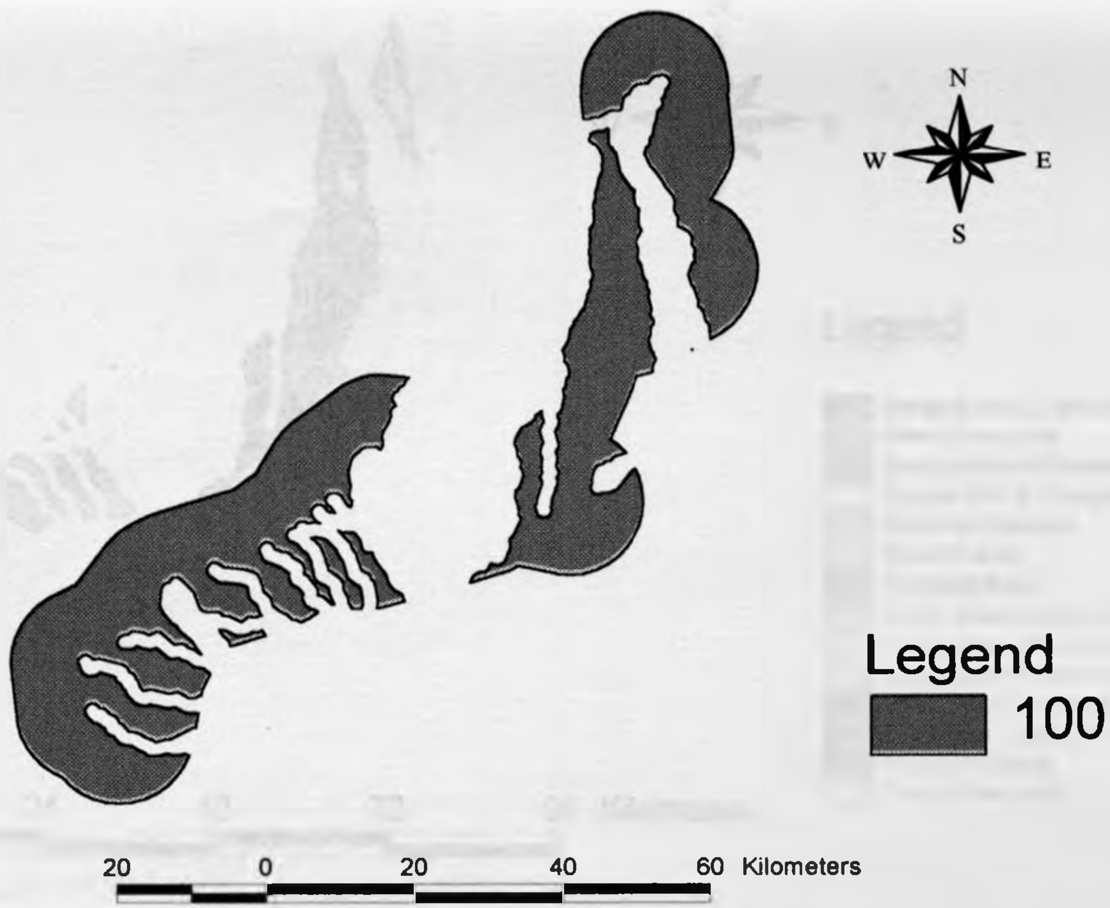


Fig 5.6c: Area within 10km of the main road and >1km from the rivers

F.N. KAMIRU, 1996

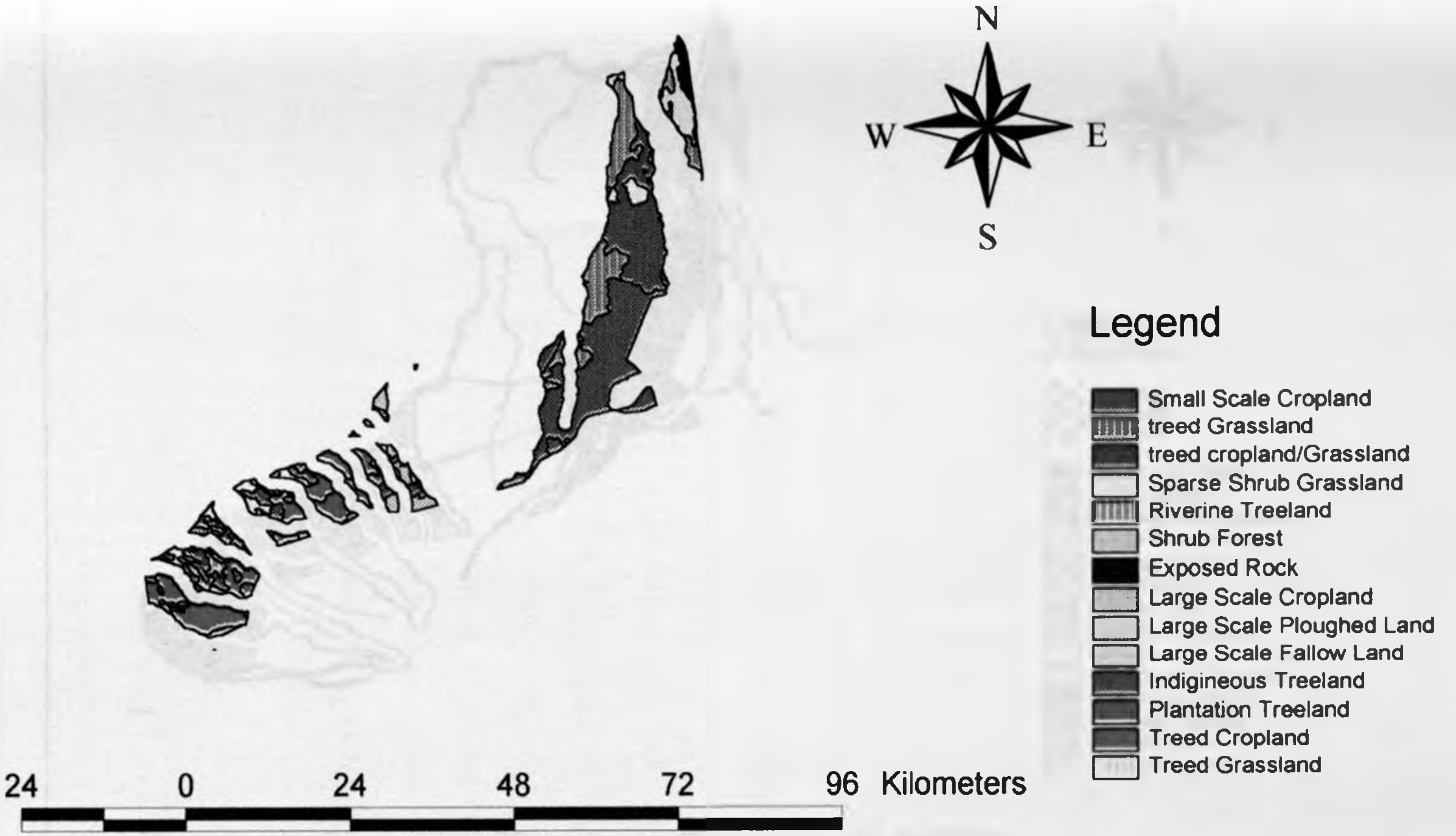


Fig 5.6: Land-use/Land-cover within 5Km of the main road and >1Km from the rivers

F.N. KAMIRU, 1996

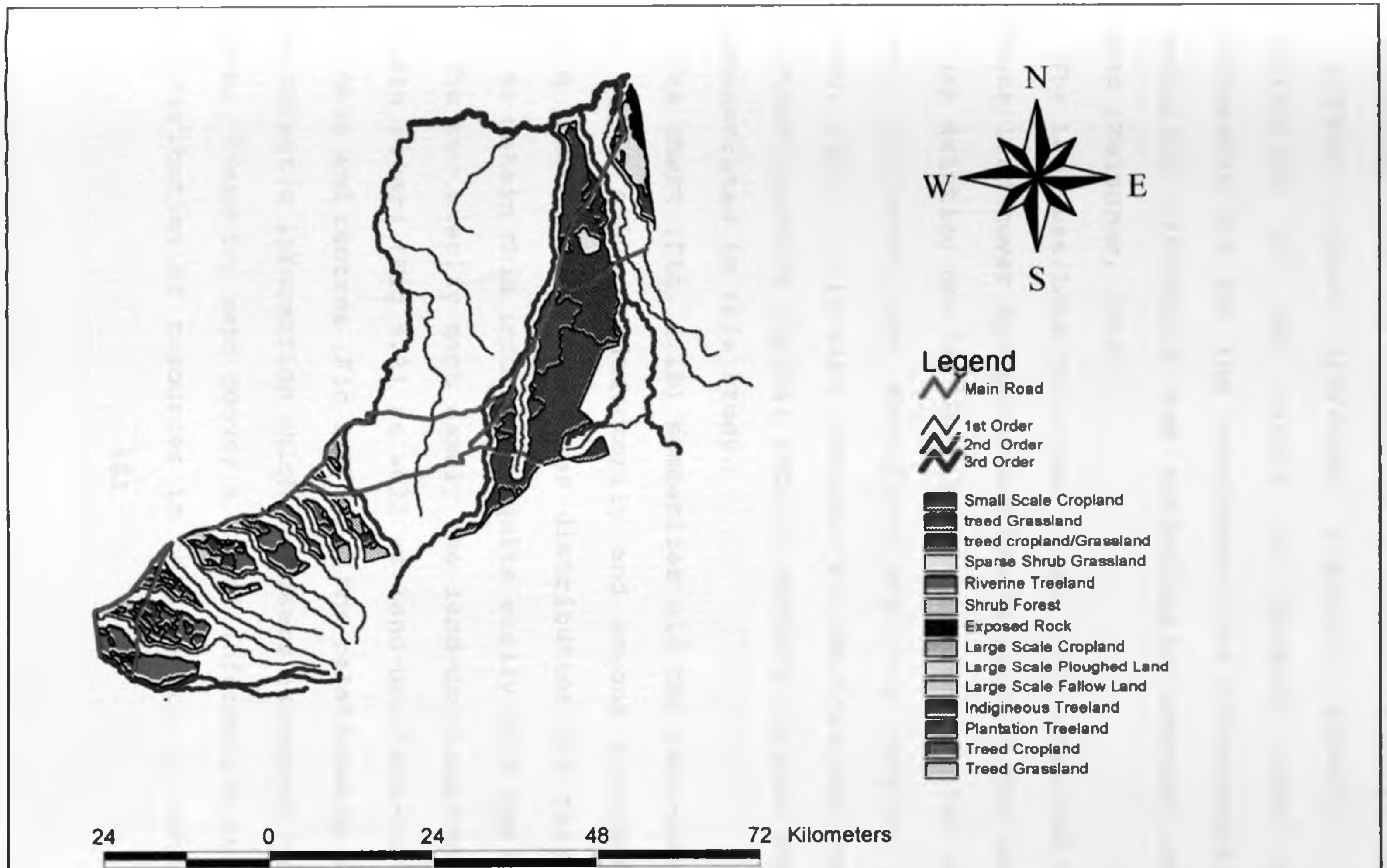


Fig 5.7: Output of Fig 5.6 together with the rivers and main roads coverages

F.N. KAMIRU, 1996

5.2 ANALYSIS OF RESULTS

Considering the different thematic aspects, GIS enables the management and the processing of complex spatial datasets and subject under different thematic aspects. The visualization of the result in dynamic maps is an indispensable aid for the development and recommendation of economically affordable and ecologically adapted land-use systems [Meissner, 1996].

The Land-use/Land-cover map (Fig. 5.1a) shows the various land-use/land-cover types derived from a Landsat MSS imagery. This map existing now in digital form can be modified at will to suit different user specifications, e.g varying scale, colours, etc. It is also possible to use this map together with other existing digital data to perform various analysis as demonstrated in this study.

The chart (Fig. 5.1b) summarizes all the land-use/land-cover types quite satisfactorily and anyone interested in knowing the land-use/land-cover distribution for this study area can obtain this information quite easily from the chart.

The two overlay maps namely the land-use/land-cover and the main rivers (Fig 5.2) as well as land-use/land-cover and main towns and centres (Fig 5.3) give the relationship between these thematic information which the users expressed the need to have. These two maps convey a lot of information as far as the distribution of resources in this region is concerned.

For instance, how well the region is serviced by roads, rivers, and how far the land-use/land-cover types are from the main centres.

The possibility of extracting any information of interest has been demonstrated. Fig 5.4 shows area covered by indigenous treeland alone. Forestry is one of the resources that forms the backbone of our economy, and therefore the status of indigenous forest would be useful information to planners who would in turn advice the Ministry of Environment and Natural Resources to take the necessary action so as to curb its depletion.

Buffering is done with an aim of identifying areas within a certain distance of point, line or area features and the resulting output is always a polygon feature. It can also be performed in conjunction with overlay operations in a bid to establish the distribution of the resources for purposes of locating say a site e.g. tea or coffee factory, or to establish whether irrigation is feasible among other needs. Figures 5.5, 5.6, and 5.7 are as a result of these operations but containing different thematic information depending on the criteria employed.

Accessibility has always been one of the major bottlenecks in some parts of our country. Some places which are productive are not accessible and farmers have to walk for very long distances to reach a shopping centre where they can sell their produce. Consequently, the information provided in Fig 5.5 is an example of what planners could use to assess areas that are accessible and which land-uses/land-cover are prevalent and thereby advice the Ministry of Transport and Communication on how communication can be improved to enhance the productivity of farmers and businessmen, thus uplifting their standard of living.

Information provided in Fig 5.6 can be used by planners in two ways:-

a) If land-use within the region is for instance, large scale cropland (tea), then an appropriate site can be zoned for a tea factory.

b) In identifying areas that can be irrigated to increase crop yield, other than relying on rainfall which is sometimes unreliable, thus ensuring constant supply of foods like horticultural crops (cabbages, onions, carrots, etc). The nearness to the road would ensure that these crops are not only consumed within but are sold to other parts thus generating some income for the small scale farmer.

Consequently, the power of GIS in integrating data which were originally in different formats, scales, spatial and temporal resolution has been demonstrated. For instance the land-use/land-cover map was obtained from a Landsat MSS imagery taken on 30th January 1973 at a resolution of 79 x 79m, whereas the main rivers, roads, and towns were digitized from topographic sheets at a scale of 1:50,000.

Thus spatial analysis facilitates in:

a) identifying trends in data;

b) creating new relationships in the data

c) viewing complex relationships between data sets

d) making better decisions

The benefits accruing from using GIS to manipulate different thematic information stored in the database are enormous. Different user specifications can be met within a very short time compared to the conventional methods which would otherwise take days or months and more man-power depending on the complexity of the output. Based on the Survey Act Cap 299, using the conventional methods to produce a land-use/land-cover map for this area would require not less than Ksh. 15 million, and not short of 1 year to complete the work, with a man-power of about 2 surveyors and 10 technical assistants. On the other hand, using GIS and Remote Sensing techniques would require approximately Ksh. 500,000 3 months to complete the work, and a man-power of 1 GIS analyst and 1 field assistant for the ground truth exercise. Moreover, the data obtained from using the conventional method is in hardcopy format whereas that from the current techniques is in digital form. This implies that manipulating data in digital form is much easier than in hardcopy form.

However, the data available is quite old and may not reflect what is currently on the ground. Nevertheless, this information provided forms a basis for temporal analysis or trends and the GIS updating capabilities can be exploited when current data is available to update this information. Despite the afore mentioned constraints the intended user needs have been addressed.

CHAPTER 6

DISCUSSION

6.0 DISCUSSION

This study aimed at investigating the use of GIS and Remote Sensing in natural resource management for the Upper Uaso Ny'iro river catchment.

The specific objectives included:-

a) Formulation of mapping strategies based on user requuirements.

b) Production of the required databases and maps.

c) Application of databases and maps to natural resource management.

In order to address the above objectives the following procedure was adopted:-

a) user needs analysis,

b) image interpretation,

c) database design and implementation,

d) GIS analysis of the study area, and

e) map production.

Various outputs were generated (see section 5.1) and Table 6.1 summarizes these results.

FIGURE	DESCRIPTION OF GIS OUTPUT GENERATED
5.1a	Land-use/land-cover map
5.1b	Summary of area coverage of each land-use/land cover type
5.2	Land-use/land-cover and main rivers overlay map
5.3	Land-use/land-cover, main road and centres overlay map
5.4	Area under indigeneous treeland
5.5	Land-use/land-cover within 10Km of the main road
5.6a	Main road buffer coverage
5.6b	River buffer coverage
5.6c	Area within 5Km of the main road and >1Km from the river
5.6	Land-use/land-cover types within 5Km of the main road and >1Km from the river
5.7	Overlay of Fig. 5.6 and original river and road coverages

Table 6.1: Summary of the GIS outputs.

The basic output is the land-use/land-cover map (Fig. 5.1) from where together with the drainage network, main road and centres, all the other outputs were derived using Arc/Info and ArcView analysis tools. It is evident, from the above results, that a broad range of analytical operations can be undertaken thereby yielding different outputs depending on the criteria employed (e.g. Figures 5.2, 5.3, 5.4, 5.5, 5.6a, 5.6b, 5.6c, 5.6, and 5.7). Therefore it is very important to clearly define the problem (i.e. the user requirements) before embarking on the analysis. This ensures that all the data required for analysis is ready e.g. it is georeferenced, no missing spatial and attribute data, all the coverages are in the same working space to facilitate easy manipulation, etc, to avoid wasting time and frustrations once the analysis commences.

However the objectives of this study have been met satisfactorily regardless of the constraints encountered of e.g. image data format, age and resolution, and financial constraints. The available image was quite old and therefore did not necessary reflect what was on the ground as shown by the ground truth results (see section 4.3.2) and on the other hand it was in hardcopy format which meant that interpretation had to be manual and thereafter the output digitized. This made it susceptible to errors of omission and ccmission. Morever the coarse resolution of the image resulted in the generalization of information extracted, thus limiting its application to some studies e.g. soil erosion modelling.

The speed, consistency and precision with which GIS operates is trully impressive, and this has been clearly demonstrated in this study. Unlike using the conventional methods, different user specifications can be met within a very short time which would otherwise take days or months and more man-power depending on the complexity of the output.

However a substantial investment needs to be placed in the development and maintenance of the database.

CHAPTER 7

CONCLUSION

Discussed in this chapter are the conclusions and the relevant recommendations arrived at as a result of this study.

7.1 SUMMARY

The main objective of this study was to investigate the use of GIS and Remote Sensing in natural resource management for the Upper Uaso Ny'iro river catchment. The specific objectives included:-

i) Formulation of mapping strategies based on user requirements.

ii) Production of the required databases and maps.

iii) Application of databases and maps to natural resource management.

The work done towards achieving these objectives involved:

a) Carrying out a user needs analysis so as to establish the desirable contents of a proposed GIS database.

b) The availabe Landsat MSS image was manually interpreted to produce a land-use/land-cover map, after which ground truth exercise was conducted to verify the correctness of the interpretation and amendments made where appropriate.

c) The land-use/land-cover map generated was then digitized and stored as a separate layer in the database.

d) The land-use/land-cover coverage was then combined with other data (such as the road network, drainage network, and major centres) already in the database and analysis performed using Arc/Info and ArcView software packages. Various GIS products, which could be useful for various user needs, were generated.

7.2 CONCLUSIONS

The conclusions arising from the work done in addressing the objectives revealed that the efficiency and success of monitoring, modelling and managing natural resources of the Upper Uaso Ny'iro river basin requires tools that can generate information fast at specified temporal and spatial resolutions.

During image interpretation three main observations were made namely ; the spatial and temporal resolutions of data,and the data format available for this particular study area. The image available, was taken on 30th January 1973 which implies that the information extracted was about 23 years old and hence not current. The image was in hardcopy format and hence interpretation had to be done manually which meant that the amount of information that could be extracted from it depended entirely on the interpretators visual capability. On the other hand the resolution of a Landsat MSS is quite coarse which also has a direct implication on the accuracy of data that can be extracted.

Prior understanding of user needs is essential in the successful formulation of mapping strategies. This ensures that user needs are adequately addressed during database design and implementation. The observations made at this stage were mainly during digitizing where the problems encountered were those of polygon misclosures and slivers. However during topology building Arc/Info corrects for most overshoots but not for undershoots in which case these arcs were digitized again. Another problem was that of having either no label or assigning two labels to one polygon. The software has a facility for detecting this error which made editing much easier and faster. Also a comparison of the original map and digitized coverage was made to ensure that no error of commission or omission were committed.

GIS analysis of the study area which essentially involved database query, buffer and overlay operations revealed that, given specific user needs, appropriate maps and tables could be generated successfully. However, the most important thing at this level is first to define the problem clearly and thereafter set out a step by step procedure to solve the problem. This facilitates the detection of any problems before the analysis can be performed, e.g. missing spatial or attribute data, data not georeferenced, data not available and therefore seek alternatives, etc which essentially saves a lot of time and frustrations. Nevertheless, with the right kind of data and the problem well defined GIS analysis is one of the most interesting undertakings, since one is able to illuminate underlying trends in geographical data and thus make new information available.

The maps generated from this study revealed that Arc/Info is a very powerful tool for complex spatial analysis e.g. buffer generation and map overlays, whereas ArcView is a very powerful tool in simple database queries, chart and map production. It also enabled modifications in maps to suit the specifications desired e.g. editing a legend, applying user defined colours, adding a title, scale bar and a north arrow. The handicap encountered, however, in the production of maps was the limitation of the output device available for the study, which supported only A4 size paper. As a result the outputs had to be reduced to a scale of 1:1,500,000 so as to fit on an A4 size paper.

7.3 RECOMMENDATIONS

This study provides a baseline land-use/land-cover map which can be used for trend analysis by comparing for instance land-use/land-cover for another year or more years to establish how much change has occurred. However, for studies that require more detailed information e.g. soil erosion modelling, this map may only serve as a guide but a large scale image like Spot is recommended.

Planners rely on current information to plan and manage natural resources. However, the land-use/land-cover map originated from a Landsat MSS image taken on 30th January 1973. Consequently, this study recommends that whenever a current image is available it can be used to update the already existing map thus ensuring current information which planners can rely on.

On the other hand, it is proposed that in future a digital image should be used so as to ensure that more details are extracted as opposed to using a hardcopy image. Also it is easy to manage and manipulate digital data than its hardcopy counterpart. This removes the task of having to delineate the land-use/land-cover types manually and then digitizing the delineated features which is time consuming and subject to errors.

It has become apparent that the generation and maintenance of geographic databases is a major bottleneck and expense in the implementation of GIS. Consequently, a good database system should be adopted which will ensure that the integrity and the security of these databases are maintained. There are two kinds of database configuration namely; distributed and centralized database systems. A distributed database is one where databases are distributed in different locations without replicating and any user can access the databases without being aware of their locations, whereas a centralized database is where all the information is stored in one central database and this has a major drawback in the sense that system failure would lead to major losses in the organization and a complicated operating system is required to manage the database [Waema, 1992]. In this regard this study recommends the use of a distributed database system for this river basin. Different databases can be located in the various district headquarters (e.g. Isiolo, Laikipia, Nyeri, Samburu, etc) that are within the river basin and through some communication protocols access to these databases can be effected. Consequently users can view the constituent parts of the Upper Uaso Ny'iro river basin databases as one continuous database.

The contribution of GIS and Remote Sensing tools have successfully been demonstrated in this study and it is therefore hoped that these modern techniques will be adopted not only for the Upper Uaso Ny'iro river basin, but also for any other regions in Kenya where they have not been employed.

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APPENDIX A : FIELD DATA

A1 SAMPLE QUESTIONNAIRE

A2 LIST OF INTERVIEWEES

A3 GROUNDTRUTH BOOKING SHEET FORMAT

APPENDIX A1: SAMPLE QUESTIONNAIRE

This questionnaire is designed to establish user needs in respect of the contents of a proposed GIS database for the Upper Uaso Nyiro Catchment area.

Your co-operation will go a long way in ensuring that this objective is achieved.

Please tick ( ) the appropriate response.

NAME OF INTERVIEWEE:______________________________

DATE:____

1. What is your current designation?
   - ☐ Planner
   - ☐ Administrator
   - ☐ Surveyor
   - ☐ Engineer
   - ☐ Farmer
   - ☐ Businessman
   - ☐ Any other (specify)

2. Do you handle any spatial data?
   - ☐ Yes
   - ☐ No

3. What kind of spatial data do you deal with in general?

☐ Drainage network

☐ Topography

☐ Communication network

☐ Land-use/land-cover

☐ Soil types

☐ Land ownership

☐ All

☐ Any other (specify)

4. What scale/scales do you normally employ?

☐ 1:50,000

☐ 1:100,000

☐ 1:200,000

☐ 1:250,000

☐ All

☐ Any other (specify)

5. What are your accuracy requirements?

☐ <= 0.1mm

☐ > 0.1mm

☐ Any other (specify)

6. How do you handle your spatial data?

☐ Using computers

☐ Manually

☐ Any other (specify)

7. What is your opinion about how you handle data currently?

☐ Complex

☐ Easy

☐ Can not tell

8. Are you comfortable with the way data is being handled currently?

- ☐ Yes
- ☐ No

REASON____

____

9. How reliable is the information derived from data currently?

- ☐ Very reliable
- ☐ Acceptable
- ☐ Not reliable
- ☐ Do not know

10. What is your level of awareness of Geographic Information Systems (GIS)?

- ☐ I have used it
- ☐ Know a little about it
- ☐ Just heard about it
- ☐ Never heard about it.

11. What solutions would you suggest for your current system?

- ☐ Computerization
- ☐ Status quo
- ☐ Do not Know

General Remark.

APPENDIX A2: LIST OF INTERVIEWEES

1. **Antony Kiarie:** Administrator
2. **B.P. Kiteme:** Planner
3. **Gikonyo J.K.:** Engineer
4. **James Kimathi:** Research Assistant
5. **James Maina:** Businessman
6. **Joseph Ndungu:** Administrator
7. **Joseph Munyao:** Planner
8. **Karuga J.K.:** Surveyor
9. **Kironchi G.:** Soil Scientist
10. **Nicholas Wangondu:** Farmer
11. **Njeru Lewis:** Hydrologist
12. **Noah Sempeo:** Businessman
13. **Mary Muiruri:** Farmer
14. **Samwel Mwangi:** Engineer

APPENDIX A3

SAMPLE AREA No. : ____________ DATE : ________ AREA DESCRIPTION : ____________

REFERENCE POINT	POINT DESCRIPTION	GPS 3-D CO-ORDINATES	LAND-USE / LAND-COVER CLASSIFICATION	% COVER							% SOIL COVER	REMARKS
				T	G	C	B	S	U	I		

APPENDIX B: POLYGON ATTRIBUTE TABLES (PAT)

B1a LAND-USE/LAND-COVER PAT

B1b AREA COVERAGE SUMMARY PAT

B2 LAND-USE/LAND-COVER TYPES WITHIN 10km FROM THE MAIN ROAD PAT

B3 ROAD BUFFER PAT

B4 RIVER BUFFER PAT

B5 ROAD AND RIVER BUFFERS OVERLAY PAT

B6 LAND-USE/LAND-COVER TYPES WITHIN 5Km FROM THE ROAD AND < 1Km FROM THE RIVER PAT

APPENDIX B1a: LAND-USE/LAND-COVER PAT

Area	Perimeter	Lulcov5_	Lulcov5_id	Lulcov_typ
5.638564e+007	70636.340000	2	33	SSG
1.316715e+007	38029.710000	3	61	ER
2.633737e+008	240595.700000	4	31	tG
5.140013e+006	10757.930000	5	33	SSG
3.464476e+007	32786.310000	6	32	tcG
1.564825e+007	23578.170000	7	33	SSG
7.246238e+007	49454.830000	8	32	tcG
2.703233e+008	150418.500000	9	33	SSG
2.231411e+007	23463.760000	10	33	SSG
1.713754e+008	148471.000000	11	32	tcG
2.131998e+006	6419.417000	12	43	RT
982956.800000	4232.685000	13	43	RT
1.125448e+006	5316.837000	14	43	RT
1.820875e+006	11242.200000	15	43	RT
4.118521e+006	19630.220000	16	43	RT
643347.100000	3299.616000	17	43	RT
282381.100000	2497.849000	18	43	RT
372951.300000	2538.638000	19	43	RT
9.319974e+006	12741.990000	20	33	SSG
8.403216e+006	12402.670000	21	31	tG
2.790706e+006	6340.592000	22	33	SSG
1.793449e+006	6054.580000	23	43	RT
2.511747e+006	6895.223000	24	33	SSG
5.669968e+006	12207.680000	25	31	tG
3.141291e+006	11395.890000	26	43	RT
607117.200000	6953.862000	27	32	tcG
2.057215e+007	70950.350000	28	43	RT
1.510773e+006	5439.390000	29	43	RT
7.963332e+007	68459.050000	30	31	tG
1.171806e+006	4600.662000	31	43	RT
2.977977e+006	17539.370000	32	43	RT
1.721617e+007	32888.490000	33	31	tG
3.445851e+006	17704.400000	34	43	RT
7.465839e+006	25879.700000	35	43	RT
1.828609e+006	5323.985000	36	32	tcG
9.266127e+007	88897.700000	37	31	tG
1.482894e+008	102734.500000	38	33	SSG
6.643331e+007	82747.600000	39	211	LSC
4.665168e+008	235074.100000	40	22	SSC
9.163751e+007	124452.300000	41	32	tcG
5.727368e+007	63023.980000	42	22	SSC
786908.300000	3470.592000	43	43	RT
1.233769e+007	18164.510000	44	32	tcG
1.201239e+006	5424.814000	45	43	RT
5.881233e+007	63220.470000	46	32	tcG
2.405828e+007	30666.890000	47	422	TG
3.684062e+006	9217.939000	48	411	IT
7.551554e+006	25979.050000	49	43	RT
4.937105e+007	45248.690000	50	411	IT
3.166899e+006	15192.160000	51	43	RT
1.378643e+006	5981.097000	52	22	SSC
502403.900000	3783.164000	53	22	SSC

PAT CONT.

Area	Perimeter	Lulcov5_	Lulcov5_id	Lulcov_typ
1.278470e+008	174257.600000	54	211	LSC
2.742866e+006	6811.505000	55	22	SSC
1.686027e+006	6645.274000	56	213	LSFL
2.159269e+006	8750.452000	57	212	LSPL
6.765461e+006	11985.740000	58	22	SSC
5.286594e+006	11172.570000	59	212	LSPL
200161.100000	1714.189000	60	213	LSFL
3.293119e+006	8991.740000	61	213	LSFL
1.217406e+006	5289.288000	62	213	LSFL
3.870272e+006	9119.859000	63	213	LSFL
67804.690000	1057.426000	64	213	LSFL
3.843916e+006	11634.210000	65	211	LSC
4.955259e+006	12305.920000	66	213	LSFL
8.610135e+006	22636.530000	67	213	LSFL
6.445942e+006	20645.040000	68	43	RT
1.486431e+006	4813.155000	69	212	LSPL
1.976038e+006	6170.723000	70	212	LSPL
370584.600000	2307.189000	71	213	LSFL
3.586338e+006	8592.825000	72	213	LSFL
2.768963e+006	7962.374000	73	211	LSC
3.334184e+006	11833.910000	74	213	LSFL
340391.800000	2361.900000	75	213	LSFL
3.249927e+006	12530.990000	76	212	LSPL
840555.200000	3748.506000	77	213	LSFL
3.832634e+006	9263.410000	78	43	RT
4.345561e+006	8252.701000	79	411	IT
479492.200000	2754.619000	80	411	IT
347352.100000	2364.085000	81	213	LSFL
2.208575e+008	312860.400000	82	421	TC
748033.900000	3594.682000	83	213	LSFL
613630.300000	3018.584000	84	213	LSFL
8.600356e+006	27934.440000	85	212	LSPL
1.888728e+006	5830.707000	86	43	RT
2.167831e+007	20381.120000	87	411	IT
4.096884e+007	56828.370000	88	22	SSC
1.863977e+006	6698.832000	89	213	LSFL
1.409312e+006	4948.205000	90	213	LSFL
6.014560e+006	14210.290000	91	211	LSC
3.797446e+006	10552.640000	92	213	LSFL
6.074457e+006	18634.380000	93	211	LSC
1.924972e+006	6030.562000	94	213	LSFL
3.119988e+006	10113.820000	95	213	LSFL
1.006192e+006	5206.660000	96	213	LSFL
1.116474e+006	4106.415000	97	212	LSPL
3.024814e+008	132924.600000	98	44	SF
4.714157e+006	12021.540000	99	22	SSC
6.425517e+006	14344.430000	100	422	TG
1.154008e+006	4428.515000	101	22	SSC
684126.200000	3622.538000	102	212	LSPL
1.673245e+008	119798.500000	103	412	PT
792292.900000	3635.851000	104	211	LSC
4.759287e+006	20537.900000	105	422	TG

PAT CONT.

Area	Perimeter	Lulcov5_	Lulcov5_id	Lulcov_typ
1.365098e+007	29810.620000	106	422	TG
1.035992e+006	4951.106000	107	22	SSC
1.310456e+007	28720.710000	108	22	SSC
1.507494e+006	7884.571000	109	22	SSC
1.138484e+006	4388.469000	110	22	SSC
2.780323e+006	10304.360000	111	43	RT
4.019762e+006	10519.340000	112	422	TG
9.979490e+007	70238.340000	113	411	IT
2.161161e+006	8914.526000	114	22	SSC
4.742213e+006	9614.345000	115	22	SSC
1.823156e+006	6285.886000	116	22	SSC
3.732198e+006	11141.010000	117	22	SSC
1.975743e+007	54876.880000	118	43	RT
2.830772e+006	7827.382000	119	22	SSC
1.055114e+007	31184.540000	120	422	TG
3.397589e+006	13668.650000	121	43	RT
1.569764e+007	36534.790000	122	22	SSC
1.075590e+006	4693.750000	123	22	SSC
1.368928e+007	32377.750000	124	43	RT
2.141643e+006	7137.361000	125	22	SSC
1.496905e+006	5216.125000	126	22	SSC
4.251544e+006	12809.540000	127	22	SSC
663155.900000	3413.604000	128	22	SSC
2.201927e+007	49438.960000	129	71	GL
1.800962e+006	7979.731000	130	44	SF
601261.000000	2963.113000	131	22	SSC
902646.700000	3890.904000	132	22	SSC
558535.100000	3311.108000	133	22	SSC
1.025169e+006	5315.648000	134	22	SSC
4.229732e+006	14790.360000	135	43	RT
2.406910e+006	10558.860000	136	22	SSC

APPENDIX B 1b: Area Coverage Summary PAT

First_Lulcsm_typ	Sum_Area
ER	13167150.00
GL	22019270.00
IT	179353375.20
LSC	213774498.90
LSFL	47202140.69
LSPL	24559215.20
PT	167324500.00
RT	121285872.60
SF	304282362.00
SSC	644913888.60
SSG	532723140.00
TC	220857500.00
TG	63464966.00
tG	466957644.00
tcG	443705796.20

APPENDIX B2: LAND-USE/LAND-COVER TYPES WITHIN 10 KM OF THE MAIN ROAD PAT

Area	Perimeter	Inside	Lulcov8_	Lulcov8_id
4.186857e+008	130459.000000	100	1	0
5.638564e+007	70636.340000	100	2	33
1.316715e+007	38029.710000	100	3	61
2.097720e+008	161678.800000	100	4	31
5.140013e+006	10757.930000	100	5	33
554610.900000	3386.055000	100	1	0
1.174228e+007	14027.550000	100	10	33
1.713754e+008	148471.000000	100	11	32
2.131998e+006	6419.417000	100	12	43
3.243469e+007	45806.590000	100	9	33
982956.800000	4232.685000	100	13	43
1.125448e+006	5316.837000	100	14	43
4.118521e+006	19630.220000	100	16	43
643347.100000	3299.616000	100	17	43
282381.100000	2497.849000	100	18	43
372951.300000	2538.638000	100	19	43
9.319974e+006	12741.990000	100	20	33
2.790706e+006	6340.592000	100	22	33
1.793449e+006	6054.580000	100	23	43
2.511747e+006	6895.223000	100	24	33
3.141291e+006	11395.890000	100	26	43
607117.200000	6953.862000	100	27	32
2.057215e+007	70950.350000	100	28	43
1.510773e+006	5439.390000	100	29	43
1.171806e+006	4600.662000	100	31	43
1.721617e+007	32888.490000	100	33	31
3.445851e+006	17704.400000	100	34	43
2.654959e+007	36741.700000	100	30	31
4.228176e+006	16251.760000	100	35	43
1.828609e+006	5323.985000	100	36	32
9.266127e+007	88897.700000	100	37	31
6.117219e+006	10439.230000	100	39	211
9.854471e+007	86610.050000	100	38	33
2.560273e+008	135678.500000	100	40	22
9.163751e+007	124452.300000	100	41	32
459883.900000	2977.400000	100	40	22
3.625849e+008	218605.700000	100	1	0
5.679909e+007	61036.390000	100	42	22
2.405828e+007	30666.890000	100	47	422
7.551554e+006	25979.050000	100	49	43
4.937105e+007	45248.690000	100	50	411
3.166899e+006	15192.160000	100	51	43
1.378643e+006	5981.097000	100	52	22
502403.900000	3783.164000	100	53	22
1.278470e+008	174257.600000	100	54	211
2.742866e+006	6811.505000	100	55	22
1.685027e+006	6645.274000	100	56	213
2.159269e+006	8750.452000	100	57	212
6.765461e+006	11985.740000	100	58	22
5.286594e+006	11172.570000	100	59	212
1.276279e+008	52252.720000	100	1	0
200161.100000	1714.189000	100	60	213

PAT CONT.

Area	Perimeter	Lustri_	Lustri_id	Strtbuf_	Strtbuf_id	Inside	Lulcov8_	Lulcov8_id
3.293119e+006	8991.740000	54	53	2	1	100	61	213
1.217406e+006	5289.288000	55	54	2	1	100	62	213
3.870272e+006	9119.859000	56	55	2	1	100	63	213
67804.690000	1057.426000	57	56	2	1	100	64	213
3.843916e+006	11634.210000	58	57	2	1	100	65	211
4.955259e+006	12305.920000	59	58	2	1	100	66	213
8.610135e+006	22636.530000	60	59	2	1	100	67	213
6.445942e+006	20645.040000	61	60	2	1	100	68	43
1.486431e+006	4813.155000	62	61	2	1	100	69	212
1.976038e+006	6170.723000	63	62	2	1	100	70	212
370584.600000	2307.189000	64	63	2	1	100	71	213
3.586338e+006	8592.825000	65	64	2	1	100	72	213
2.768963e+006	7962.374000	66	65	2	1	100	73	211
3.334184e+006	11833.910000	67	66	2	1	100	74	213
340391.800000	2361.900000	68	67	2	1	100	75	213
3.249927e+006	12530.990000	69	68	2	1	100	76	212
840555.200000	3748.506000	70	69	2	1	100	77	213
3.832634e+006	9263.410000	71	70	2	1	100	78	43
4.345561e+006	8252.701000	72	71	2	1	100	79	411
479492.200000	2754.619000	73	72	2	1	100	80	411
347352.100000	2364.085000	74	73	2	1	100	81	213
2.144151e+008	04814.800000	75	74	2	1	100	82	421
748033.900000	3594.682000	76	75	2	1	100	83	213
613630.300000	3018.584000	77	76	2	1	100	84	213
8.600356e+006	27934.440000	78	77	2	1	100	85	212
1.888728e+006	5830.707000	79	78	2	1	100	86	43
1.969229e+007	19180.430000	80	79	2	1	100	87	411
4.096884e+007	56828.370000	81	80	2	1	100	88	22
1.863977e+006	6698.832000	82	81	2	1	100	89	213
1.409312e+006	4948.205000	83	82	2	1	100	90	213
6.014560e+006	14210.290000	84	83	2	1	100	91	211
3.797446e+006	10552.640000	85	84	2	1	100	92	213
6.074457e+006	18634.380000	86	85	2	1	100	93	211
1.924972e+006	6030.562000	87	86	2	1	100	94	213
3.119988e+006	10113.820000	88	87	2	1	100	95	213
1.006192e+006	5206.660000	89	88	2	1	100	96	213
1.116474e+006	4106.415000	90	89	2	1	100	97	212
4.343420e+007	53458.370000	91	90	2	1	100	98	44
4.714157e+006	12021.540000	92	91	2	1	100	99	22
6.425517e+006	14344.430000	93	92	2	1	100	100	422
1.154008e+006	4428.515000	94	93	2	1	100	101	22
684126.200000	3622.538000	95	94	2	1	100	102	212
6.008584e+007	41689.430000	96	95	2	1	100	103	412
792292.900000	3635.851000	97	96	2	1	100	104	211
4.759287e+006	20537.900000	98	97	2	1	100	105	422
1.365098e+007	29810.620000	99	98	2	1	100	106	422
1.035992e+006	4951.106000	100	99	2	1	100	107	22
1.310456e+007	28720.710000	101	100	2	1	100	108	22
1.507494e+006	7884.571000	102	101	2	1	100	109	22
1.138484e+006	4388.469000	103	102	2	1	100	110	22
2.780323e+006	10304.360000	104	103	2	1	100	111	43
4.019762e+006	10519.340000	105	104	2	1	100	112	422

PAT CONT.

Area	Perimeter	Lustri_	Lustri_id	Stribut_	Stribut_id	Inside	Lulcov8_	Lulcov8_id
125050.900000	1465.367000	106	105	2	1	100	113	411
2.263295e+006	8349.025000	107	106	2	1	100	113	411
2.161161e+006	8914.526000	108	107	2	1	100	114	22
4.742213e+006	9614.345000	109	108	2	1	100	115	22
1.823156e+006	6285.886000	110	109	2	1	100	116	22
3.732198e+006	11141.010000	111	110	2	1	100	117	22
1.875743e+007	54876.880000	112	111	2	1	100	118	43
2.830772e+006	7827.382000	113	112	2	1	100	119	22
1.055114e+007	31184.540000	114	113	2	1	100	120	422
78378.300000	1323.617000	115	114	2	1	100	103	412
50332.800000	1030.285000	116	115	2	1	100	103	412
3.397589e+006	13668.650000	117	116	2	1	100	121	43
1.569764e+007	36534.790000	118	117	2	1	100	122	22
1.075590e+006	4693.750000	119	118	2	1	100	123	22
1.368928e+007	32377.750000	120	119	2	1	100	124	43
218367.200000	1865.745000	121	120	2	1	100	103	412
2.141643e+006	7137.361000	122	121	2	1	100	125	22
1.496905e+006	5216.125000	123	122	2	1	100	126	22
4.251544e+006	12809.540000	124	123	2	1	100	127	22
21085.710000	748.138700	125	124	2	1	100	103	412
4.355977e+006	9448.604000	126	125	2	1	100	103	412
663155.900000	3413.604000	127	126	2	1	100	128	22
601261.000000	2963.113000	128	127	2	1	100	131	22
902646.700000	3890.904000	129	128	2	1	100	132	22
558535.100000	3311.108000	130	129	2	1	100	133	22
1.025169e+006	5315.648000	131	130	2	1	100	134	22
508523.200000	3265.984000	132	131	2	1	100	103	412
1.394825e+007	27043.520000	133	132	2	1	100	103	412
4.229732e+006	14790.360000	134	133	2	1	100	136	43
2.406910e+006	10558.860000	135	134	2	1	100	136	22

APPENDIX B3: ROAD BUFFER PAT

Area	Perimeter	Strbuf_	Strbuf_id	Inside
3.550885e+009	343648.800000	2	1	100

PPENDIX B4: RIVER BUFFER PAT

Area	Perimeter	Neelbuf_	Neelbuf_id	Inside
1.580207e+009	1.356624e+006	2	1	100
8.295668e+006	16782.870000	3	2	1
8.956797e+008	343104.600000	4	3	1
354032.500000	6365.884000	5	4	1
1.327046e+006	6980.830000	6	5	1
6.490875e+006	14462.380000	7	6	1
1.374653e+006	7794.005000	8	7	1
319268.500000	3365.379000	9	8	1
45536.650000	943.405300	10	9	1
3.105640e+007	39129.700000	11	10	1
1.627017e+006	6512.824000	12	11	1
44974.270000	2081.041000	13	12	1
286277.800000	4297.927000	14	13	1
154939.900000	2378.200000	15	14	1
114052.700000	2153.475000	16	15	1
1.720488e+006	9283.662000	17	16	1
577179.700000	4824.552000	18	17	1
37169.470000	2460.711000	19	18	1
1.448318e+006	10097.430000	20	19	1

APPENDIX B5: ROAD AND RIVER BUFFERS OVERLAY PAT

Area	Perimeter	Bufcov_	Bufcov_id	Inside
4.509801e+008	130812.600000	2	1	100
5.570466e+008	205292.100000	3	2	100
1210.777000	165.542700	4	3	100
1.037666e+009	358180.300000	5	4	100
2.171772e+007	30315.930000	6	5	100
1.705430e+007	25548.460000	7	6	100
5.668197e+006	14718.530000	8	7	100

APPENDIX B6: LAND-USE/LAND-COVER TYPES WITHIN 5KM FROM THE ROAD AND < 1KM FROM THE RIVER PAT

Area	Perimeter	Lulcov8_	Lulcov8_id	Bullcov_	Bullcov_id	Inside
1.257025e+007	37063.450000	3	61	2	1	100
400492.300000	2839.200000	2	33	2	1	100
2.885118e+007	40088.250000	2	33	2	1	100
4.345595e+006	12933.000000	4	31	2	1	100
2.580211e+006	8598.180000	5	33	3	2	100
4.017133e+007	42513.090000	4	31	3	2	100
1.050939e+006	6021.889000	4	31	2	1	100
1.234215e+008	101472.200000	11	32	3	2	100
140717.100000	2045.541000	4	31	2	1	100
148523.400000	1964.084000	4	31	3	2	100
7.415538e+006	16462.730000	4	31	2	1	100
809032.100000	4283.414000	14	43	3	2	100
282381.100000	2497.849000	18	43	3	2	100
372721.500000	2535.313000	19	43	3	2	100
9.319974e+006	12741.990000	20	33	3	2	100
1702.270000	445.332000	4	31	2	1	100
2.511747e+006	6895.223000	24	33	3	2	100
179285.100000	1785.584000	29	43	3	2	100
4.505354e+007	38881.780000	37	31	3	2	100
1.541589e+006	6644.355000	40	22	3	2	100
26428.200000	724.259000	41	32	3	2	100
1210.777000	165.542700	40	22	4	3	100
1.727077e+008	138101.700000	40	22	3	2	100
345523.800000	2735.216000	41	32	3	2	100
6.765462e+006	15061.110000	41	32	3	2	100
5.453135e+006	13608.890000	37	31	3	2	100
8.853903e+006	23416.000000	37	31	3	2	100
172102.800000	1906.830000	50	411	5	4	100
5.137957e+006	10977.680000	54	211	5	4	100
1.509228e+006	6928.708000	59	212	5	4	100
113528.900000	2027.070000	63	213	5	4	100
194615.900000	1744.874000	65	211	5	4	100
837148.300000	4071.545000	65	211	5	4	100
414212.400000	3907.128000	73	211	5	4	100
4.345561e+006	8252.701000	79	411	3	2	100
479492.200000	2754.619000	80	411	3	2	100
764658.200000	4865.644000	74	213	6	5	100
48102.310000	1364.771000	68	43	6	5	100
2.094109e+006	6118.598000	54	211	6	5	100
5.701253e+006	13709.460000	82	421	7	6	100
25497.870000	727.760100	78	43	7	6	100
8.131492e+006	14448.200000	82	421	5	4	100
964627.500000	5132.145000	85	212	6	5	100
1.072549e+006	5463.072000	94	213	7	6	100
4.818739e+006	12011.810000	91	211	6	5	100
3912.461000	434.961800	95	213	6	5	100
344092.500000	3104.442000	90	213	6	5	100
1.235090e+007	22781.570000	82	421	5	4	100
4.714157e+006	12021.540000	99	22	5	4	100
4.059045e+006	12337.670000	100	422	5	4	100
624369.900000	3546.148000	95	213	6	5	100
1.109877e+006	5102.467000	92	213	6	5	100

PAT CONT.

Area	Perimeter	Lulcov8_	Lulcov8_id	Bufcov_	Bufcov_id	Inside
30690.260000	1003.802000	85	212	7	6	100
779151.300000	3621.405000	101	22	5	4	100
4.332282e+006	14372.930000	103	412	5	4	100
2.835376e+006	7541.117000	103	412	7	6	100
3.679456e+006	9847.962000	87	411	3	2	100
272868.800000	3319.540000	88	22	6	5	100
503665.200000	4351.767000	93	211	6	5	100
22606.160000	779.322000	105	422	5	4	100
1.311119e+007	32002.480000	82	421	5	4	100
4.144944e+006	9975.342000	106	422	5	4	100
2.971065e+006	8311.496000	88	22	7	6	100
371856.800000	2883.352000	98	44	3	2	100
3.764174e+006	11450.420000	88	22	6	5	100
1.094208e+007	27896.750000	108	22	5	4	100
1.456202e+007	18003.010000	103	412	5	4	100
909860.900000	6378.172000	105	422	5	4	100
429238.900000	3715.967000	107	22	5	4	100
161981.600000	1770.254000	105	422	5	4	100
63604.800000	1899.360000	109	22	5	4	100
5.925979e+006	14767.050000	106	422	5	4	100
6.405080e+006	12548.860000	98	44	6	5	100
4.417876e+006	8321.162000	98	44	7	6	100
1.138484e+006	4388.469000	110	22	5	4	100
245946.900000	2414.581000	111	43	5	4	100
62146.990000	1181.498000	88	22	5	4	100
2.507868e+006	7871.417000	112	422	5	4	100
103555.500000	1314.195000	113	411	5	4	100
95489.590000	1240.138000	98	44	5	4	100
683175.800000	4277.435000	82	421	5	4	100
1.452786e+006	6629.647000	113	411	5	4	100
7.751786e+006	29732.640000	82	421	5	4	100
34496.690000	943.379100	103	412	5	4	100
2.161161e+006	8914.526000	114	22	5	4	100
3.261617e+006	11177.440000	117	22	5	4	100
504375.400000	3654.732000	115	22	8	7	100
1.216492e+006	4911.501000	103	412	8	7	100
1210.272000	195.830900	118	43	5	4	100
3.818572e+006	10607.540000	82	421	8	7	100
119946.600000	1720.655000	82	421	5	4	100
2.247673e+006	7523.141000	119	22	5	4	100
14812.200000	670.735200	118	43	5	4	100
56383.790000	1511.018000	82	421	5	4	100
78378.780000	1323.619000	103	412	8	7	100
469849.500000	5579.915000	82	421	5	4	100
50332.970000	1030.286000	103	412	8	7	100
212171.600000	2062.638000	118	43	5	4	100
6.282204e+006	25071.900000	120	422	5	4	100
243454.100000	2621.400000	118	43	5	4	100
1.631529e+006	7561.586000	82	421	5	4	100
1.205873e+007	33797.390000	122	22	5	4	100
1.062704e+007	31913.030000	118	43	5	4	100
1.075590e+006	4693.750000	123	22	5	4	100

Area	Perimeter	Lulcov8_	Lulcov8_id	Bullcov_	Bullcov_id	Inside
367790.100000	4896.153000	124	43	5	4	100
1.624549e+007	34073.290000	82	421	5	4	100
4426.074000	387.775400	124	43	5	4	100
152529.500000	2167.396000	121	43	5	4	100
1.496905e+006	5216.125000	126	22	5	4	100
4.251544e+006	12809.540000	127	22	5	4	100
341.167200	125.282300	120	422	5	4	100
5.060232e+007	59790.180000	82	421	5	4	100
1.195089e+006	4820.254000	125	22	5	4	100
2.988020e+006	7095.987000	103	412	5	4	100
663155.900000	3413.604000	128	22	5	4	100
601261.000000	2963.113000	131	22	5	4	100
902646.700000	3890.904000	132	22	5	4	100
558535.100000	3311.108000	133	22	5	4	100
1.025169e+006	5315.648000	134	22	5	4	100
39956.630000	1844.223000	124	43	5	4	100
1356.382000	271.797300	124	43	5	4	100
297401.500000	2390.980000	103	412	5	4	100
8009.661000	508.813500	103	412	5	4	100
3.380451e+006	13800.940000	103	412	5	4	100
7911.704000	690.063700	103	412	5	4	100
586.263100	348.710700	136	22	5	4	100